WORK ZONE TRAFFIC MANAGEMENT ANALYSIS USING ANALYTICAL METHODS

Participants Handout

(Updated 4/1/2020)

Rahim (Ray) F. Benekohal
rbenekoh@illinois.edu

Hongjae Jeon
hjeon17@illinois.edu

Hani Ramezani
hrameza2@illinois.edu

Juan C. Medina
jcmedina.uiuc@gmail.com

University of Illinois at Urbana-Champaign

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Federal Highway Administration

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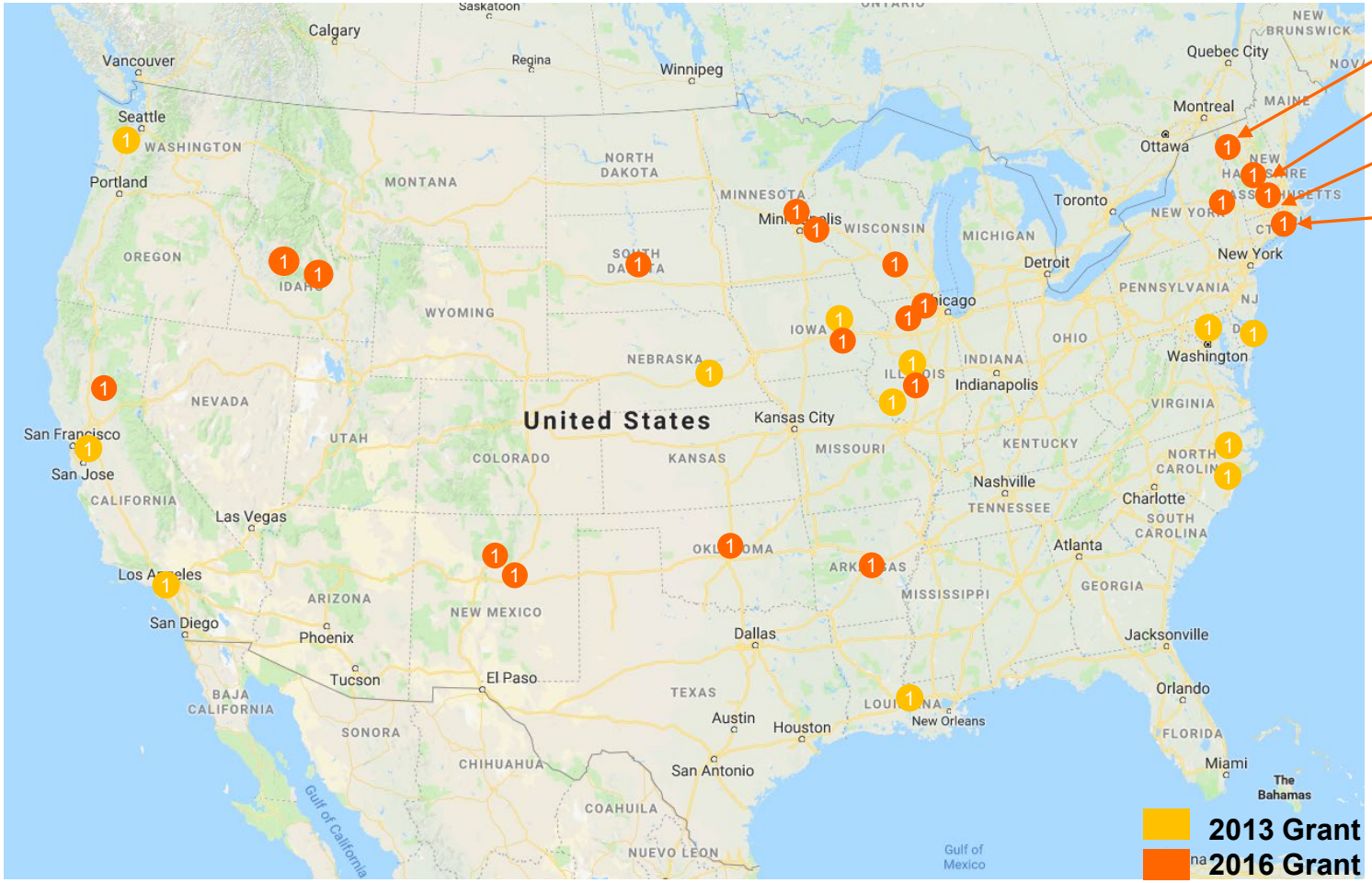
Course Objectives

Learn:

1. Analytical methods (tools) for work zone traffic management analysis
2. Computation of work zone performance measures (WZPM)
   - WZPM are: capacity, speed, queue length, delay, and users' costs
3. Hands-on experience on solving example problems to demonstrate how the tools are used to evaluate:
   - Various traffic management strategies including ITS in work zone

   to manage back-of-queue and delay

Previous Classes



Course offering: 32 times in 23 states (by June 2020)

WORK ZONE TRAFFIC MANAGEMENT ANALYSIS USING ANALYTICAL METHODS

COURSE CONTENTS

Module 1: Principles of WZ Traffic Flow and “The Rule”

Module 2: Input-Output Tools

Module 3: HCM Methods for Capacity Calculations

Module 4: WorkZoneQ-Pro and UI Spreadsheets

Module 5: Traffic Management Strategies using the Tools

Wrap up

Tentative Schedule

(Times may shift by about half hour in response to class needs)

Day 1		
Time block 1	8:00-8:10 am 8:10-10:00 am	Introductions Module 1: Principles of WZ Traffic flow and "The Rule"
Break	10:00-10:15 am	
Time block 2	10:15-12 noon	Module 2: Input-Output Methods
Lunch	12:00-1:00 pm	
Time block 3	1:00-2:30 pm	Module 3: HCM Capacity Methods
Break	2:30-2:45 pm	
Time block 4	2:45-3:30 pm 3:30-4:00 pm	Module 3: HCM Capacity Methods UI spreadsheet for HCM freeways & one-lane two way op Module 4: WorkZoneQ-Pro

Tentative Schedule (Cont.)

(Times may shift by about half hour in response to class needs)

Day 2		
Time block 5	8:00-10:00 am	Module 4, Continued UI spreadsheet for Intersections
Break	10:00-10:15 am	
Time block 6	10:15-10:30 am 10:30 -12:00 noon	Module 4, Continued Module 5: Traffic Management Strategies using the Tools
Lunch	12:00-1:00 pm	
Time Block 7	1:00-2:00 pm	Module 5, Continued Wrap up: discussion, Q&A, evaluation, PDH

Module Content and Duration

(including break time)

Module 1: **2.0 Hr**

- Discussion 1: Traffic Flow Concepts
- Discussion 2: Transportation Management Plan (Rule)
- Discussion 3: Temporary Traffic Control (TTC)
- Discussion 4: WZ capacity
- Discussion 5: WZ Analysis and Queue

Module 2: **2.0 Hr**

- QDAT Spreadsheet (Use of the tool for freeways)
- MoDOT Spreadsheet (Use of the tool for freeways)

Module Content and Duration

Module 3: **2.5 Hr**

- HCM Capacity Methods:
  - Freeways, intersections, and one-lane two way operations
- UI spreadsheet for HCM freeways & one-lane two way op.

Module 4: **3 Hr**

- WorkZoneQ Pro:
  - Freeways, midblock arterials, and one-lane two way operations
- UI spreadsheet for Intersections

Module 5: **2.5 Hr**

- Traffic Management Strategies using the Tools
- Wrap up: discussion, Q&A, evaluation, PDH

Tools Selection Process

- Considered different WZ analysis tools (Such as QuickZone2, QDAT, etc.) with emphasis on sketch planning tools

- Tools selection criteria

  Work Zone Performance Measures (WZPMs)

  Queue analysis method:
  Cumulative input-output or congestion growth-shrinkage

  Facilities:
  Freeway, one-lane two-way WZs, or streets

  Each tool should be sufficiently covered in few hours

  The latest version should be available and free

Selected Tools and Their Main Features

Criteria	QDAT Spreadsheet	MoDOT Spreadsheet	Freeval-WZ	HCM 6th edition 2016 Capacity Methods	WorkZoneQ-Pro
WZPMs	1) Capacity 2) Queue length 3) Delay	1) Capacity 2) Queue length 3) Delay 4) Users costs	1) Capacity 2) Speed 3) Queue length 4) Delay 5) Users costs	1) Capacity 2) Speed 3) Delay for intersections 4) LOS	1) Capacity 2) Speed 3) Queue length 4) Delay 5) Users costs
Queue analysis method	Input-Output Method	Input-Output Method	Shockwave propagation	_	Cell Transmission Model
Facilities	1) Freeways	1) Freeways	1) Freeways	1) Freeways 2) Intersections 3) One-lane two way operations	1) Freeways 2) Intersections* 3) Midblock arterials 4) One-lane two way operations
Sufficiently covered in few hours	Yes	Yes	Yes / May Be	Yes	Yes
Latest version available and free	Yes	Yes	Yes	Yes	Yes

**Computes users' costs based on delay and volume from HCS*

Course Materials

- **Electronic files (number of files):**
  - QDAT spreadsheet (1)
  - MoDOT spreadsheet (1)
  - WorkZoneQ Pro blank spreadsheet for:
    - Freeways WZ (Version 1.56) (1)
    - Midblock arterials (Version 1.56) (1)
    - One-lane two-way operation (Version 1.55) (1)
  - UI spreadsheets for:
    - Freeway HCM (Version 1.24) (1)
    - Calculation of users cost at intersection (Version 1.22) (1)
    - One-lane two way HCM (Version 1.22) (1)
  - Example Solution Files (51)
  - Participants Handout (1)
- **Printed material:**
  - No printed material since the class is online

MODULE 1

Principles of WZ Traffic Flow and "The Rule"

- Discussion 1: Traffic Flow Concepts
- Discussion 2: Transportation Management Plan (Rule)
- Discussion 3: Temporary Traffic Control (TTC)
- Discussion 4: WZ Capacity
- Discussion 5: WZ Analysis and Queue

DISCUSSION #1
TRAFFIC FLOW CONCEPTS

Learning Objectives:

1) Understand variables affecting traffic flow

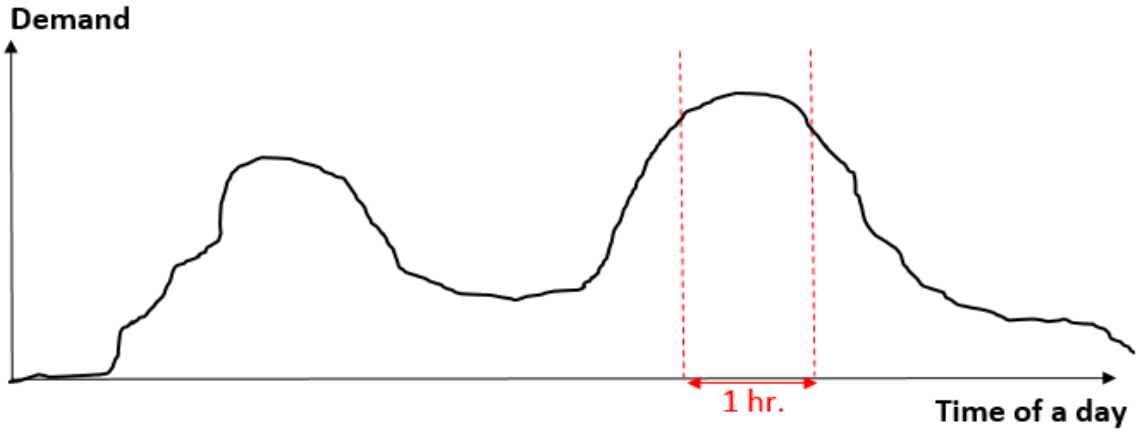
2) Learn how variables are interrelated

Variable	HCM Notation	Unit
Speed	S	mph, fps (ft/s)
Density	D	veh/miles (vpm)
Flow	F	veh/hour (vph), veh/sec
Free flow speed	S_f	mph
Speed at capacity	S_{cap}	mph
Jam density	D_j	vpm
Density at capacity	D_{cap}	vpm
Flow at capacity	F_{max}	vph

Different Types of Volume

- **Flow (or volume):** No. of vehicles passing a point during a given time interval.

- **Peak hour volume**: Highest hourly volume (veh/hr)



- **ADT**: Average Daily Traffic (veh/day)
  ADT is estimated based on volume count data for less than a year

- **AADT**: Annual Average Daily Traffic (veh/day)
  AADT is estimated based on volume count data for a year or more

Volume Variation

- Volume on a road varies over time and/or space
- Volume variation (month, day, hour, sub-hour, and hwy type)

What is the difference in routes in Exh 3-1 (a) and (b)?

What is the main reason for different trends in Exh 3-2?

What is the main cause for different graphs in Exh 3-3?

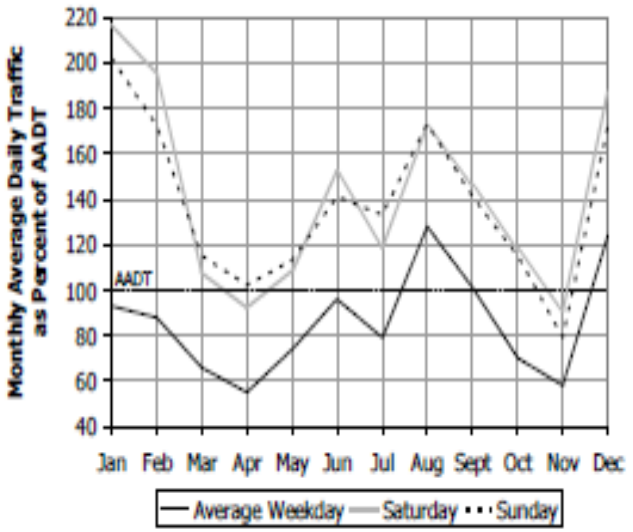
What are main causes for different graphs in Exh 3-5 to 3-6?

Monthly Volume Variation
Recreational Traffic vs. Intercity Traffic

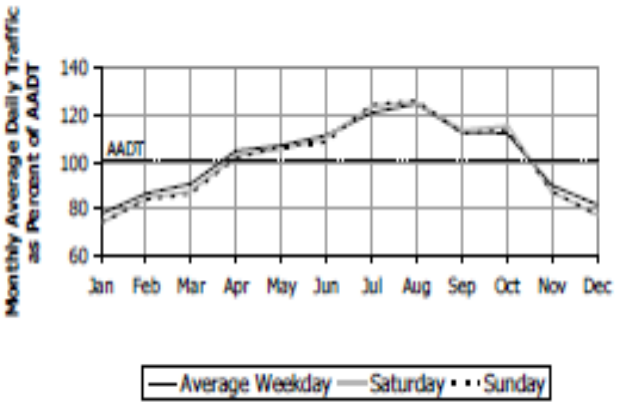
Exhibit 3-1
Examples of Monthly Traffic Volume Variations for a Highway

Monthly volume variations for routes with recreational traffic show much higher seasonal peaking than for routes with predominantly intercity traffic.

The average daily traffic averaged over a full year is referred to as the annual average daily traffic, or AADT, and is often used in forecasting and planning.



(a) Routes with Significant Recreational Traffic



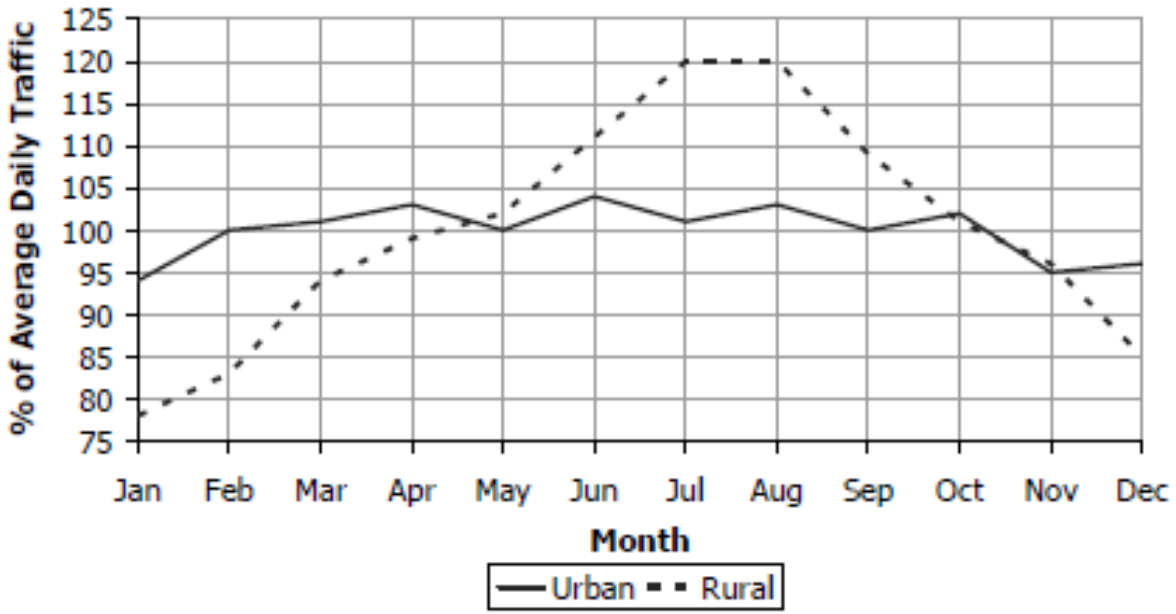
(b) Routes with Significant Intercity Traffic

Note: (a) Highway 35 south of Parkdale, Oregon; (b) US-97 north of Wenatchee, Washington.
Source: (a) Oregon DOT, 2007; (b) Washington State DOT, 2007.

Monthly Volume Variation
Urban vs. Rural

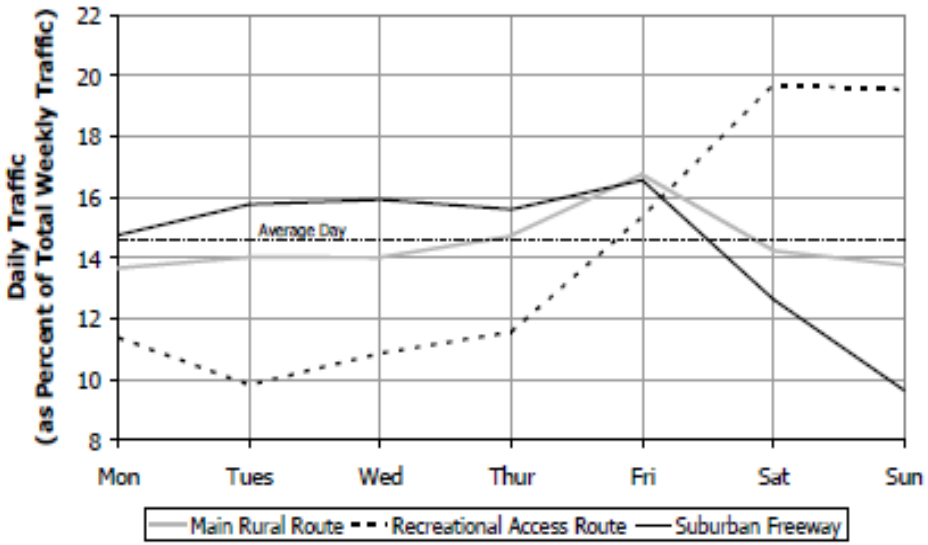
Exhibit 3-2
Examples of Monthly Traffic Volume Variations for the Same Interstate Highway (Rural and Urban Segments)

Monthly volume variations for rural segments of Interstate highways show much higher seasonal peaking than for urban segments of the same highway. This may reflect both recreational and agricultural traffic impacts.



Note: Urban, I-84 east of I-5 in Portland; rural, I-84 at Rowena.
Source: Oregon DOT, 2006.

Daily Volume Variation and Route Type



Notes: Suburban freeway, I-182 in Richland, Washington; main rural route, US-12 southeast of Pasco, Washington; recreational access route, Highway 35 south of Parkdale, Oregon.
Source: Washington State DOT, 2007, and Oregon DOT, 2007.

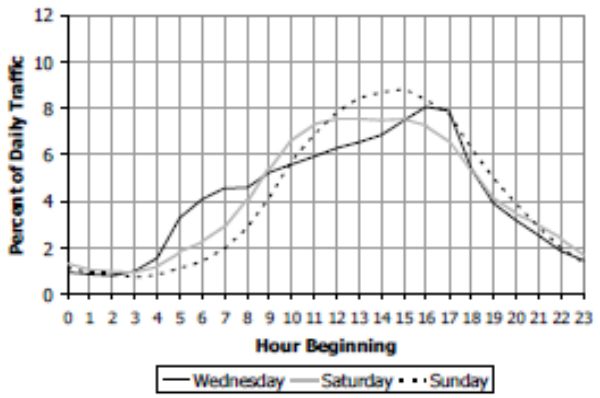
Exhibit 3-3
Examples of Daily Traffic Variation by Type of Route

Daily volume variations through the week show higher weekday volumes and lower weekend volumes for routes primarily serving commuter and intercity traffic, but the opposite for segments serving recreational traffic. Fridays are typically the peak weekday.

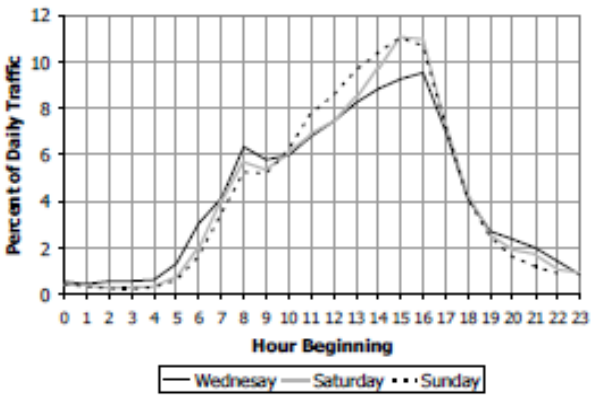
Hourly Volume Variation and Route Type

Exhibit 3-5
Examples of Hourly Traffic Variations for Rural Routes

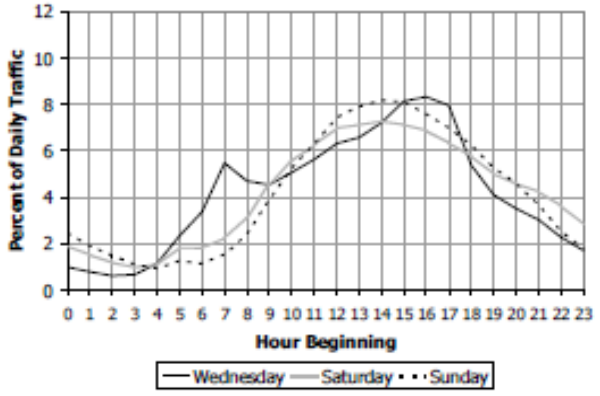
Traffic variation during the day by day of week for rural routes.



(a) Intercity Route



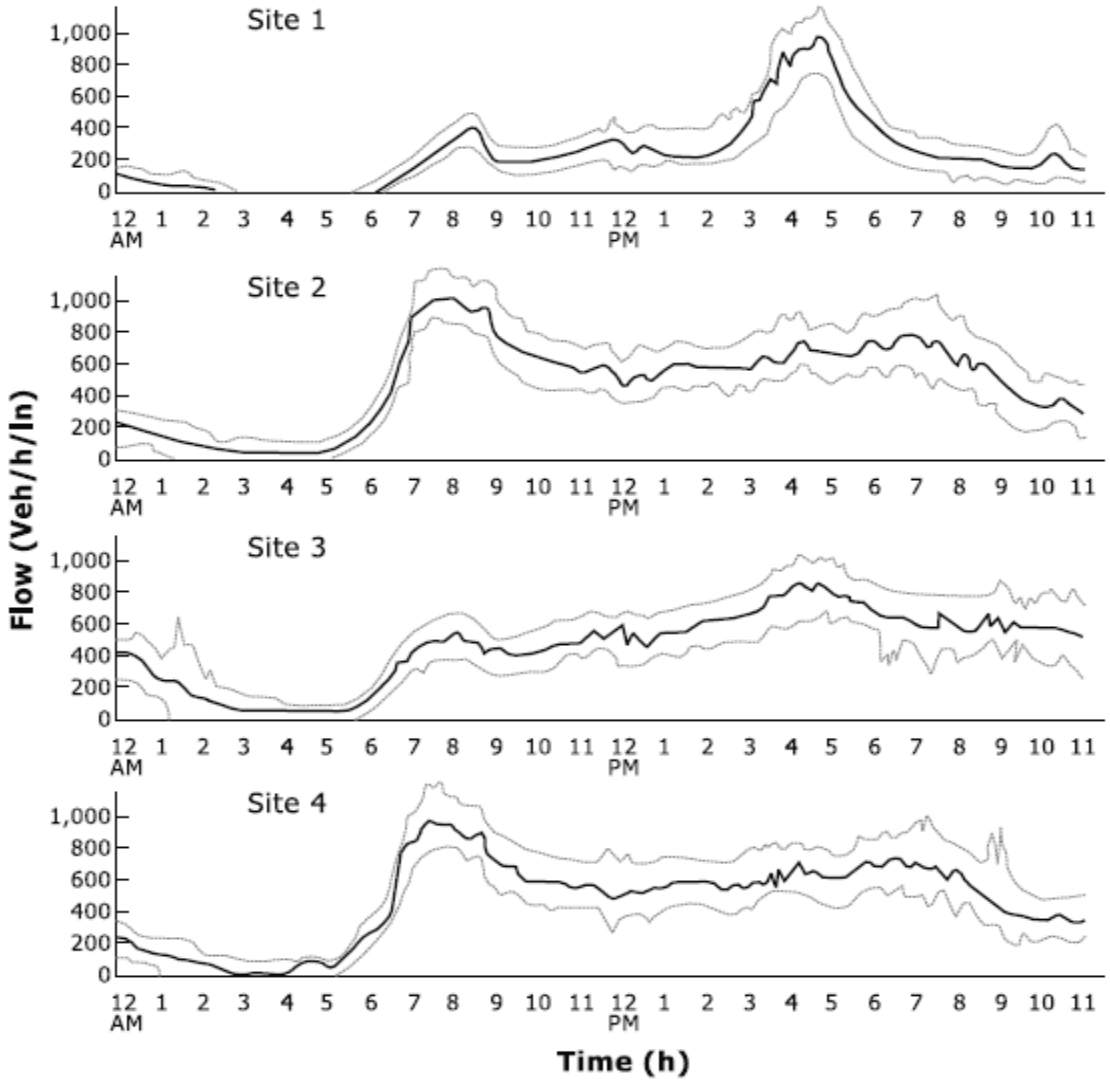
(b) Recreation Access Route



(c) Local Route

Notes: (a) US-395 south of Kennewick, Washington; (b) Highway 35 south of Parkdale, Oregon; (c) US-97 near Wapato, Washington.
Source: Washington State DOT, 2007, and Oregon DOT, 2007.

Hourly Volume Variation and Urban Streets



Notes: Sites 2 and 4 are one block apart on the same street, in the same direction. All sites are two moving lanes in one direction.
Source: McShane and Crowley (*3*).

Exhibit 3-6
Repeatability of Hourly Traffic Variations for Urban Streets

Repeatability of hourly patterns.

Volume Distribution

- Directional design hour volume(DDHV) can be estimated from AADT:

  DDHV=AADT*K*D

  - K= % of AADT occurring in peak hour (Exh 3-9 of HCM),
    - K decreases as AADT increases
    - K decreases as development density increases
    - For many urban and rural highways k is around 0.10
  - D= % peak hour traffic in the peak direction
    - D factors (Exh 3-10 of HCM)

- Directional hourly volume= (% of 24 volume) * AADT*D

- Group Discussion
  - Where can I get the 24-hour volume distributions?
  - What is the role of the volume distribution on queue?

Exhibit 3-9: Example K-Factors by AADT

AADT	Average *K*-Factor	Number of Sites Included in Average *K*-Factor		
		Urban	Recreational	Other Rural
0-2,500	0.151	0	6	12
2,500-5,000	0.136	1	6	8
5,000-10,000	0.118	2	2	14
10,000-20,000	0.116	1	2	15
20,000-50,000	0.107	11	5	10
50,000-100,000	0.091	14	0	4
100,000-200,000	0.082	11	0	0
>200,000	0.067	2	0	0

Note: *K*-factors are for the 30th-highest traffic volume hour of the year.
Source: Washington State DOT (*5*).

Exhibit 3-10: Example Directional Distribution Characteristics

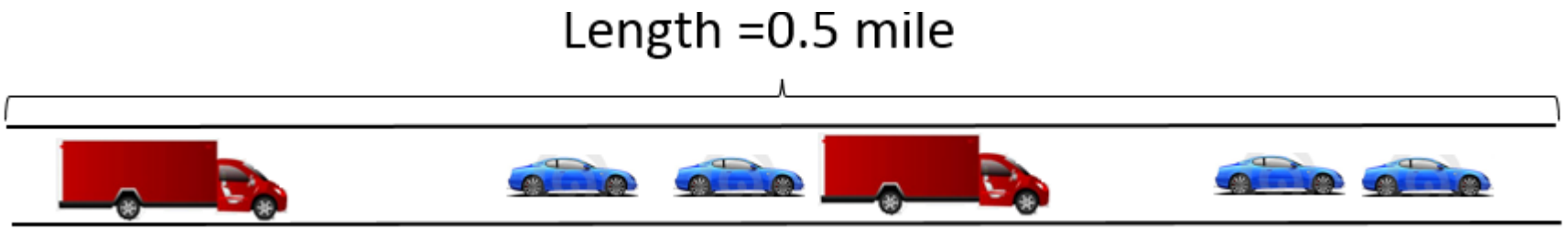
Freeway Type	*D*-Factor
Rural-intercity	0.59
Rural-recreational and intercity	0.64
Suburban circumferential	0.52
Suburban radial	0.60
Urban radial	0.70
Intraurban	0.51

Notes: Rural–intercity, I-5 at Willows; rural–recreational and intercity, I-80 west of Donner Summit; suburban circumferential, I-680 in Danville; suburban radial, I-80 in Pinole; urban radial, Highway 94 at I-5, San Diego; intraurban, I-880 in Hayward.
Source: Caltrans, 2007.

Density

- **Density**: Number of vehicles occupying a section of road (vpm)

  Example: There are 6 vehicles on a 0.5 mile section of a road



Density = 6/0.5 = 12 vpm

- **Jam density**: Density when all vehicles are stopped in a queue
- **Critical density**: Density when traffic is moving at capacity level

The Fundamental Relationship

Flow rate = Speed * Density

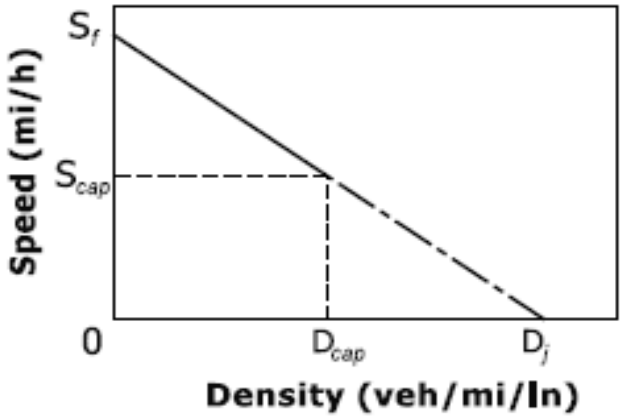
F = S * D

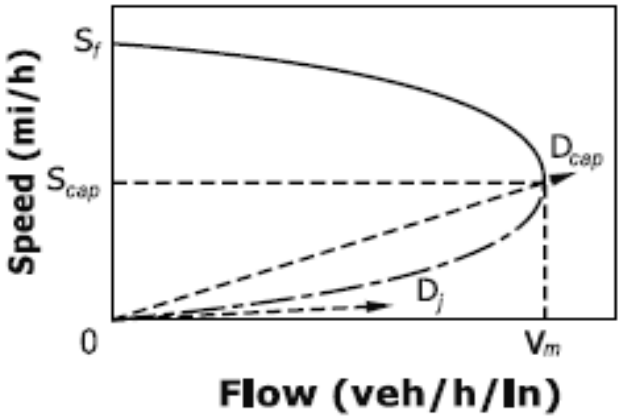
[*veh/hr*] = [*mile/hr*] * [*veh/mile*]

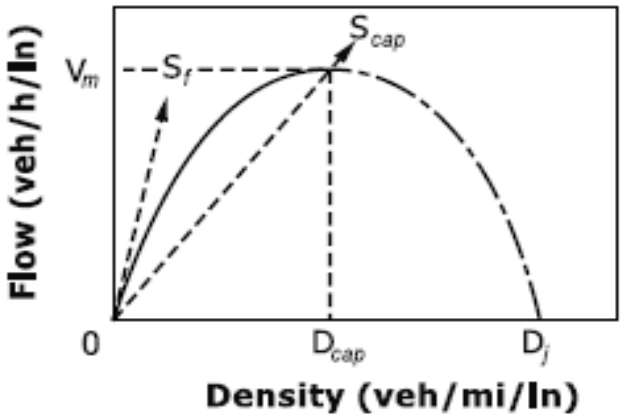
This is called fundamental relationship of traffic flow

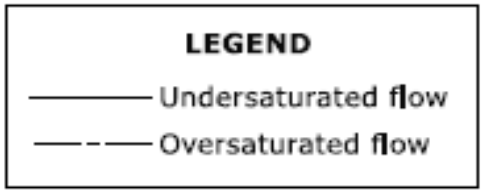
Relationship Among Traffic Variables

Assuming a linear relationship between speed and density (Greenshields Model)







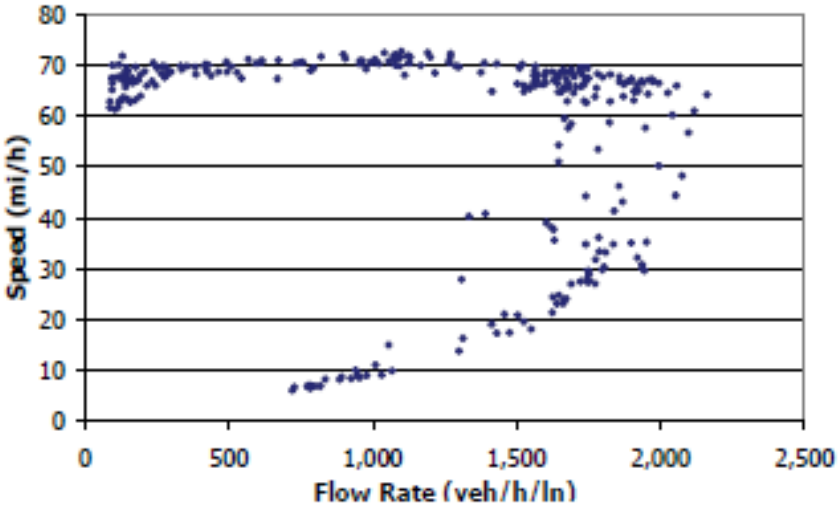


HCM 2010-Exh 4-3

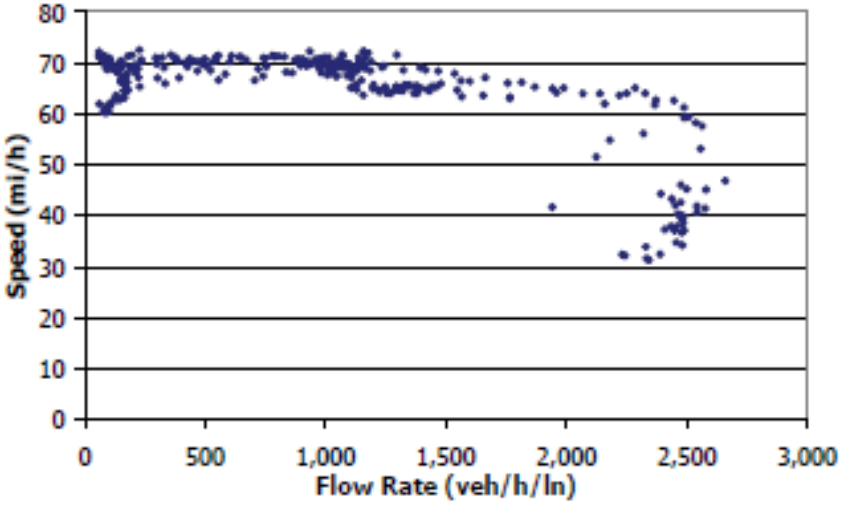
Source: Adapted from May (*3*).

Example of freeway speed-flow data

At low and moderate volumes, speed does not change with flow



(a) I-405, Los Angeles, California



(b) I-805, San Diego, California

Source: California Department of Transportation, 2008.

HCM 2010-Exh 4-4

Relationship between Spacing and Density

Average spacing: Distance between front bumpers of two successive vehicles

$$\text{Average spacing} = \frac{5280}{D}$$

Example: For a density of 100 vpm → Avg. spacing = $\frac{5280}{100} = 52.8\ ft$

Relationship between Headway and Flow Rate

Average headway: Time interval between successive vehicles passing a point

$$\text{Average headway} = \frac{3600}{F}$$

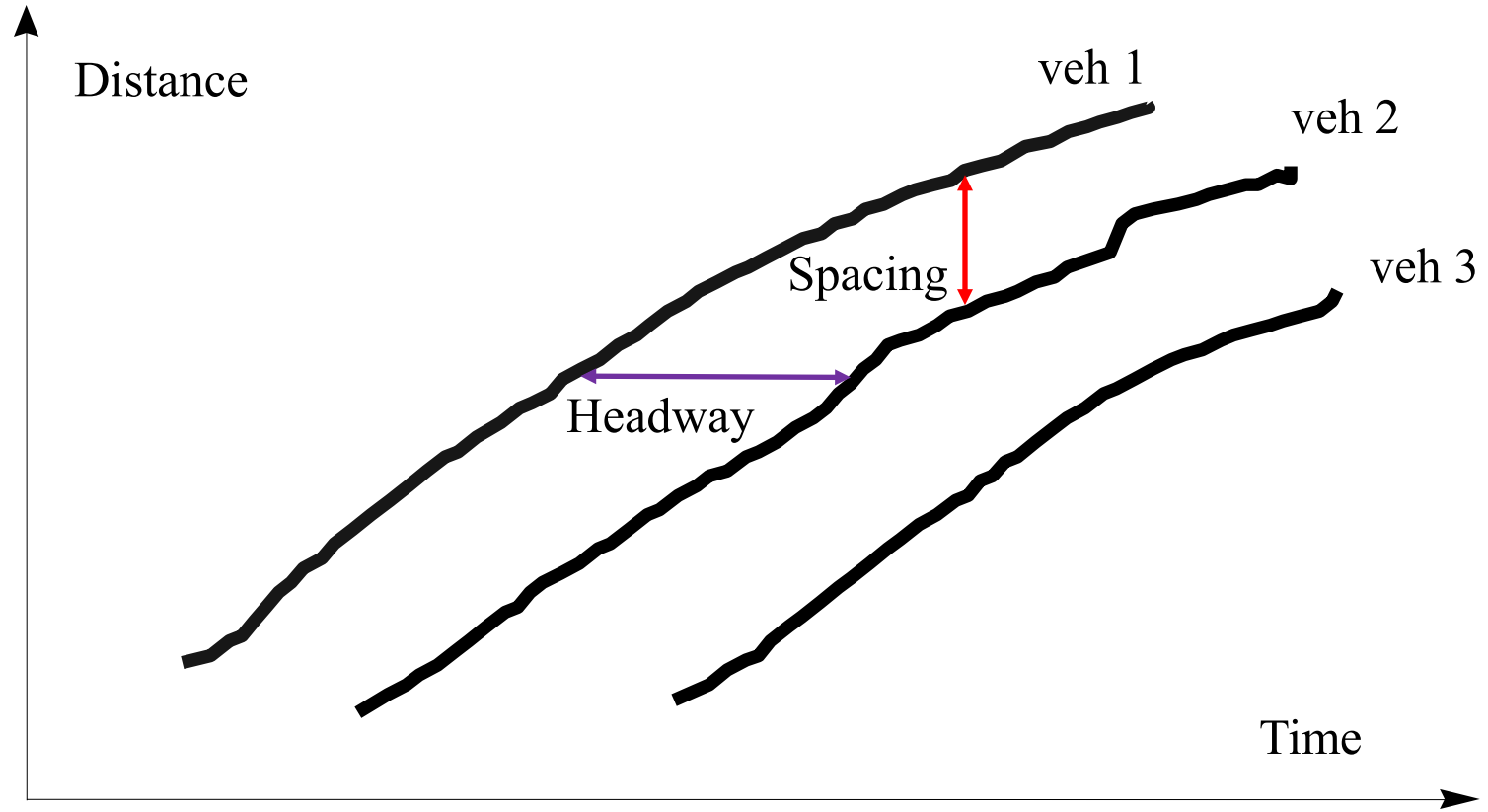
Example: For a flow rate of 1800 vph → Avg. headway= $\frac{3600}{1800} = 2\ sec$

Relationship between Spacing and Headway

Spacing = Speed * Headway

Time-Space Diagram

It shows vehicle trajectories, time headway, and spacing



Example – How the Variables are Related

Given: flow rate=1800 vph and speed is 30 mph,

Find:

density = 1800/30=60 vpm

avg spacing = 5280/60=88 ft

avg headway = 3600/1800=2 sec

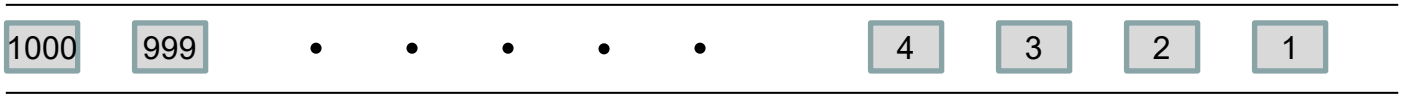
Also, we it should agree that

avg headway=avg spacing/speed

avg headway = (88/1.467)/(30)=2 sec

Storage Space for Stopped Queue versus Moving Queue

- What would be the required storage space for stopped queue?



Storage space = No. of vehicles*spacing in stopped queue

= 1000 * 25 = 25000 ft ≈ 4.73 miles

- What would be the required storage space for moving queue?

Storage space = No. of vehicles*spacing in moving queue

For flow rate=1800 & speed = 30 mph, Average spacing is 88 ft:

Storage space = 1000 * 88 = 88000 ft ≈ 16.67 miles

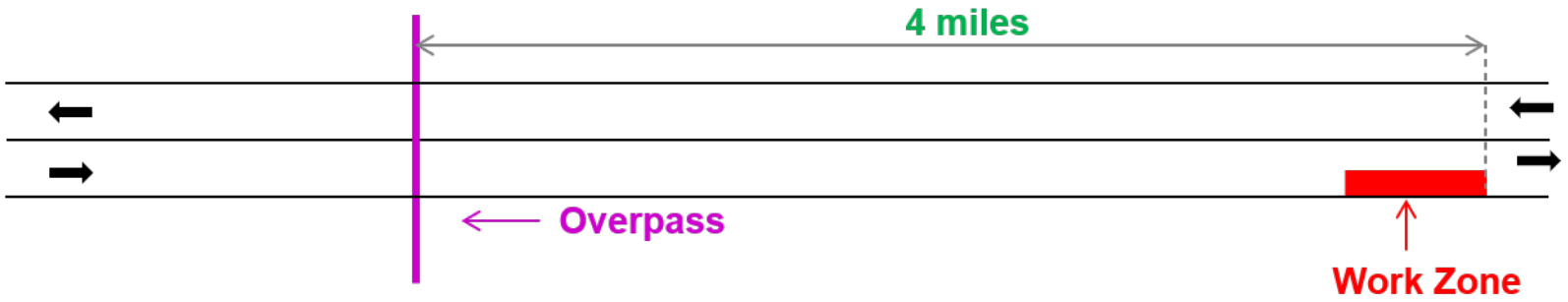
- What is spacing is 66 ft

Storage space = 1000 * 66 = 66000 ft ≈ 12.5 miles

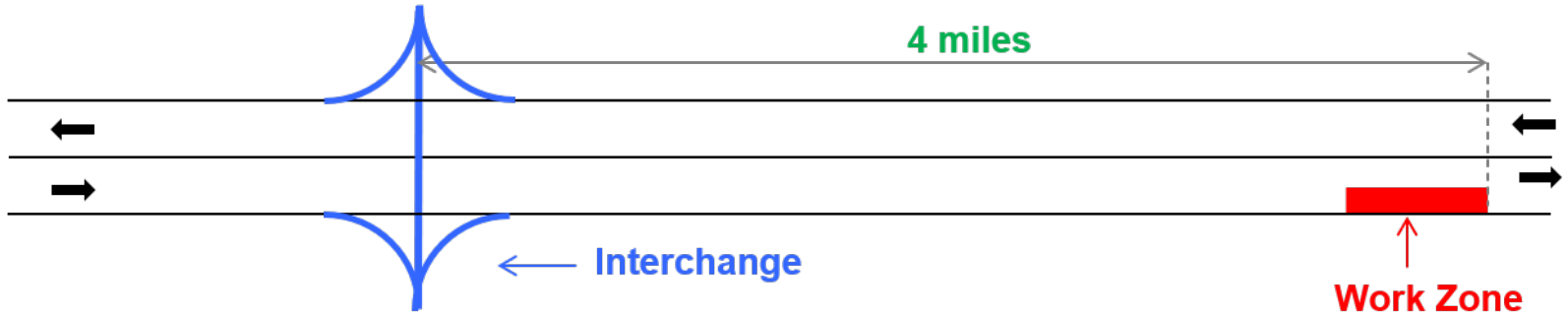
Effects of Upstream Interchange on Queue

- Assume calculated queue length from the tools is 5 miles. For which one of the following corridors are the calculations valid?

Corridor with an overpass:



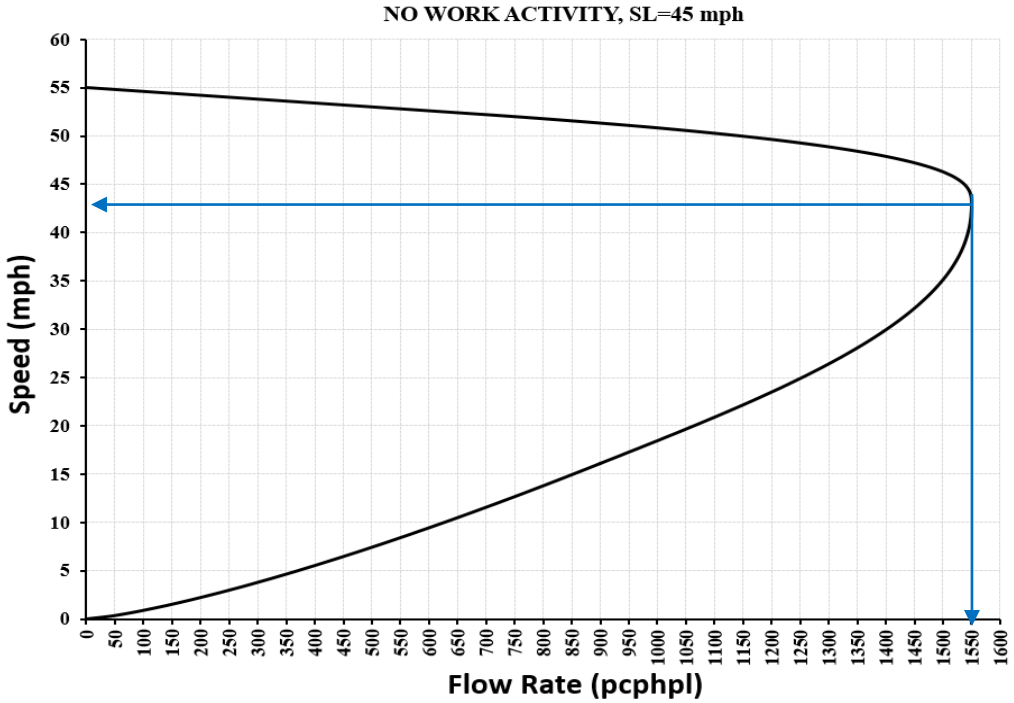
Corridor with an interchange:



Group Discussions

- Q.1.1: What is the relationship between K- factor and AADT?
- Q.1.2: Compute DDHV when AADT is 25000 and K-factor and D-factor are 0.1 and 0.6, respectively.
- Q.1.3: For the following speed-flow curve find:

  a) Free flow speed
  b) Capacity, and corresponding headway
  c) Speed at capacity
  d) Density at capacity, and corresponding spacing



DISCUSSION #2
TRANSPORTATION MANAGEMENT PLANS

Learning Objectives:

1) Understand the requirements of the "Work Zone Safety and Mobility" Rule (known as the Rule or Subpart J)

2) Review of FHWA guidance on Developing and Implementing Transportation Management Plans (TMP) for Work Zones

2004 FHWA Work Zone Safety and Mobility Rule

Developed to address safety and mobility issues in WZs

- **Purpose:**

  "...establishes requirements and provides guidance for systematically addressing the safety and mobility impacts of work zones, and developing strategies to help manage these impacts on all Federal-aid highway projects"

- **Policy:**
  - The States **shall implement** a policy to manage WZ impacts on all Federal-aid highway projects
  - The States are encouraged to implement this policy for non-Federal-aid projects as well

- **State-level processes and procedures:**

  "States should develop and implement systematic procedures to assess work zone impacts in project development, and to manage safety and mobility during project implementation"

  Therefore, TMPs should be developed

FHWA Issued 4 documents to help transportation agencies understand and implement the provisions of the Rule

- *Implementing the Rule on Work Zone Safety and Mobility*
  (Pub. No. FHWA-HOP-05-065)

- *Work Zone Public Information and Outreach Strategies*
  (Pub. No. FHWA-HOP-05-067)

- *Work Zone Impacts Assessment: An Approach to Assess and Manage Work Zone Safety and Mobility Impacts of Road Projects*
  (Pub. No. FHWA-HOP-05-068)

- *Developing and Implementing Transportation Management Plans for Work Zones*
  (Pub. No. FHWA-HOP-05-066)

Deals with traffic management → We will focus on this document

Developing and Implementing Transportation Management Plans (TMP) for Work Zones

Contents:

1. Introduction

2. Process for TMP Development, Implementation, and Assessment

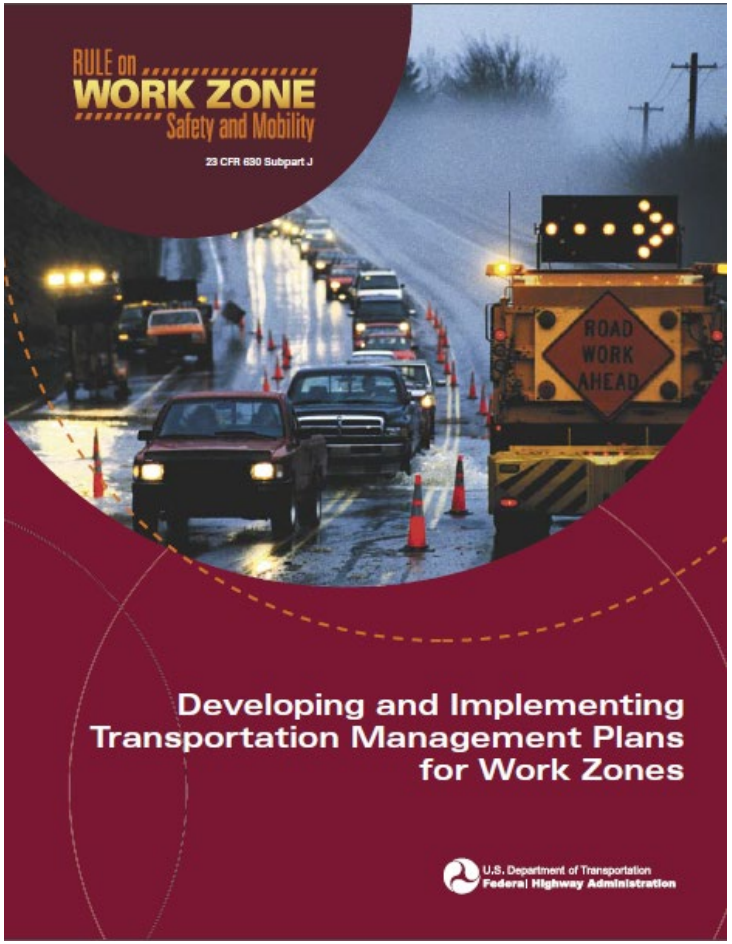
3. Potential TMP Components

4. WZ Impacts Management Strategies

5. Current TMP Use, Examples, and Practices

Appendix A - Transportation Management Plan Potential Components Checklist

Appendix B - Work Zone Management Strategies Matrix



TMP Components

I. Temporary Traffic Control (TTC) plan

(Required for all federal-aid highway projects)

II. Public Information (PI) component

(Required for Significant Projects)*

III. Transportation Operations (TO) component

(Required for Significant Projects)*

Guidance on strategies for all TMP components can be found in Appendix B of the FHWA document. Some examples are presented here

* Encouraged to be considered even if project is not significant

What is a Significant Project?

- "Section 630.1010 of the Rule defines a significant project as one that, alone or in combination with other concurrent projects nearby, is anticipated to cause sustained work zone impacts that are greater than what is considered tolerable based on State policy and/or engineering judgment.

- All Interstate system projects within the boundaries of a designated Transportation Management Area (TMA) that occupy a location for more than three days with either intermittent or continuous lane closures shall be considered as significant projects."

I) Temporary Traffic Control (TTC) Plan

(Required for all federal-aid highway projects)

- "Addresses traffic safety and control through the work zone"
- Consistent with:
  - MUTCD Part 6 (Details in *Discussion 3*)
  - AASHTO Roadside Design Guide-WZ hardware in Ch. 9
- Quantify **expected queue length** and incorporate that information to design the taper for the project, design lane-widths, set the WZ speed limits, estimate costs of TTC
- Different management strategies can be used, as described next…

(**Queues** and **delays** are part of key technical issues in impact analysis)

I) Temporary Traffic Control (TTC) Plan

(Required for all federal-aid highway projects)

3 Categories of Strategies:

IA - Control strategies

IB - Traffic control devices

IC - Project coordination, contracting, and innovative construction strategies

IA - Control Strategies

- IA1 Construction phasing/staging
- IA2 Full roadway closures
- IA3 Lane shifts or closures
  - Reduced lane widths to maintain number of lanes (constriction)
  - Lane closures to provide worker safety
  - Reduced shoulder width to maintain number of lanes
  - Shoulder closures to provide worker safety
  - Lane shift to shoulder/median to maintain number of lanes
- IA4 One-lane, two-way operation
- IA5 Two-way traffic on one side of divided facility (crossover)
- IA6 Reversible lanes
- IA7 Ramp closures/ relocation
- IA8 Freeway-to-freeway interchange closures
- IA9 Night work
- IA10 Weekend work
- IA11 Work hour restrictions for peak travel
- IA12 Pedestrian/bicycle access improvements
- IA13 Business access improvements
- IA14 Off-site detours/use of alternate routes

IA - Control Strategies

Guidance is provided for each strategy in the document:

Example:

Strategy IA11- Work hour restrictions for peak travel **

Mobility Improvement	Motorist Safety Improvement	Worker Safety Improvement	Triggers for Consideration
✓			-Urban areas -High traffic volume -Significant peaking of traffic -Where significant capacity reductions are necessary

Potential Pros	Potential Challenges	Other Considerations
-Maintains normal capacity during traffic peak times -Fewer delays	-May extend project duration	-Duration of work restrictions will vary by location

**** In Module 3 (HCM Capacity), we will show effects of day vs night. Also, the last section of the course describes and example to find hours of operation to meet mobility criteria**

II) Public Information (PI) Component

(Required for Significant Projects*)

2 Categories of Strategies:

IIA - Public awareness strategies

IIB - Motorist information strategies

* Encouraged to be considered even if project is not significant

IIB - Motorist Information Strategies

- IIB1 Traffic radio
- IIB2 Changeable message signs (CMS)
- IIB3 Temporary motorist information signs
- IIB4 Dynamic speed message sign
- IIB5 Highway advisory radio (HAR)
- IIB6 Extinguishable signs
- IIB7 Highway information network (web-based)
- IIB8 511 traveler information systems (wireless, handhelds)
- IIB9 Freight travel information
- IIB10 Transportation management center (TMC)

IIB - Motorist Information Strategies

Example:

PI Strategy: IIB2-Changeable Message Sign (CMS) **

Mobility Improvement	Motorist Safety Improvement	Worker Safety Improvement	Triggers for Consideration
✓	✓	✓	-Projects with multiple phases/ construction stages -Alternate routes available -When work zone conditions are subject to frequent or on-going changes (e.g., lane and/or ramp closures expected)

Potential Pros	Potential Challenges	Other Considerations
-Provides real time information to motorists -Gives public advance warning to make decisions -Provides information to motorists directly affected by the project	-Needs to be accurate information, otherwise the information is not credible	-Needs means of controlling/updating messages, such as a TMC -Supports incident management -Need to keep information up to date and useful

** The last section of the course describes and example to analyze the effects of a CMS in a WZ

III) Transportation Operations (TO) Component

(Required for Significant Projects*)

4 Categories of Strategies:

IIIA - Demand Management Strategies

IIIB - Corridor/network management Strategies

IIIC - Safety Management Strategies

IIID - Traffic Incident Management and Enforcement Strategies

* Encouraged to be considered even if project is not significant

IIIB - Corridor/network management Strategies

- IIIB1 Signal timing/ coordination improvements
- IIIB2 Temporary traffic signals
- IIIB3 Street/intersection improvements
- IIIB4 Bus turnouts
- IIIB5 Turn restrictions
- IIIB6 Parking restrictions
- IIIB7 Truck/heavy vehicle restrictions
- IIIB8 Separate truck lanes
- IIIB9 Reversible lanes
- IIIB10 Dynamic lane closure system
- IIIB11 Ramp metering
- IIIB12 Temporary suspension of ramp metering
- IIIB13 Ramp closures
- IIIB14 Railroad crossings controls
- IIIB15 Coordination with adjacent construction site(s)

IIIB - Corridor/network management Strategies

Example:

Strategy: IIIB7-Truck/heavy vehicle restrictions **

Mobility Improvement	Motorist Safety Improvement	Worker Safety Improvement	Triggers for Consideration
✓	✓		-Projects with high truck volume -When significant reduction in capacity anticipated -When the location has heavy truck traffic but also has potential alternate truck routes -When capacity/safety concerns exist for truck movements through work zone -Passenger cars are expected to be significantly delayed due to truck traffic

Potential Pros	Potential Challenges	Other Considerations
-Improves passenger car flow through the work zone by removing trucks from the traffic stream	-Provision of an alternate truck route may adversely affect other traffic or roads -Requires additional signage/ personnel to enforce truck restrictions	-Availability and sustainability of alternate routes for the trucks must be considered -Federal, State, and/or local ordinances that govern truck traffic access must be considered -Appropriate design and geometric concerns related to trucks would need to be addressed -Noise and business impacts from use of detour route may need to be considered

** An example in the Appendix C describes the effects of variable vehicle composition in the WZ operation

TMP Use, Examples, and Practices

States use a variety of criteria to specify work zone mobility and operational performance, including:

- Delay (total, average per vehicle)
- Queue (length, duration)
- Capacity (volume/capacity ratio, LOS)
- Volume (throughput)
- Speed (average speed, % of time at free-flow speed)
- % work zones meeting expectations for traffic flow
- User complaints, road user surveys
- Frequency, duration of incidents

* ***Sources:***

- *Best Practices in Work Zone Assessment, Data Collection, and Performance Evaluation. NCHRP – Scan 08-04. 2010.*
- *Synthesis of Work-Zone Performance Measures. Center for Transportation Research and Education (CTRE). Iowa State University. 2013*
- *FHWA Best Practices compilation: http://www.ops.fhwa.dot.gov/wz/practices/practices.htm*

TMP Use, Examples, and Practices

Indiana DOT *establishes different queue length thresholds depending on their duration:*

- *No queues present 6 continuous hours or more than 12 hours total per day*
- *Queues between 0.5 and 1 mile are limited to 4 continuous hours*
- *Queues between 1 and 1.5 miles are limited to 2 continuous hours*
- *Queues greater than 1.5 miles are not permitted*

Maryland *SHA has different mobility criteria for different facilities:*

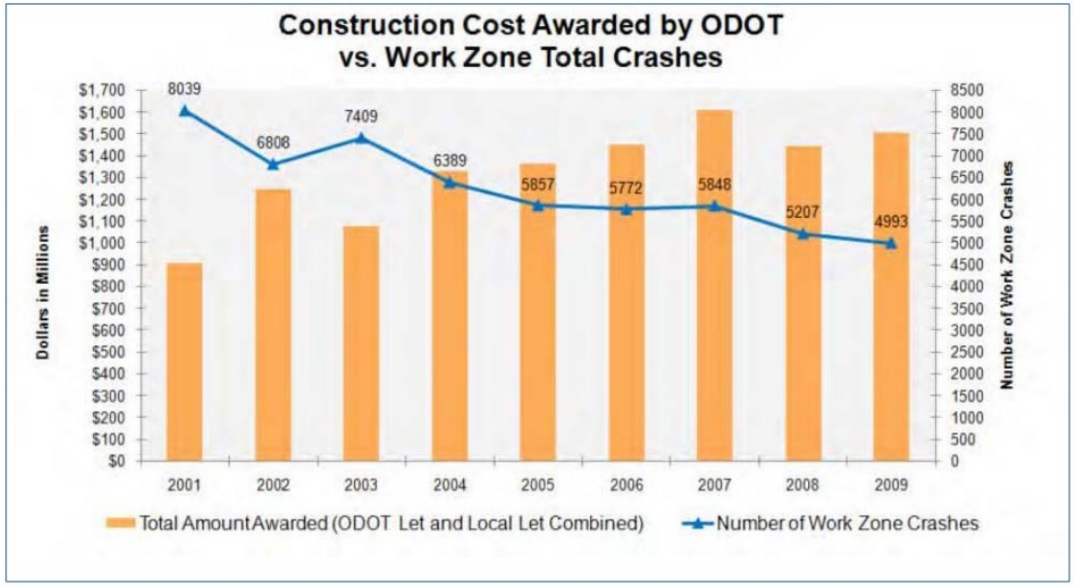
- *For freeways, queues greater than 1.5 miles are not acceptable, and queues between 1.0 and 1.5 miles are limited up to 2 hours*
- *For arterials, delays are restricted to 15 minutes*
- *For signalized intersections the increase in control delay and change in LOS are restricted; and a similar criteria is imposed for unsignalized intersections.*

- *What is your state's policy?*

TMP Use, Examples, and Practices

*In **California**, DD-60-R2 and Caltrans TMP guidelines defined* "Significant Traffic Impact" as "an individual traffic delay of 30 minutes or more above normal recurrent travel time on the existing facility or the delay time set by the District Traffic Manager (DTM), whichever is less. Significant traffic impacts can also occur when motorists experience shorter individual delays that may extend over several months or years. In some cases a full closure of a freeway segment may be justified for a short duration when compared to several months of weekend closures that may severely impact the business community and the public in general. The objective in developing TMP strategies is to balance short-term and long-term impacts to the traveling public with the safe, efficient delivery of highway construction projects and work zone activities."

*"Most agencies tracked **crash frequencies** (annual, quarterly, or monthly) while a few considered crash severity or crash type." "**Ohio DOT (ODOT)** uses annual construction budget as an exposure measure and compares total annual work zone crash frequency to annual construction budget." "…ODOT also examines work zone crashes for a selected number of significant projects..." using ADT to estimate crash rates is million-vehicle miles*



Group Discussion

Q. 2.1. What are the components of a TMP?

Q. 2.2. What is a Significant Project and what are the implications of significant projects in the components required for TMPs?

Q. 2.3. Do you know what are the mobility and safety criteria used in your State?

DISCUSSION #3
TEMPORARY TRAFFIC CONTROL (TTC)

Learning Objectives:

1) Overview of MUTCD Part 6 -Temporary Traffic Control

2) WZ components, duration, typical applications, and signage

3) Provide basic information about TTC used in this training course

MUTCD

- **M**anual on **U**niform **T**raffic **C**ontrol **D**evices (**MUTCD)**
- Written by National Committee on Uniform Traffic Control Devices; latest edition is 2009
- Published by US DOT (FHWA)
- "By setting minimum standards and providing guidance, ensures uniformity of traffic control devices across the nation." *(**Source :** http://mutcd.fhwa.dot.gov/kno-overview.htm)*
- Chapter 6 describes Temporary Traffic Control

Chapter 6 in MUTCD: Temporary Traffic Control

- Chapter 6A: General
- Chapter 6B: Fundamental Principles
- Chapter 6C: Temporary Traffic Control Elements
- Chapter 6D: Pedestrian and Worker Safety
- Chapter 6E: Flagger Control
- Chapter 6F: Temporary Traffic Control Zone Devices
- Chapter 6G: Type of Temporary Traffic Control Zone Activities
- Chapter 6H: Typical Applications
- Chapter 6I: Control of Traffic Through Traffic Incident Management Areas

We will discuss items in red

Chapter 6C: Temporary Traffic Control Elements

Definition of TTC zone:

"an area of a highway where **road user conditions are changed** because of a work zone, an incident zone, or a planned special event through the use of TTC devices, uniformed law enforcement officers, or other authorized personnel."

Components of TTC zones

1) **Advanced warning area**

Drivers are informed about upcoming TTC zone

2) **Transition area**

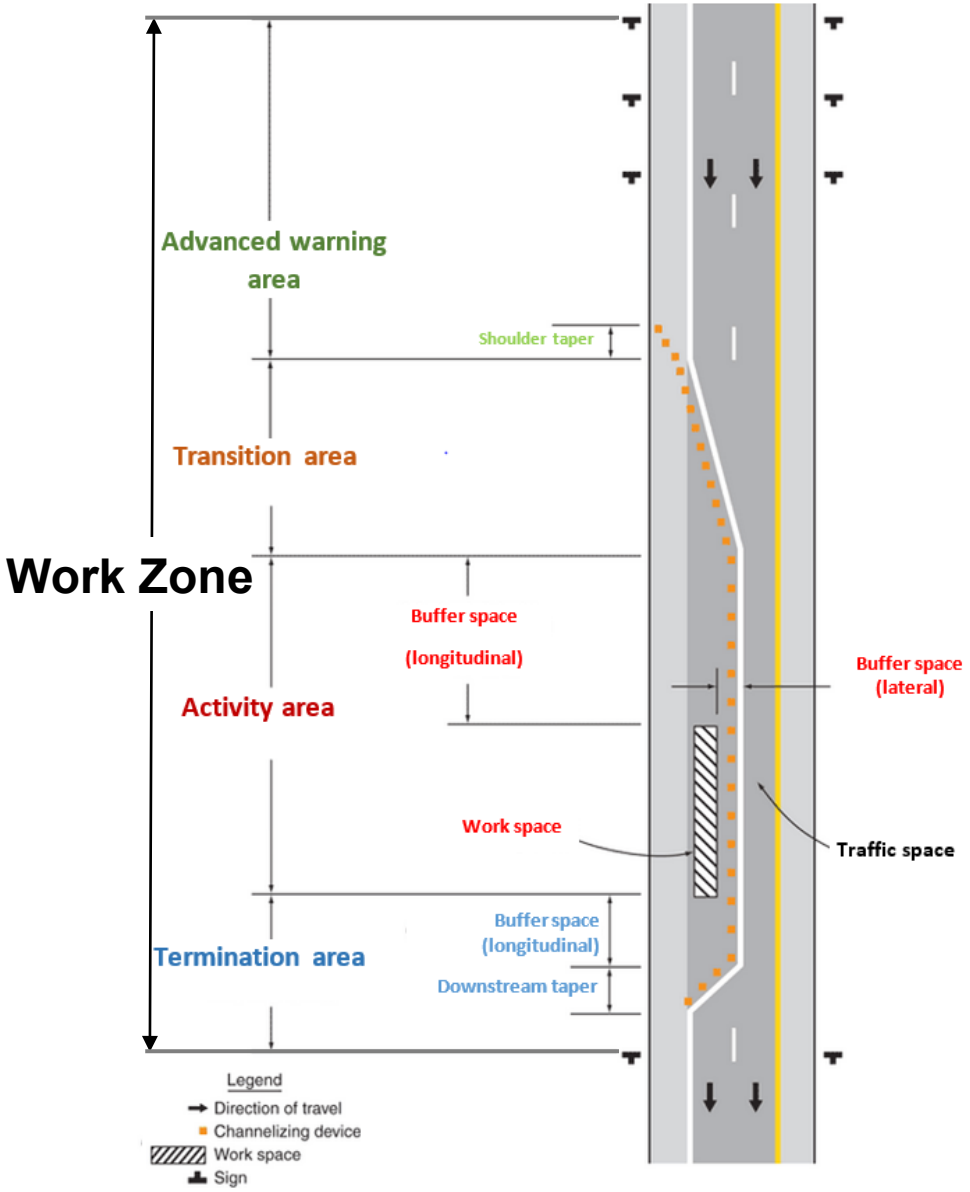
Drivers may be asked to change their normal path

3) **Activity area**

"It is comprised of
the work space,
the traffic space, and
the buffer space ."

4) **Termination area**

Drivers return to the normal path



Advanced Warning Area Signs

- Distance between the signs depends on road type
- Read the distances from, Table 6C-1

Table 6C-1. Recommended Advance Warning Sign Minimum Spacing

Road Type	Distance Between Signs**		
	A	B	C
Urban (low speed)*	100 feet	100 feet	100 feet
Urban (high speed)*	350 feet	350 feet	350 feet
Rural	500 feet	500 feet	500 feet
Expressway / Freeway	1,000 feet	1,500 feet	2,640 feet

*Speed category to be determined by the highway agency
** Schematic definitions of A, B, and C are provided in Figures 6H-1 through 6H-46 (Typical Applications)

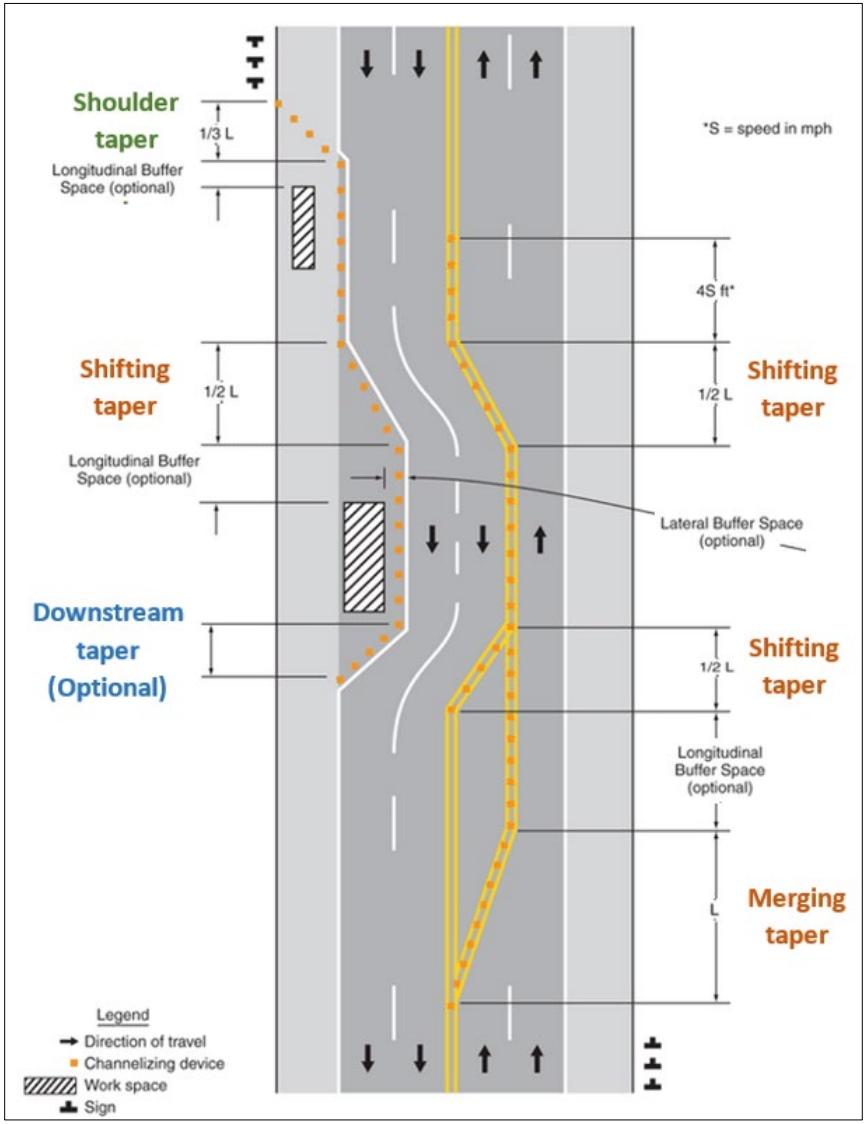
Note: "The distances contained in Table 6C-1 are approximate, are intended for guidance purposes only, and should be applied with engineering judgment." (Section 6C.04, Guidance 06)

Taper

- Provides smooth flow from one lane to another

- Types of tapers:
  1) Shoulder taper
  2) Shifting taper
  3) Merging taper
  4) Downstream taper

Note: Merging, Shifting and Shoulder tapers should be at least the distance shown in the figure



Taper Length

Use Tables 6C-3 and 6C-4

Table 6C-3. Taper Length Criteria for Temporary Traffic Control Zones

Type of Taper	Taper Length
Merging Taper	At least L
Shifting Taper	At least 0.5 L
Shoulder Taper	At least 0.33 L
One-Lane, Two-Way Traffic Taper	50 feet minimum, 100 feet maximum
Downstream Taper	100 feet per lane

Note: Use Table 6C-4 to calculate L

Table 6C-4. Formulas for Determining Taper Length

Speed (S)	Taper Length (L) in feet
40 mph or less	L = WS^2 / 60
45 mph or more	L = WS

Where:
L = Taper length (ft)
W = Width of offset (ft)
S = Posted speed limit, or off-peak 85th-percentile speed prior to work starting, or the anticipated operating speed (mph)

Taper Length

Example:

a) Compute merging taper length when speed limit is 35 mph and width of the closed lane is 12 ft.

$$L = \frac{WS^2}{60} = \frac{12 * 35^2}{60} = 245\ ft$$

b) What would be the taper length is operating speed is 70 mph for the same offset width?

$$L = WS = 12 * 70\ = 840\ ft$$

Note:

Doubling speed increased taper length by more than 3 times

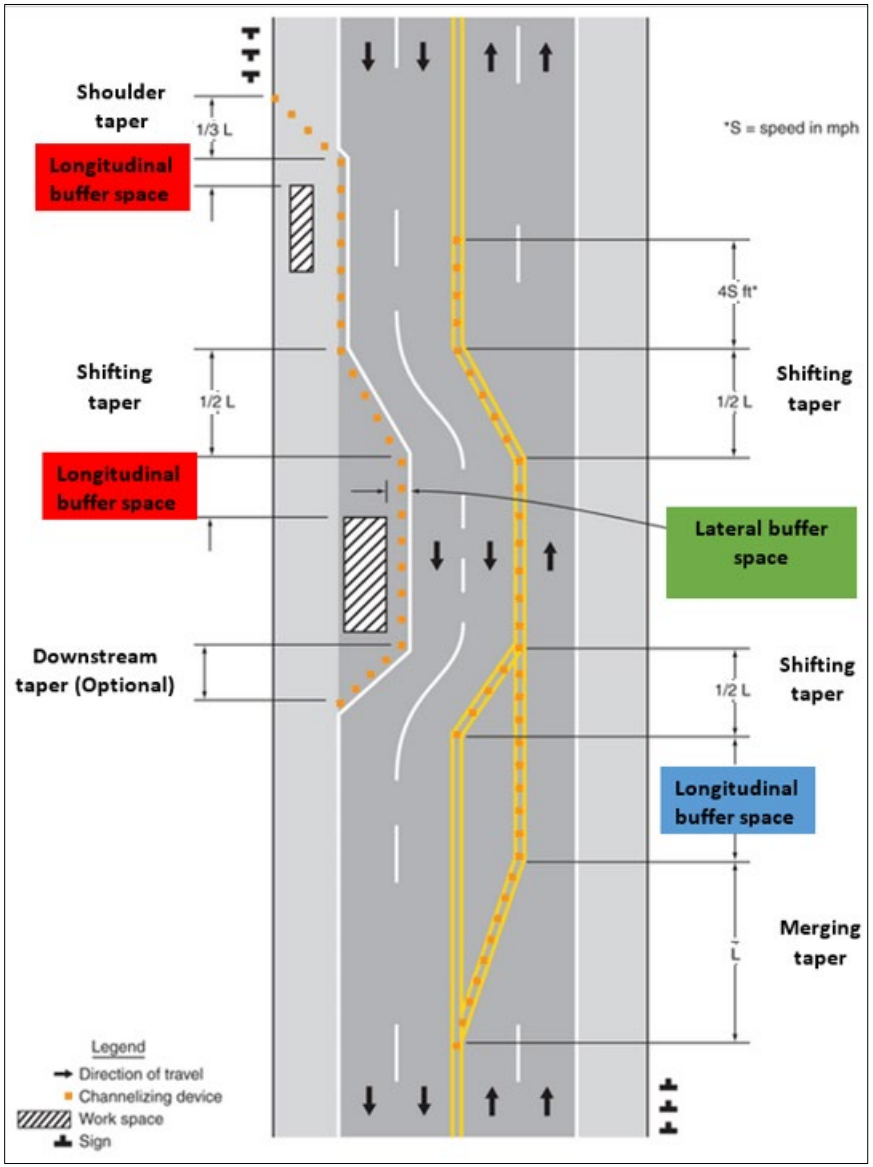
Buffer Space

1) Longitudinal:

- In advance of work space, or
- to "separate opposing road user flows that use portions of the same traffic lane"

2) Lateral:

- To separate traffic space from work space



Longitudinal Buffer Length

- Are given in Table 6C-2
  - Equal to Stopping Sight Distance (SSD)
  - SSD increases with speed

Lateral Buffer Width

- "The width of a lateral buffer space should be determined by engineering judgment"
  (section 6C.06, Guidance 15)

Table 6C-2. Stopping Sight Distance as a Function of Speed

Speed*	Distance
20 mph	115 feet
25 mph	155 feet
30 mph	200 feet
35 mph	250 feet
40 mph	305 feet
45 mph	360 feet
50 mph	425 feet
55 mph	495 feet
60 mph	570 feet
65 mph	645 feet
70 mph	730 feet
75 mph	820 feet

** Posted speed, off-peak 85th-percentile speed prior to work starting, or the anticipated operating speed*

Chapter 6G: Type of Temporary Traffic Control Zone Activities

5 Categories of WZ (based on their duration):

A. Long-term stationary: "occupies a location more than 3 days".

B. Intermediate-term stationary: "occupies a location more than one daylight period up to 3 days, or nighttime work lasting more than 1 hour."

C. Short-term stationary: "daytime work that occupies a location for more than 1 hour within a single daylight period."

D. Short duration: "occupies a location up to 1 hour."

E. Mobile: "moves intermittently or continuously."

Long-term stationary WZ
(Source: http://www.mmucc.us/mmucc-training/lessons/crashevents/mostharmfulevent_files/mostharmfulevent12.htm)

Short-term stationary WZ
(Source: http://www.ops.fhwa.dot.gov/wz/resources/final_rule/webcast/020112wztpdi/rush_ppt/rush.htm)

Chapter 6H. Typical Applications (Standard Plans)

46 Typical Applications (TAs), based on work duration and location

Table 6H-1. Index to Typical Applications

Typical Application Description	Typical Application Number
Work Outside of the Shoulder (see Section 6G.06)	
Work Beyond the Shoulder	TA-1
Blasting Zone	TA-2
Work on the Shoulder (see Section 6G.07 and 6G.08)	
Work on the Shoulder	TA-3
Short Duration or Mobile Operation on a Shoulder	TA-4
Shoulder Closure on a Freeway	TA-5
Shoulder Work with Minor Encroachment	TA-6
Work Within the Traveled Way of a Two-Lane Highway (see Section 6G.10)	
Road Closed with a Diversion	TA-7
Roads Closed with an Off-Site Detour	TA-8
Overlapping Routes with a Detour	TA-9
Lane Closure on a Two-Lane Road Using Flaggers	TA-10
Lane Closure on a Two-Lane Road with Low Traffic Volumes	TA-11
Lane Closure on a Two-Lane Road with Traffic Control Signals	TA-12
Temporary Road Closure	TA-13
Haul Road Crossing	TA-14
Work in the Center of a Road with Low Traffic Volumes	TA-15
Surveying Along the Center Line of a Road with Low Traffic Volumes	TA-16
Mobile Operations on a Two-Lane Road	TA-17
Work Within the Traveled Way of an Urban Street (see Section 6G.11)	
Lane Closure on a Minor Street	TA-18
Detour for One Travel Direction	TA-19
Detour for a Closed Street	TA-20

TAs highlighted are later analyzed with the WZ tools

Chapter 6H. Typical Applications

Continued…

Work Within the Traveled Way at an Intersection and on Sidewalks (see Section 6G.13)	
Lane Closure on the Near Side of an Intersection	TA-21
Right-Hand Lane Closure on the Far Side of an Intersection	TA-22
Left-Hand Lane Closure on the Far Side of an Intersection	TA-23
Half Road Closure on the Far Side of an Intersection	TA-24
Multiple Lane Closures at an Intersection	TA-25
Closure in the Center of an Intersection	TA-26
Closure at the Side of an Intersection	TA-27
Sidewalk Detour or Diversion	TA-28
Crosswalk Closures and Pedestrian Detours	TA-29
Work Within the Traveled Way of a Multi-Lane, Non-Access Controlled Highway (see Section 6G.12)	
Interior Lane Closure on a Multi-Lane Street	TA-30
Lane Closure on a Street with Uneven Directional Volumes	TA-31
Half Road Closure on a Multi-Lane, High-Speed Highway	TA-32
Stationary Lane Closure on a Divided Highway	TA-33
Lane Closure with a Temporary Traffic Barrier	TA-34
Mobile Operation on a Multi-Lane Road	TA-35
Work Within the Traveled Way of a Freeway or Expressway (see Section 6G.14)	
Lane Shift on a Freeway	TA-36
Double Lane Closure on a Freeway	TA-37
Interior Lane Closure on a Freeway	TA-38
Median Crossover on a Freeway	TA-39
Median Crossover for an Entrance Ramp	TA-40
Median Crossover for an Exit Ramp	TA-41
Work in the Vicinity of an Exit Ramp	TA-42
Partial Exit Ramp Closure	TA-43
Work in the Vicinity of an Entrance Ramp	TA-44
Temporary Reversible Lane Using Movable Barriers	TA-45
Work in the Vicinity of a Grade Crossing (see Section 6G.18)	
Work in the Vicinity of a Grade Crossing	TA-46

TAs highlighted are later analyzed with the WZ tools

Group Discussion

Q.3.1. What are the different “spaces” within the Activity Area?

Q.3.2. What is a longitudinal buffer space?
How is the length of that buffer estimated?

Q.3.3. What criteria does MUTCD use to categorize WZs?
What are the categories?

Q.3.4. What is the relationship between traffic speed and taper length? Is the relationship always linear?

DISCUSSION #4
WZ CAPACITY

Learning Objectives:

1) Learn the concept of WZ capacity

2) Identify factors that affect WZ capacity

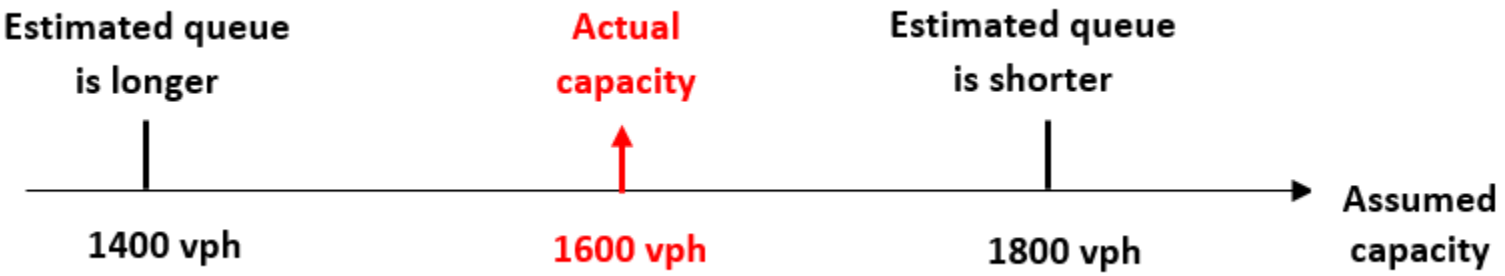
3) Understand different models to estimate WZ capacity

Why is Capacity Important?

Accurate estimation of capacity is important in finding reliable delay and queue length:

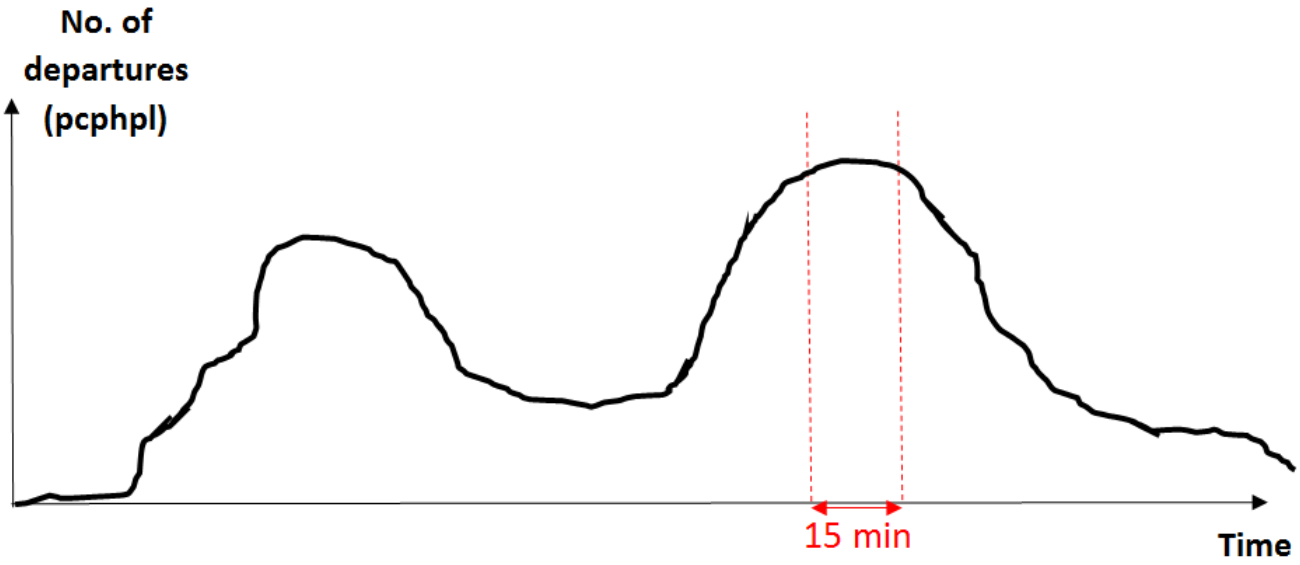
- Capacity underestimation → Queue overestimation
- Capacity overestimation → Queue underestimation

Example:



Definition of Capacity

Capacity is “the maximum sustainable hourly flow rate ….under prevailing conditions” (HCM 2010)



Demand profile

Factors Affecting Capacity *

There are 4 categories of factors:

1) Construction Factors

2) WZ Geometry

3) Traffic-related Factors

4) General Factors

* ***Source:***
- *Traffic Analysis Toolbox Volume XII: Work Zone Traffic Analysis – Applications and Decision Framework*

Factors Affecting Capacity *

1) Construction Factors:

a) Work intensity
b) Work zone duration (long-term or short-term)
c) Work time (daytime or nighttime)
d) Work day (weekday or weekend)

These factors will be discussed in Modules 2, 3, and 4

Factors Affecting Capacity *

2) WZ Geometry:

a) Number of lanes
b) Number of lanes closed
c) Lane width
d) Lateral clearance
e) Work zone layout
(e.g. Lane closure, crossover, and lane shifting only)
f) Length of work zone
g) Presence of ramps

These factors will be discussed in Modules 2, 3, and 4

Factors Affecting Capacity *

3) Traffic-related Factors:

a) Percentages of trucks
b) Work zone speed limit
c) Driver composition
(Commuters or non-commuters)
d) Presence of traffic control devices

These factors will be discussed in Modules 2, 3, and 4

Factors Affecting Capacity *

4) General Factors:

a) Work zone location (urban or rural)

b) Weather conditions

(Rain and snow adversely affect capacity)

c) Pavement conditions

(Dry, wet, or icy)

d) Pavement grade (Slope of road)

(Affects PCE)

These factors will be discussed in Module 3 (HCM Procedure)

How to Estimate WZ Capacity

A) HCM 2010 method (the same formula in HCM 1985):

- For SHORT term WZs:

$$C_a = \{(1600 + I) * f_{HV} * N\} - R$$

C_a: Adjusted capacity (vph)

I : Work intensity adjustment (pcphpl),
(Ranges between ±160 pcphpl)

f_{HV}: Heavy vehicle adjustment factor

N : Number of open lanes through the WZ

R : Adjustment for presence of on-ramp in WZ (vph)

(Used in QDAT & MoDOT Spreadsheets – Module 2)

How to Estimate WZ Capacity

A) HCM 2010 method:

- For LONG term WZs: Lookup table

State	Normal Lanes to Reduced Lanes						Source
	2 to 1	3 to 2	3 to 1	4 to 3	4 to 2	4 to 1	
TX	1,340		1,170				(4)
NC	1,690		1,640				(5)
CT	1,500-1,800		1,500-1,800				(6)
MO	1,240	1,430	960	1,480	1,420		(7)
NV	1,375-1,400		1,375-1,400				(6)
OR	1,400-1,600		1,400-1,600				(6)
SC	950		950				(6)
WA	1,350		1,450				(6)
WI	1,560-1,900		1,600-2,000		1,800-2,100		(6, 8)
FL	1,800		1,800				(9)
VA	1,300	1,300	1,300	1,300	1,300	1,300	(10)
IA	1,400-1,600	1,400-1,600	1,400-1,600	1,400-1,600	1,400-1,600	1,400-1,600	(11)
MA	1,340	1,490	1,170	1,520	1,480	1,170	(12)
Default	1,400	1,450	1,450	1,500	1,450	1,350	

Source: Adapted from Chatterjee et al. (*13*).

HCM 2010 Exhibit 10-14: Capacity of Long Term Construction Zones (veh/h/ln)

How to Estimate WZ Capacity

B) NCHRP 3-107 / HCM 2016:

Will be discussed in Module 3

C) Using speed-flow curves of WorkZoneQ:

Will be discussed in Module 4 (also in Appendix I)

Group Discussion

Q.4.1. What is the effect of capacity overestimation on queue length?

Q.4.2. Mention at least 3 geometry factors and 3 traffic-related factors that affect capacity

Q.4.3. How does HCM 2010 estimate capacity for short-term WZs? Is it similar for long-term WZs?

Discussion #5
Work Zone Analysis and Queue

Learning Objectives:

1) Identify typical methods for WZ analysis

2) Learn the different types of queue and how to estimate it using input-output methods

WZ Analysis

- Appropriate WZ analysis can improve planning, design, operation and safety

- **Mobility and safety criteria** vary between states. Common performance measures are:
  - Delay
  - Queue length and duration

- Different WZ **analysis approaches are available**

Approaches to Conduct WZ Analysis

Factors Performance Measures	Summary	Transportation Modeling Approach: Sketch-Planning and HCM Methodologies	Travel Demand Models	Traffic Signal Optimization	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation	Case Study
Measure of Effectiveness	●= Performance measure is often calculated by the transportation modeling approach. ⦸= Performance measure is sometimes calculated by the transportation modeling approach. ○= Performance measure is rarely calculated by the transportation modeling approach. n/a = Transportation modeling approach should not be used to calculate the performance measure.							
Travel Time	Amount of time it takes vehicles to travel through the work zone.	●	⦸	n/a	○	●	●	Utah DOT I-15 Reconstruction Design-Build Evaluation Glacier National Park: Going to the Sun Road Rehabilitation Project Caltrans I-15 Pavement Reconstruction Project
Delay	Amount of time drivers spend in traveling through the work zone.	●	⦸	n/a	○	●	●	Yosemite Nation Park: Yosemite Village Roadway Reconstruction
Queue Length	Number of vehicles or total length of vehicles queued to travel through the work zone due to reduction in roadway capacity caused by the construction.	●	n/a	n/a	○	●	●	Zion National Park: Entrance Booth Reconstruction Woodrow Wilson Bridge: Roadway Closure Analysis

Tools covered in this training

Not covered in this training.
Licensed software and extensive training required

* ***Source:***
- *Traffic Analysis Toolbox Volume IX: Work Zone Modeling and Simulation – A guide for Analysts*

Sketch-planning Tools

- **Simple** methods, yield approximate results and estimates before deciding if more complex tools are needed
- Require **fewer calculations**/equations and fewer inputs
- They also provide **fewer outcomes** compared to simulation
- **Suitable** for:
  - Individual WZs
  - Straightforward cases/conditions
  - Analysis of immediate area surroundings of the WZ

Types of Queue

1) **Stopped Queue**:

Vehicles are stopped or nearly stopped. **Spacing** between vehicles is short

2) **Moving Queue**:

Vehicles move at much lower speed than expected speed. **Spacing** between vehicles depends on speed

Two methods for Queue Analysis

Cumulative input-output

- Simpler approach
- Rough estimations of "**stopped" queue** length

Congestion growth-shrinkage
(CTM of Shockwave propagation)

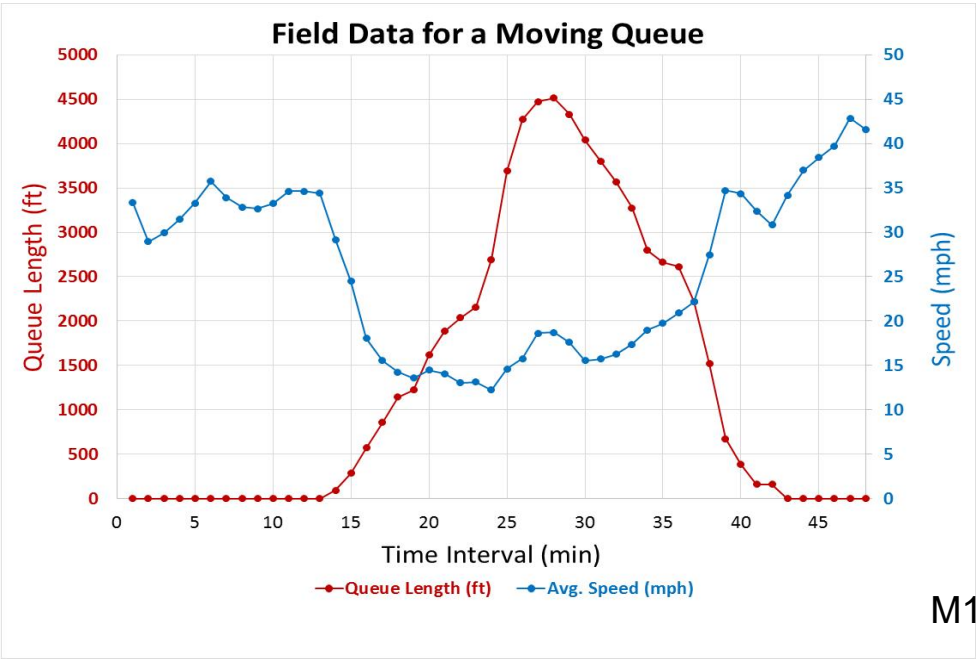
- More complex approach
- More accurate "**stopped" queue** length
- Analysis of **moving queues**

Tools covering both methods will be presented

When do We Have Queue?

1. **Demand < Capacity** ⇨ **No queue**
2. **Demand = Capacity** ⇨ **May or may not have queue**
3. **Demand > Capacity** ⇨ **Queue**

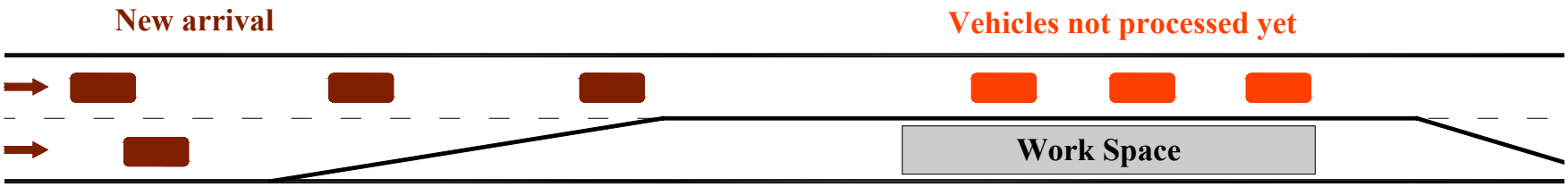
- **Queue length** is expressed in distance (ft, miles) or number of vehicles
- Example of a moving queue:



Number of Excess Vehicles using Cumulative Values

- **No. of excess vehicles ("queue") = Demand – Capacity**

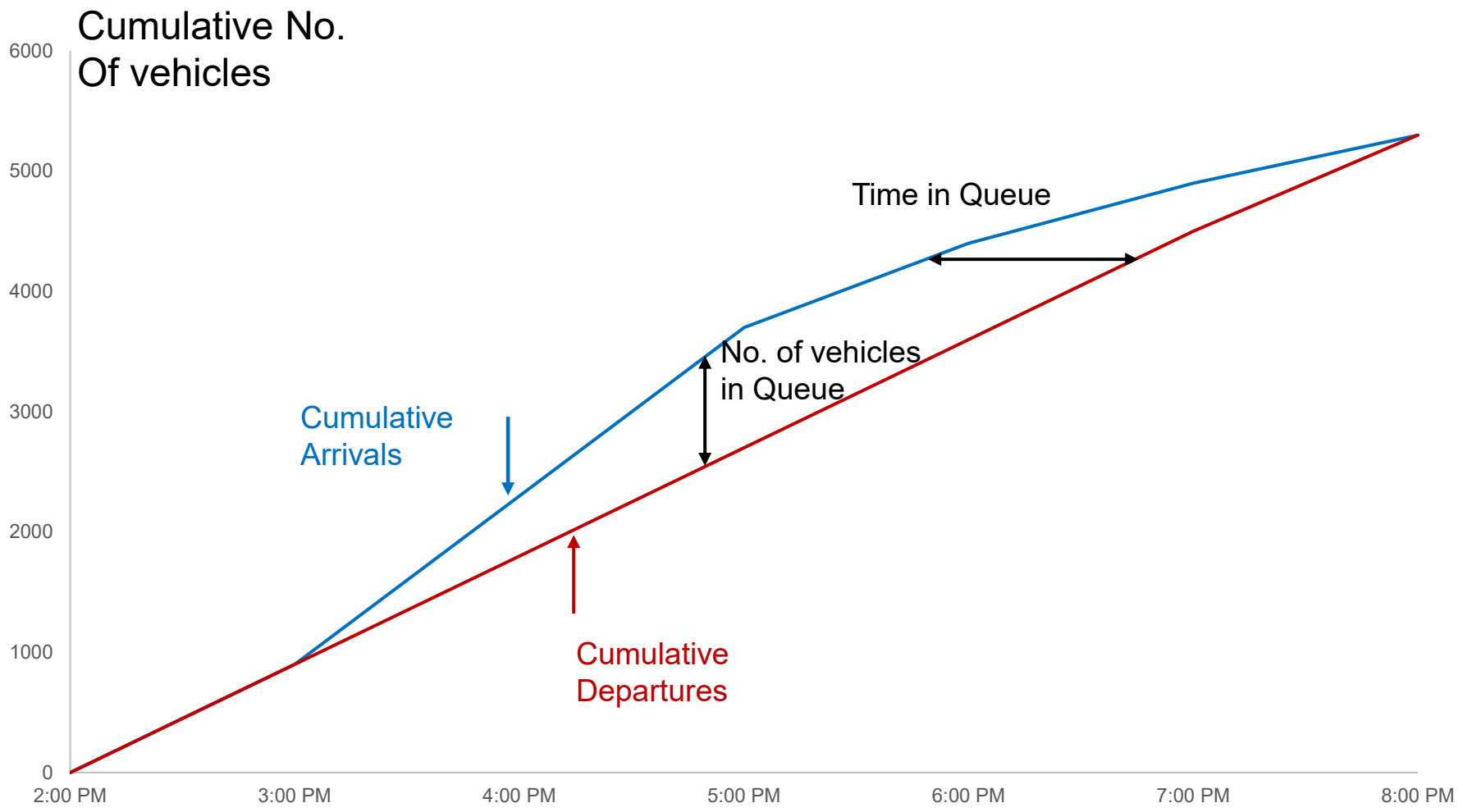
Demand (for an interval) = (New Arrival) + (No. of vehicles not processed yet)



- **Example:**

Interval	Arrival	Capacity	Cumulative Arrival	Cumulative Departure	Excess Vehicles
2 - 3 pm	900	900	900	900	**0**
3 - 4 pm	1400	900	2300	1800	**500**
4 - 5 pm	1400	900	3700	2700	**1000**
5 - 6 pm	700	900	4400	3600	**800**
6 - 7 pm	500	900	4900	4500	**400**
7 - 8 pm	400	900	5300	5300	**0**

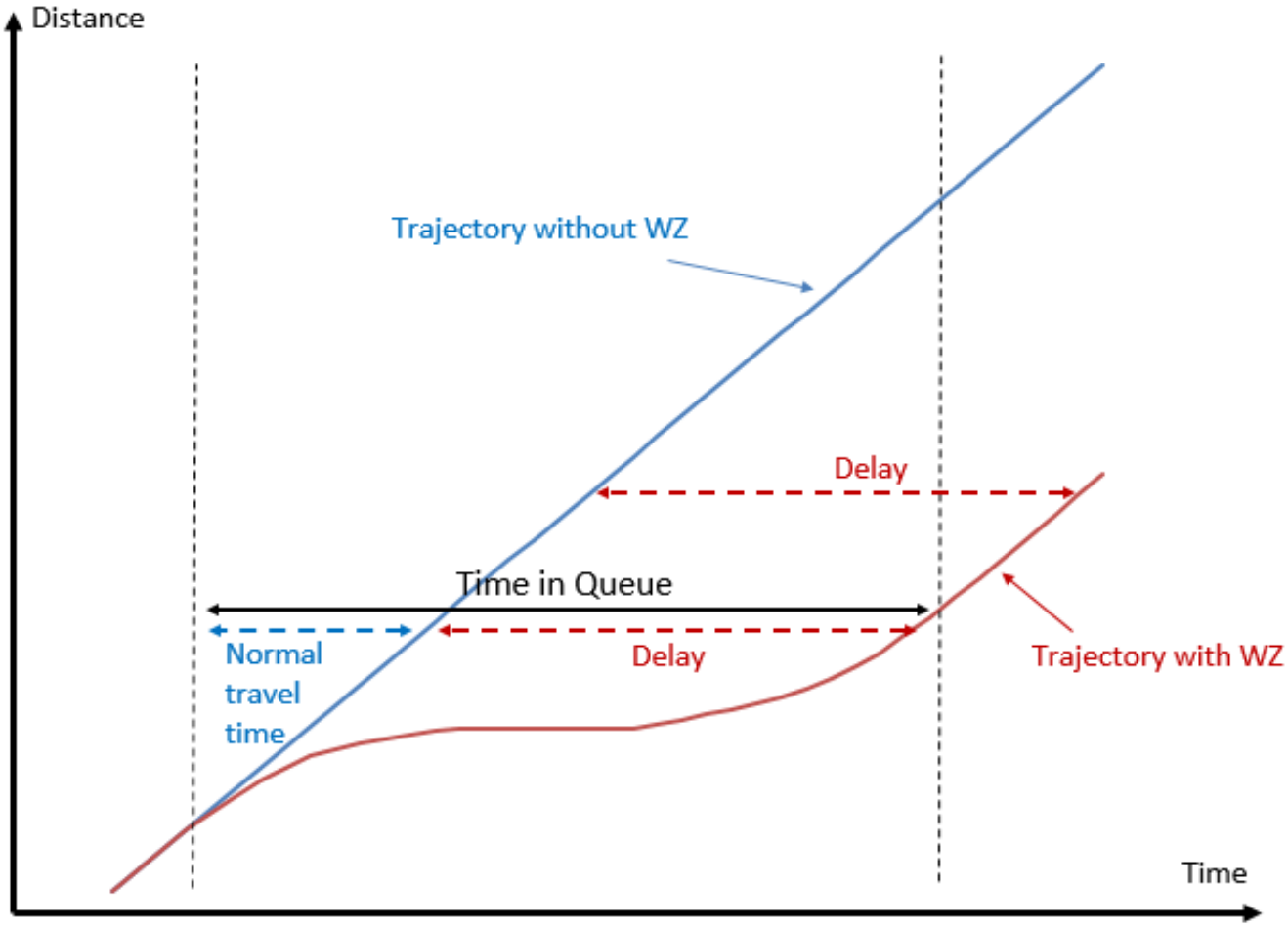
Input-Output Analysis for Freeways



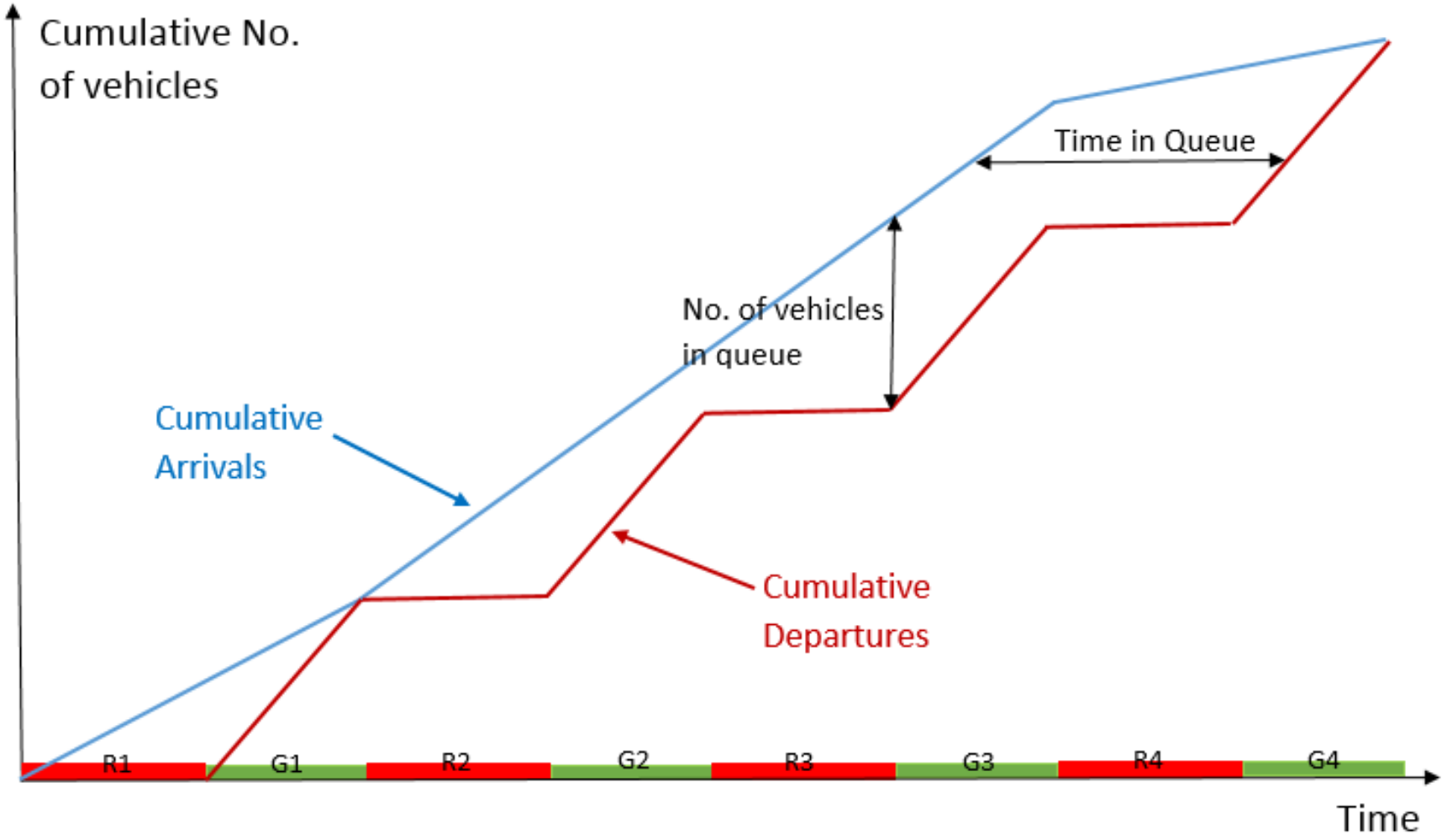
Is Delay Equal to Time Spent in Queue?

Freeways

Time in queue is NOT equal to d**elay**



Input-Output Analysis for Intersection/ one-lane two way Operation



Group Discussion

- Q 5.1 : What are some advantages/disadvantages of cumulative input-output analysis?
- Q 5.2 : In general, do vehicles have larger spacing in stopped queue or in moving queue?
- Q 5.3 : Which method of queue estimation is appropriate for stopped queues? (Cell transmission, cumulative input-output, or both)
- Q 5.4 : Which method of queue estimation is appropriate for moving queues? (Cell transmission, cumulative input-output, or both)

MODULE 2

Input-Output Tools

Tool 1: QDAT Spreadsheet (TxDOT)

Tool 2: MoDOT Spreadsheet

Tool 1

QDAT Spreadsheet (TxDOT)

QDAT Texas DOT

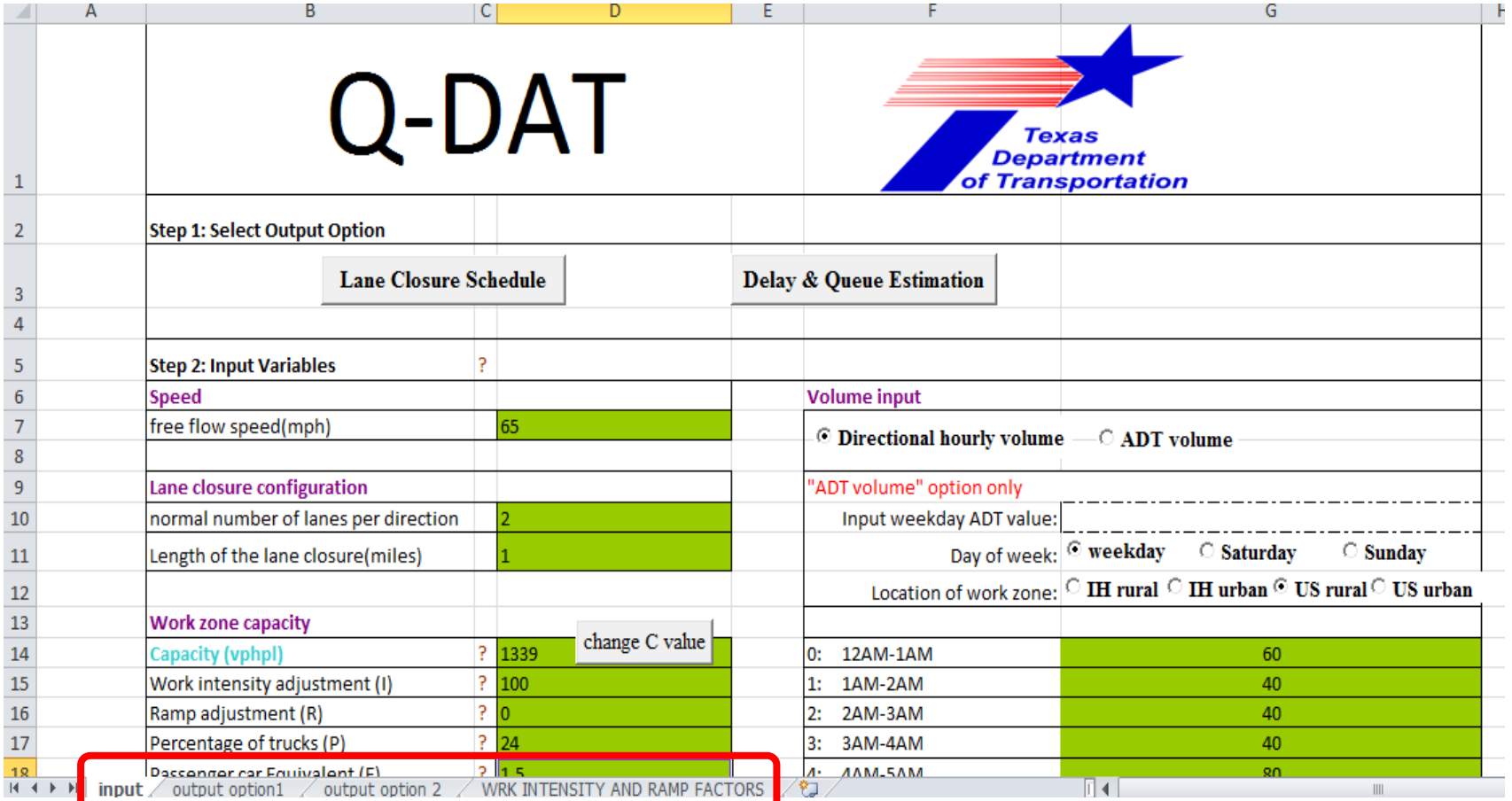
- Is an Excel spreadsheet with macros. Similar logic used in QUEWZ
- Latest version from August 2010
- Capacity follows HCM 2000 **or** it can be input manually
- Created for full-access controlled roadways (**freeways/expressways**)
- However, as stated by the authors:

  "…the tool can provide reasonable estimates of queues and delays on partially-controlled access **multi-lane roadways** (i.e., US and SH highways)…" as long as the WZ is not located near intersections

Interface

4 worksheets:

- Input
- Output option 1
- Output option 2
- Work intensity and ramp factors



Type of Analyses

ANALYSIS	OUTPUT
1) Delay and queue analysis	•Average Queue for each hour •Average Delay for each hour
2) Lane closure schedule	The hours that lane(s) can be closed without exceeding "Maximum acceptable delay" or "Critical length of queue"

1) Delay and Queue Analysis

INPUT DATA

Traffic Characteristics:

- Free flow speed
- Traffic volume

Work Zone Characteristics:

- Number of lanes (without WZ)
- Length of lane closure
- Capacity
- Number of closed lanes
- Hour lane closure begins
- Hour lane closure ends

1) Delay and Queue Analysis

OUTPUT DATA

Generated for thee cases (as a form of “sensitivity analysis”):

Case	Capacity	Traffic Volume
~~Best Case~~ Call it Alternate Red	+10%	-10%
Expected	Specified by user	Specified by user
~~Worst Case~~ Call it Alternate Blue	-10%	+10%

* ***Source for conducting sensitivity analysis:***
- *Traffic Analysis Toolbox Volume XII: Work Zone Traffic Analysis – Applications and Decision Framework*

Example Problem #1
Delay and Queue Analysis

Traffic Characteristics:

Lane Closure

	2-3pm	3-4pm	4-5pm	5-6pm	6-7pm	7-8pm
Volume (veh/h/lane)	1200	1300	1500	1600	1200	1000

Percentage of trucks = 10%

WZ Characteristics:

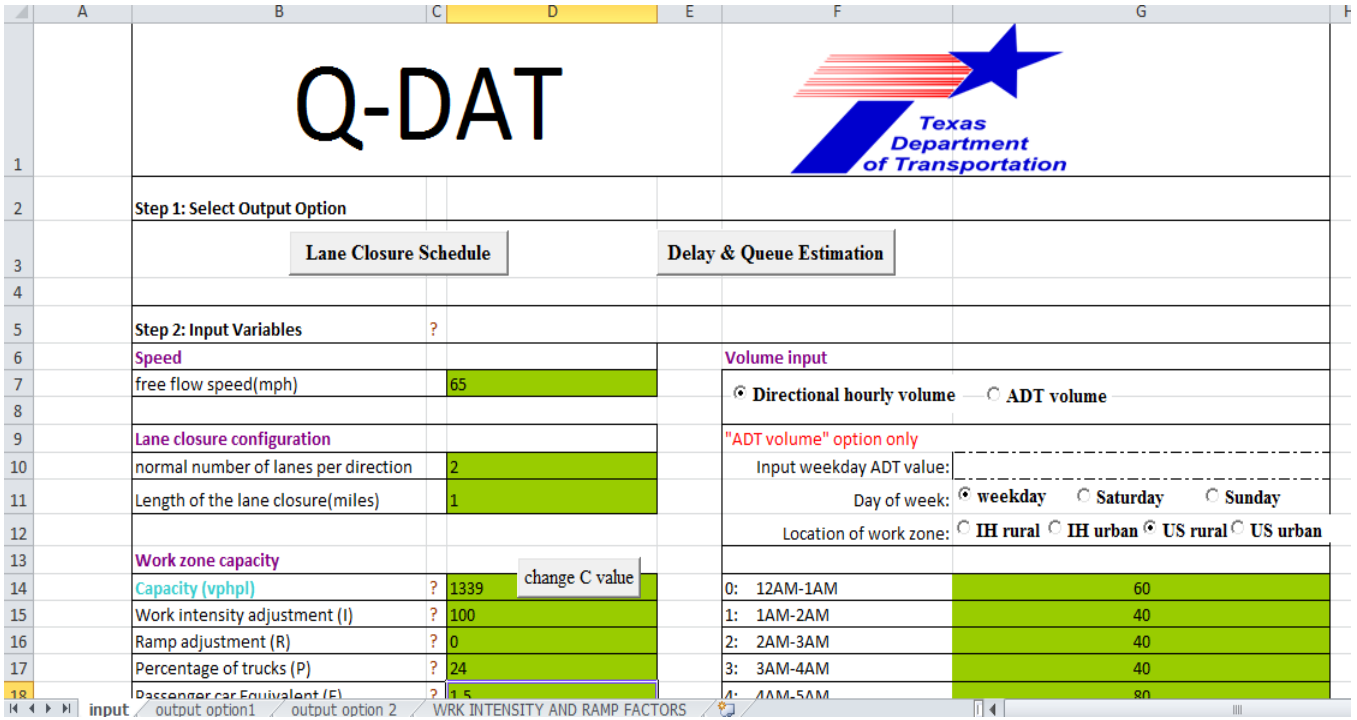
- Interstate Highway: one lane open, one lane closed for 1.5 miles
- Lane closure from 4pm to 7pm during daytime
- Info for HCM Capacity:
  - Speed limit outside of the WZ: 65 mph
  - Work activities next to travel lane (Work Intensity adjustment factor = 100)
  - No ramps closer than 1500 ft from the beginning of the taper (Adj. for ramps = 0)
  - Passenger car equivalents of trucks = 1.5

- What is the maximum delay and queue?
- At what time does the queue start and end?

Example Problem #1
Delay and Queue Analysis

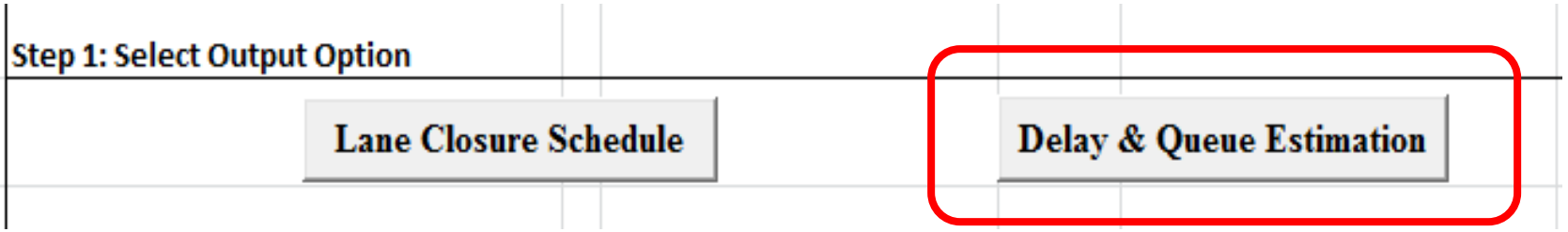
Open the QDAT spreadsheet to start the example

By default the file will open on the "input" tab



Input

Step 1/3: Select the type of analysis



When the analysis is selected, the background of input cells will change to **green**.

Input

Step 2/3: Input Data:

Cells with "?" give useful info about the variables

Step 2: Input Variables	?	
Speed		
free flow speed(mph)		65
Lane closure configuration		
normal number of lanes per direction		2
Length of the lane closure(miles)		1.5
Work zone capacity		
Capacity (vphpl)	?	1428
Work intensity adjustment (I)	?	100
Ramp adjustment (R)	?	0
Percentage of trucks (P)	?	10
Passenger car Equivalent (E)	?	1.5

change C value

Input cells

First, Input values as given in the example problem

Second, input values to calculate capacity

How is capacity calculated?
(Explained later)

Third, click this button to update capacity

change C value

Input

Step 2/3: Input Data

"Lane Closure Schedule" output option only		
Excessive Queuing	?	
◉ Critical length of Queue ○ Maximum acceptable delay		
Critical length of queue (miles)	?	1
Maximum acceptable delay(minutes)	?	20

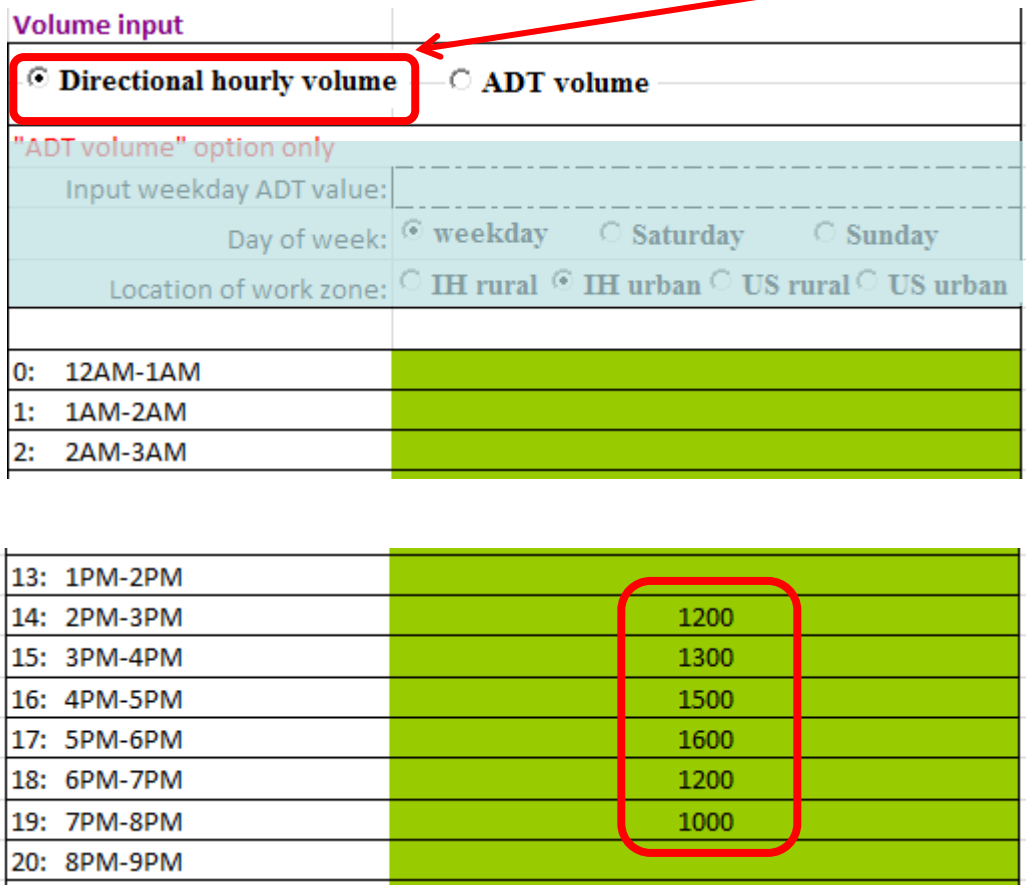
"Delay & Queue Estimation" output option only		
Schedule of Work Activity	?	
Number of Closed Lanes		1
Hour lane closure begins	?	16
Hour lane closure ends	?	19

Continue with these inputs

Numbers must be integer
(e.g. can't start at 4:30pm)

Input

Step 2/3: Volume Input



Select this option because we have hourly volumes

When "directional hourly volume" is selected, these options do not have any effect

Input the hourly volumes

Note: The ADT option estimates hourly volumes from daily counts based on data from Texas

Input

Step 3/3: Run the Program

Step 3: Run the Program	!			
		RUN		

Output

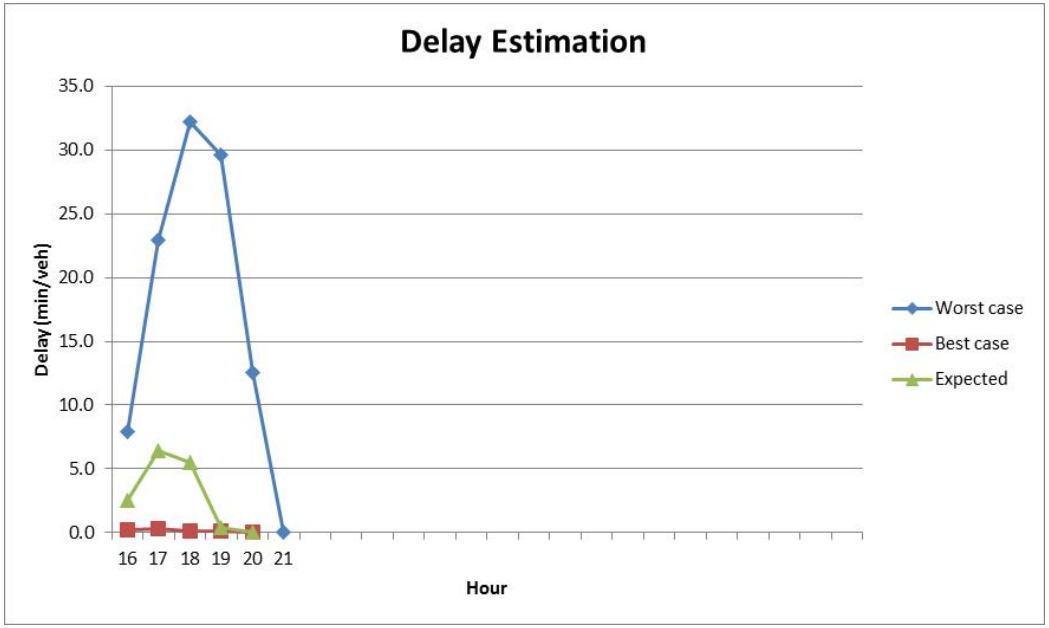
Go to "Output option 2" (the third worksheet)

Delay

Expected: Estimated Delay(min/veh)		
start hour	16	2.5
	17	6.4
	18	5.5
end hour	19	0.4
	20	0.0

Best case: Estimated Delay(min/veh)		
start hour	16	0.2
	17	0.3
	18	0.1
end hour	19	0.1
	20	0.0

Worst case: Estimated Delay(min/veh)		
start hour	16	7.9
	17	22.9
	18	32.2
end hour	19	29.6
	20	12.5
	21	0.0



Note:

significant variations in Delay among the 3 cases.

Which one should be used?

The "**Expected**" Delay

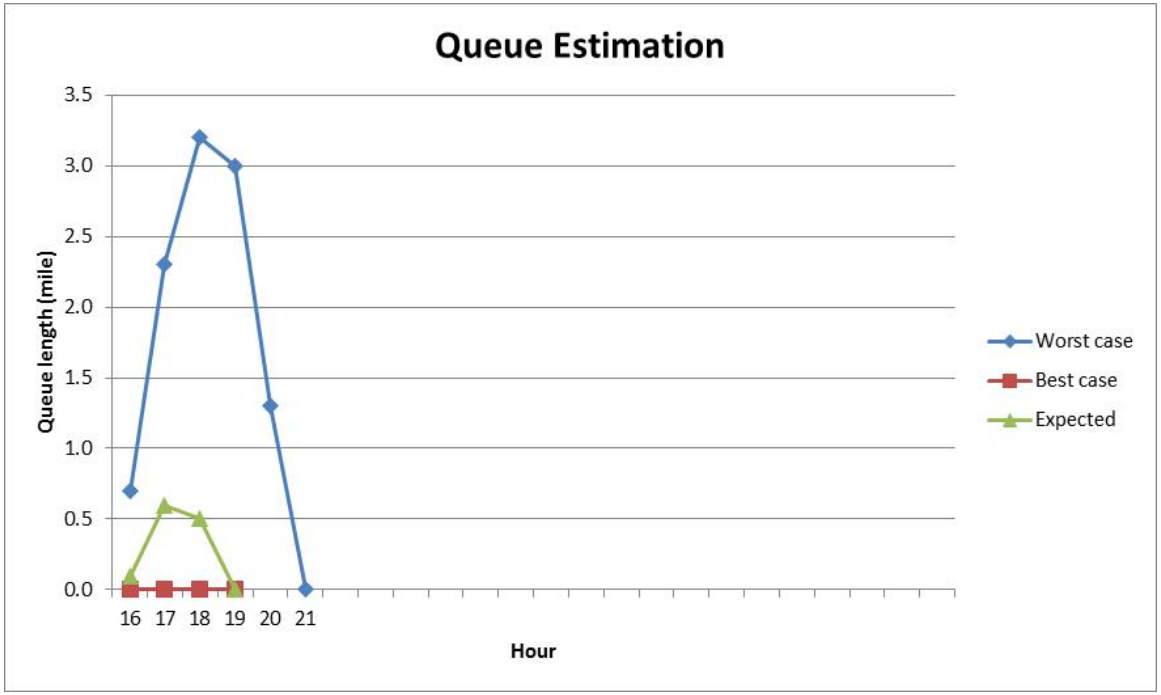
Output

Queue

Expected: Estimated Queue(mile)		
start hour	16	0.1
	17	0.6
	18	0.5
end hour	19	0.0

Best case: Estimated Queue(mile)		
start hour	16	0.0
	17	0.0
	18	0.0
end hour	19	0.0

Worst case: Estimated Queue(mile)		
start hour	16	0.7
	17	2.3
	18	3.2
end hour	19	3.0
	20	1.3
	21	0.0



Note:

significant variations in queue among the 3 cases.

Which one should be used?

The "**Expected**" Queue

Calculations in QDAT

- **Capacity (based on HCM 2000)**
- **Queue length**
- **Delay**

Capacity

- Capacity can be entered as an input by the user

OR

- It can be computed when the change C value button is clicked, from this formula:

$$\textbf{Capacity} = (1600 - I - R) \times (Number\ of\ open\ lanes) \times \frac{100}{100+[P*(E-1)]}$$

Heavy vehicle adj. factor

I = adjustment for the effect of work activities on capacity
R = adjustment for entrance ramp traffic entering the highway right before the lane closure
P = percent trucks
E= passenger car equivalents of trucks

Guidance on these variables given in the worksheet "WRK INTENSITY AND RAMP FACTORS"

Capacity

I = adjustment for the effect of work activities on capacity

- Default value = 0 (one open lane, but buffer between traffic and work activity)
- Range: ± 160
- Guidance:

Scenario *	*I*
Work occurring behind concrete barrier	-160 (increase capacity)
2 or more lanes open through the WZ	-100 (increase capacity)
Work occurring right next to the travel lane	100 (decrease capacity)
One lane open, large trucks entering and exiting the WZ	160 (decrease capacity)

Scenarios are described as shown in QDAT instructions (Word file)
Similar descriptions found in the spreadsheet

Capacity

R = adjustment for entrance ramp right before the lane closure

- Default value = 0 (no effect)
- If there is a ramp upstream of lane closure within 500 feet:
  - *R* = average ramp volume during the hours of the lane closure *
- If the entrance ramp serves an extremely large demand:
  - Traffic in the right lane will alternate with the ramp, therefore: maximum R = 800 *

**** R values as shown in QDAT instructions (Word file). The worksheet "Input" has been updated to accept a value up to 800, but the worksheet "WRK INTENSITY AND RAMP FACTORS" has not been updated to reflect this change (it shows up to 160)***

Capacity

P = percent trucks

- Default value = 8%

E= passenger car equivalents of trucks

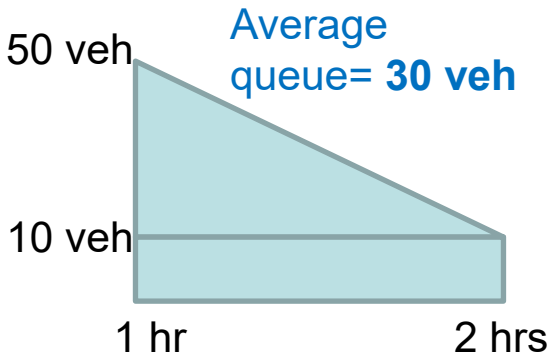
- Default value = 1.7 *

**** This default value is the same as in HCM 1985.***
Default value in HCM 2016 is 2.0 (1.5 in HCM 2010). Refer to HCM for further details

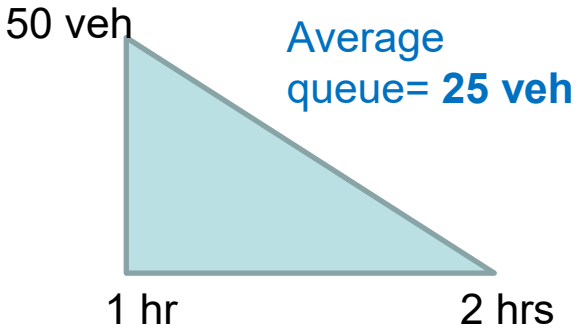
Queue Length

For each hour, it calculates the **average number of vehicles in queue** as the mean of initial and final number of vehicles in queue

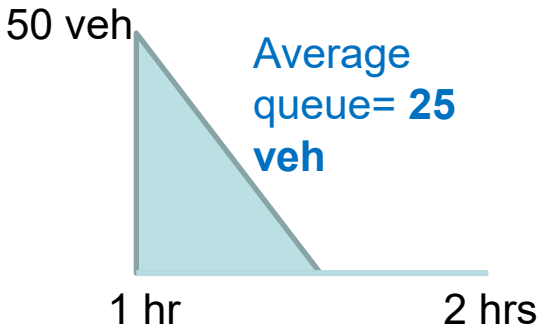
Example 1



Example 2



Example 3



Then, the **average queue LENGTH** is calculated as:

$$\textbf{Average Queue Length (Miles)} = \frac{Average\ \#\ veh\ in\ queue}{\#\ of\ lanes} \times \frac{40ft^{*} \times 1\ mile}{5280ft}$$

**** Vehicle spacing is assumed to be 40 ft for all queue length calculations***

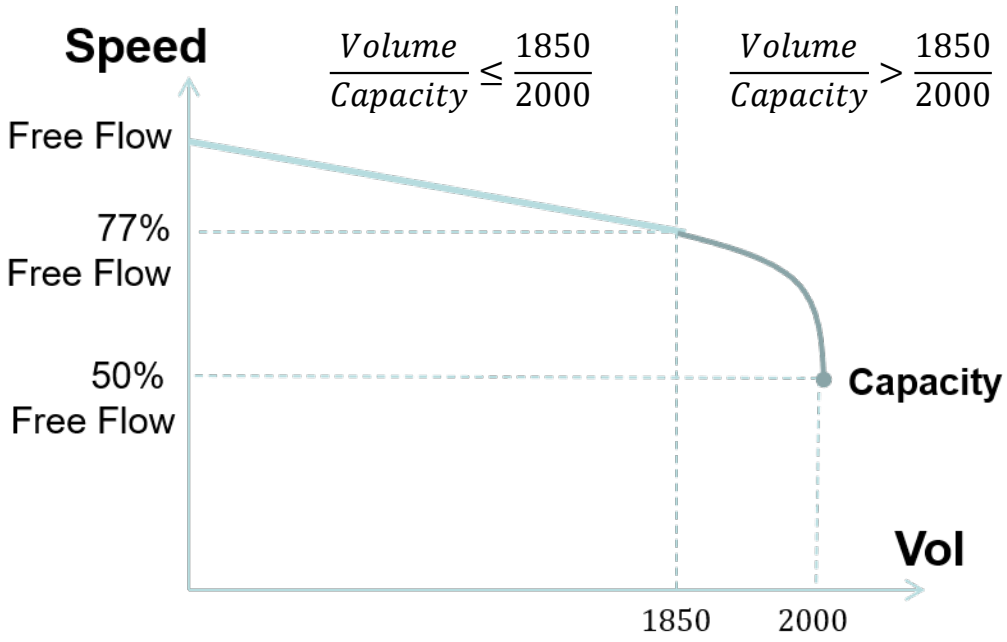
Delay

For each hour, **Delay = Travel time with WZ - Travel time without WZ**

$$TT_{without\ WZ} = \frac{Distance}{Speed} = \frac{Lane\ Closure + Queue\ length}{Speed}$$

Speed

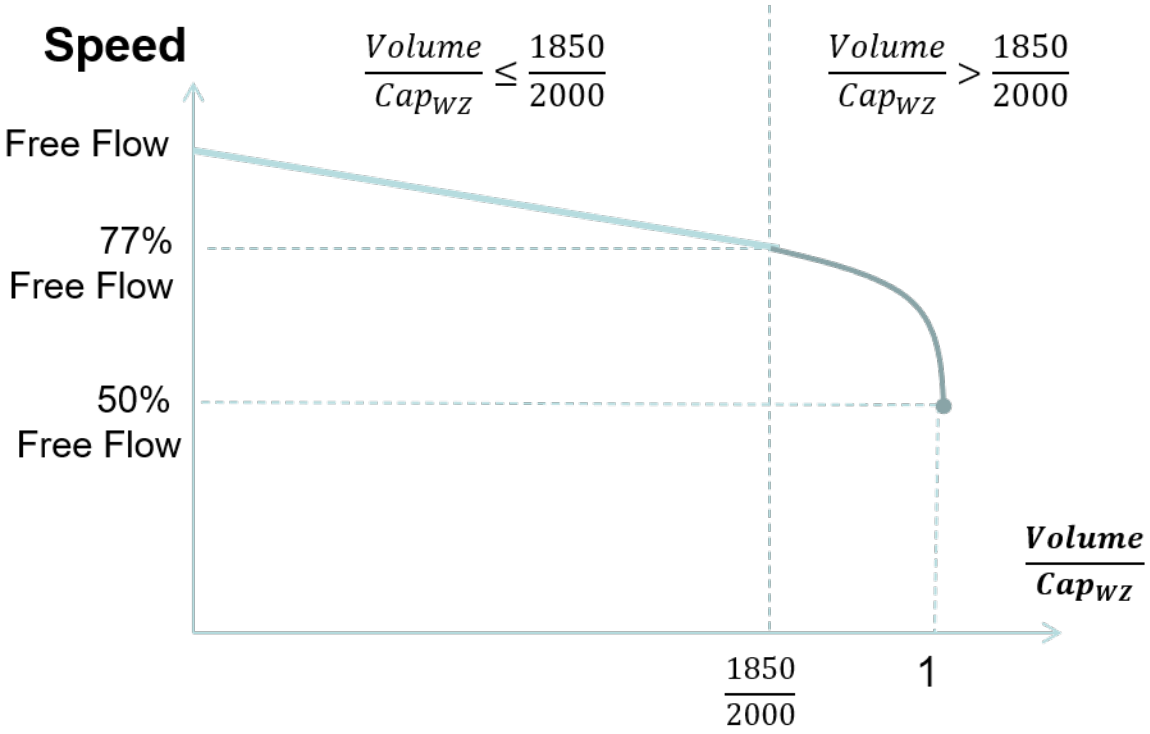
- Vol ≤ 1850 → speed from linear section
- Otherwise → speed from curved section



*** This graph does not change for different WZs and it is similar to the graph from HCM 1985**

Delay

$$TT_{with\ WZ} = \frac{Distance}{Speed} = \frac{Lane\ Closure}{Speed\ in\ WZ} + \frac{Queue\ Length}{Speed\ in\ the\ Queue}$$



*** This graph does not change for different WZs , and it is similar to HCM 1985 graph**

Delay

Speed in WZ

- If Queue > 0 → speed = 50% free flow
- If $\frac{Vol}{Cap_{WZ}} > 1$ → speed = 50% free flow
- $\frac{Vol}{Cap_{WZ}} \leq \frac{1850}{2000}$ → speed from linear section
- Otherwise → speed from curved section

Delay

Speed in the queue

Speed in the Queue = speed at capacity * (1-Factor)

$$\text{Factor} = \sqrt{1 - \frac{Capacity\ with\ WZ}{Capacity\ without\ WZ}}$$

This indicates that the speed in the queue (outside of the WZ) is lower than the speed at capacity (inside of the WZ)

Limitations QDAT

- WZ capacity does not change over time for a WZ

- For example, for a lane closure that lasts for 6 hours, the following cases can't be analyzed in QDAT:

  - If flagger stays for 2 hours (less than the total lane closure)
  - If police is present for 3 hours (less than the total lane closure)
  - If work intensity changes sometime during the 6 hours

Limitations QDAT

- Volume variations can be entered only in 1 hour intervals
- Lane width changes in WZ not considered
- Only “stopped” queue is reported: Vehicle spacing in queue is constant at 40 ft
- Can not do multiple time periods in one analysis

Capability of Spreadsheets

To consider the effects of	Spreadsheets			
	QDAT spreadsheet	MoDOT spreadsheet	HCM 2016 WZ capacity method	WZQ-Pro
1) Lane width				
2) Shoulder width				
3) Work intensity				
4) Speed limit inside WZ on capacity				
5) Speed control techniques in WZ				
6) Barrier type (concrete vs others)				
7) WZ capacity changes during analysis period.				
8) % of trucks changes during analysis period.				
9) Adverse weather conditions				
10) Night time operation				
11) Urban vs rural				
12) Flagger operation				

Tool 2

MoDOT Spreadsheet

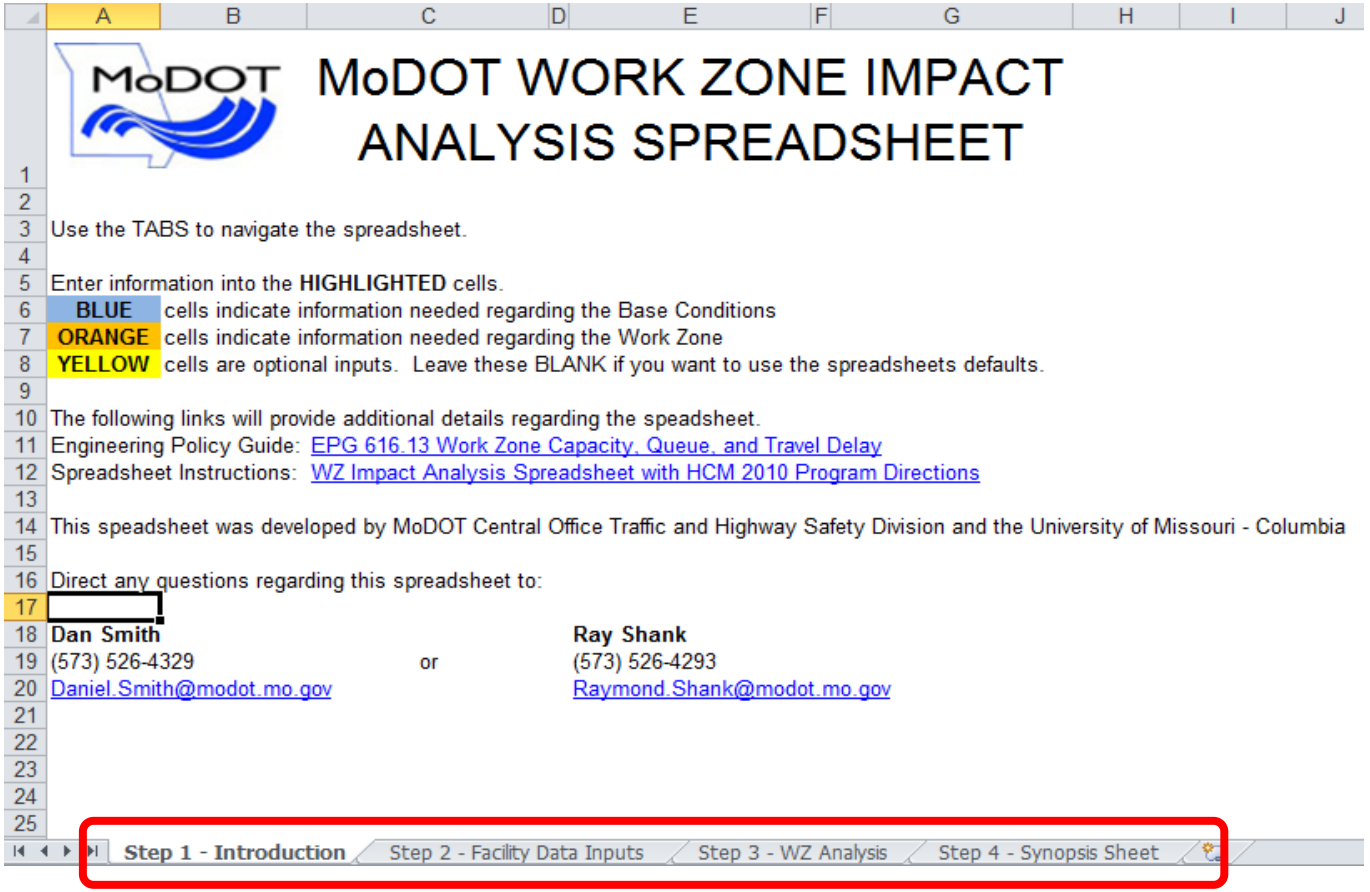
MoDOT - WZ Impact Analysis Spreadsheet

- Excel spreadsheet mainly for freeway use (similar to QDAT)
- Capacity is based on HCM 2010 **or** it can be input manually
- The spreadsheet generates:
  - Delay and queue estimation by hour
  - Total users costs, Max Queue Length, and Max Delay per day

Interface

4 worksheets:

- Step 1: Introduction
- Step 2: Facility Data Inputs
- Step 3: WZ Analysis
- Step 4: Synopsis Sheet



MoDOT WORK ZONE IMPACT ANALYSIS SPREADSHEET

Use the TABS to navigate the spreadsheet.

Enter information into the **HIGHLIGHTED** cells.

BLUE	cells indicate information needed regarding the Base Conditions
ORANGE	cells indicate information needed regarding the Work Zone
YELLOW	cells are optional inputs. Leave these BLANK if you want to use the spreadsheets defaults.

The following links will provide additional details regarding the speadsheet.
Engineering Policy Guide: EPG 616.13 Work Zone Capacity, Queue, and Travel Delay
Spreadsheet Instructions: WZ Impact Analysis Spreadsheet with HCM 2010 Program Directions

This speadsheet was developed by MoDOT Central Office Traffic and Highway Safety Division and the University of Missouri - Columbia

Direct any questions regarding this spreadsheet to:

Dan Smith
(573) 526-4329
Daniel.Smith@modot.mo.gov

or

Ray Shank
(573) 526-4293
Raymond.Shank@modot.mo.gov

Step 1 - Introduction | Step 2 - Facility Data Inputs | Step 3 - WZ Analysis | Step 4 - Synopsis Sheet

Example Problem #1
WZ Analysis and Users' Costs

Traffic Characteristics:

Lane Closure

	2-3pm	3-4pm	4-5pm	5-6pm	6-7pm	7-8pm
Volume (veh/h/lane)	1200	1300	1500	1600	1200	1000

Percentage of trucks = 10%

WZ Characteristics:

- Interstate Highway: one lane open, one lane closed for 1.5 miles
- Basic freeway segment (open lane capacity = 1900 veh/h/lane) ← Capacity for the specific traffic mix in this example
- Users' cost per car/h = $12.5; per truck/h = $25.2
- Lane closure from 4pm to 7pm during daytime
- Info for HCM Capacity:
  - Speed limit outside of the WZ: 65 mph
  - Workers and equipment less than 4ft from travel lane
  - Travel lane width = 11ft, level terrain
  - Passenger car equivalents of trucks = 1.5

- Find maximum queue length. At what time will there be queue?
- What is the expected users' cost associated to WZ congestion?

Step 1: Introduction

Open the MoDOT spreadsheet to start the example

Color coding and usage:

Use the TABS to navigate the spreadsheet.

Enter information into the **HIGHLIGHTED** cells.

BLUE	cells indicate information needed regarding the Base Conditions
ORANGE	cells indicate information needed regarding the Work Zone
YELLOW	cells are optional inputs. Leave these BLANK if you want to use the spreadsheets defaults.

Additional resources (including users' manual) and contact info:

The following links will provide additional details regarding the speadsheet.
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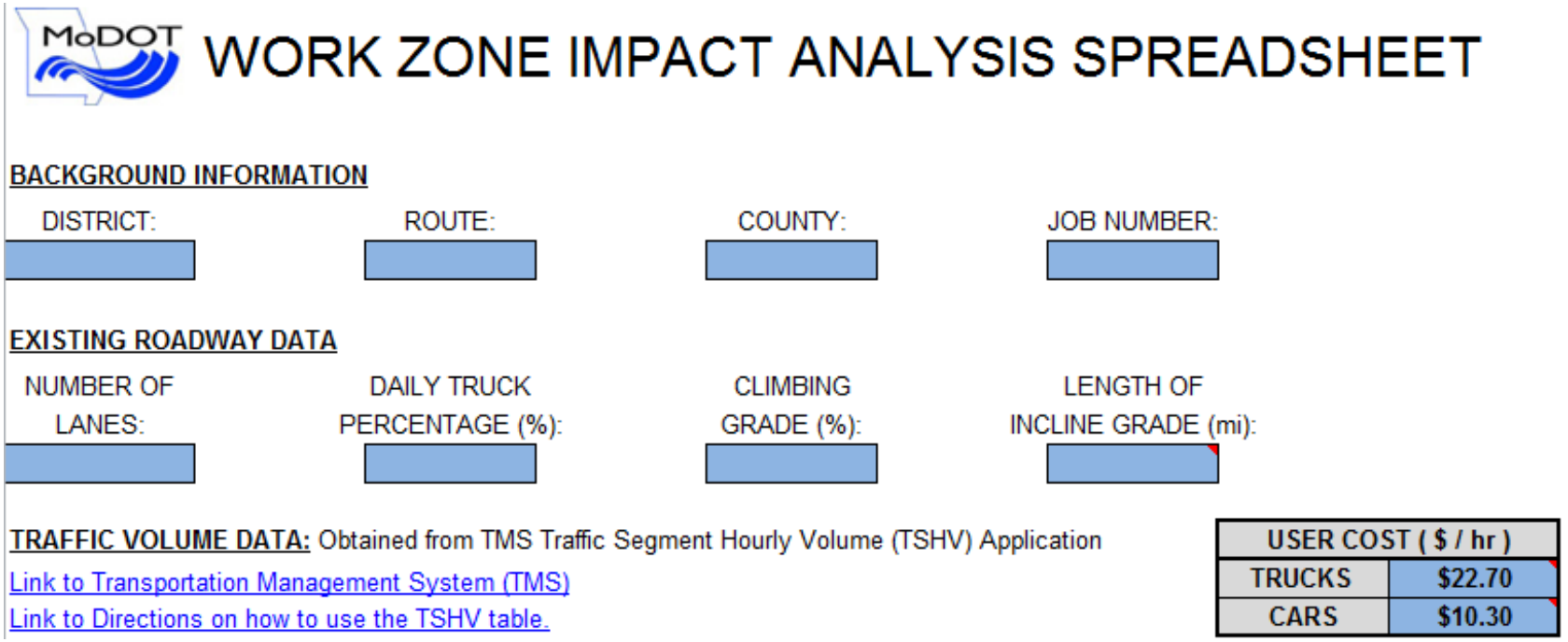
Step 2: Facility Data Inputs

Select the second tab "Step 2: Facility Data Inputs"



MoDOT WORK ZONE IMPACT ANALYSIS SPREADSHEET

BACKGROUND INFORMATION

DISTRICT: | ROUTE: | COUNTY: | JOB NUMBER:

EXISTING ROADWAY DATA

NUMBER OF LANES: | DAILY TRUCK PERCENTAGE (%): | CLIMBING GRADE (%): | LENGTH OF INCLINE GRADE (mi):

TRAFFIC VOLUME DATA: Obtained from TMS Traffic Segment Hourly Volume (TSHV) Application

Link to Transportation Management System (TMS)

Link to Directions on how to use the TSHV table.

USER COST ($ / hr)	
TRUCKS	$22.70
CARS	$10.30

Step 2: Facility Data Inputs

Input the Background Information and the Existing Roadway Data:

MoDOT WORK ZONE IMPACT ANALYSIS SPREADSHEET

BACKGROUND INFORMATION

DISTRICT:	ROUTE:	COUNTY:	JOB NUMBER:

EXISTING ROADWAY DATA

NUMBER OF LANES:	DAILY TRUCK PERCENTAGE (%):	CLIMBING GRADE (%):	LENGTH OF INCLINE GRADE (mi):
2	10%	< 2	0.00

TRAFFIC VOLUME DATA: Obtained from TMS Traffic Segment Hourly Volume (TSHV) Application

Link to Transportation Management System (TMS)

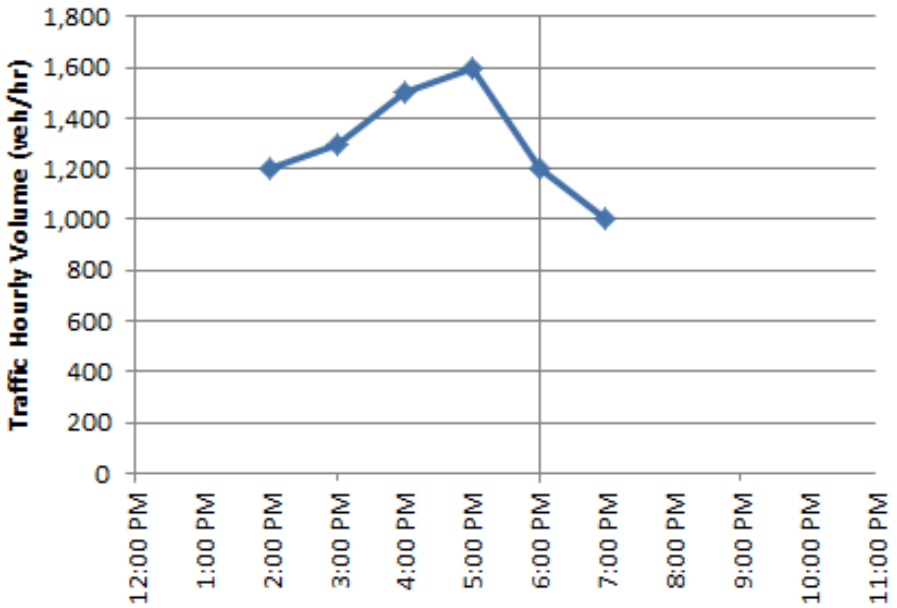
Link to Directions on how to use the TSHV table.

USER COST ($ / hr)	
TRUCKS	$25.20
CARS	$12.50

Step 2: Facility Data Inputs

Input the Demand:

Time of Day		
	10:00 - 11:00 AM	
	11:00 - 12:00 NOON	
PM	12 NOON - 1:00 PM	
PM	1:00 - 2:00 PM	
PM	2:00 - 3:00 PM	1200
PM	3:00 - 4:00 PM	1300
PM	4:00 - 5:00 PM	1500
PM	5:00 - 6:00 PM	1600
PM	6:00 - 7:00 PM	1200
PM	7:00 - 8:00 PM	1000
PM	8:00 - 9:00 PM	
PM	9:00 - 10:00 PM	
PM	10:00 - 11:00 PM	
PM	11 PM - 12:00 MIDNIGHT	
TOTAL ADT		7800



A chart displaying the demands is automatically generated

Step 3: WZ Analysis

Input the WZ Data:

BASE CONDITIONS

Open Lane Capacity (veh/h/lane):	1900

Base Conditions Capacity (Total for ALL Lanes): 3800 veh/h

WORKZONE DETAILS

Work Description:	Example Module 2
Work Location:	Workers & equipment less than 4 feet from travel lane
Travel Lane Width (ft):	10 - 11.5
Number of Lanes Open:	1
ESTIMATED Work Zone Capacity (veh/h):	1248
USER DEFINED Work Zone Capacity (veh/h):	
Start Time:	4:00 PM
End Time:	7:00 PM
Duration of Closure (hrs):	3

RESULTS

Measure of Effectiveness	Base Conditions	Work Zone	Total
Max Queue Length (mi):	0.0	1.6	1.6
Max Delay (minutes):	0	29	29
Cost ($):	$0	$8,100	$8,100

Note: this value is for a specific traffic mix and is in veh/h/lane

This data is used to estimate the WZ capacity

User can enter a capacity value in yellow cell (this overrides the Estimated capacity)

Step 3: WZ Analysis

Computed Results

BASE CONDITIONS

Open Lane Capacity (veh/h/lane):	1900

Base Conditions Capacity (Total for ALL Lanes): 3800 veh/h

WORKZONE DETAILS

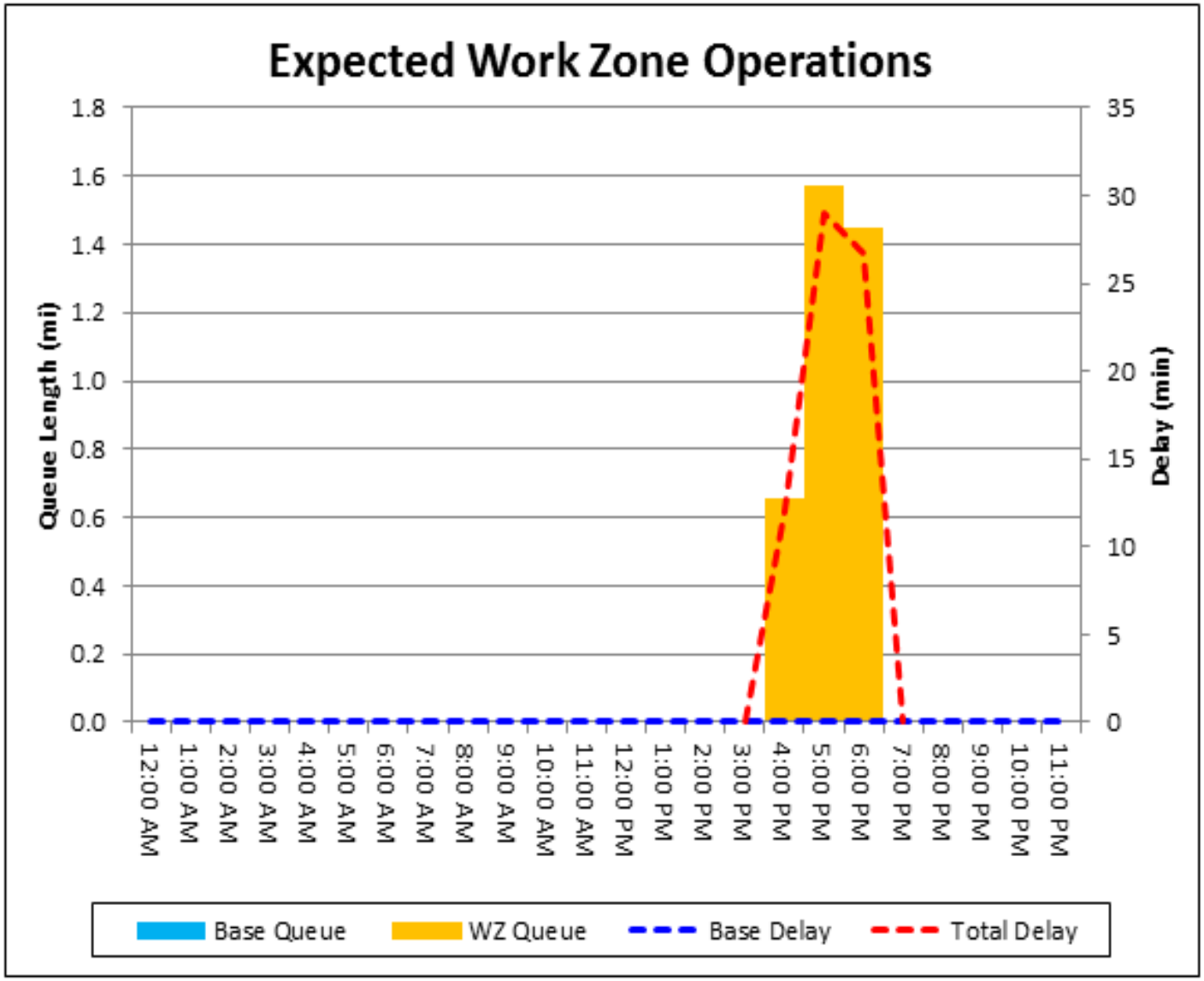
Work Description:	(Example: Pothole Patching - Close One Lane OR Joint Repair - Two Lanes Closed)
Work Location:	Workers & equipment less than 4 feet from travel lane
Travel Lane Width (ft):	10 - 11.5
Number of Lanes Open:	1
ESTIMATED Work Zone Capacity (veh/h):	1248
USER DEFINED Work Zone Capacity (veh/h):	
Start Time:	4:00 PM
End Time:	7:00 PM
Duration of Closure (hrs):	3

RESULTS

Measure of Effectiveness	Base Conditions	Work Zone	Total
Max Queue Length (mi):	0.0	1.6	1.6
Max Delay (minutes):	0	29	29
Cost ($):	$0	$8,100	$8,100

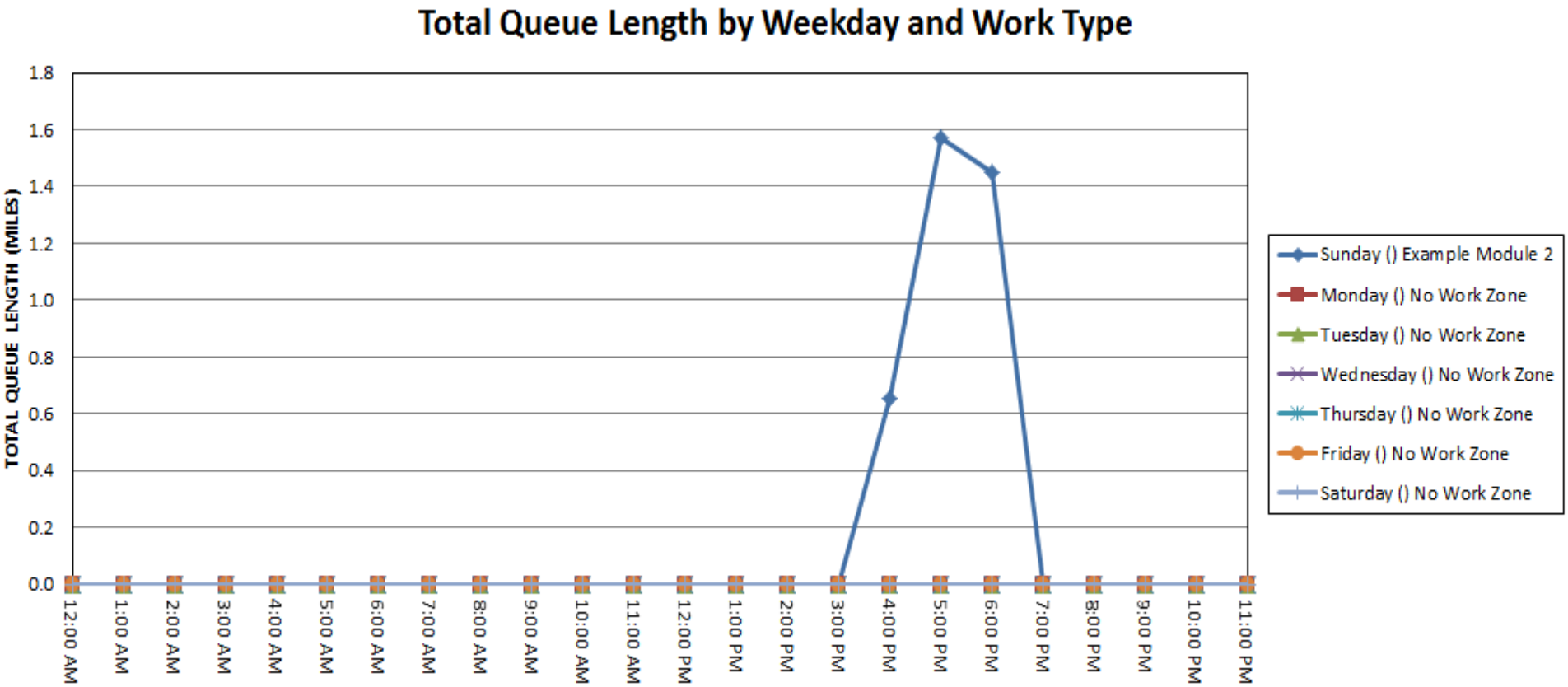
Step 3: WZ Analysis

Give Hourly queue length and hourly delay



Step 4: Synopsis Sheet

A summary of the queue by day and work type is generated automatically in the synopsis sheet:



Calculations in MoDOT Spreadsheet

- Capacity
- Queue length
- Delay
- Users' costs

Capacity

Equation based on HCM 2010:

$$\textbf{Capacity} = (1600 - I) \times (Number\ of\ open\ lanes) \times (Heavy\ Veh.\ Adj.\ Factor) \times f_{LW}$$

Considers the adjustment for the Intensity of Work (I), but it does not consider the adjustment for entrance ramp right before the lane closure (*R*). The user may account for the influence of entrance ramps by manually inputting the Work Zone Capacity

It also considers an adjustment *f*actor for Lane Width

Capacity

I = adjustment for the effect of work activities on capacity

The value of *I* is determined by the option chosen in the description of the Work Location (in Step 3 – WZ Analysis)

Work Location:	Value of *I*
No Work Zone (Use for Calibrating Existing Conditions)	0
Workers & equipment less than 4 feet from travel lane	-160
Workers & equipment greater than 4-feet from travel lane	0
Barrier located less than 2 feet from travel lane	-100
Barrier located greater than 2 feet from travel lane	0
Ramp (used as bypass)	+80
Crossover on Divided Highway	+160

Capacity

f_{LW} = adjustment factor for lane width

Three options are given in the dropdown menu:

Travel Lane Width (ft)	f_{LW}
> 11.5	1.00
10 – 11.5	0.91
< 10	0.86

Capacity

Heavy Vehicle Adjustment Factor

Passenger car equivalents for trucks on upgrades use HCM 2010 values, shown below:

Passenger - Car Equivalents for Trucks on Upgrades

Climbing Grade (%)*	Length (mi)		E_T - Passenger - Car Equivalents for Trucks on Upgrades Percentage of Trucks											
			2%	4%	5%	6%	8%	10%	15%	20%	25%	30%	35%	40%
< 2		1	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
>2-3	0 - 0.49	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	0.50 - 1.00	3	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>1.00	4	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
>3-4	0 - 0.49	5	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5
	0.50 - 1.00	6	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0
	>1.00	7	4.0	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5	2.5
>4-5	0 - 0.49	8	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	0.50 - 1.00	9	4.0	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	>1.00	10	5.0	4.0	4.0	4.0	3.5	3.5	3.0	3.0	3.0	3.0	3.0	3.0
>5-6	0 - 0.49	11	4.5	4.0	3.5	3.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
	0.50 - 1.00	12	5.5	5.0	4.5	4.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	>1.00	13	6.0	5.0	5.0	4.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
>6	0 - 0.49	14	5.0	4.5	4.0	4.0	3.5	3.0	2.5	2.5	2.5	2.5	2.5	2.5
	0.50 - 1.00	15	6.0	5.5	5.0	5.0	4.5	4.0	3.5	3.5	3.5	3.5	3.5	3.5
	>1.00	16	7.0	6.0	5.5	5.5	5.0	4.5	4.0	4.0	4.0	4.0	4.0	4.0

*Climbing Grade can be located anywhere throughout the entire work zone project.

Queue Length

The number of vehicles in queue are found using the input – output method explained in Module 1

Then, queue length is calculated as:

$$\underset{(Miles)}{Queue\ Length} = \frac{Queued\ Vehicles \times \left[\left(25ft \times (100 - \%trucks)\right) + (50ft \times \%trucks)\right]}{5280 * Total\ number\ of\ lanes}$$

Max Queue is also reported for the complete 24-hr period

**** Vehicle spacing is assumed to be 25ft for cars and 50ft for trucks***

Delay

The average delay per vehicle is computed hourly increments using the following expression:

$$Average\ Delay\ per\ Vehicle\ (Minutes) = \frac{Queued\ Vehicles}{Capacity} \times \frac{60\ min}{1\ h}$$

Max delay is also reported for the complete 24-hr period

Users' Costs

The calculation is based on unit costs for cars ($cost_{car}$) and trucks ($cost_{truck}$) defined in the input values

For each hour (each row), the hourly users' cost is computed as:

$$COST/Hour\ (\$): \left(\text{Queued Vehicles} \times \frac{\text{Delay}}{60}\right) \times [\%Trucks * Cost_{Truck} + (100 - \%Trucks) * Cost_{Car}]$$

Only the users' cost for the complete 24 hr period is reported

Limitations MoDOT Spreadsheet

- Similar to QDAT:
  - WZ capacity does not change over time for a WZ
  - Only “stopped” queue is reported (spacing of cars = 25ft and trucks = 50ft)
  - Can not do multiple time periods in one analysis

- Does not take into account speed limits inside or outside the WZ

- User cannot specify mobility criteria, thus it does not automatically generate possible work hours when criteria is met

Summary of **User Inputs** QDAT and MoDOT Spreadsheet

INPUT	QDAT	MoDOT Spreadsheet
Number of open and closed lanes	✓	✓
Hourly volume	✓	✓
Length of lane closure	✓	-
Lane width	-	✓
Truck %	✓	✓
Start/end time of lane closure	✓	✓
Work area intensity adjustment	✓	✓
Ramp adjustment	✓	-
Speed limit outside WZ	✓	-
Speed limit inside WZ	-	-
Unit costs for cars and trucks	-	✓
Capacity outside WZ	-	✓
Max allowable queue/delay	✓	-

Summary of **Outputs**
QDAT and MoDOT Spreadsheet

OUTPUT	QDAT	MoDOT Spreadsheet
WZ capacity (HCM-type procedure)	✓	✓
Queue length	✓	✓
Delay	✓	✓
Users' costs	-	✓
"Sensitivity" analysis	✓	-
Graphs with delays over time	✓	✓
Graphs with queues over time	✓	✓
Scheduling based on queue/delay criteria	✓	-

Capability of Spreadsheets

To consider the effects of	Spreadsheets			
	QDAT spreadsheet	MoDOT spreadsheet	HCM 2016 WZ capacity method	WZQ-Pro
1) Lane width	N			
2) Shoulder width	N			
3) Work intensity	Y			
4) Speed limit inside WZ on capacity	N			
5) Speed control techniques in WZ	N			
6) Barrier type (concrete vs others)	N			
7) WZ capacity changes during analysis period.	N			
8) % of trucks changes during analysis period.	N			
9) Adverse weather conditions	N			
10) Night time operation	N			
11) Urban vs rural	N			
12) Flagger operation	N			

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MODULE 3

HCM 2016 Methods for Work Zone Capacity Calculations

HCM Methods for Capacity Calculations

Three facilities will be covered:

1. **Basic Freeway Segments:**

   HCM Chapters 10, 12, 25, 26

2. **Signalized Intersections:**

   HCM Chapters 19 and 31

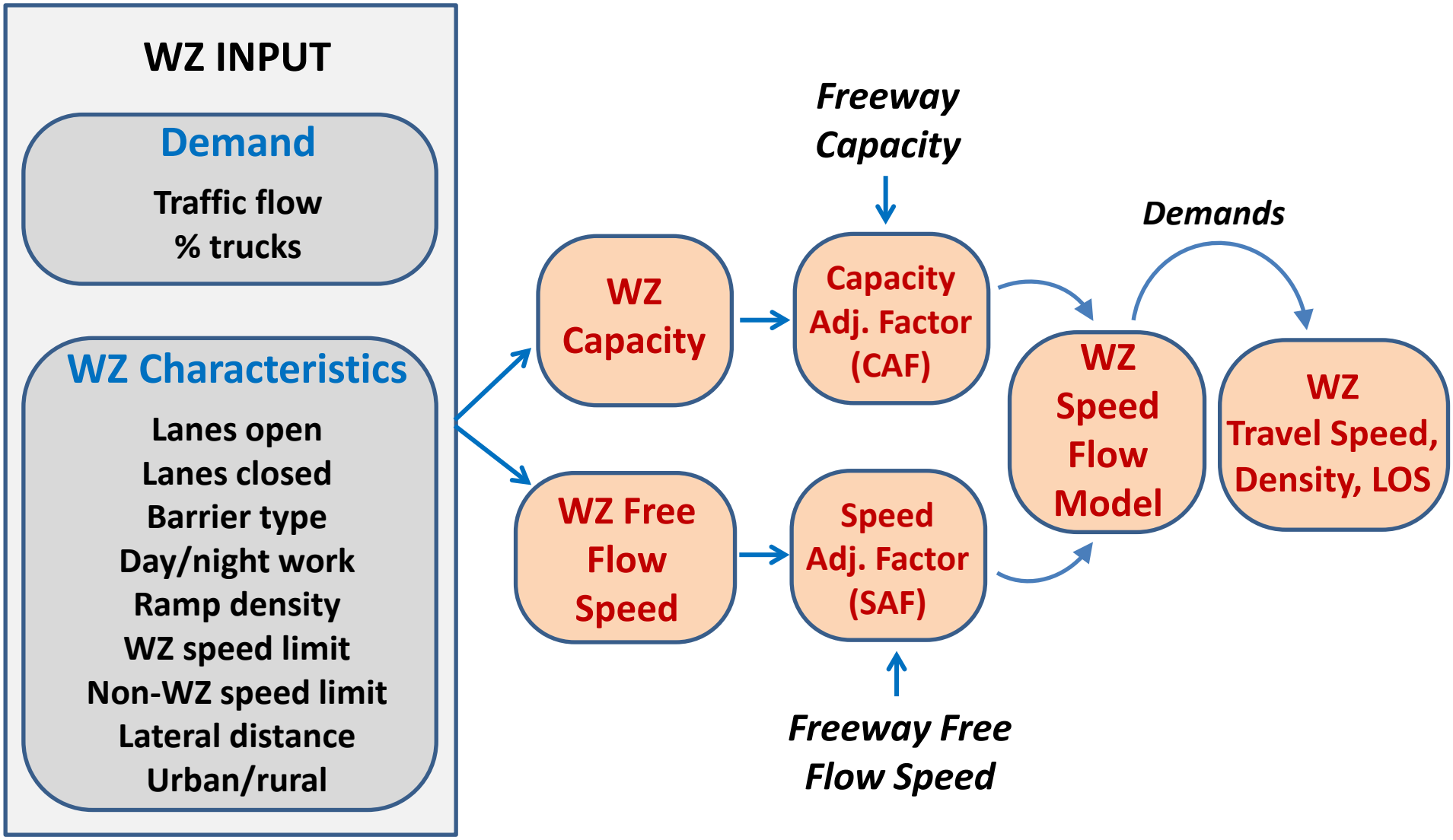
   WZ capacity is in HCM Part IV (on-line)

3. **Two-lane Highways (**one-lane two way operation**)**

   HCM Chapters 15 and 26

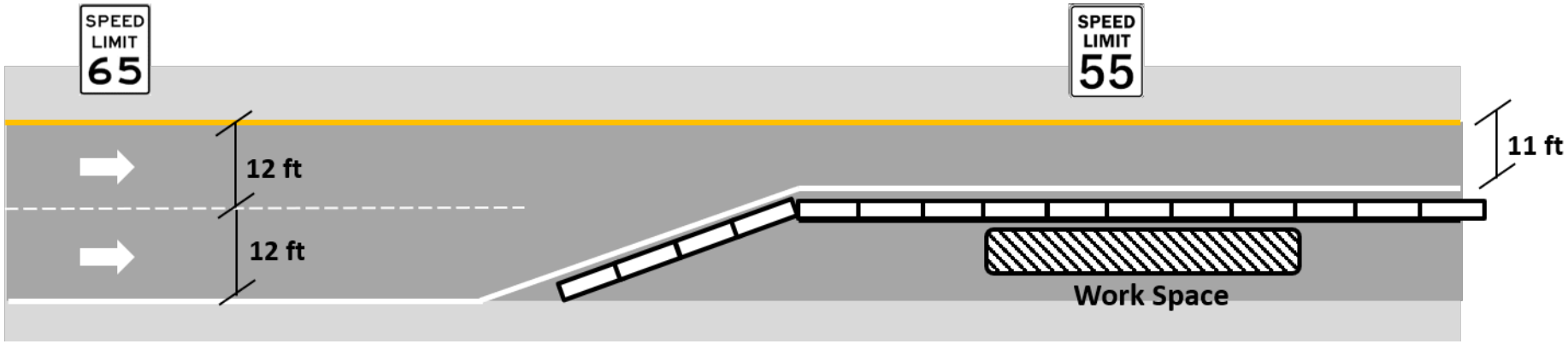
   WZ capacity is in HCM Part IV (on-line)

Facility 1: WZ on Basic Freeway Segments



Example Problem #1 – Freeway Segments

WZ on a freeway with one lane open and one lane closed, rural area and level terrain
- The segment without the WZ (Non-Work Zone) has a speed limit of 65 mph, and a capacity of 2350 pcphpl
- The speed limit inside the WZ (Work Zone speed limit) is 55 mph
- The lane width in work space is 11 feet, right shoulder width (lateral distance) is 2 feet
- Concrete barriers are used
- 3 miles upstream and 3 miles downstream of the WZ, there are 3 on-ramps and 3 off-ramps
- There is no work activity
- The highest expected demand is 1600 vph, with 5% trucks



What is the capacity and the travel speed in this WZ?

Estimate the WZ Capacity… by Estimating QDR

It is difficult to determine **capacity directly**,

but it can be estimated in terms of queue discharge rate (QDR):

WZ capacity
(c_{wz})

"Maximum sustainable flow rate immediately preceding a breakdown"
(i.e. **pre-breakdown capacity**)

Difficult to measure

>

WZ queue discharge rate
(QDR_{wz})

"Average flow rate immediately downstream of an active bottleneck (following breakdown) measured over a 15-min sampling interval while there is active queuing upstream of the bottleneck"

Easier to measure

Estimate the WZ Capacity… by Estimating QDR

The relationship between capacity and QDR is:

$$c_{wz} = \frac{QDR_{wz}}{100 - \alpha_{wz}} \times 100 \qquad (c_{wz}, QDR_{wz} \text{ in pcphpl})$$

Percentage drop in pre-breakdown capacity at the WZ due to queue conditions

Guidance

- If possible use field data to estimate α_{wz}
- In freeway WZs: average $\alpha_{wz} = 13.4\%$
- $$c_{wz} = QDR_{wz} \times \frac{100}{100-13.4}$$
$$= QDR_{wz} \times 1.155$$

How to Estimate QDR_{wz}

$$QDR_{wz} = 2093 - (154 \times f_{LCSI}) - (194 \times f_{Br}) - (179 \times f_{A}) + (9 \times f_{LAT}) - (59 \times f_{DN})$$

f_{LCSI} = Lane closure severity index (*next slide*)

f_{Br} = **Barrier type**

- **0** Concrete and hard barrier separation
- **1** Cone, plastic drum, or other soft barrier separation

f_{A} = **Area type**

- **0** Urban areas (High development densities or concentrations of population)
- **1** Rural areas (widely scattered development and low housing and employment densities)

f_{LAT} = "**Lateral distance** from the edge of travel lane adjacent to the work zone to the barrier, barricades, or cones (0-12 ft)"

f_{DN} = **Daylight/night**

- **0** Daylight
- **1** Night

How to Estimate QDR_{wz}

f_{LCSI} (Lane Closure Severity Index)

Number of Total Lanes(s)	Number of Open Lane(s)	Open Ratio	f_{LCSI}
3	3	1.00	0.33
2	2	1.00	0.50
4	3	0.75	0.44
3	2	0.67	0.75
4	2	0.50	1.00
2	1	0.50	2.00
3	1	0.33	3.00
4	1	0.25	4.00

How to Estimate QDR_{wz}

$$QDR_{wz} = 2093 - (154 \times f_{LCSI}) - (194 \times f_{Br}) - (179 \times f_A) + (9 \times f_{LAT}) - (59 \times f_{DN})$$

f_{LCSI} = 2 lanes total, 1 lane closed = 2.0

$f_{Br} = 0$ Concrete and hard barrier separation

$f_A = 1$ Rural area

f_{LAT} = **2** ft

$f_{DN} = 0$ Daylight

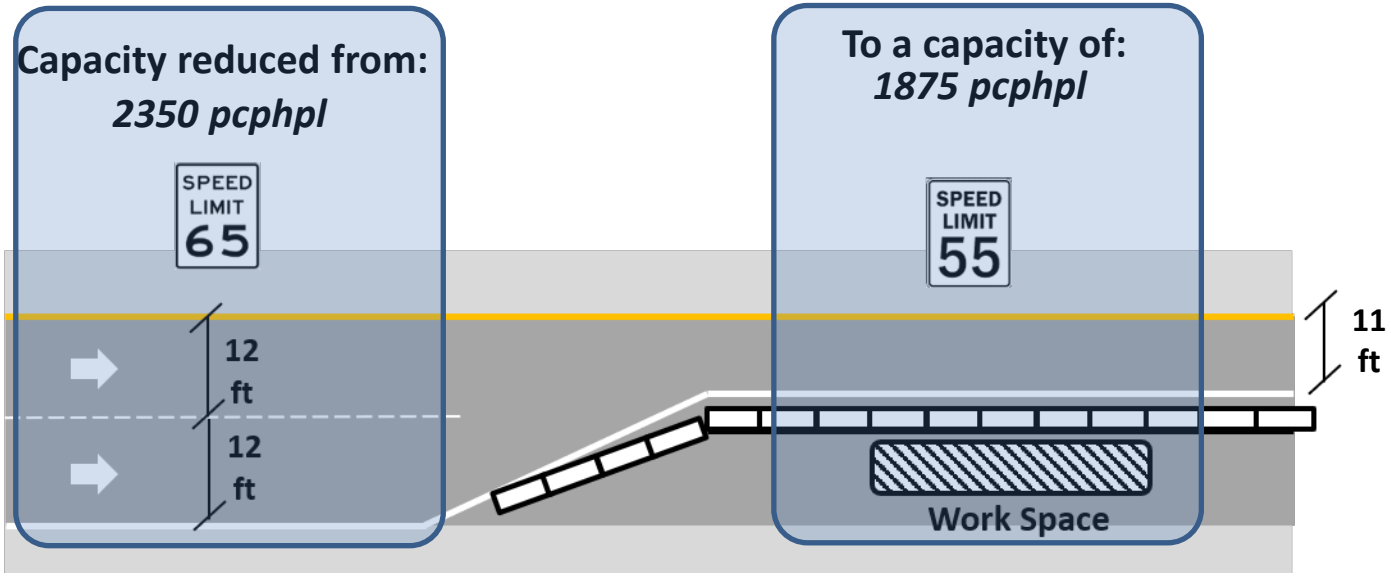
$$QDR_{wz} = 2093 - (154 \times 2) - (194 \times 0) - (179 \times 1) + (9 \times 2) - (59 \times 0)$$

$QDR_{wz} = 1624$ *pcphpl*

Now we can Estimate Capacity

$$c_{wz} = \frac{1624}{100 - 13.4} \times 100 = 1875\ pcphpl$$

This value can be used as input for WZ analysis in sketch-planning tools

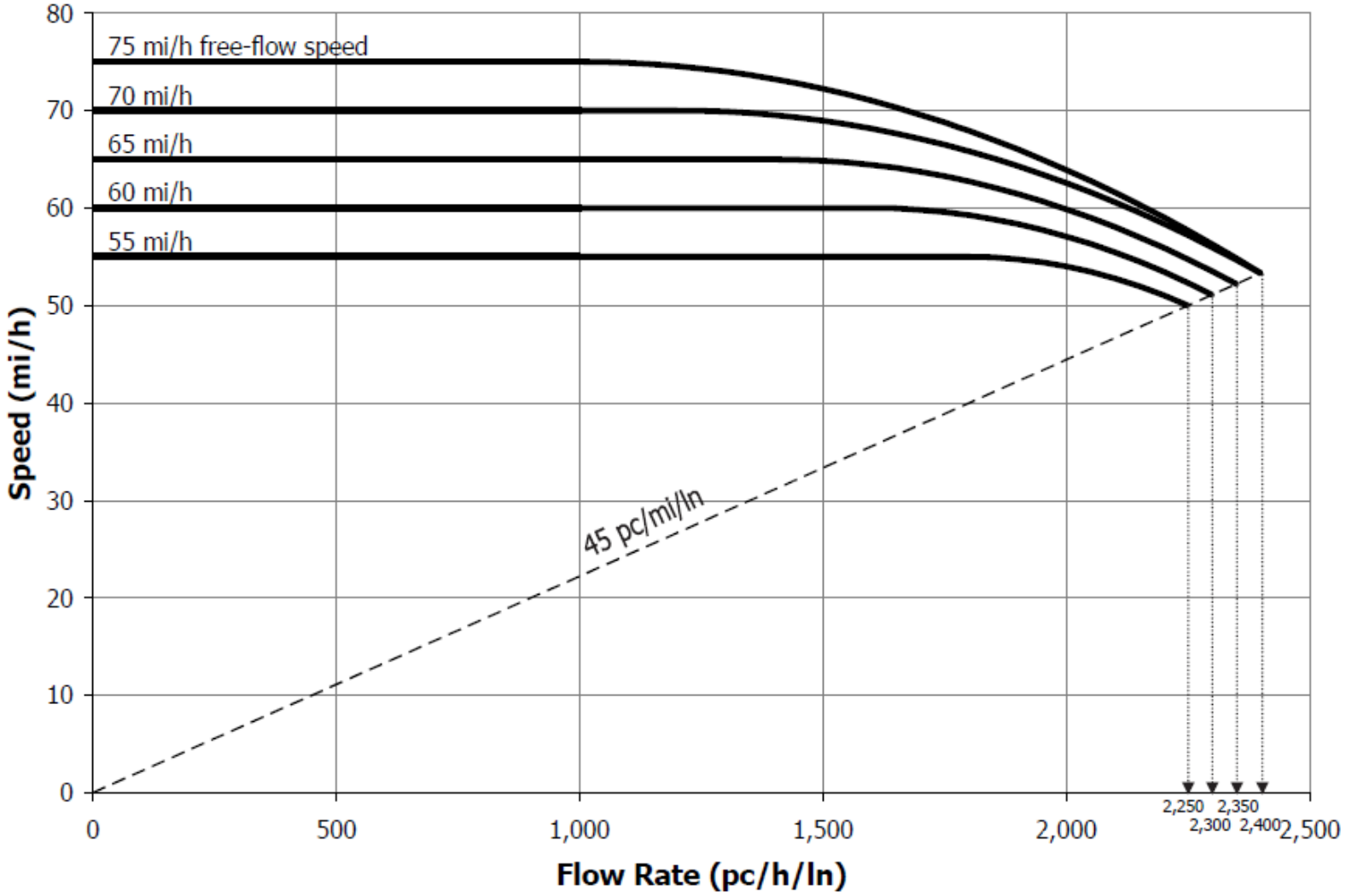


The WZ capacity adjustment factor is:

$$CAF = \frac{1875}{2350} = 0.80$$

How about the operating speed of this WZ?

Speed Flow Curve from HCM



(EXH 11-2)

WZ Free-flow Speed

The WZ free flow speed (FFS_{WZ}) is calculated as:

$$FFS_{wz} = 9.95 + (33.49 \times f_{Sr}) + (0.53 \times f_S) - (5.60 \times f_{LCSI}) - (3.84 \times f_{Br}) - (1.71 \times f_{DN}) - (8.7 \times f_{TRD})$$

f_{Sr} = Speed ratio (decimal); the ratio on non-WZ speed limit to WZ speed limit

f_S = Work zone speed limit (mi/h)

f_{TRD} = Total ramp density along the facility within three miles upstream and downstream of the work-zone area (ramps/mi)

f_{LCSI}, f_{Br}, f_{DN} as defined before in slide M3-9

Note: The work zone FFS should not be greater than the non-work zone FFS, and the result of the equation should be capped as needed

WZ Free-flow Speed

For our example we find the free flow speed as:

$$FFS_{wz} = 9.95 + (33.49 \times f_{Sr}) + (0.53 \times f_S) - (5.60 \times f_{LCSI}) - (3.84 \times f_{Br}) - (1.71 \times f_{DN}) - (8.7 \times f_{TRD})$$

f_{Sr} = 65 mph / 55 mph = 1.18

f_S= 55 mph

f_{TRD}= 1 (ramps/mi)

f_{LCSI}= 2.0

f_{Br} = 0

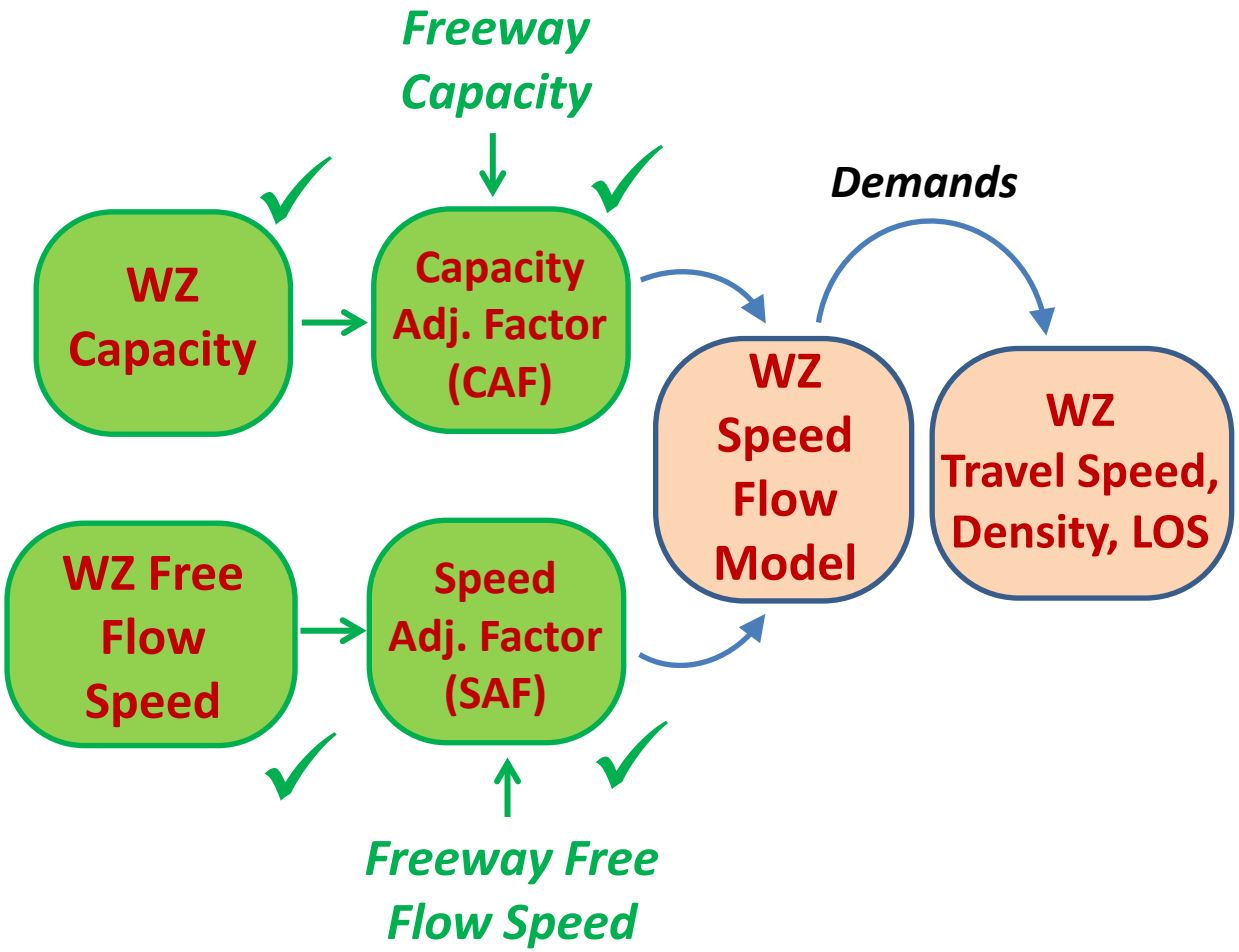
f_{DN} = 0

$$FFS_{wz} = 58.8 \ mph$$

The WZ speed adjustment factor is:

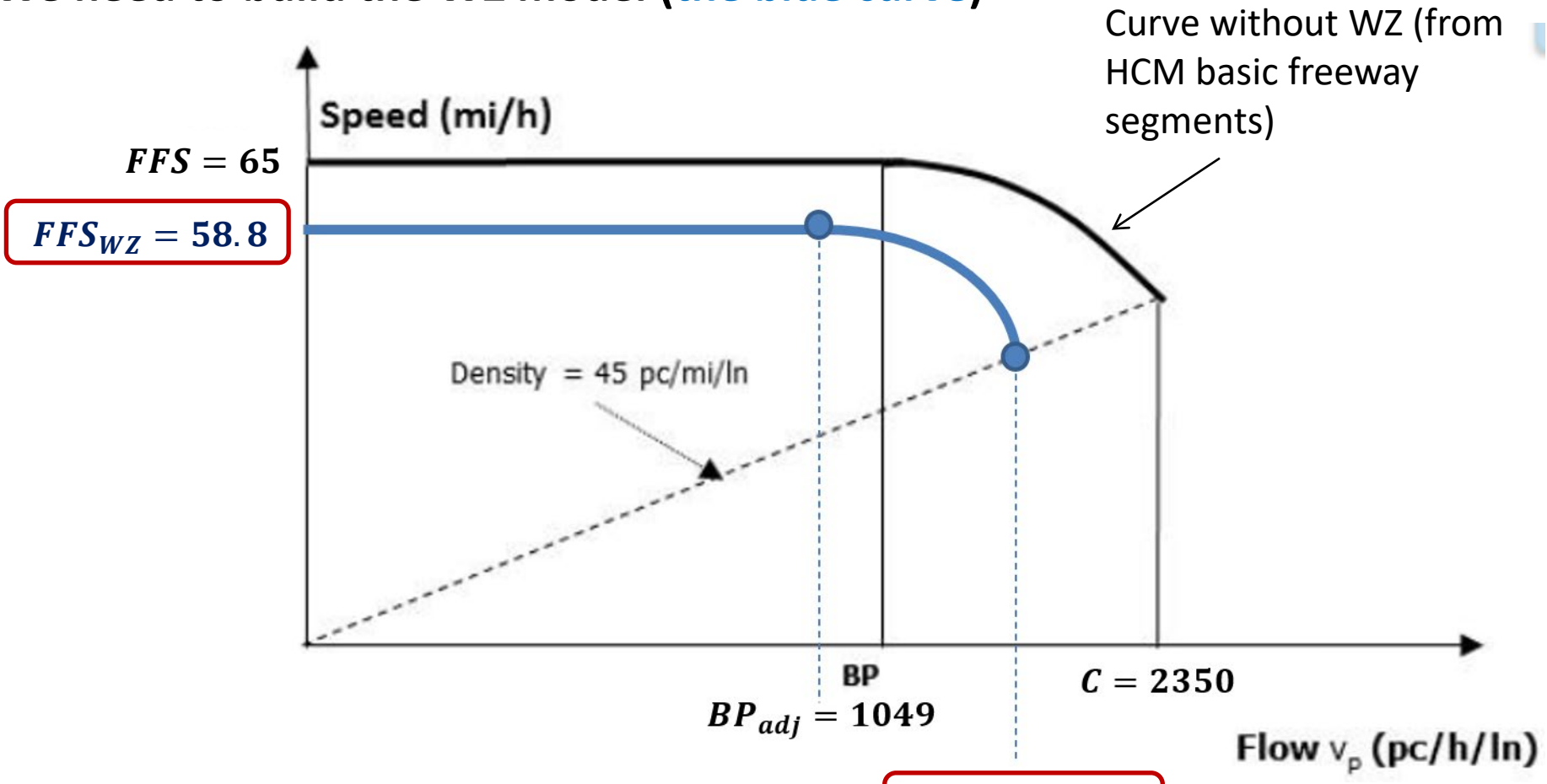
$$SAF = \frac{58.8}{65} = 0.9$$

WZ Speed-flow Model



WZ Speed-flow Model

We need to build the WZ model (the blue curve)

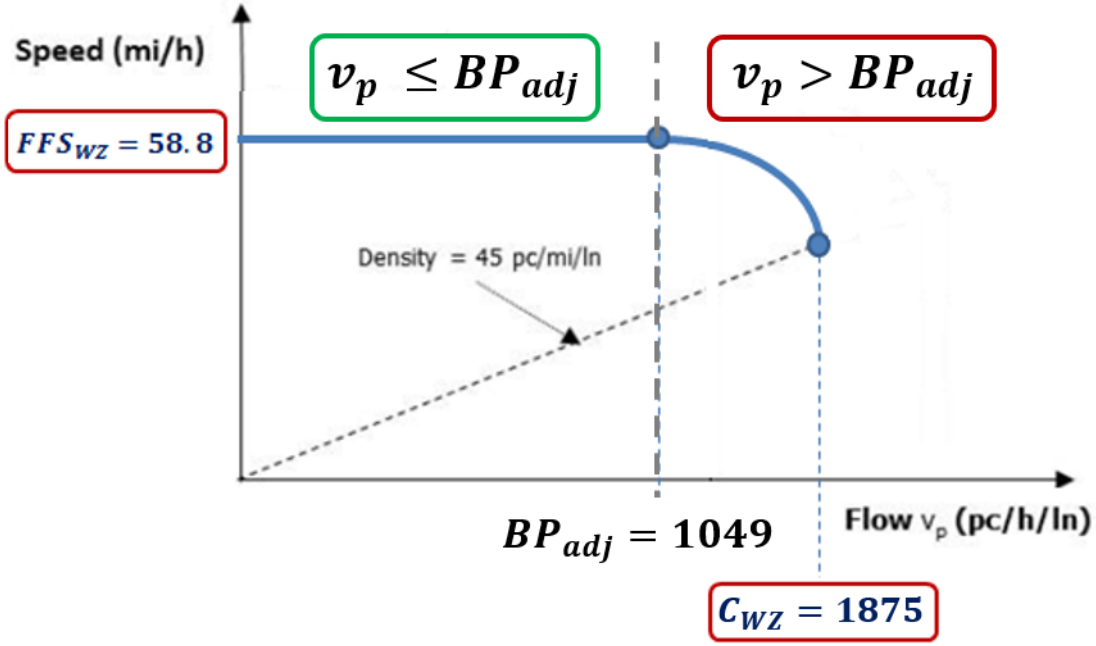


$$BP_{adj} = [1000 + 40 \times (75 - FFS_{adj})] \times CAF^2$$

$$BP_{adj} = 1049$$

WZ Speed-flow Model

Now we can find the travel speed ***S*** along the curve for any demand (v_p):



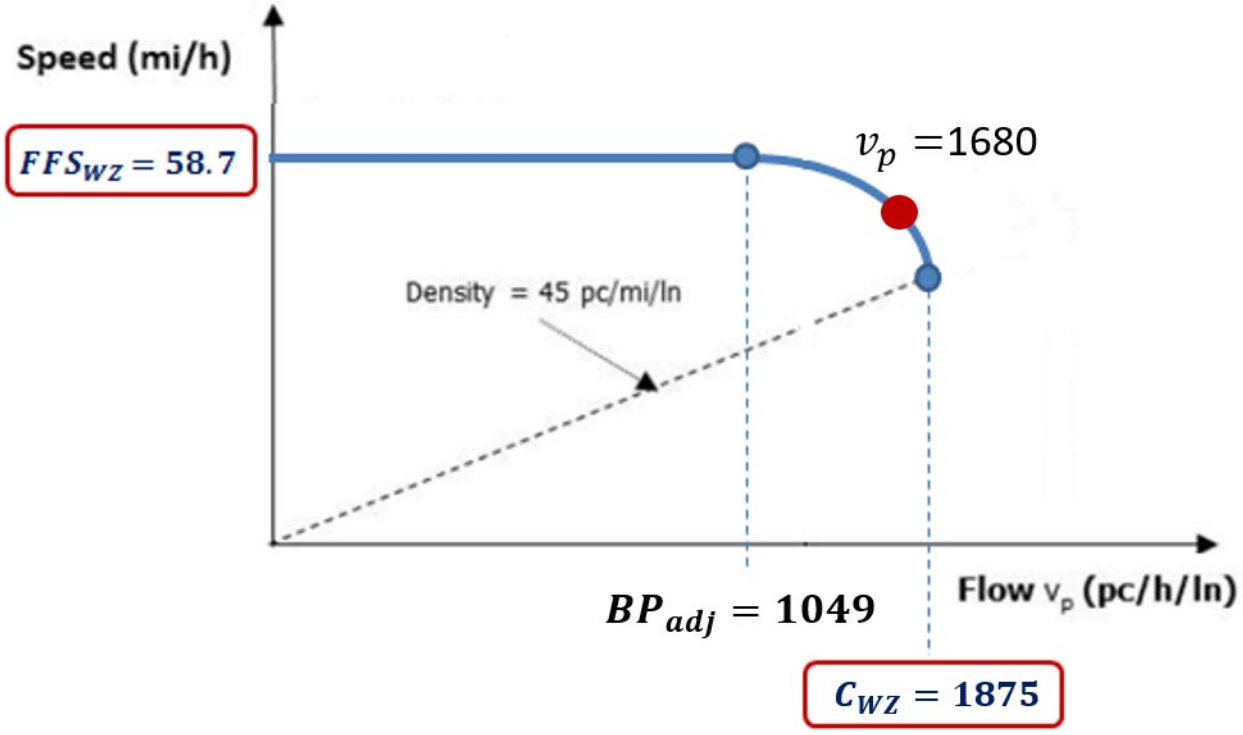
if $v_p \leq BP_{adj}$ *then* $S = FFS_{WZ} = 58.8\ mph$ **(Linear section)**

if $v_p > BP_{adj}$ *then* $S = FFS_{WZ} - \dfrac{\left(FFS_{WZ} - \frac{c_{WZ}}{45}\right)(v_p - BP)^2}{(c_{WZ} - BP)^2}$ **(Curved section)**

WZ Speed-flow Model

In our WZ, the maximum expected demand is 1600 vph with 5% trucks

Converting the volume to *pc/h*: $v_p = \frac{1600\ vph}{f_{HV}} = \frac{1600\ vph}{\frac{1}{1+0.05(2.0-1)}} = 1680\ pc/h$



Plugging the values in the equation we obtain:

Travel speed S =**48.8 mph**

Do we expect stopped queues at the WZ?

NO, because demand is lower than capacity vehicles can be processed without stopped queues

WZ Speed-flow Model

After finding the speed (S) for a corresponding flow rate (v_p), the density can be computed and the LOS in the WZ segments can be obtained:

$$\textbf{\textit{Density}}\ (\text{pc/mi/ln}) = \frac{Flow\ rate\ (\text{pc/h/ln})}{Speed\ (\text{mi/h})} = \frac{1680}{48.8} = 34.4\ \text{pc/mi/ln}$$

LOS	Density (pc/mi/ln)
A	≤ 11
B	$> 11 - 18$
C	$> 18 - 26$
D	$> 26 - 35$
E	$> 35 - 45$
F	Demand exceeds capacity or density > 45

Group Discussion about HCM WZ capacity & speed

1. Is capacity of a WZ at night higher (lower) than its capacity in day time?

   By how much?

2. Is capacity of a WZ with concrete barriers higher(lower) than its capacity with non-concrete barrier (cone, drums, ...)?

   By how much?

3. Is capacity an urban WZ higher(lower) than rural WZ?

   By how much?

Group Discussion about HCM WZ capacity & speed

4. Does HCM consider effects of work intensity on WZ capacity?

5. Does HCM consider WZ speed limit on WZ capacity?

6. Does HCM consider effects of lane width on WZ capacity?

7. Does HCM consider effects of lane width on WZ speed?

8. Does HCM consider effects of lateral clearance on WZ capacity?

9. Does HCM consider effects of lateral clearance on WZ speed?

Limitations of the Speed-Flow Methodology

(according to HCM)

- The methodology estimates the **capacity, speed, and density** of the WZ segment, given the segment's traffic demand and characteristics. However, "**Alternative tools offer additional performance measures**, including
  - delay,
  - stops,
  - queue length,
  - fuel consumption,
  - pollution,
  - and operating costs."

Limitations of the Speed-Flow Methodology

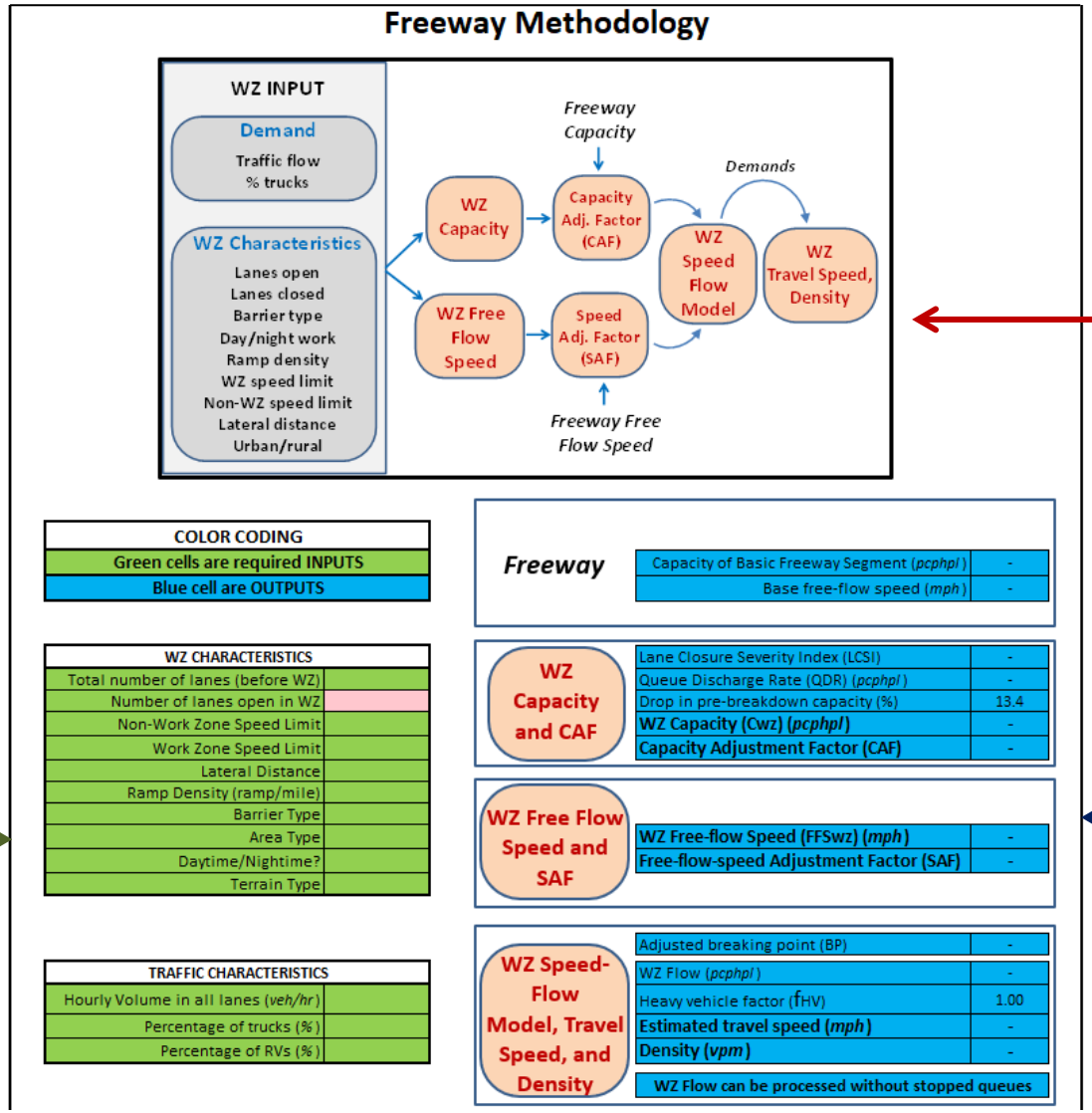
(according to HCM)

- The methodology does not take into account:
  - Speed enforcement practices
  - Presence of ITS related to vehicle or driver guidance
  - Operational effects of oversaturated conditions

- The methodology does not apply to:
  - Freeway segments with FFS > 75 mph, or multilane highways with FFS > 60 mph
  - Freeway segments with a base FFS < 55 mph, or multilane highways with base FFS < 45 mph

UI Spreadsheet V1.24 for HCM Freeway WZs

UI team developed a spreadsheet for the calculations of the methodology



Overview of methodology

Inputs

Outputs

UI Spreadsheet V1.24 for HCM Freeway WZs

COLOR CODING
Green cells are required INPUTS
Blue cell are OUTPUTS

WZ CHARACTERISTICS	
Total number of lanes (before WZ)	2
Number of lanes open in WZ	1
Non-Work Zone Speed Limit	65
Work Zone Speed Limit	55
Lateral Distance	2
Ramp Density (ramp/mile)	1
Barrier Type	Concrete
Area Type	Rural
Daytime/Nightime?	Daytime
Terrain Type	Level

TRAFFIC CHARACTERISTICS	
Hourly Volume in all lanes (*veh/hr*)	1600
Percentage of trucks (%)	5
Percentage of RVs (%)	0

Freeway

Capacity of Basic Freeway Segment (*pcphpl*)	2350
Base free-flow speed (*mph*)	65

WZ Capacity and CAF

Lane Closure Severity Index (LCSI)	2.000
Queue Discharge Rate (QDR) (*pcphpl*)	1624
Drop in pre-breakdown capacity (%)	13.4
WZ Capacity (Cwz) (*pcphpl*)	**1875**
Capacity Adjustment Factor (CAF)	**0.80**

WZ Free Flow Speed and SAF

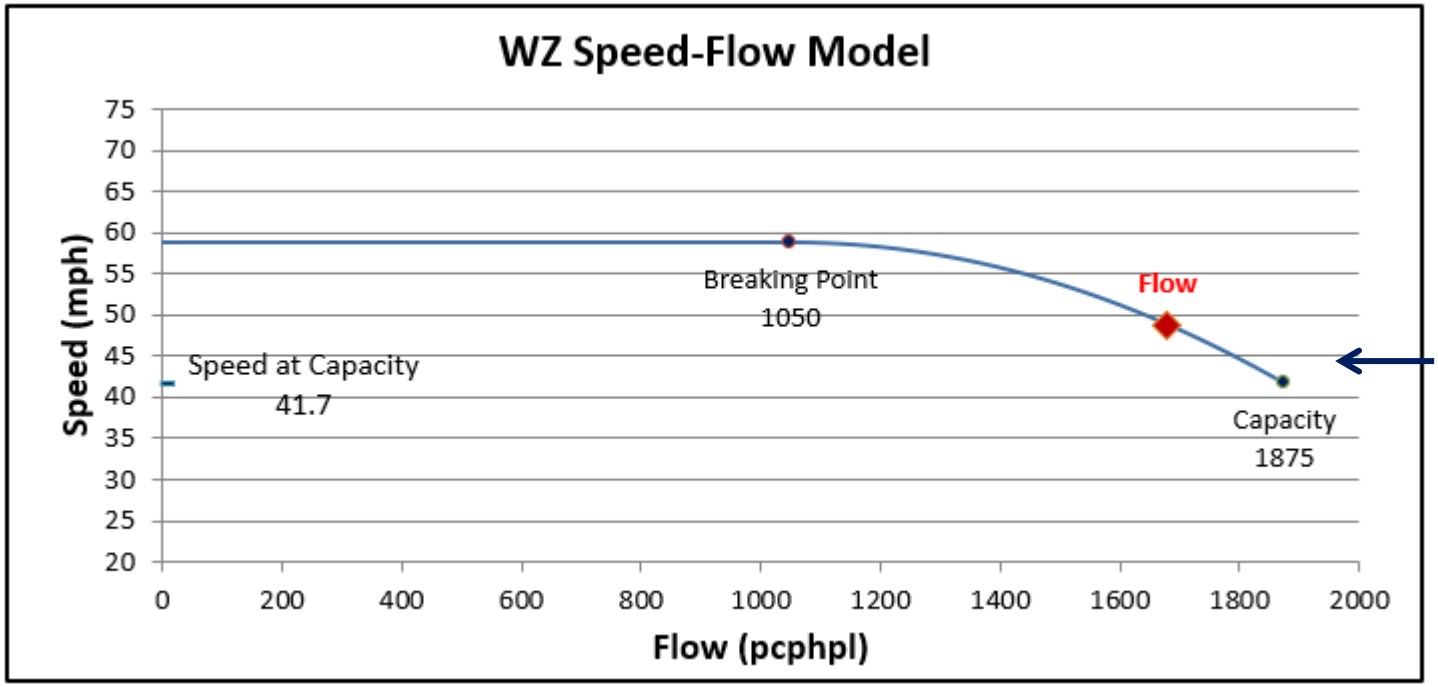
WZ Free-flow Speed (FFSwz) (*mph*)	**58.8**
Free-flow-speed Adjustment Factor (SAF)	**0.90**

WZ Speed-Flow Model, Travel Speed, and Density

Adjusted breaking point (BP)	1050
WZ Flow (*pcphpl*)	1680
Heavy vehicle factor (f_{HV})	0.95
Estimated travel speed (*mph*)	**48.8**
Density (*vpm*)	**34.4**

WZ Flow can be processed without stopped queues

UI Spreadsheet V1.24 for HCM Freeway WZs



Displays the corresponding speed-flow model automatically

Facility 2: WZ at Intersections

- **Estimation of WZ presence Adjustment Factor**

As described in HCM Chapter 19 (Signalized Intersections), the adjusted saturation flow rate per lane is calculated by applying 13 adjustment factors (lane width, heavy vehicle and grade, parking, bus blockage, area type, lane utilization, right turn, left turn, ped-bike conflict with left turners, ped-bike conflict with right turners, work zone, downstream lane blockage, sustained spill back) :

$$s = s_o \, f_w \, f_{HVg} \, f_p \, f_{bb} \, f_a \, f_{LU} \, f_{LT} \, f_{RT} \, f_{Lpb} \, f_{Rpb} \, f_{wz} \, f_{ms} \, f_{sp}$$

Adjustment factor for WZ presence at the intersection

Estimation of WZ presence Adjustment Factor

A WZ is “on the intersection approach” if some (or all) of the WZ is located within 250 ft from the stop line. The WZ may be located on the shoulder, or it may include the closure of one or more lanes.

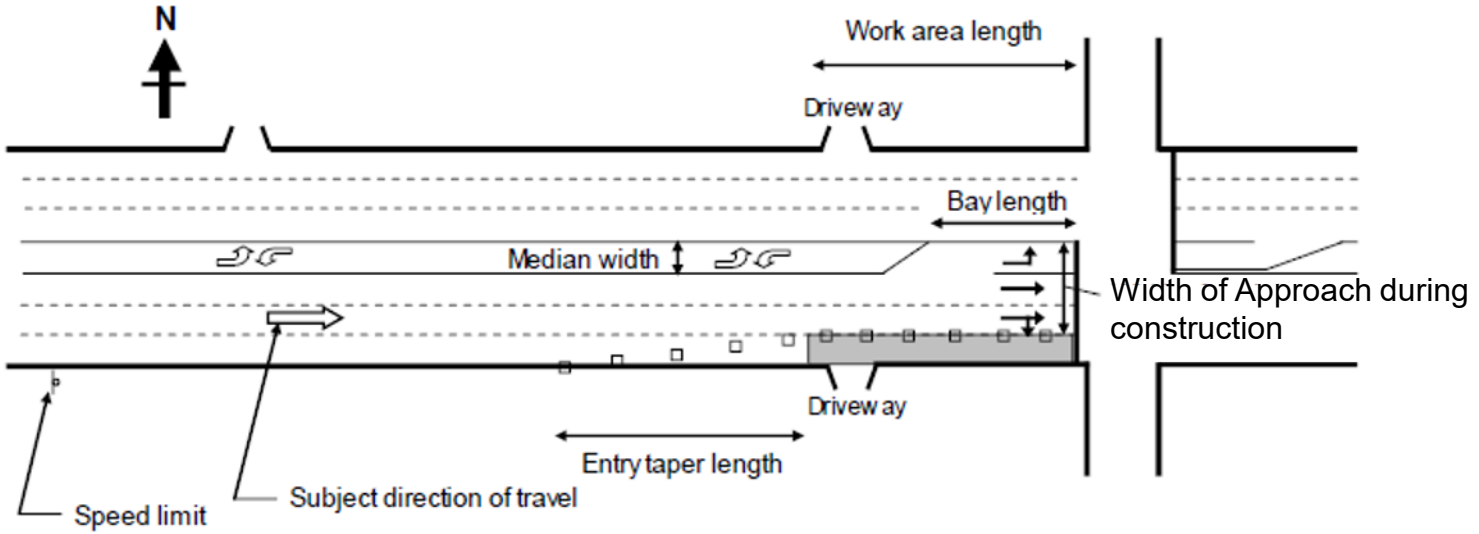


Exhibit 31-9
Work Zone on an Intersection Approach

Number of lanes open on the approach of the WZ

- Count of left-turn and through lanes open when WZ present
- It does not include any exclusive right-turn lanes in this count
- The number of lanes are counted in the WZ, and if it varies the smallest number of lanes open to motorists is used

Approach lane width during WZ (a_w)

- Total width of all open left-turn, through, and right-turn lanes on the intersection approach when WZ is present

Adjustment factor for WZ presence at the intersection (f_{wz})

$$f_{wz} = 0.858 \times f_{wid} \times f_{reduce} \leq 1.0$$

$$f_{wid} = \frac{1}{1 - 0.0057(a_w - 12)} \qquad f_{reduce} = \frac{1}{1 + 0.0402(n_o - n_{wz})}$$

f_{wid} = Adj. factor for approach width

f_{reduce} = Adj. factor for reducing lanes during WZ presence

a_w = Approach lane width during WZ (*ft*)

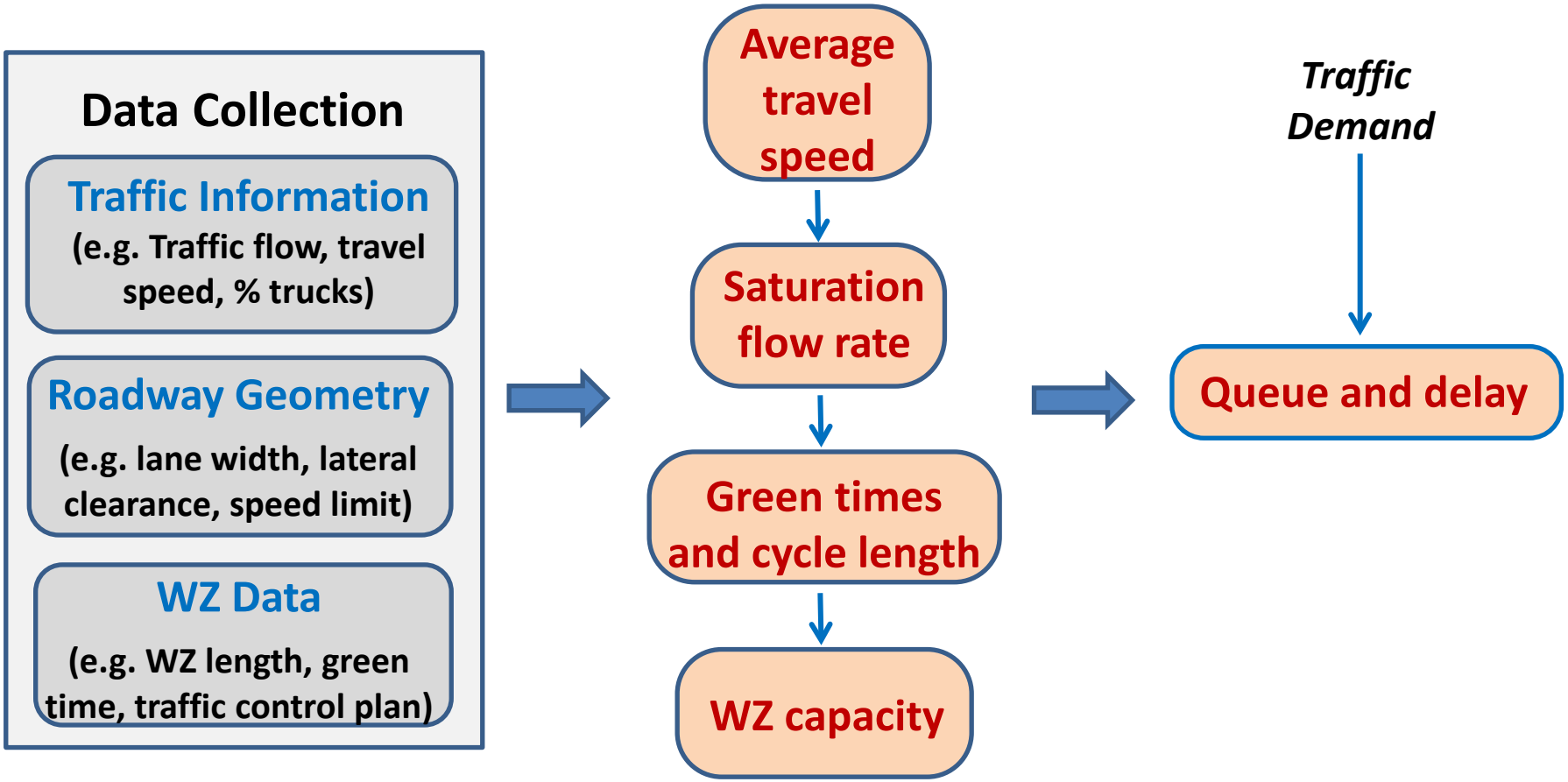
n_o = Number of left-turn and through lanes open during normal operation (*lanes*)

n_{wz} = Number of left-turn and through lanes open during WZ presence (*lanes*)

Note: one value is computed for (and is applicable to) all lane groups on the subject intersection approach

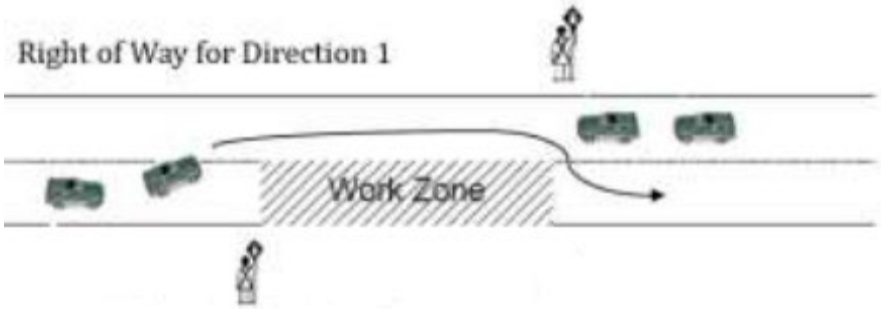
Facility 3: Two-lane Highways: one-lane two way Operation

Methodology is analogous to the capacity analysis for a two-phase signalized intersection.



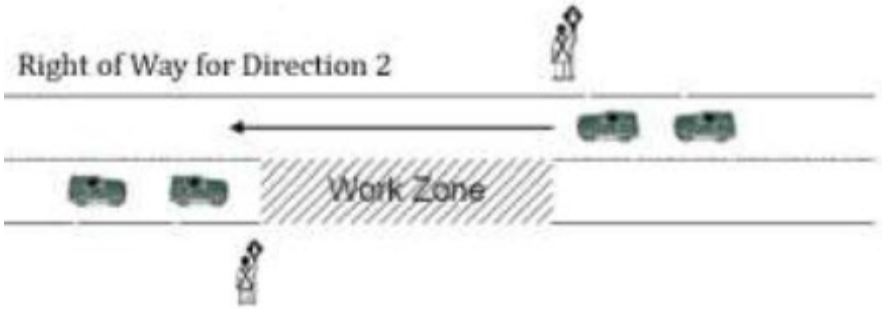
Details about this procedure is given in Appendix Q.

Labeling the Two Traffic Directions



Direction 1

Travel direction whose **lane is closed**



Direction 2

Travel direction with the **open lane**

Example for one-lane two way Operations

The work space is 1000 ft and temporary traffic signals are used. Other info are:

Roadway Parameters				
Direction	Lane width (ft)	Shoulder width (ft)	Access-point per mile	Grade condition
1	12	3	0	Rolling Terrain
2	12	3	0	Rolling Terrain

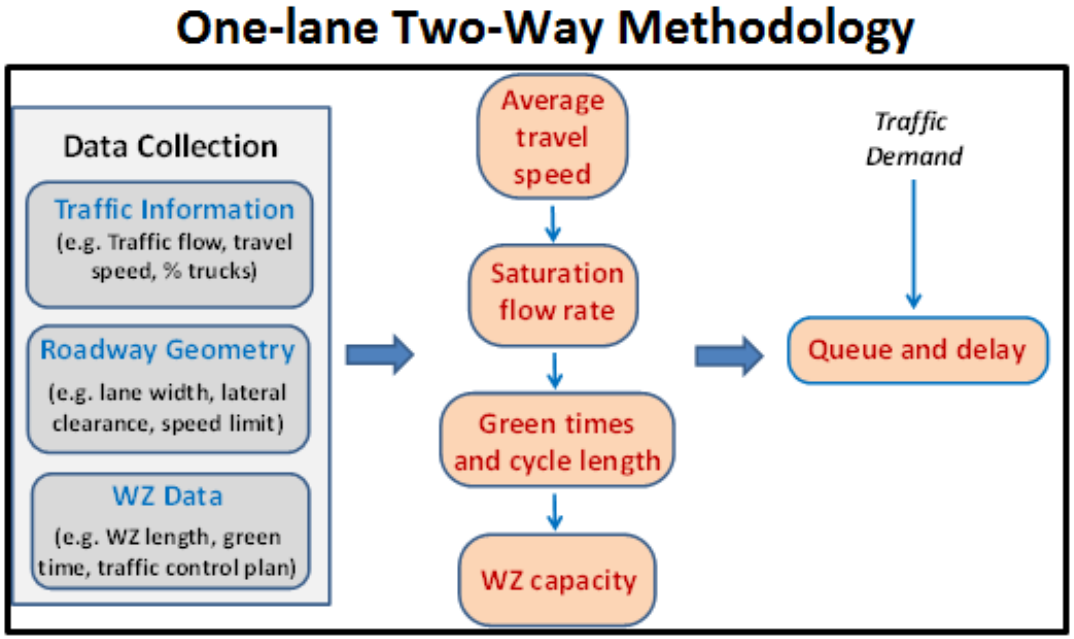
Traffic Parameters				
Direction	Speed limit (mi/h)	Traffic Demand (veh/h)	Truck Percentage	Recreational Vehicle (RV) Percentage
1	45	300	10.0 %	10.0 %
2	45	300	10.0 %	10.0 %

(HCM found that 37.5 sec is the optimal green time).

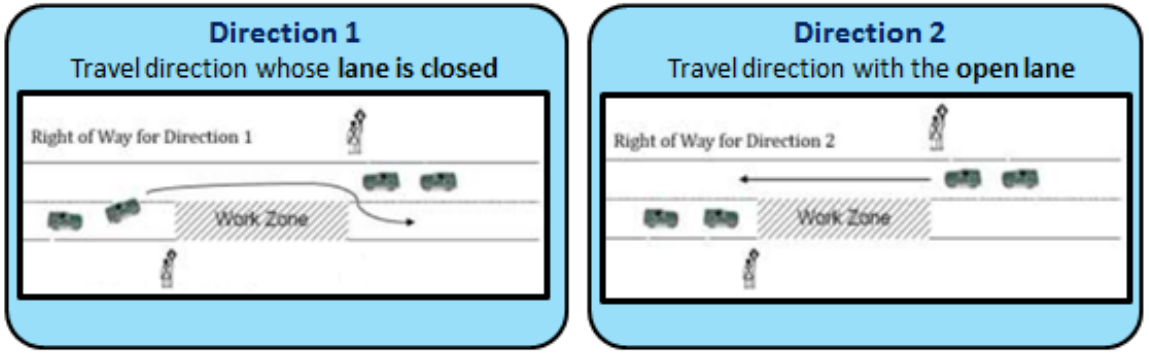
Find queue and average delay

UI Spreadsheet V1.22 for HCM one-lane two-way Operations

UI team developed a spreadsheet for the calculations of the methodology



← **Overview of methodology**



UI Spreadsheet V1.22 for HCM one-lane two-way Operations

COLOR CODING
Green cells are required INPUTS
Blue cell are OUTPUTS

Inputs

Outputs

INPUT WZ CHARACTERISTICS	
Speed Limit of the one-lane segment (*mph*)	45
Lane width (*ft*)	≥12
Shoulder width (*ft*)	≥2 <4
Access points per mile (both directions)	0
Work zone length (*ft*)	1000

Average travel speed

Saturation flow rate

	Direction 1	Direction 2
Adjustment for lane and shoulder width (f_{LS})	2.6	
Adjustment for access-point density (f_A)	0	
Adjustment factor for no passing zones (*mph*)	2.4	
Average Travel speed (V_i) (*mph*)	22.7	26.1
Base headway (*s*)	1.89	
Travel speed adjustment ($f_{speed\ i}$)	1.11	1.09
Saturation flow rate (S_i) (*pc/h*)	1713	1741

INPUT GREEN TIMES	
Input your own signal timing? (e.g. from field)	Yes
Input green time for Direction 1 (*s*)	37.5
Input green time for Direction 2 (*s*)	37.5
Flagger control with similar directional demands?	No
Optimal effective green time for each direction (*s*)	-

Green times and cycle length

WZ capacity

	Direction 1	Direction 2
Effective green time (*s*)	37.5	37.5
Cycle length (*s*)	135.1	
Capacity per direction (Ci) (*pc/h*)	475	483
Total WZ capacity (C1 + C2) (*pc/h*)	958	

INPUT DEMANDS TO CHECK GREEN TIMES	
Highest hourly demand in Direction 1 (*veh/h*)	300
Highest hourly demand in Direction 2 (*veh/h*)	300
Percentage Heavy Vehicles (%)	10
Percentage RVs (%)	10
Terrain Type	Rolling

Are green times adequate?

	Direction 1	Direction 2
Highest hourly demand (*pc/h*)	336	336
Queues fully discharged at the end of cycle?	**Yes**	**Yes**

INPUT TRAFFIC FOR QUEUE ANALYSIS	
Hourly demand in Direction 1 (*veh/h*)	300
Hourly demand in Direction 2 (*veh/h*)	300

Queue and delay

	Direction 1	Direction 2
Maximum Queue (*pc*)	**9.1**	**9.1**
Uniform Control Delay ($d_{1,i}$) (*s/pc*)	43.9	43.7
Incremental Delay ($d_{2,i}$) (*s/pc*)	9.0	8.4
Control Delay per Vehicle (*s/pc*)	**52.8**	**52.1**
Average Control Delay (*s/pc*)	**52.5**	

Capability of Spreadsheets

To consider the effects of	Spreadsheets			
	QDAT spreadsheet	MoDOT spreadsheet	HCM 2016 WZ capacity method	WZQ-Pro
1) Lane width	N	Y		
2) Shoulder width	N	N		
3) Work intensity	Y	Y		
4) Speed limit inside WZ on capacity	N	N		
5) Speed control techniques in WZ	N	N		
6) Barrier type (concrete vs others)	N	N		
7) WZ capacity changes during analysis period.	N	N		
8) % of trucks changes during analysis period.	N	N		
9) Adverse weather conditions	N	N		
10) Night time operation	N	N		
11) Urban vs rural	N	N		
12) Flagger operation	N	N		

Left Blank Intentionally

MODULE 4

WorkZoneQ – Pro
and
UI spreadsheet for Intersections*

*Computes users' costs based on delay and volume from HCS

WorkZoneQ-Pro (WZQ-Pro) - Overview

- An Excel spreadsheet with **macros and VBA**
- Estimates **capacity, speed, queue length, delay, users' costs**
- Computes both **moving queue and stopped queue lengths**

WorkZoneQ-Pro (WZQ-Pro) - Overview

Three facilities will be covered:

1 – Freeways A variation of Cell Transmission Model

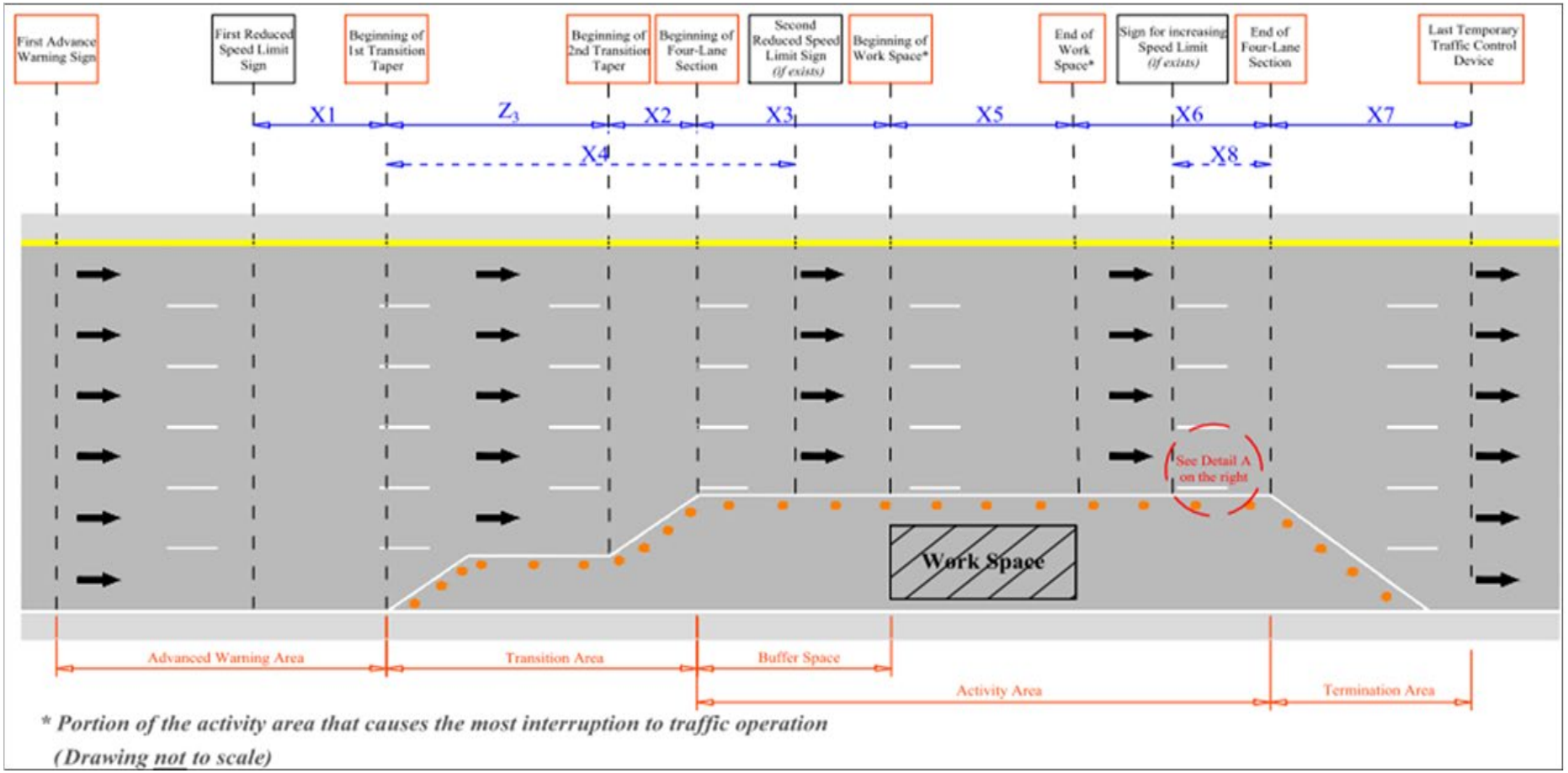
2 – Two-lane Highways Similar to HCM approach
(one-lane two-way operation)

3 - Arterials

- WZ at intersection Similar to HCM approach
- WZ at midblock A variation of Cell Transmission Model

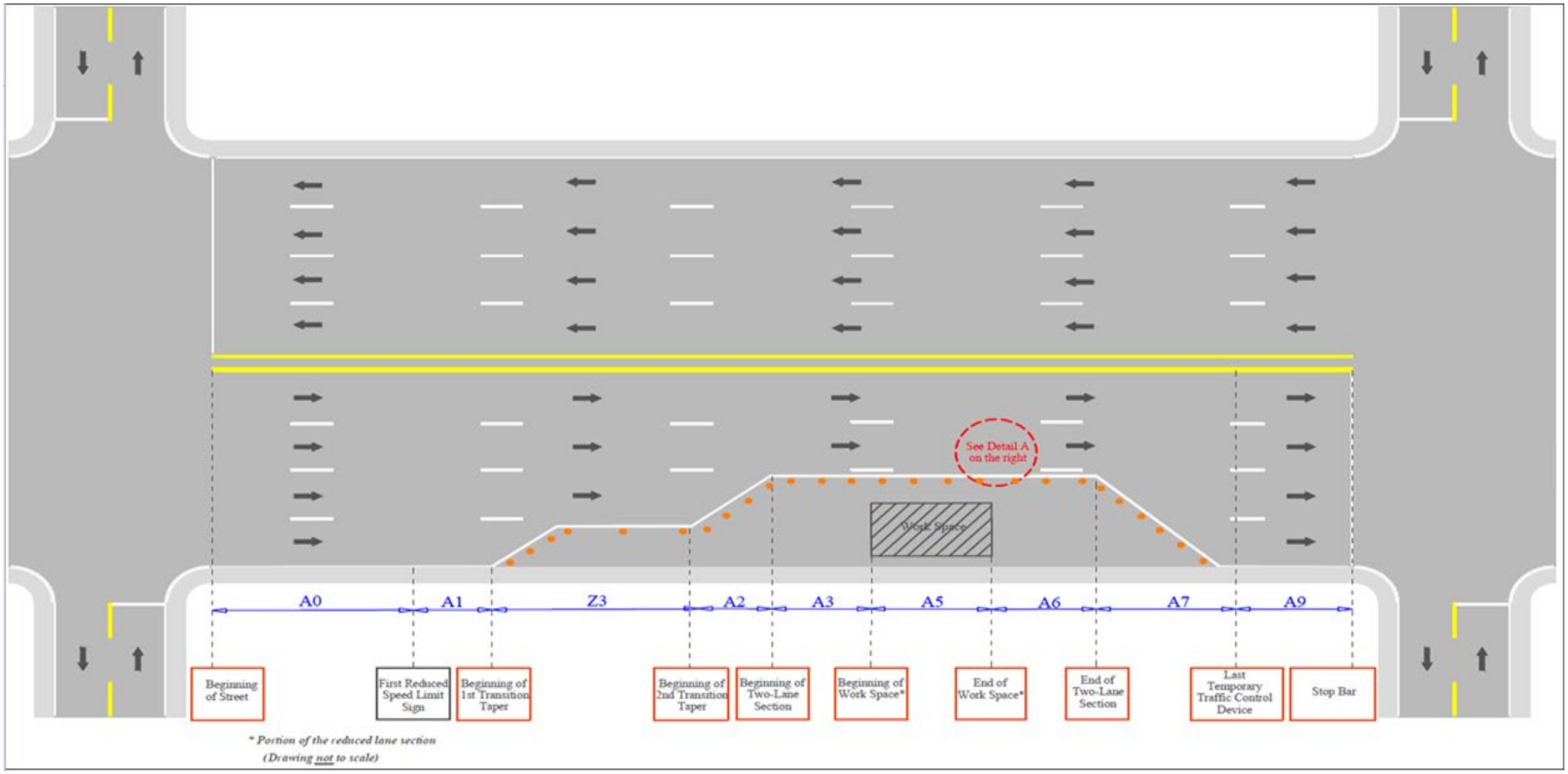
WorkZoneQ-Pro Freeway WZs

Covers up to 6 lanes per direction



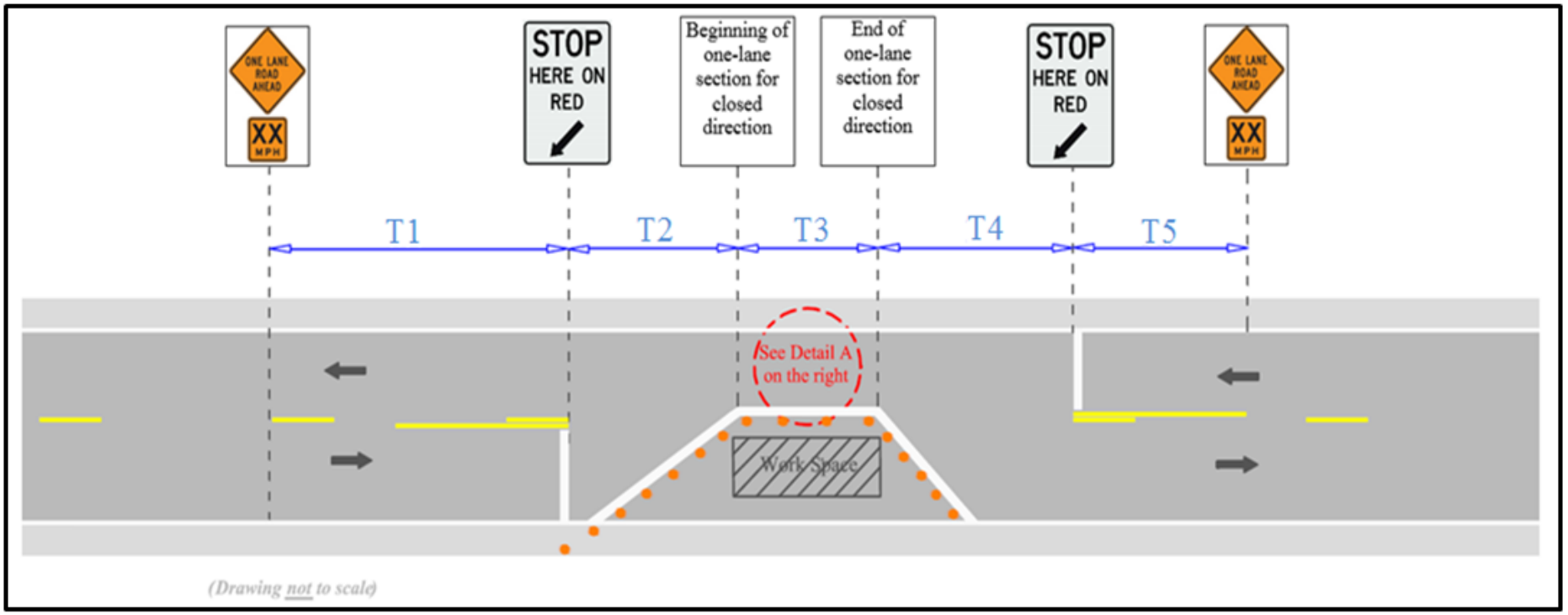
WorkZoneQ-Pro Midblock Arterial WZs

Covers up to 4 lanes per direction



WorkZoneQ-Pro One-lane Two-way Operation

Controlled by traffic signal



WorkZoneQ-Pro (WZQ-Pro) - Overview

Queue length (moving and stopped) is computed by CTM and is more precise than input-output in terms of time and space

Use specified values and defaults:

- Roadway is divided into cells of length **L** ft
- Traffic variables are computed every **T** sec

- For freeways, L=500 ft and T=4 sec
- For arterials, current values are L=250 ft and T=2 sec

Details about this method is given in Appendix H

WorkZoneQ-Pro Interface

Four linked worksheets:

1) GeoCond

    WZ Layout, geometric data, work activity, speed limit,etc

2) TrafficInfo

    Volume (vph), % trucks, PCE, etc

3) UserComp

    Hourly cost figures, avg. no of occupants, etc. shows results

4) Queue-Speed Plot

WZQ-Pro

Facility 1: Freeway WZs

Example Problem #1T

Find delay and users' costs.

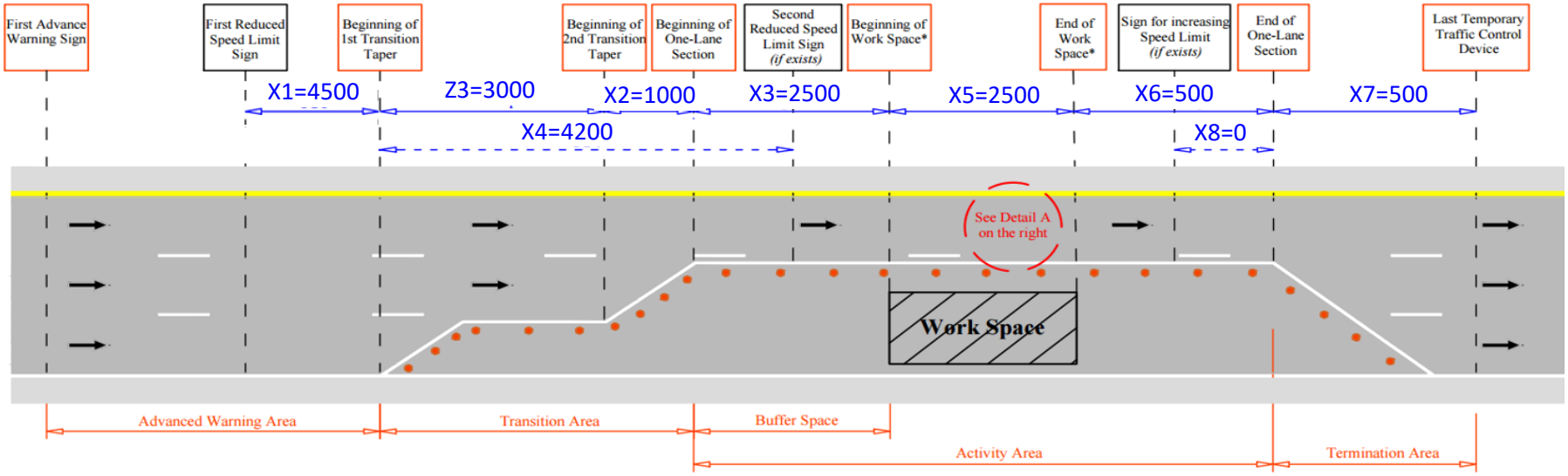
Description:

Freeway, rural area, daytime, clear weather condition

Geometric data: Longitudinal distances in the sketch below

Lane width(Y1) = 11 ft, Right shoulder width(Y2) = 1 ft, Left shoulder width(Y3) = 1 ft

Speed limit outside of the WZ is 65 mph. First and second speed limits inside the WZ are 55 mph.



Description (Continued…)

Interval	% single-unit Trucks	% combination Trucks	% recreational vehicles	Volume (veh)
1:00 PM-2:00 PM	2	8	0	1000
2:00 PM-3:00 PM	2	8	0	1250
3:00 PM-4:00 PM	2	8	0	1300
4:00 PM-5:00 PM	2	11	0	1100
5:00 PM-6:00 PM	2	11	0	950
6:00 PM-7:00 PM	2	11	0	800
7:00 PM-8:00 PM	2	11	0	750

Condition 1: There is no work activity

Condition 2: See the info in the table.

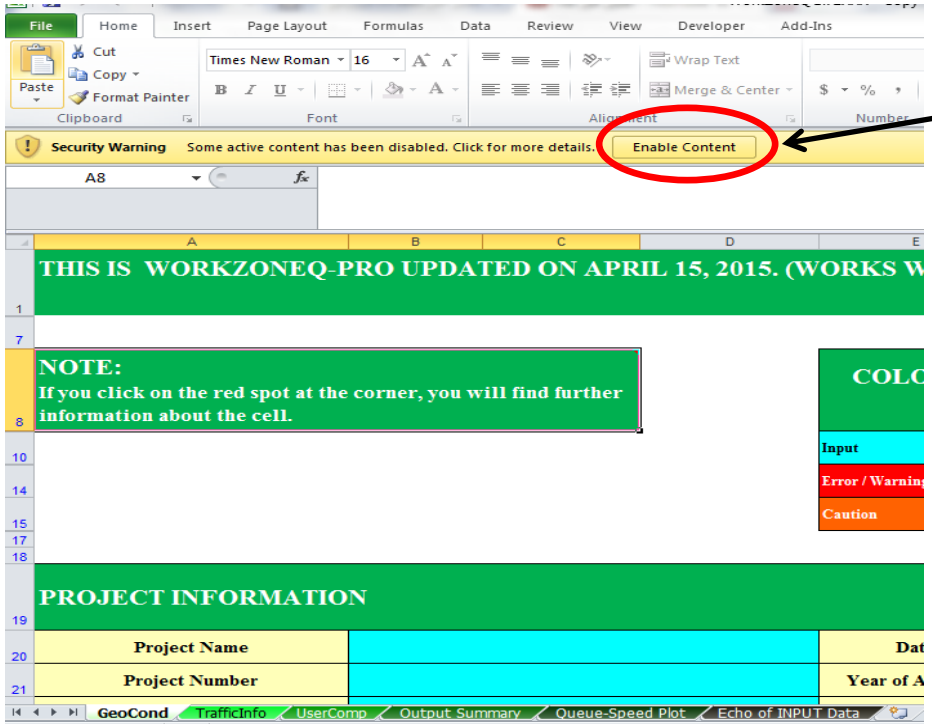
Time duration	WZ characteristics for Condition 2
1:00 PM-2:00 PM	Speed limit=55 mph
2:00 PM-4:00 PM	Speed limit=45 mph, Moderate work activity Work activity area is separated from travel lane by means of barrels
4:00 PM-8:00 PM	Speed limit=55 mph

Condition 3: Condition 2, but assume the WZ is on a rolling terrain.

Condition 4: Condition 3, divert 15% of traffic to other roads.

Open "WZQ-Pro V 1.56 for Freeway WZ" to start the example

- The program automatically opens on the "GeoCond" worksheet by default
- Click the "Enable Content" button to enable macro as shown below:



Note: Enable Content

color codes

COLOR CODING OF THE CELLS	
Input	Output
Error / Warning	Input / output title
Caution	Guidance

"GeoCond" Worksheet

Condition 1: There is no work activity

- Input geometric information

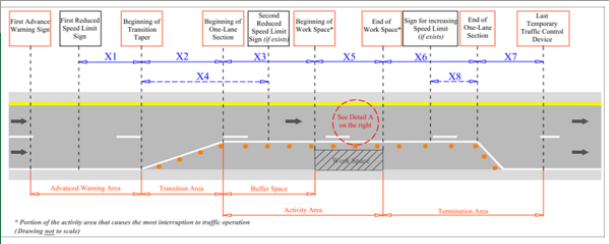
PROJECT INFORMATION

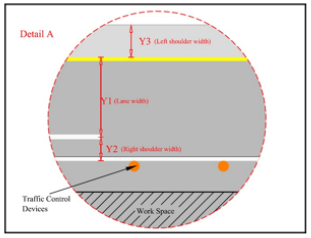
Project Name		Date	
Project Number		Year of Analysis	
Site		Analyst Name	

STEP 1: WZ GEOMETRIC DATA FOR PROJECT NUMBER

Number of open lanes outside the work zone	Number of open lanes in the work zone	Select interval length (min) for analysis	Select start of analysis	Speed limit outside of the work zone (mph)
2	1			

Prepare sketches like below and enter the values of "X1-X8" and "Y1-Y3" in the cells.





CLICK TO SHOW Intermediate Calculations for Lane and Shoulder Width

Enter horizontal and lateral distances in row 33	Distance X1 (Write "0" if there is no speed limit reduction) (ft)	Distance Z1 (ft)	Distance Z2 (ft)	Distance Z3 (ft)	Distance X2 (ft)	Distance X3 (ft)	Distance X4 (Write "0" if there is no second speed limit) (ft)	Distance X5 (ft)	Distance X6 (ft)	Distance X7 (ft)	Distance X8 (Write "0" if there is no speed limit increase sign after Work Space)	Lane width Y1 (ft)	Right shoulder width Y2 (ft)	Left shoulder width Y3 (ft)

CLICK to SHOW Advanced Inputs for Capacity and Speed Adjustments

ERROR! INPUT FOR STEP 1 NOT COMPLETE! INPUT ALL DATA INTO CELLS C33 THROUGH L33.

CLICK TO SHOW ALL INTERVALS IN 24 HOURS

CLICK TO SHOW ONLY SELECTED

Start of Interval	End of Interval	Put "Y" if this interval is analyzed	Put "Y" if crew or construction equipment is closer than 9 ft to edge of travel lane.	Select the first speed limit from the drop down menu	Select the second speed limit from the drop down menu	Put "S" for short term work zones (concrete barriers are used), and "O" for short term work zones (other devices such as cones and drums are used).	Put "L" for low work intensity, "M" for moderate work intensity, "H" for high work intensity.	Put "F" if flagger is present.	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?	Select the Speed Control Technique (if any) from the drop down menu. 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.* (mph)	Select capacity adjustment factors (CAFs) due to inclement weather condition. Otherwise leave it as 100%.	Select percent capacity increase for urban areas. Otherwise leave it as 0%.	Select percent capacity reduction due to night time operation. Otherwise leave it as 0%.	Enter percent capacity reduction if you know effect of other factors such as ramp, and unevenness of pavement. Otherwise leave it as 0%.	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 (pcph)
12:00 AM	1:00 AM	N																				
1:00 AM	2:00 AM	N																				
2:00 AM	3:00 AM	N																				

"GeoCond" Worksheet

Condition 1: There is no work activity

- Input project information on cells from B20 to F22
- Input number of open lanes inside and outside of the WZ

Number of open lanes outside the work zone	Number of open lanes in the work zone
3	1

- Select interval length, start of analysis, and speed limit outside of WZ

Select interval length (min) for analysis	Select start of analysis	Speed limit outside of the work zone (mph)
○ 15 min ○ 30 min ◉ 60 min (DEFAULT)	1:00 PM	65

"GeoCond" Worksheet

Condition 1: There is no work activity

- Enter the longitudinal distances from problem description

Distance X1 (Write "0" if there is no speed limit reduction) (ft)	Distance Z1 (ft)	Distance Z2 (ft)	Distance Z3 (ft)	Distance X2 (ft)	Distance X3 (ft)
4,500			3,000	1,000	2,500

Distance X4 (Write "0" if there is no second speed limit) (ft)	Distance X5 (ft)	Distance X6 (ft)	Distance X7 (ft)	Distance X8 (Write "0" if there is no speed limit increase sign after Work Space) (ft)
4,200	2,500	500	500	0

- Enter lane and shoulder widths

Lane width Y1 (ft)	Right shoulder width Y2 (ft)	Left shoulder width Y3 (ft)
11.0	1.0	1.0

"GeoCond" Worksheet

Condition 1: There is no work activity

- Enter the traffic control plan data:

CLICK TO SHOW ALL INTERVALS IN 24 HOURS

CLICK TO SHOW ONLY SELECTED

Start of Interval	End of Interval	Put "Y" if this interval is analyzed	Put "Y" if crew or construction equipment is closer than 9 ft to edge of travel lane.	Select the first speed limit from the drop down menu	Select the second speed limit from the drop down menu	Put "C" for long term work zones (concrete barriers are used), and "O" for short term work zones (other devices such as cones and drums are used).	Put "L" for low work intensity, "M" for moderate work intensity, "H" for high work intensity.	Put "F" if flagger is present.
1:00 PM	2:00 PM	Y	N	55	55	O		N
2:00 PM	3:00 PM	Y	N	55	55	O		N
3:00 PM	4:00 PM	Y	N	55	55	O		N
4:00 PM	5:00 PM	Y	N	55	55	O		N
5:00 PM	6:00 PM	Y	N	55	55	O		N
6:00 PM	7:00 PM	Y	N	55	55	O		N
7:00 PM	8:00 PM	Y	N	55	55	O		N

Click this button CLICK TO SHOW ONLY SELECTED to remove rows showing time intervals not analyzed

"GeoCond" Worksheet

Condition 1: There is no work activity

- Highlighted outputs

Adjusted free flow speed

Capacity

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		53.4	1,509	41.9	1,509
62.0		53.4	1,509	41.9	1,509
62.0		53.4	1,509	41.9	1,509
62.0		53.4	1,509	41.9	1,509
62.0		53.4	1,509	41.9	1,509
62.0		53.4	1,509	41.9	1,509
62.0		53.4	1,509	41.9	1,509

"TrafficInfo" Worksheet

- Default Values
- Increase/decrease on the expected traffic volume

STEP 8: PASSENGER CAR EQUIVALENCY (PCE) FOR PROJECT NUMBER		Click to SHOW/HIDE Speed Contour and Advanced Features
Terrain Type and PCE values for Specific Grade	PCE for heavy vehicles	Put "X" if there is variation in traffic demand within an interval
Level	2.0	X

STEPS 9-10: TRAFFIC VOLUME AND PERCENT TRUCKS DATA FOR PROJECT NUMBER								
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)	Heavy vehicle adjustment factor	Adjusted volume (pcph)	Capacity (vphpl)
1:00 PM	2:00 PM							
2:00 PM	3:00 PM							
3:00 PM	4:00 PM							
4:00 PM	5:00 PM							
5:00 PM	6:00 PM							
6:00 PM	7:00 PM							

"TrafficInfo" Worksheet (Step 1)

- Enter default PCE values (HCM values for Level terrain)

B	C
Terrain Type and PCE values for Specific Grade	PCE for heavy vehicles
Level	2.0

- Input traffic volume and composition data

B	C	D	E	F	H	L	M	U
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)	Heavy vehicle adjustment factor	Adjusted volume (pcph)	Capacity (vphpl)
1:00 PM	2:00 PM	2.0	8.0	0.0	1,000	0.91	1,100	1,372
2:00 PM	3:00 PM	2.0	8.0	0.0	1,250	0.91	1,375	1,372
3:00 PM	4:00 PM	2.0	8.0	0.0	1,300	0.91	1,430	1,372
4:00 PM	5:00 PM	2.0	11.0	0.0	1,100	0.88	1,243	1,336
5:00 PM	6:00 PM	2.0	11.0	0.0	950	0.88	1,074	1,336
6:00 PM	7:00 PM	2.0	11.0	0.0	800	0.88	904	1,336
7:00 PM	8:00 PM	2.0	11.0	0.0	750	0.88	848	1,336

"UserComp" Worksheet

Condition 1: There is no work activity

- Enter hourly cost figures (for this problem they are default values)

	STEPS 11-15: VEHICLE OCCUPANCY AND COST FIGURES FOR PROJECT NUMBER					
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 ($/hr)	Hourly delay cost for a combination truck ($/hr)	Hourly delay cost for a recreational vehicle ($/hr)	Hourly delay cost for a passenger car ($/hr)
4	1.25	2.00	$25	$30	$21	$21

"UserComp" Worksheet

Condition 1: There is no work activity

Highlighted outputs:

No. of vehicles in queue

Distance queue occupied

Avg. speed

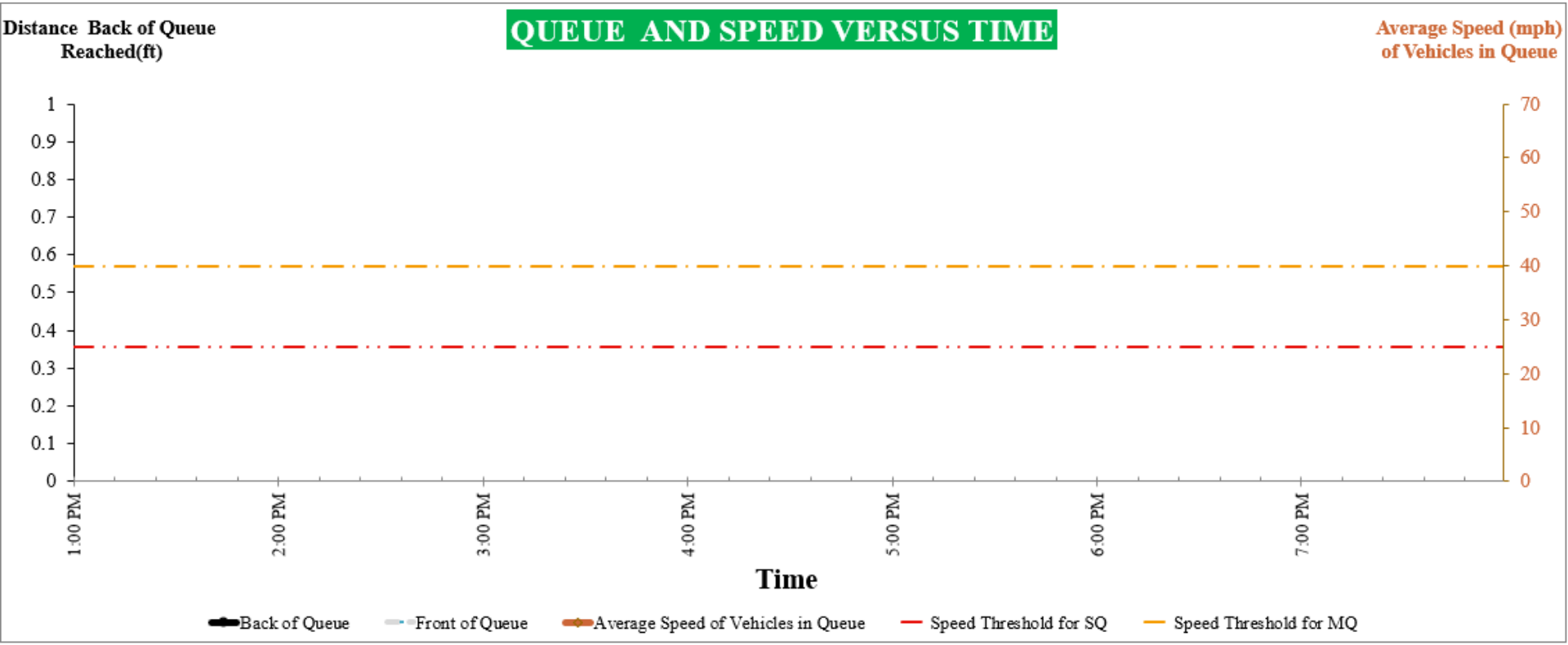
Users' costs

Start of Interval	End of Interval	No. of vehicles in queue*	Average spacing between vehicles in queue (ft)	Front-of-queue (ft)	Back-of-queue (ft)	Distance queue occupied (ft)	Average speed in queue (mph)	Summary of Users' Costs ($) All (SQ+MQ+SMV)	
								Based on WZ speed limit	Based on speed limit outside of the WZ
1:00 PM	2:00 PM	0	0	0	0	0	-	$72.62	$192.01
2:00 PM	3:00 PM	0	-	-	-	-	-	$157.30	$306.53
3:00 PM	4:00 PM	0	-	-	-	-	-	$174.23	$329.44
4:00 PM	5:00 PM	0	-	-	-	-	-	$114.04	$245.92
5:00 PM	6:00 PM	0	-	-	-	-	-	$63.01	$176.91
6:00 PM	7:00 PM	0	-	-	-	-	-	$26.85	$107.91
7:00 PM	8:00 PM	0	-	-	-	-	-	$20.38	$84.90
					Maximum distance back-of-queue reached (ft)	Maximum distance queue occupied (ft)		SUM All	SUM All
*: At the end of the corresponding interval or when there is no more vehicle in quei					0	0		$628.44	$1,443.62

"Queue-Speed Plot" Worksheet

Condition 1: There is no work activity

There is no queue for Condition 1



"GeoCond" Worksheet

Condition 2: Work activity start from 2:00 PM to 4:00 PM and consequently speed limit is reduced to 45 mph

Step 2) Work activity and the second speed limit in the WZ change

In the "GeoCond" worksheet,

- Enter Work activity data in Columns E, I, and J
- Enter second speed limit in Column H

Start of Interval	End of Interval	Put "Y" if this interval is analyzed	Put "Y" if crew or construction equipment is closer than 9 ft to edge of travel lane.	Select the first speed limit from the drop down menu	Select the second speed limit from the drop down menu	Put "C" for long term work zones (concrete barriers are used), and "O" for short term work zones (other devices such as cones and drums are used).	Put "L" for low work intensity, "M" for moderate work intensity, "H" for high work intensity.
1:00 PM	2:00 PM	Y	N	55	55	O	
2:00 PM	3:00 PM	Y	Y	55	45	O	M
3:00 PM	4:00 PM	Y	Y	55	45	O	M
4:00 PM	5:00 PM	Y	N	55	55	O	
5:00 PM	6:00 PM	Y	N	55	55	O	
6:00 PM	7:00 PM	Y	N	55	55	O	
7:00 PM	8:00 PM	Y	N	55	55	O	

- There are no changes in "TrafficInfo" worksheet

"UserComp" Worksheet

Condition 2: Work activity start from 2:00 PM to 4:00 PM and consequently speed limit is reduced to 45 mph

Start of Interval	End of Interval	No. of vehicles in queue*	Average spacing between vehicles in queue (ft)	Front-of-queue (ft)	Back-of-queue (ft)	Distance queue occupied (ft)	Average speed in queue (mph)	Summary of Users' Costs ($) All (SQ+MQ+SMV)	
								Based on WZ speed limit	Based on speed limit outside of the WZ
1:00 PM	2:00 PM	0	0	0	0	0	-	$72.62	$192.01
2:00 PM	3:00 PM	344	48	0	10,500	10,500	14.8	$4,065.03	$4,305.14
3:00 PM	4:00 PM	713	42	0	15,000	15,000	10.4	$12,496.87	$12,772.67
4:00 PM	5:00 PM	458	50	2,500	13,500	11,000	11.5	$13,882.22	$14,139.41
5:00 PM	6:00 PM	52	87	2,500	6,600	4,100	16.0	$5,768.84	$5,986.57
6:00 PM	7:00 PM	0	87	0	0	0	28.0	$60.52	$146.33
7:00 PM	8:00 PM	0	-	-	-	-	-	$20.38	$84.90
					Maximum distance back-of-queue reached (ft)	Maximum distance queue occupied (ft)		SUM All	SUM All
*: At the end of the corresponding interval or when there is no more vehicle in quei					*15,000*	*15,000*		*$36,366.49*	*$37,627.04*

"UserComp" Worksheet

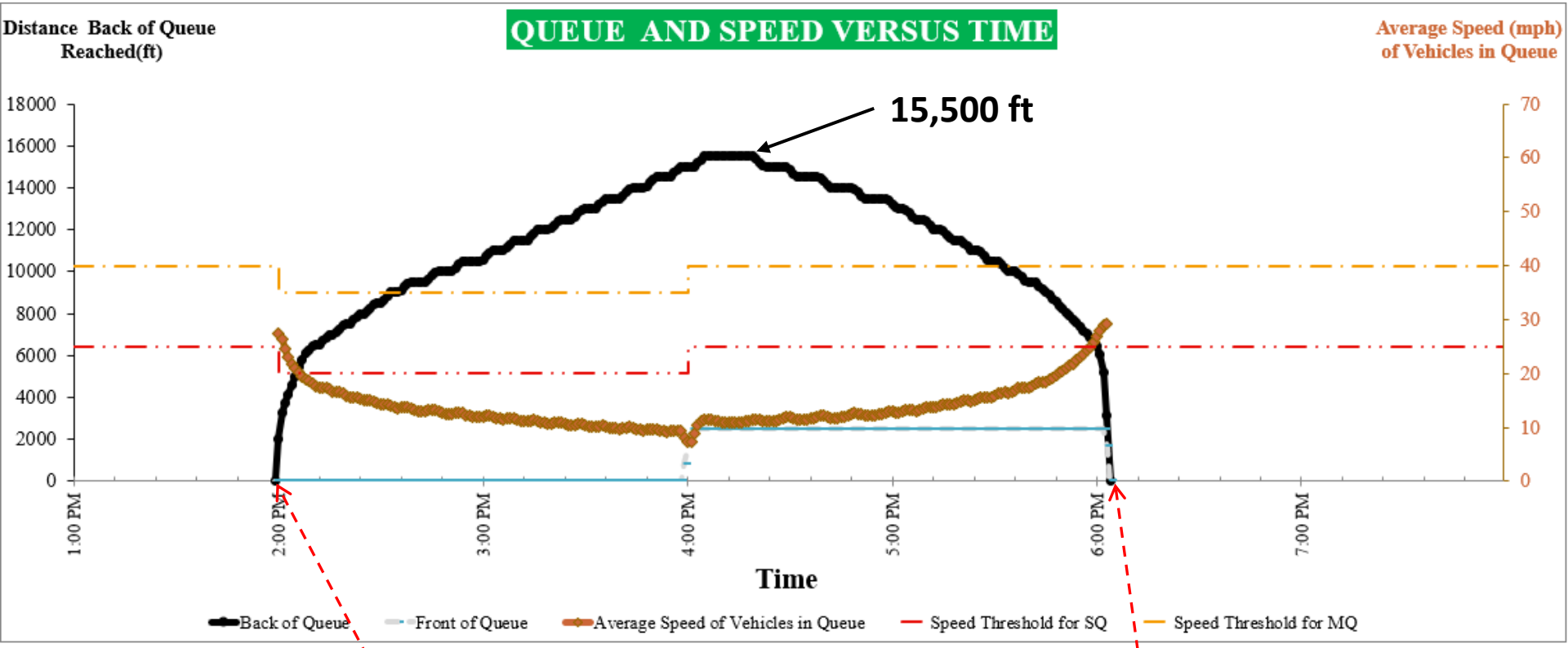
- **Thresholds for moderate and severe queues (congestion)**

Traffic State	WZ Speed limit ≥ 50 mph	
	Speed thresholds	Color code
Slower Moving Vehicles (SMV)	40 ≤ Speed < posted speed limit	Blue
Moderate queue (congestion) (MQ)	25 ≤ Speed < 40	Orange
Severe queue (congestion) (SQ)	Speed < 25	Red

Traffic State	WZ Speed limit ≤ 45 mph	
	Speed thresholds	Color code
Slower Moving Vehicles (SMV)	35 ≤ Speed < posted speed limit	Blue
Moderate queue(congestion) (MQ)	20 ≤ Speed < 35	Orange
Severe queue (congestion) (SQ)	Speed < 20	Red

"Queue-Speed Plot" Worksheet

Condition 2: Work activity start from 2:00 PM to 4:00 PM and consequently speed limit is reduced to 45 mph



Queue begins (2:00 PM)

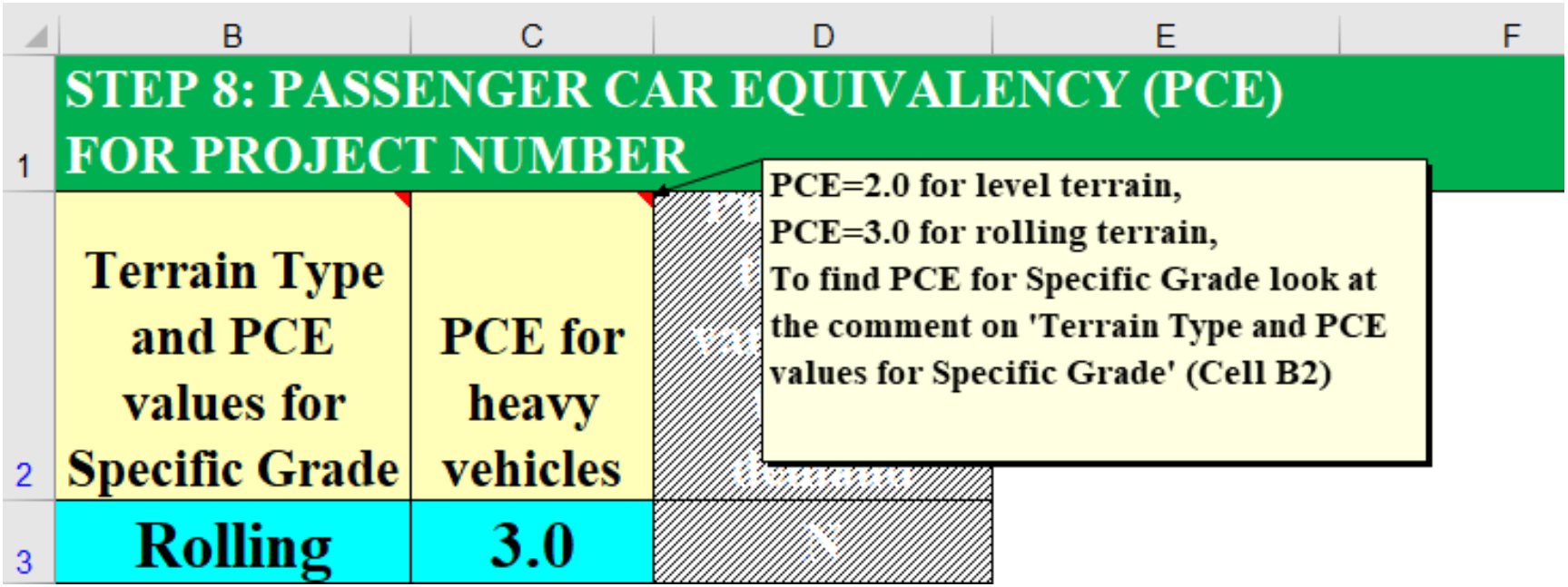
Queue ends (6:04 PM)

"TrafficInfo" Worksheet

Condition 3: Solve the problem for Condition 2 assuming the WZ is on a rolling terrain (PCE values change)

- There are no changes in "GeoCond" worksheet
- In "TrafficInfo" worksheet,

Select Rolling in Cell B3 or click on the red spots in Cell C2 to read the PCE values for rolling terrain and enter the values in Cell C3



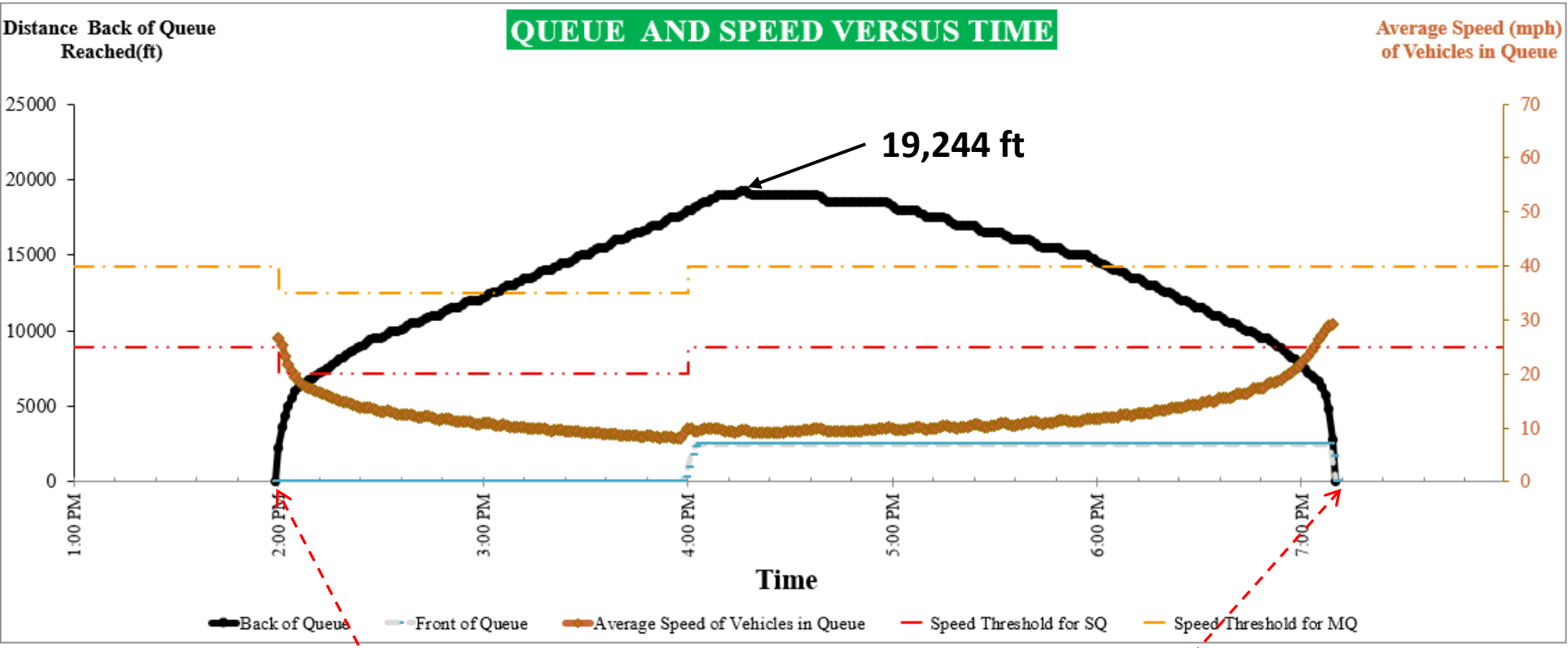
"UserComp" Worksheet

Condition 3: Solve the problem for Condition 2 assuming the WZ is on a rolling terrain (PCE values change)

Start of Interval	End of Interval	No. of vehicles in queue*	Average spacing between vehicles in queue (ft)	Front-of-queue (ft)	Back-of-queue (ft)	Distance queue occupied (ft)	Average speed in queue (mph)	Summary of Users' Costs ($) All (SQ+MQ+SMV)	
								Based on WZ speed limit	Based on speed limit outside of the WZ
1:00 PM	2:00 PM	0	0	0	0	0	-	$94.79	$214.18
2:00 PM	3:00 PM	428	49	0	12,000	12,000	13.6	$5,155.41	$5,384.70
3:00 PM	4:00 PM	880	44	0	17,833	17,833	9.2	$15,772.68	$16,031.12
4:00 PM	5:00 PM	771	49	2,500	18,500	16,000	9.5	$20,167.01	$20,397.03
5:00 PM	6:00 PM	504	52	2,500	14,667	12,167	10.5	$15,429.62	$15,666.26
6:00 PM	7:00 PM	91	83	2,500	8,000	5,500	14.5	$6,841.38	$7,050.09
7:00 PM	8:00 PM	0	83	0	0	0	25.1	$177.21	$270.49
					Maximum distance back-of-queue reached (ft)	Maximum distance queue occupied (ft)		SUM All	SUM All
*: At the end of the corresponding interval or when there is no more vehicle in quer					*18,500*	*17,833*		*$63,638.11*	*$65,013.87*

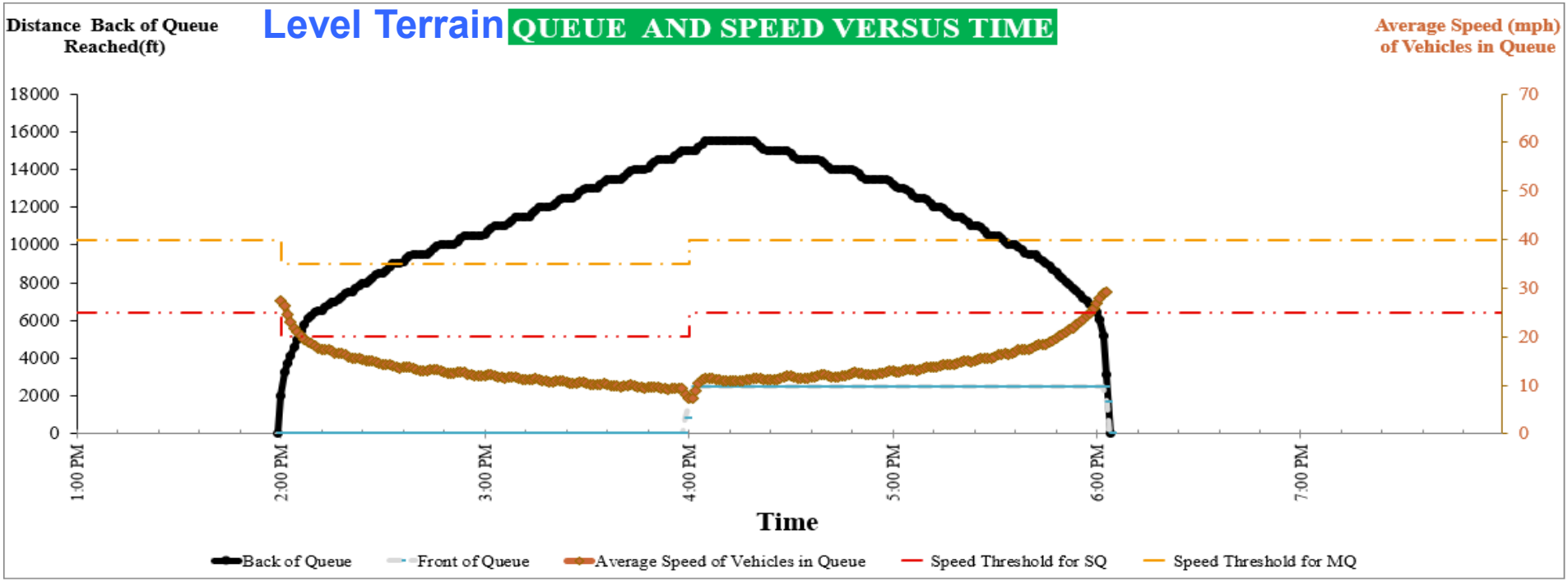
"Queue-Speed Plot" Worksheet

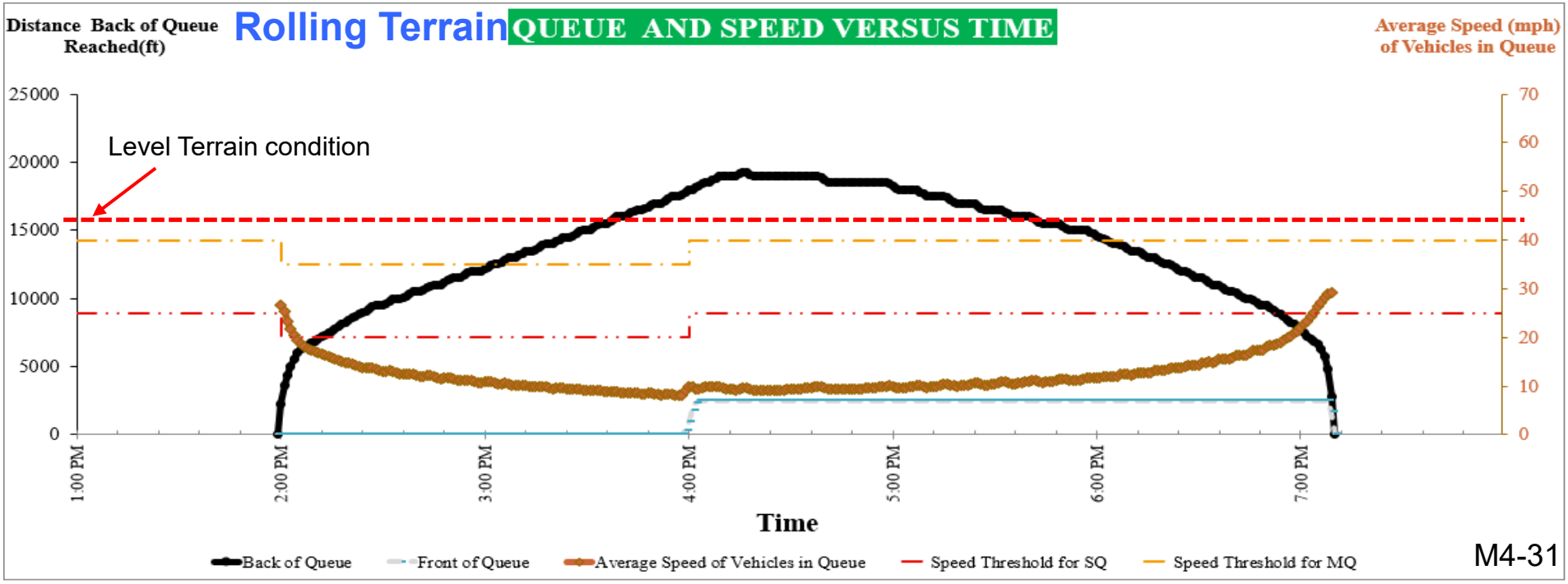
Condition 3: Solve the problem for Condition 2 assuming the WZ is on a rolling terrain (PCE values change)



Queue begins (2:00 PM)

Queue ends (7:10 PM)


Distance Back of Queue Reached(ft)
Level Terrain
QUEUE AND SPEED VERSUS TIME
Average Speed (mph) of Vehicles in Queue
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
70
60
50
40
30
20
10
0
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
Time
Back of Queue
Front of Queue
Average Speed of Vehicles in Queue
Speed Threshold for SQ
Speed Threshold for MQ

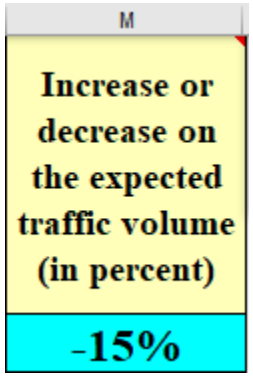

Distance Back of Queue Reached(ft)
Rolling Terrain
QUEUE AND SPEED VERSUS TIME
Average Speed (mph) of Vehicles in Queue
Level Terrain condition
25000
20000
15000
10000
5000
0
70
60
50
40
30
20
10
0
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
Time
Back of Queue
Front of Queue
Average Speed of Vehicles in Queue
Speed Threshold for SQ
Speed Threshold for MQ

"TrafficInfo" Worksheet

Condition 4: Solve the problem for Condition 3 assuming 15% of traffic is diverted (Traffic volume change)

- There are no changes in "GeoCond" worksheet
- In "TrafficInfo" worksheet, Click Following button

- Input 85 % of traffic volume to Column H by entering -15% on Cell M3



- Click following button to apply 85% of traffic volume

"TrafficInfo" Worksheet

Condition 4: Solve the problem for Condition 3 assuming 15% of traffic is diverted (Traffic volume change)

- Result of inputting 85 % of traffic volume to Column H

B	C	D	E	F	H	L	M	U
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)	Heavy vehicle adjustment factor	Adjusted volume (pcph)	Capacity (vphpl)
1:00 PM	2:00 PM	2.0	8.0	0.0	850	0.83	1,020	1,258
2:00 PM	3:00 PM	2.0	8.0	0.0	1,063	0.83	1,275	870
3:00 PM	4:00 PM	2.0	8.0	0.0	1,105	0.83	1,326	870
4:00 PM	5:00 PM	2.0	11.0	0.0	935	0.79	1,178	1,198
5:00 PM	6:00 PM	2.0	11.0	0.0	808	0.79	1,017	1,198
6:00 PM	7:00 PM	2.0	11.0	0.0	680	0.79	857	1,198
7:00 PM	8:00 PM	2.0	11.0	0.0	638	0.79	803	1,198

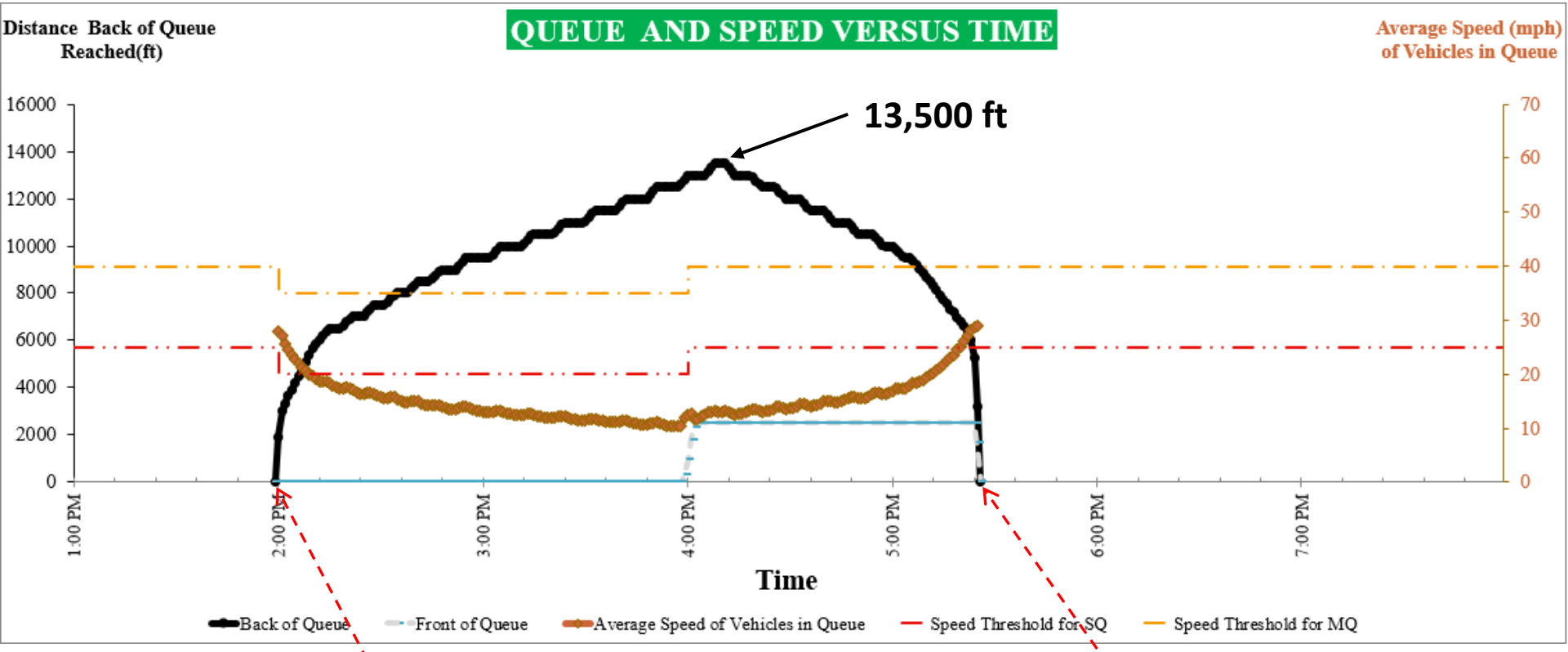
"UserComp" Worksheet

Condition 4: Solve the problem for Condition 3 assuming 15% of traffic is diverted (Traffic volume change)

Start of Interval	End of Interval	No. of vehicles in queue*	Average spacing between vehicles in queue (ft)	Front-of-queue (ft)	Back-of-queue (ft)	Distance queue occupied (ft)	Average speed in queue (mph)	Summary of Users' Costs ($) All (SQ+MQ+SMV) Based on WZ speed limit	Summary of Users' Costs ($) All (SQ+MQ+SMV) Based on speed limit outside of the WZ
1:00 PM	2:00 PM	0	0	0	0	0	-	$43.99	$145.47
2:00 PM	3:00 PM	232	58	0	9,500	9,500	16.1	$2,609.70	$2,820.86
3:00 PM	4:00 PM	479	50	0	12,867	12,867	11.6	$8,181.25	$8,422.44
4:00 PM	5:00 PM	195	64	2,500	10,000	7,500	14.0	$7,778.95	$7,990.08
5:00 PM	6:00 PM	0	64	0	0	0	20.5	$967.46	$1,093.39
6:00 PM	7:00 PM	0	-	-	-	-	-	$19.24	$79.54
7:00 PM	8:00 PM	0	-	-	-	-	-	$13.74	$63.77
					Maximum distance back-of-queue reached (ft)	Maximum distance queue occupied (ft)		SUM All	SUM All
*: At the end of the corresponding interval or when there is no more vehicle in quei					12,867	12,867		$19,614.33	$20,615.54

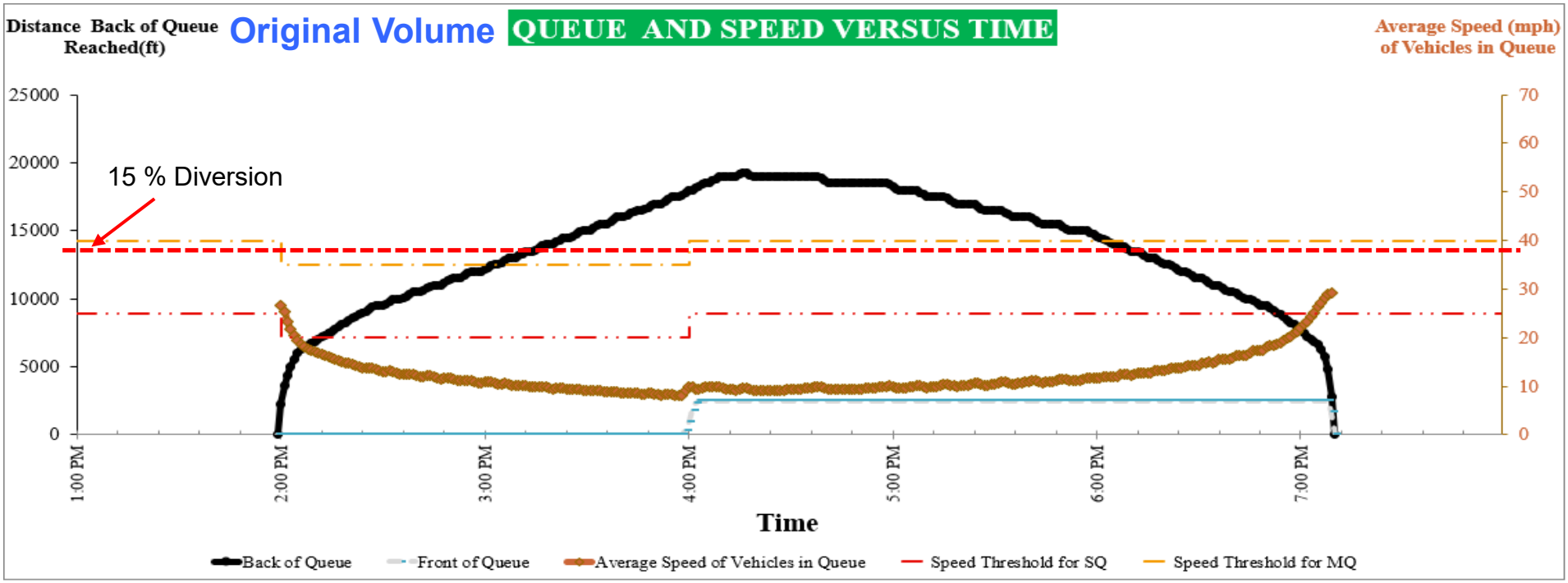
"Queue-Speed Plot" Worksheet

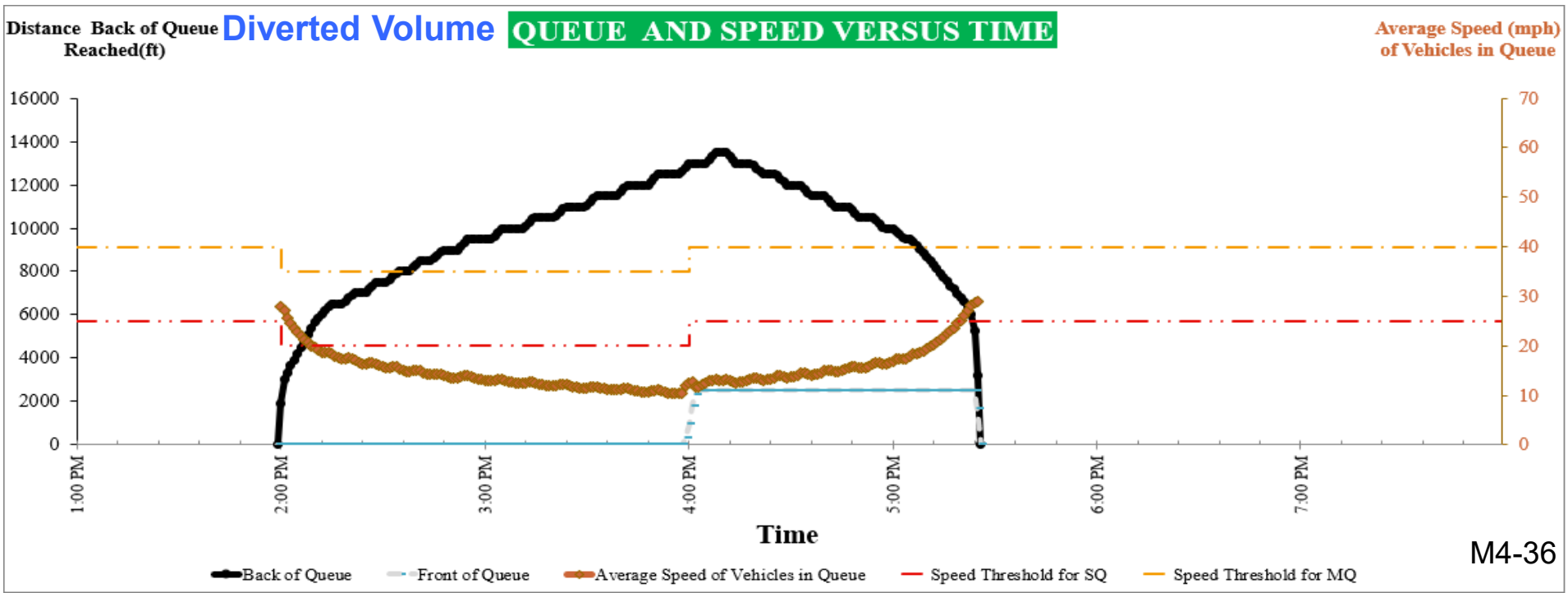
Condition 4: Solve the problem for Condition 3 assuming 15% of traffic is diverted (Traffic volume change)



Queue begins (2:00 PM)

Queue ends (5:26 PM)


Distance Back of Queue Reached(ft)
Original Volume
QUEUE AND SPEED VERSUS TIME
Average Speed (mph) of Vehicles in Queue
15 % Diversion
25000
20000
15000
10000
5000
0
70
60
50
40
30
20
10
0
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
Time
Back of Queue
Front of Queue
Average Speed of Vehicles in Queue
Speed Threshold for SQ
Speed Threshold for MQ


Distance Back of Queue Reached(ft)
Diverted Volume
QUEUE AND SPEED VERSUS TIME
Average Speed (mph) of Vehicles in Queue
16000
14000
12000
10000
8000
6000
4000
2000
0
70
60
50
40
30
20
10
0
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
Time
Back of Queue
Front of Queue
Average Speed of Vehicles in Queue
Speed Threshold for SQ
Speed Threshold for MQ

Questions about Example Problem 1T - Group Discussion

1. Why is there a users cost for Condition 1?
2. How much additional users cost incurred due the two-hour work activity in Condition 2?
3. For how long was queue present in Condition 2?
4. How much additional users cost was there due to changing terrain from level to rolling?
5. What was the increase in queue length due to changing terrain from level to rolling?
6. How much users cost reduced due to 15 % diversion?
7. What was the effects in queue length due to 15% diversion?

Capability of Spreadsheets

To consider the effects of	Spreadsheets			
	QDAT spreadsheet	MoDOT spreadsheet	HCM 2016 WZ capacity method	WZQ-Pro
1) Lane width	N	Y	N	
2) Shoulder width	N	N	Y	
3) Work intensity	Y	Y	N	
4) Speed limit inside WZ on capacity	N	N	N	
5) Speed control techniques in WZ	N	N	N	
6) Barrier type (concrete vs others)	N	N	Y	
7) WZ capacity changes during analysis period.	N	N	N	
8) % of trucks changes during analysis period.	N	N	N	
9) Adverse weather conditions	N	N	N	
10) Night time operation	N	N	Y	
11) Urban vs rural	N	N	Y	
12) Flagger operation	N	N	N	

Comparison between HCM and WZQ-Pro

using data from Example Problem 1T in Module 4

Condition Changes	**Work zone capacity and capacity changes**							
	HCM				WZQ-Pro			
	No Crew		With Crew		No Crew		With Crew	
	Base	Change	Base	Change	Base	Change	Base	Change
Other barrier **to** concrete barrier	1463	1687 (+ 224)	1463	1687 (+ 224)	1509	1579 (+ 70)	1044	1255 (+ 211)
Rural area **to** urban area		1670 (+ 207)		1670 (+ 207)		1650 (+ 141)		1141 (+ 97)
Day **to** nighttime operation		1395 (- 68)		1395 (- 68)		1404 (- 105)		971 (- 73)
1 ft right shoulder **to** 2 ft		1473 (+ 10)		1473 (+ 10)		1519 (+ 10)		1054 (+ 10)
1 ft right shoulder **to** 4 ft		1494 (+ 31)		1494 (+ 31)		1530 (+ 21)		1073 (+ 29)
1 ft right shoulder **to** 6 ft		1515 (+ 52)		1515 (+ 52)		1542 (+ 33)		1093 (+ 49)
1 ft right shoulder **to** 8 ft		1536 (+ 73)		1536 (+ 73)		1542 (+ 33)		1093 (+ 49)

Example Problem #2T

Example Problem # 2T is moved to Appendix S

It is very similar to Example Problem 1

WZQ-Pro

Facility 2: Two-lane Highways (one-lane two-way operation)

One-lane Two Way Work Zones

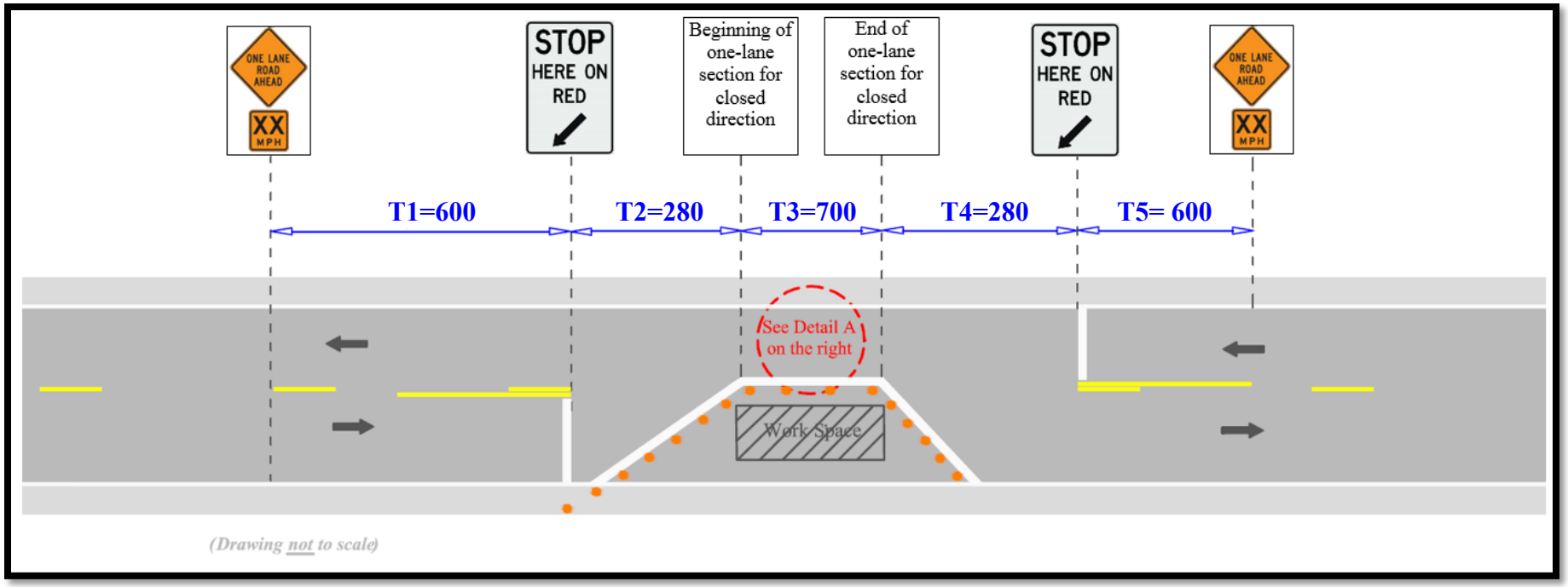
- On a two-lane highway only one lane is open
- One direction stops while the other direction is moving
- Operation is similar to a two-phase traffic signal
- Delay and queue length is computed based on equations given in HCM 2016, but signal timing is not HCM's
- Speed calculation is not the same as in HCM 2016, because WZQ-Pro considers effects of work intensity and speed control techniques on travel speed

Example Problem #1T

Find delay and users' costs for closed and open directions

Description:

Concrete barriers are used in the following WZ with a lane width = 12 ft, left plus right shoulder width = 2 ft, grade =0%, level terrain, and clear weather conditions. Speed limit outside of the WZ is 55 mph



Description (Continued…)

- Work activity and speed limit:

Time duration	WZ Conditions
3:00 PM-4:00 PM	Low work activity, Speed limit=35 mph
4:00 PM-5:00 PM	**High** work activity, Speed limit=35 mph
5:00 PM-6:00 PM	Low work activity, Speed limit=35 mph

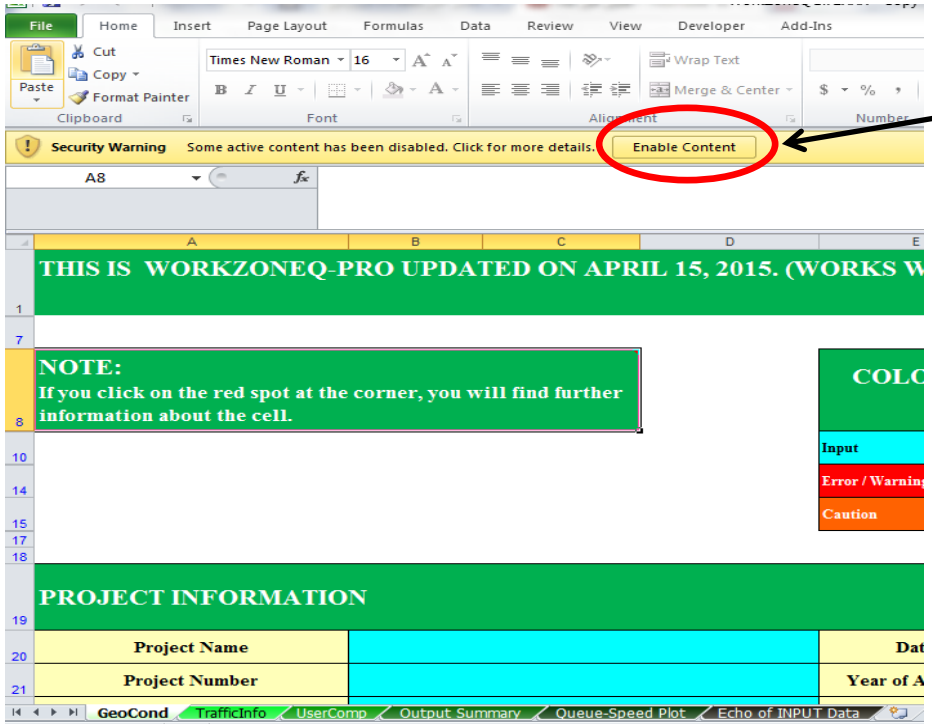
- Traffic data:

	Closed direction			Open direction		
Interval	% Trucks	% Recreational vehicles	Volume (vph)	% Trucks	% Recreational Vehicles	Volume (vph)
3:00 PM-4:00 PM	10	1	500	12	1	550
4:00 PM-5:00 PM	10	1	600	12	1	650
5:00 PM-6:00 PM	10	1	300	12	1	350

- Signal timing information:
  - **Use initial values calculated by WZQ-Pro**

Open WZQ-Pro V 1.55 for One-Lane Two Way WZ

- The program automatically opens on the “GeoCond” worksheet by default
- Click the “Enable Content” button to enable macro as shown below:



Note: Enable Content

color codes

COLOR CODING OF THE CELLS	
Input	Output
Error / Warning	Input / output title
Caution	Guidance

"GeoCond" Worksheet

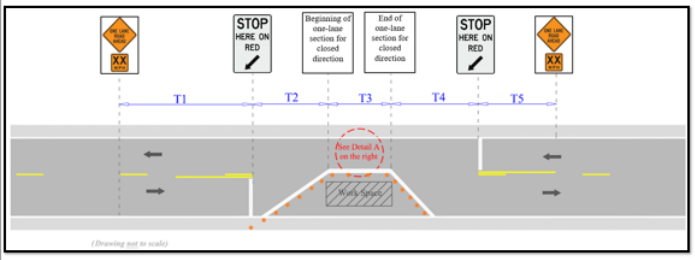
- Input geometric information

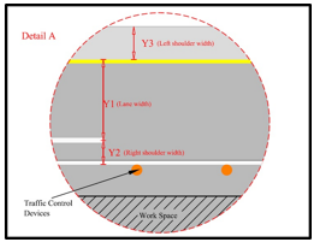
Project Name		Date	
Project Number		Year of Analysis	
Site		Analyst Name	

STEP 1: WZ GEOMETRIC DATA FOR PROJECT NUMBER

Select interval length (min) for analysis	Select start of analysis	Speed limit outside of the work zone	Saturation flow rate in the open direction (default is 1900	Select number of phases (default is 2 phase)
			1900	

Prepare sketches like below and enter the values of "T1-T5" and "Y1-Y3" in the cells.





Enter horizontal and lateral distances in row 33	Distance T1 (ft)	Distance T2 (ft)	Distance T3 (ft)	Distance T4 (ft)	Distance T5 (ft)	Grade (%) at stop bar for the closed direction *Negative is downhill*	Lane width Y1 (ft)	Shoulder width Y2+Y3 (ft)	Speed reduction due to lane width and shoulder width (mph)

ERROR! INPUT FOR STEP 1 NOT COMPLETE! INPUT ALL DATA INTO CELLS C33 THROUGH L33.

CLICK TO SHOW ALL INTERVALS IN 24 HOURS

CLICK TO SHOW ONLY SELECTED

Start of Interval	End of Interval	Put "Y" if this interval is analyzed	Put "Y" if crew or construction equipment is closer than 9 ft to edge of travel lane.		Select the speed limit (mph) in the Work Space	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 menu. 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.*	Select capacity adjustment factors (CAFs) due to inclement weather condition. *Otherwise leave it blank.*	Free flow speed for both directions (mph)	Speed reduction due to work intensity for both directions (mph)	Outputs for closed direction		Outputs for open direction	
													Adjusted speed (mph)	Saturation flow rate (pcphpl)	Adjusted speed (mph)	Saturation flow rate (pcphpl)
12:00 AM	1:00 AM	N														
1:00 AM	2:00 AM	N														
2:00 AM	3:00 AM	N														
3:00 AM	4:00 AM	N														
4:00 AM	5:00 AM	N														

"GeoCond" Worksheet

- Input project information on cells from B20 to F22
- Select interval length, start of analysis, speed limit outside of WZ, saturation flow rate in the open direction, and number of phases

Select interval length (min) for analysis	Select start of analysis	Speed limit outside of the work zone (mph)	Saturation flow rate in the open direction (default is 1900 pcphpl) (pcphpl)	Select number of phases (default is 2 phase)
○ 15 min ○ 30 min ◉ 60 min (DEFAULT)	3:00 PM	55	1900	◉ 2 Phase ○ 3 Phase

- Enter the longitudinal distances from problem description

Distance T1 (ft)	Distance T2 (ft)	Distance T3 (ft)	Distance T4 (ft)	Distance T5 (ft)
600	280	700	280	600

"GeoCond" Worksheet

- Enter grade, lane width, and shoulder width for both directions

Grade (%) at stop bar for the closed direction *Negative is downhill*	Lane width Y1 (ft)	Shoulder width Y2+Y3 (ft)	Speed reduction due to lane width and shoulder width (mph)
0	12.0	2.0	2.6

- Enter the traffic control plan data

Start of Interval	End of Interval	Put "Y" if this interval is analyzed	Put "Y" if crew or construction equipment is closer than 9 ft to edge of travel lane.		Select the speed limit (mph) in the Work Space	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.
3:00 PM	4:00 PM	Y	Y		35	C	L
4:00 PM	5:00 PM	Y	Y		35	C	H
5:00 PM	6:00 PM	Y	Y		35	C	L

"GeoCond" Worksheet

- Outputs for closed and open directions

Adjusted speed

Sat. flow rate

Free flow speed for both directions (mph)	Speed reduction due to work intensity for both directions (mph)	Outputs for closed direction		Outputs for open direction	
		Adjusted speed (mph)	Saturation flow rate (pcphpl)	Adjusted speed (mph)	Saturation flow rate (pcphpl)
40.0	1.3	36.1	1805	36.1	1,900
40.0	3.3	34.1	1805	34.1	1,900
40.0	1.3	36.1	1805	36.1	1,900

"TrafficInfo" Worksheet

Increase/decrease in expected traffic volume

Terrain Type and PCE values for Specific Grade	PCE for heavy vehicles
Level	2.0

% Increase or decrease in expected traffic volumes for CLOSED direction	To get the ORGINAL expected traffic volumes for CLOSED direction, put zero in Cell G3, and CLICK here	CLICK here to UPDATE expected traffic volumes for CLOSED direction
0%		

% Increase or decrease in expected traffic volumes for OPEN direction	To get the ORGINAL expected traffic volumes for OPEN direction, put zero in Cell N3, and CLICK here	CLICK here to UPDATE expected traffic volumes for OPEN direction
0%		

STEPS 9-10: TRAFFIC VOLUME AND PERCENT TRUCKS DATA FOR PROJECT NUMBER

Start of Interval	End of Interval	Traffic Info for CLOSED direction						Traffic Info for OPEN direction					
		Percentage of trucks (%)	Percentage of recreational vehicles (%)	Expected traffic volume during the interval (veh)	Heavy vehicle adjustment factor	Adjusted volume (pcph)	Capacity (vphpl)	Percentage of trucks (%)	Percentage of recreational vehicles (%)	Expected traffic volume during the interval (veh)	Heavy vehicle adjustment factor	Adjusted volume (pcph)	Capacity (vphpl)
3:00 PM	4:00 PM	0.0	0.0		1.00	ERROR! Enter data in	Enter phase	0.0	0.0		1.00	#VALUE!	Enter phase plan in
4:00 PM	5:00 PM	0.0	0.0		1.00	ERROR! Enter data in	Enter phase	0.0	0.0		1.00	#VALUE!	Enter phase plan in
5:00 PM	6:00 PM	0.0	0.0		1.00	ERROR! Enter data in	Enter phase	0.0	0.0		1.00	#VALUE!	Enter phase plan in

ENTER PHASE PLAN INFORMATION

Select "Road clearance time" unless both directions are not used by travelers (due to TEMPORARY use of the open lane for work activities)

- ● Road clearance time
- ○ Both directions are not used by travelers

Phase plan for CLOSED direction				Phase plan for OPEN direction			
Green time (sec)	Yellow time (sec)	Road clearance time	Skip Red time	Green time (sec)	Yellow time (sec)	Road clearance time	Skip Red time
Suggest Initial Values							

CLICK TO COMPUTE INITIAL VALUES FOR PHASE PLAN

"TrafficInfo" Worksheet

- Enter Terrain type as Level to set PCE values

Terrain Type and PCE values for Specific Grade	PCE for heavy vehicles *(Default is 2.0)*
Level	2.0

- Input traffic volume and composition data for both directions

Traffic Info for CLOSED direction		
Percentage of trucks (%)	Percentage of recreational vehicles (%)	Expected traffic volume during the interval (veh)
10.0	1.0	500
10.0	1.0	600
10.0	1.0	300

Traffic Info for OPEN direction		
Percentage of trucks (%)	Percentage of recreational vehicles (%)	Expected traffic volume during the interval (veh)
12.0	1.0	550
12.0	1.0	650
12.0	1.0	350

- Click on CLICK TO COMPUTE INITIAL VALUES FOR PHASE PLAN then the program computes the initial values

Phase plan for CLOSED direction				Phase plan for OPEN direction			
Green time (sec)	Yellow time (sec)	Road clearance time (sec)	Stop time (sec)	Green time (sec)	Yellow time (sec)	Road clearance time (sec)	Stop time (sec)
Suggest Initial Values							
119	4	34		124	4	33	
119	4	34		124	4	33	

"UserComp" Worksheet

- Enter hourly cost figures; for this problem they are default values.

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 ($/hr)	Hourly delay cost for a combination truck ($/hr)	Hourly delay cost for a recreational vehicle ($/hr)	Hourly delay cost for a passenger car ($/hr)
1.25	2.00	$25	$30	$21	$21

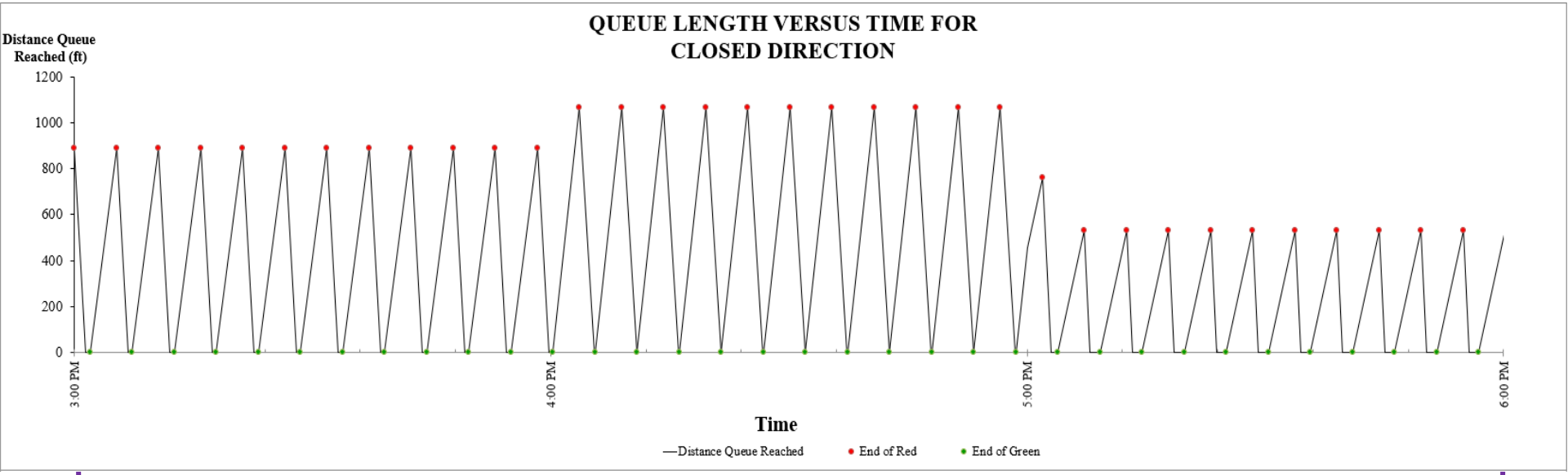
- Highlighted outputs for CLOSED direction

No. of vehicles in queue — Distance queue reached — Delay — Users' cost

Results for CLOSED direction					
No. of vehicles in queue in the beginning of green*	Average spacing between vehicles in queue (ft)	Distance queue reached (ft)	Average delay per vehicle (hr)	Delay experienced by all vehicles on CLOSED direction (hr)	Users' costs ($) in the CLOSED direction
31	29	897	0.028	14.1	$376.89
37	29	1,071	0.041	24.9	$665.73
18	29	521	0.022	6.6	$175.98
		Maximum distance queue reached (ft)		SUM delay	SUM users' costs
		1,071		*45.5*	*$1,218.59*

"Queue Plot" Worksheet

- Queue plot for CLOSED direction



No queue at the end of green

"UserComp" Worksheet

- Highlighted outputs for OPEN direction

No. of vehicles in queue

Distance queue reached

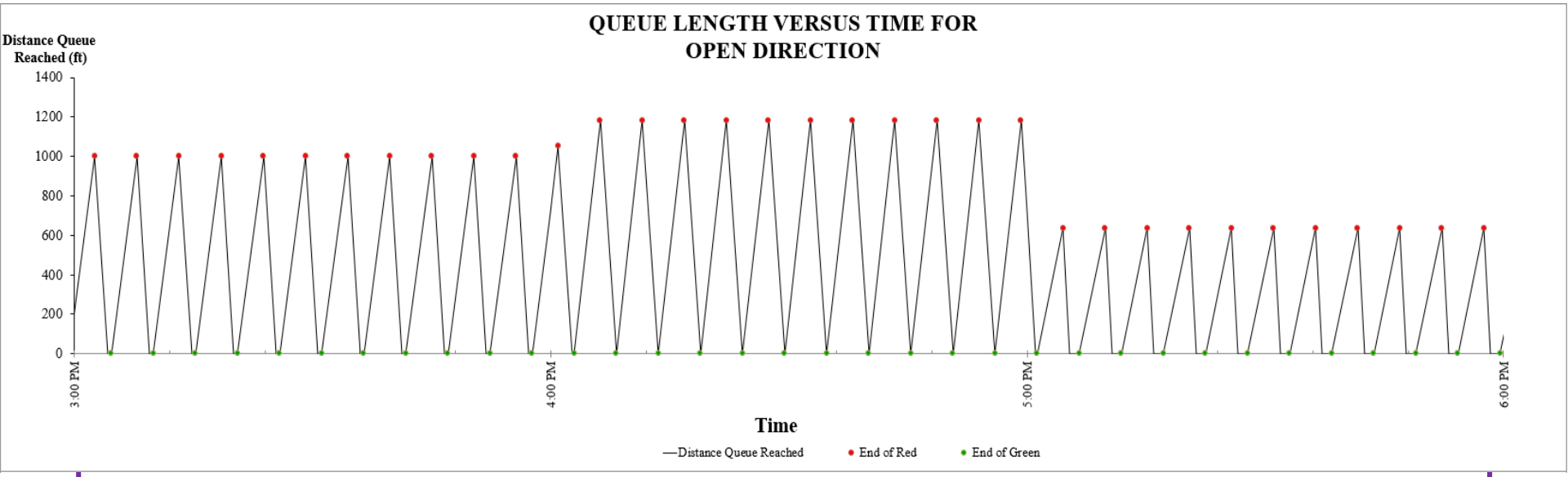
Delay

Users' cost

Results for OPEN direction					
No. of vehicles in queue in the beginning of green*	Average spacing between vehicles in queue (ft)	Distance queue reached (ft)	Average delay per vehicle (hr)	Delay experienced by all vehicles on OPEN direction (hr)	Users' costs ($) in the OPEN direction
33	30	985	0.028	15.2	$408.91
40	30	1,194	0.041	26.6	$714.73
21	30	627	0.022	7.5	$202.16
		Maximum distance queue reached (ft)		SUM delay	SUM users' costs
		1,194		*49.4*	*$1,325.80*

"Queue Plot" Worksheet

- Queue plot for OPEN direction



No queue at the end of green

Effects of changing signal timing variables - Group Discussion

1. Is the green times used optimal values?

2. What are the effects of increasing green time for one direction on queue and users' costs?

3. What are the effects of increasing green time on both directions on queue and users' costs?

4. Can the suggested road clearance time be increased? decreased?

WZQ-Pro

Facility 3: Arterials

3.1: Midblock WZ

WZ at Midblock Arterial

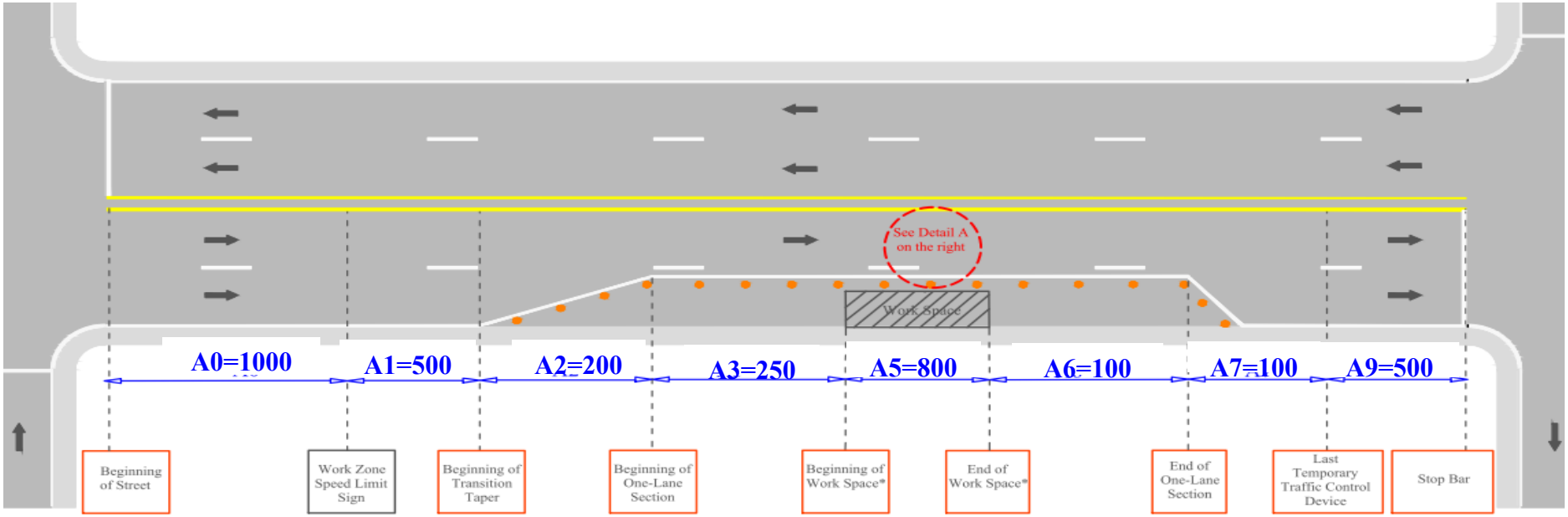
- Lane is closed in the middle of an arterial link
- May cause speed reduction and create moving queue
- Delay and queue length is computed based on Cell Transmission Model (CTM)
- WZQ-Pro estimates speed, capacity, queue length, delay, users' costs.
- It also give a warning when queue reaches the upstream intersection.

Example Problem #1T

Would the queue back up reach the upstream intersection?

Description:

This WZ is on level train and barrels are used. Lane width = 10.5 ft, total lateral clearance width = 2 ft, daytime WZ, clear weather condition, and speed reduction due to access points = 1.6 mph. Speed limit outside of the WZ is 55 mph



Description (Continued…)

- Work activity and speed limit:

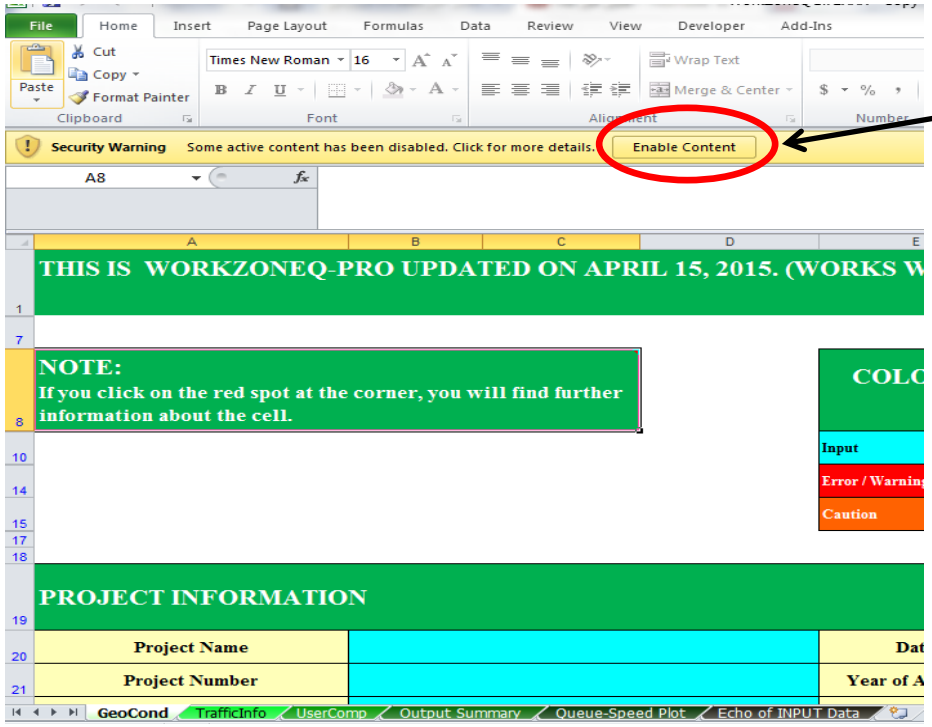
Time duration	WZ Conditions
7:00 AM-9:00 AM	Speed limit=45 mph
9:00 AM-11:00 AM	Moderate work activity, Speed limit=35 mph
11:00 AM-12:00 PM	Speed limit=45 mph

- Traffic data:

Interval	% Single-unit trucks	% Combination trucks	% Recreational vehicles	Volume (veh)
7:00 AM-8:00 AM	5	15	2	900
8:00 AM-9:00 AM	5	15	2	800
9:00 AM-10:00 AM	5	15	2	650
10:00 AM-11:00 AM	5	15	2	700
11:00 AM-12:00 PM	5	15	2	750

Open WZQ-Pro 1.56 for Midblock Arterials to start the example

- The program automatically opens on the “GeoCond” worksheet by default
- Click the “Enable Content” button to enable macro as shown below:



Note: Enable Content

color codes

COLOR CODING OF THE CELLS	
Input	Output
Error / Warning	Input / output title
Caution	Guidance

"GeoCond" Worksheet

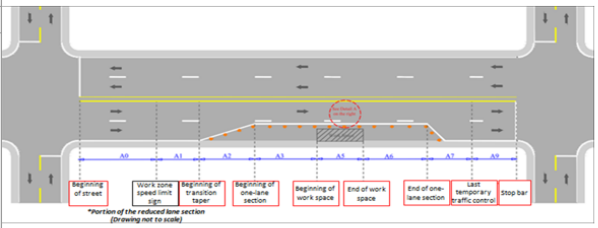
- Input geometric information

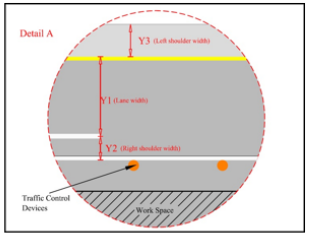
Project Name		Date	
Project Number		Year of Analysis	
Site		Analyst Name	

STEP 1: WZ GEOMETRIC DATA FOR PROJECT NUMBER

No. of lanes outside the work zone	No. of lanes inside the work zone	Select interval length (min) for analysis	Select start of analysis	Speed limit outside of the work zone (mph)
2	1			

Prepare sketches like below and enter the values of "A0-A9" and "Y1-Y3" in the cells.





CLICK TO SHOW Intermediate Calculations for Lane and Lateral Clearance Width

Enter horizontal and lateral distances in row 33	Distance A0 (ft)	Distance Z2 (ft)	Distance Z3 (ft)	Distance A1 (ft)	Distance A2 (ft)	Distance A3 (ft)	Distance A5 (ft)	Distance A6 (ft)	Distance A7 (ft)	Distance [illegible] (ft)	Distance A9 (ft)	Lane width Y1 (ft)	Total lateral clearance "Y2 + Y3". See comments (ft)
in feet													

CLICK to SHOW Advanced Inputs for Capacity and Speed Adjustments

ERROR! INPUT FOR STEP 1 NOT COMPLETE! INPUT ALL DATA INTO CELLS C33 THROUGH L33.

CLICK TO SHOW ALL INTERVALS IN 24 HOURS

CLICK TO SHOW ONLY SELECTED

Start of Interval	End of Interval	Put "Y" if this interval is analyzed	Put "Y" if crew or construction equipment is closer than 9 ft to edge of travel lane.	Select the speed limit in the work space	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.	Put "F" if flagger is present.	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?	Select the Speed Control Technique (if any) from the drop down menu. Otherwise, leave it blank.	If there is any additional speed reduction due to any other factors, including those in HCM, enter here. Otherwise leave it blank. (mph)	Select capacity adjustment factors (CAFs) due to inclement weather condition. Otherwise leave it as	Select percent capacity increase for urban areas, Otherwise leave it as 0%.	Select percent capacity reduction due to night time operation. Otherwise leave it as 0%.	Enter percent capacity reduction if you know effect of other factors such as ramp, and unevenness of pavement. Otherwise leave it as 0%.	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)	P o
12:00 AM	1:00 AM	N																Not Valid			
1:00 AM	2:00 AM	N																Not Valid			
2:00 AM	3:00 AM	N																Not Valid			
3:00 AM	4:00 AM	N																Not Valid			
4:00 AM	5:00 AM	N																Not Valid			
5:00 AM	6:00 AM	N																Not Valid			

"GeoCond" Worksheet

- Input project information on cells from B20 to F22
- Input number of open lanes inside and outside of the WZ

No. of lanes outside the work zone	No. of lanes inside the work zone
2	1

- Select interval length, start of analysis, and speed limit outside of WZ

Select interval length (min) for analysis	Select start of analysis	Speed limit outside of the work zone (mph)
○ 15 min ○ 30 min ◉ 60 min (DEFAULT)	7:00 AM	55

"GeoCond" Worksheet

- Enter the longitudinal distances from problem description

Distance A0 (ft)	Distance Z2 (ft)	Distance Z3 (ft)	Distance A1 (ft)	Distance A2 (ft)	Distance A3 (ft)
1,000			500	200	250

Distance A5 (ft)	Distance A6 (ft)	Distance A7 (ft)	Distance X8 (Write "0" if there is no 55-mph speed limit sign after Work Space)	Distance A9 (ft)
800	100	100		500

- Enter lane and shoulder widths

Lane width Y1 (ft)	Total lateral clearance "Y2 + Y3", See comments (ft)
10.5	2.0

"GeoCond" Worksheet

- Enter the traffic control plan data

Start of Interval	End of Interval	Put "Y" if this interval is analyzed	Put "Y" if crew or construction equipment is closer than 9 ft to edge of travel lane.	Select the speed limit in the work space	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.	Put "F" if flagger is present.	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?	Select the Speed Control Technique (if any) from the drop down menu. Otherwise, leave it blank.	If there is any additional speed reduction due to any other factors, including those in HCM, enter here. Otherwise leave it blank (mph)
7:00 AM	8:00 AM	Y	N	45	O	M	N	N			1.6
8:00 AM	9:00 AM	Y	N	45	O	M	N	N			1.6
9:00 AM	10:00 AM	Y	Y	35	O	M	N	N			1.6
10:00 AM	11:00 AM	Y	Y	35	O	M	N	N			1.6
11:00 AM	12:00 PM	Y	N	45	O	M	N	N			1.6

"GeoCond" Worksheet

- Highlighted outputs

Speed

Capacity

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)
50.0		41.3	1,208	33.5	1,208
50.0		41.3	1,208	33.5	1,208
40.0	8.0	23.3	758	21.0	758
40.0	8.0	23.3	758	21.0	758
50.0		41.3	1,208	33.5	1,208

"TrafficInfo" Worksheet

- Increase/decrease in expected traffic volumes

STEP 8: PASSENGER CAR EQUIVALENCY (PCE) FOR PROJECT NUMBER

Click to SHOW/HIDE Speed Contour and Advanced Features

Terrain Type and PCE values for Specific Grade	PCE for heavy vehicles	Put "Y" if there is variation in traffic demand within an interval
Level	2.0	N

STEPS 9-10: TRAFFIC VOLUME AND PERCENT TRUCKS DATA FOR PROJECT NUMBER

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)	Heavy vehicle adjustment factor	Adjusted demand (pcph)	Capacity (vphpl)
7:00 AM	8:00 AM	0.0	0.0	0.0		1.00	ERROR! Enter data	1,208
8:00 AM	9:00 AM	0.0	0.0	0.0		1.00	ERROR! Enter data	1,208
9:00 AM	10:00 AM	0.0	0.0	0.0		1.00	ERROR! Enter data	758
10:00 AM	11:00 AM	0.0	0.0	0.0		1.00	ERROR! Enter data	758
11:00 AM	12:00 PM	0.0	0.0	0.0		1.00	ERROR! Enter data	1,208

"TrafficInfo" Worksheet

- Select level for terrain type to set PCE value
- Input traffic volume and composition data

Terrain Type and PCE values for Specific Grade	PCE for heavy vehicles
Level	2.0

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)
7:00 AM	8:00 AM	5.0	15.0	2.0	900
8:00 AM	9:00 AM	5.0	15.0	2.0	800
9:00 AM	10:00 AM	5.0	15.0	2.0	650
10:00 AM	11:00 AM	5.0	15.0	2.0	700
11:00 AM	12:00 PM	5.0	15.0	2.0	750

"UserComp" Worksheet

- Enter hourly cost figures; for this problem they are default values.

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 ($/hr)	Hourly delay cost for a combination truck ($/hr)	Hourly delay cost for a recreational vehicle ($/hr)	Hourly delay cost for a passenger car ($/hr)
1.25	2.00	$25	$30	$21	$21

- Highlighted outputs

Queue **Speed** **Users' costs**

No. of vehicles in queue in the link*	Average spacing between vehicles in queue (ft)	Front-of-Queue (ft)	Back-of-Queue (ft)	Distance queue occupied (ft)	Average speed in queue (mph)	Summary of Users' Costs ($) All (SQ+MQ+SMV) Based on WZ speed limit	Summary of Users' Costs ($) All (SQ+MQ+SMV) Based on speed limit outside of the WZ
0	0	0	0	0	-	$33.91	$67.00
0	-	-	-	-	-	$25.99	$55.41
33	69	0	1,750	1,750	15.5	$377.31	$441.99
the upstre	the upstre	ed the upstream	ed the upstream	ed the upstream	the upstrea	l the upstrea	ned the upstream
0	53	0	0	0	8.7	$273.39	$304.62
			Maximum distance back-of-queue reached (ft)	Maximum distance queue occupied (ft)		SUM All	SUM All
ueue			hed the upstream	ed the upstream		d the upstrea	hed the upstream i

Queue blocked Intersection

Note: Calculations stopped after queue reached the upstream intersection

Midblock WZ Effects - Group Discussion

1. How would I “estimate/guestimate” how far the queue is extended beyond the upstream intersection?

2. What can I do if the queue reaches upstream intersection?

3. Should this procedure be used for “multilane” highways?

Limitations of WorkZoneQ-Pro

- There is no dedicated spreadsheet for WZ on multilane highways or intersections, but an approximate method for multilane highways are given in Appendix T

- User cannot specify mobility criteria, thus it does not automatically generate possible work hours when criteria is met

- It does not compute diversion. To represent diversion, the user should reduce demands by the amount of diverted traffic

Output from WorkZoneQ-Pro

- Capacity
- Speed
  - Free flow speed
  - Speed at capacity
- Queue
  - No. of vehicles in queue and queue length
  - When queue starts and ends
  - Where front and back of queue is
  - Average speed of vehicles in queue
- Delay
  - Average delay per vehicle
  - Delay for each period of analysis
- Users' cost for vehicles
  - In severe queue
  - In moderate queue
  - slower moving vehicles

Advanced Features in WorkZoneQ-Pro

- Speed control techniques (CMS, Police Presence, etc.)
- Weather condition
- Location of WZ (urban and rural)
- Night time operation
- Increase/decrease speed and/or capacity due to a known factor
- Others (PCE, occupancy, hourly cost, etc.)

How to Set Speed Control Technique?

First click button “Click to SHOW Advanced Inputs for Capacity and Speed Adjustments”

CLICK to SHOW Advanced Inputs for Capacity and Speed Adjustments

Change appropriate speed control technique from dropdown menu in column M

L	M	N
For how many minutes will the traffic be stopped in this interval?	**Select the Speed Control Technique (if any) from the drop down menu. 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.* (mph)

L	M	N
For how many minutes will the traffic be stopped in this interval?	**Select the Speed Control Technique (if any) from the drop down menu. 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.* (mph)
	Police Presence	
	Police Presence	
	Police Presence	

How to Set Weather Condition?

First click button “Click to SHOW Advanced Inputs for Capacity and Speed Adjustments”

CLICK to SHOW Advanced Inputs for Capacity and Speed Adjustments

Change appropriate weather condition from comment and copy it in column O

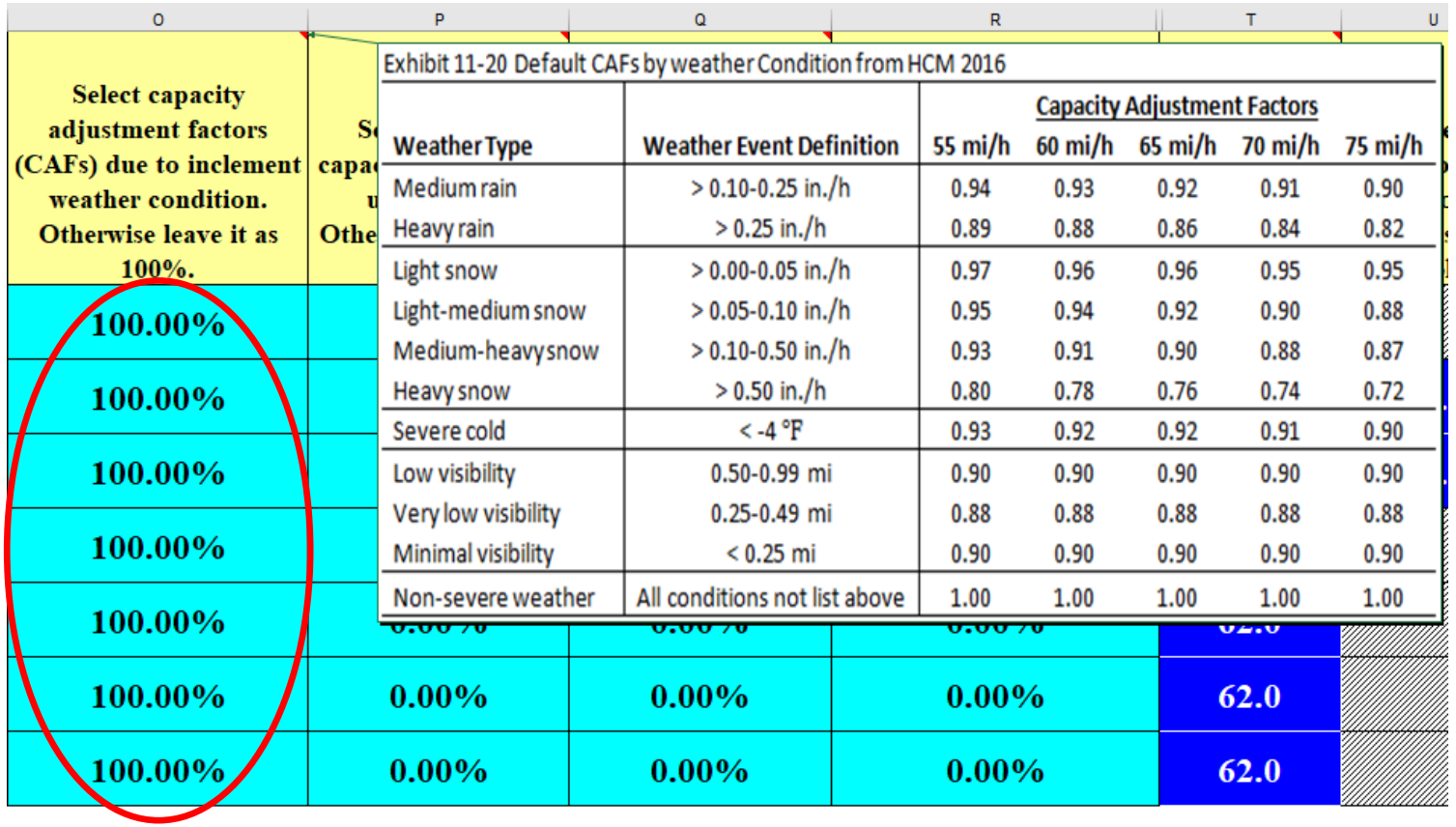


Exhibit 11-20 Default CAFs by weather Condition from HCM 2016

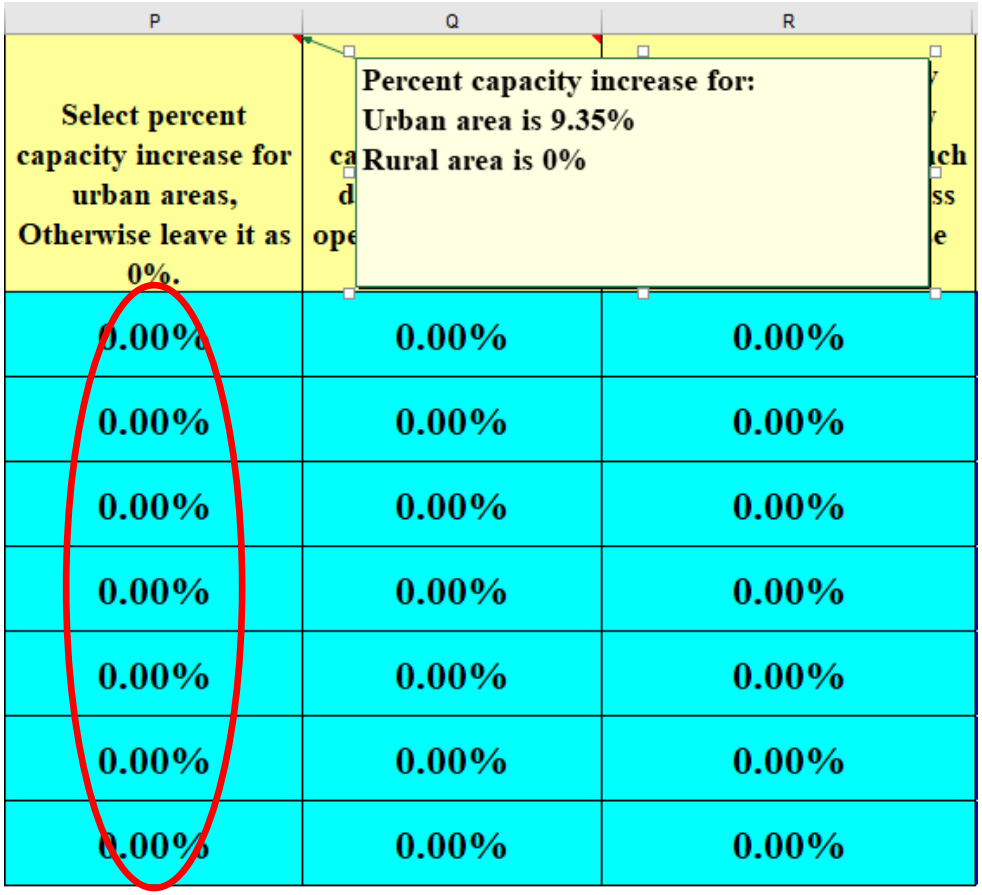
Weather Type	Weather Event Definition	Capacity Adjustment Factors 55 mi/h	60 mi/h	65 mi/h	70 mi/h	75 mi/h
Medium rain	> 0.10-0.25 in./h	0.94	0.93	0.92	0.91	0.90
Heavy rain	> 0.25 in./h	0.89	0.88	0.86	0.84	0.82
Light snow	> 0.00-0.05 in./h	0.97	0.96	0.96	0.95	0.95
Light-medium snow	> 0.05-0.10 in./h	0.95	0.94	0.92	0.90	0.88
Medium-heavy snow	> 0.10-0.50 in./h	0.93	0.91	0.90	0.88	0.87
Heavy snow	> 0.50 in./h	0.80	0.78	0.76	0.74	0.72
Severe cold	< -4 °F	0.93	0.92	0.92	0.91	0.90
Low visibility	0.50-0.99 mi	0.90	0.90	0.90	0.90	0.90
Very low visibility	0.25-0.49 mi	0.88	0.88	0.88	0.88	0.88
Minimal visibility	< 0.25 mi	0.90	0.90	0.90	0.90	0.90
Non-severe weather	All conditions not list above	1.00	1.00	1.00	1.00	1.00

How to Set Urban Area?

First click button “Click to SHOW Advanced Inputs for Capacity and Speed Adjustments”

CLICK to SHOW Advanced Inputs for Capacity and Speed Adjustments

Change appropriate capacity increase for urban area in column P



How to Set Night Time Operation?

First click button “Click to SHOW Advanced Inputs for Capacity and Speed Adjustments”

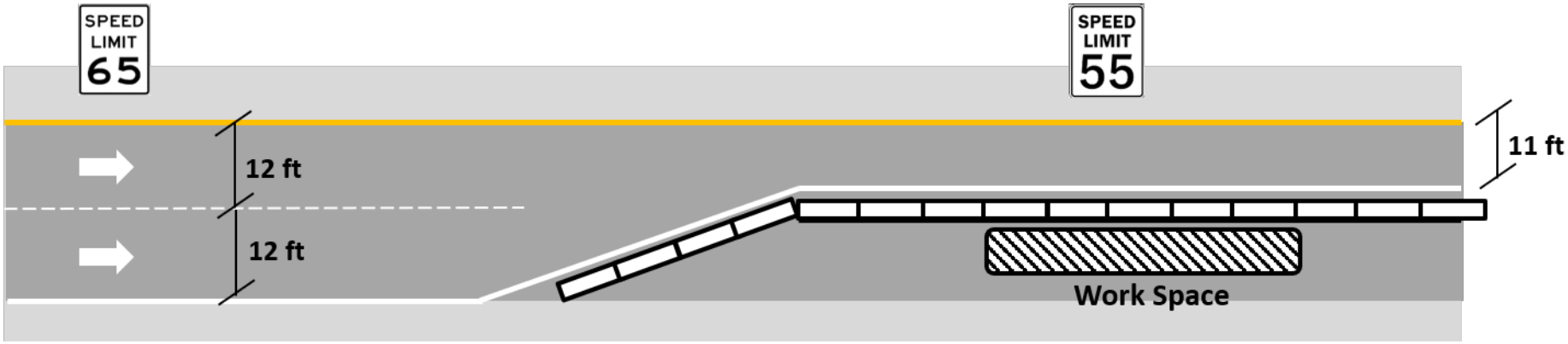
Change appropriate capacity reduction for night time operation in column Q

Q	R	T
Select percent capacity reduction due to night time operation. Otherwise leave it as 0%.	Percent capacity reduction for: Night is 7% ef as ramp, and unevenness of pavement. Otherwise leave it as 0%.	Free flow speed (mph)
0.00%	0.00%	62.0
0.00%	0.00%	55.0
0.00%	0.00%	55.0
0.00%	0.00%	62.0
0.00%	0.00%	62.0
0.00%	0.00%	62.0
0.00%	0.00%	62.0

How to Set HCM Capacity Value?

HCM capacity example

WZ on a freeway with one lane open and one lane closed, rural area and level terrain
- The segment without the WZ (Non-Work Zone) has a speed limit of 65 mph, and a capacity of 2350 pcphpl
- The speed limit inside the WZ (Work Zone speed limit) is 55 mph
- The lane width in work space is 11 feet, right shoulder width (lateral distance) is 2 feet
- Concrete barriers are used
- 3 miles upstream and 3 miles downstream of the WZ, there are 3 on-ramps and 3 off-ramps
- There is no work activity
- The highest expected demand is 1600 vph, with 5% trucks



Compute HCM Capacity Value

$$QDR_{wz} = 2093 - (154 \times f_{LCSI}) - (194 \times f_{Br}) - (179 \times f_A) + (9 \times f_{LAT}) - (59 \times f_{DN})$$

f_{LCSI} = 2 lanes total, 1 lane closed = 2.0

$f_{Br} = 0$ Concrete and hard barrier separation

$f_A = 1$ Rural area

f_{LAT} = **2** ft

$f_{DN} = 0$ Daylight

$$QDR_{wz} = 2093 - (154 \times 2) - (194 \times 0) - (179 \times 1) + (9 \times 2) - (59 \times 0)$$

$$QDR_{wz} = 1624 \; pcphpl$$

$$c_{wz} = \frac{1624}{100 - 13.4} \times 100 = 1875 \; pcphpl$$

HCM Capacity Value

First click button “Click to SHOW Advanced Inputs for Capacity and Speed Adjustments”

Change appropriate percent reduction to match with computed HCM capacity value in column R

R	T	U	V	W	X	Y
Enter percent capacity reduction if you know effect of other factors such as ramp, and unevenness of pavement. Otherwise leave it as 0%.	**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)
0.00%	62.0		55.2	1,627	47.6	1,627
0.00%	62.0		55.2	1,627	47.6	1,627
0.00%	62.0		55.2	1,627	47.6	1,627
0.00%	62.0		55.2	1,627	47.6	1,627
0.00%	62.0		55.2	1,627	47.6	1,627
0.00%	62.0		55.2	1,627	47.6	1,627

HCM Capacity Value

Input -15.25% to Column R to match capacity with HCM capacity value

R	T	U	V	W	X	Y
Enter percent capacity reduction if you know effect of other factors such as ramp, and unevenness of pavement. Otherwise leave it as 0%.	**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)
-15.25%	62.0		64.5	1,875	55.0	1,875
-15.25%	62.0		64.5	1,875	55.0	1,875
-15.25%	62.0		64.5	1,875	55.0	1,875
-15.25%	62.0		64.5	1,875	55.0	1,875
-15.25%	62.0		64.5	1,875	55.0	1,875
-15.25%	62.0		64.5	1,875	55.0	1,875

Considerations to Use WorkZoneQ-Pro

- If the traffic is temporarily stopped, the duration of stoppage must be only a portion of the interval length (not all of it).

- When there is a flagger in the work zone, maximum speed reduction due to Speed Control Techniques is limited to 5 mph, and this only is applied when the work zone has a police presence or speed photo enforcement

- When there is no flagger in a work zone, the Speed Control Techniques could reduce the average speed by the stated amount in the table, and the maximum speed reduction is 9 mph when more than one treatment is used.

Considerations to Use WorkZoneQ-Pro

- Thresholds used to define queue (congestion) levels.

Traffic State	WZ Speed limit ≤ 45 mph	WZ Speed limit ≥ 50 mph
Slower Moving Vehicles (SMV)	35 ≤ Speed < posted speed limit	40 ≤ Speed < posted speed limit
Moderate Queue(Congestion) (MQ)	20 ≤ Speed < 35	25 ≤ Speed < 40
Severe Queue (congestion) (SQ)	Speed < 20	Speed < 25

- Vehicles in excess of capacity that are not in MQ or SQ, are considered to be in SMV.
- "Affected work space" length represents only a portion of the reduced-lane section that causes the most influence in traffic operation.
- "Affected work space" length should be used as X5 instead of the length of the reduced–lane section. Affected work space is limited to 500-10,000 ft.

Facility3 : Arterial

3.2: Intersection

Use

UI Spreadsheet for Intersections

UI Spreadsheet for Intersection WZ

- A lane is closed at the intersection
- May cause reductions in saturation flow rate and capacity
- To compute capacity, delay, and queue length, we propose operational analysis using HCS for two conditions:

    1) Before construction

    2) During construction

- Use HCS outputs to compute users' costs

Operational Analysis Using HCS 2010

Overview

1. Compute f_{WZ} using HCM 2016 methodology
2. Enter base sat. flow rate (= 1900* f_{WZ}) in HCS 2010, other adjustment factors will be applied to this by the software
3. Enter traffic demand and phase plan for all approaches
4. Computes capacity, delay, and queue length
5. Input selected values from HCS output into the spreadsheet to compute users' costs

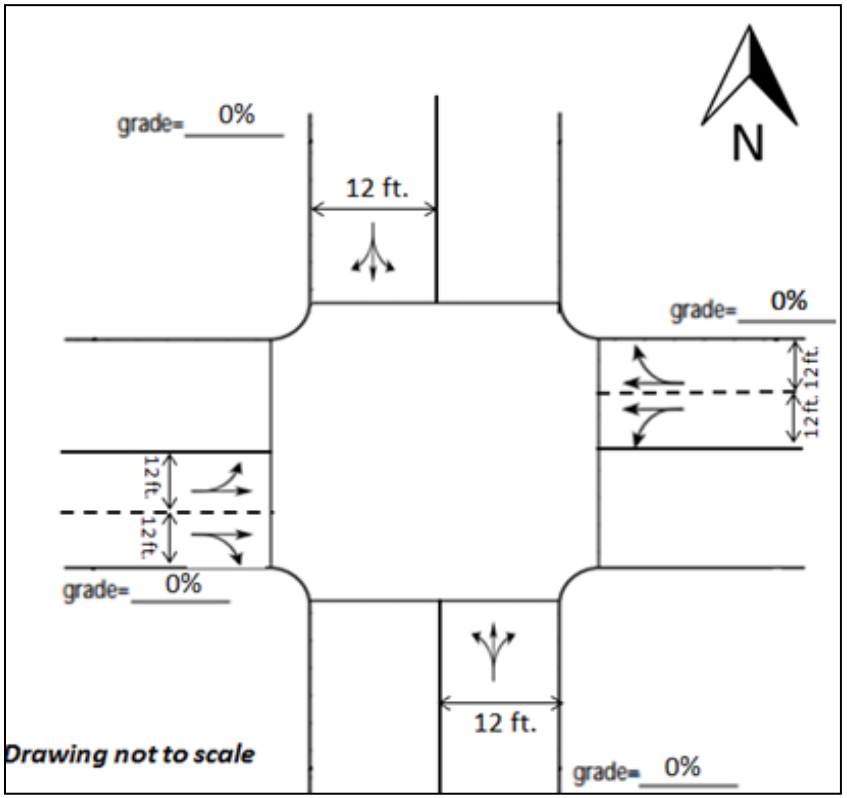
Example Problem #1

The goal of this example is to estimate delay and users' costs due to the WZ at a signalized intersection (considering all approaches)

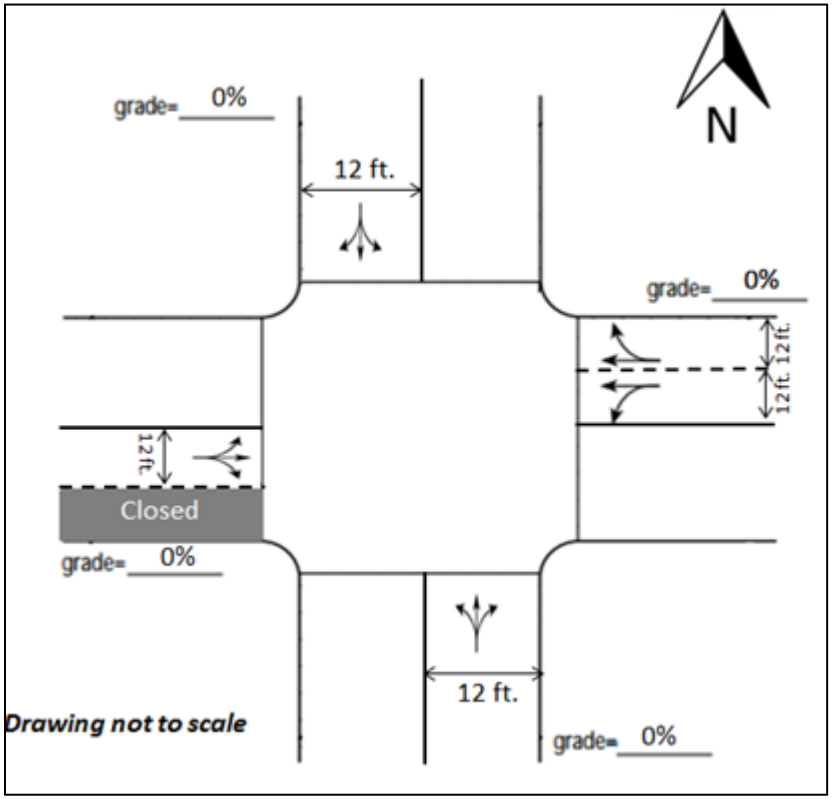
Description:

One lane closed on EB approach, non-CBD area, other info given in the sketches

Before construction



During construction



Description (Continued…)

Assume the following input data are the same for before and after construction:

- Traffic Signal Timing Settings:

  Cycle length=70 s, two-phase plan:

Green	24.0	36.0
Yellow	4.0	4.0
Red	1.0	1.0

- Traffic Demands:

	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Volume (Veh/h)	65	350	35	30	450	20	30	370	20	40	510	50
Heavy Vehicles %	5%	5%	5%	5%	5%	5%	8%	8%	8%	8%	8%	8%

Bicycle volume=20 bicycles/hr, all approaches

Pedestrian volume=100 pedestrians/hr, all approaches

Use default values for other input data

Before Construction

- Highlighted outputs in the "Movement Group Results" from HCS

Adjusted flow rate →

Capacity →

Back of queue →

Intersection delay →

Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement	5	2	12	1	6	16	3	8	18	7	4	14
Adjusted Flow Rate (*v*), veh/h	238		251	283		260		457			652	
Adjusted Saturation Flow Rate (*s*), veh/h/ln	1179		1543	1700		1588		1658			1657	
Queue Service Time (g_s), s	4.3		8.9	0.0		9.0		0.0			6.8	
Cycle Queue Clearance Time (g_c), s	13.3		8.9	8.5		9.0		12.1			21.4	
Green Ratio (*g*/*C*)	0.34		0.34	0.34		0.34		0.51			0.51	
Capacity (*c*), veh/h	471		529	640		545		908			907	
Volume-to-Capacity Ratio (*X*)	0.506		0.474	0.442		0.478		0.503			0.719	
Available Capacity (c_a), veh/h	471		529	640		545		908			907	
Back of Queue (*Q*), veh/ln (50th percentile)	3.5		3.3	3.6		3.5		4.4			7.9	
Queue Storage Ratio (*RQ*) (50th percentile)	0.00		0.00	0.00		0.00		0.00			0.00	
Uniform Delay (d_1), s/veh	18.8		18.0	17.9		18.1		11.2			13.4	
Incremental Delay (d_2), s/veh	3.8		3.0	2.2		3.0		2.0			4.9	
Initial Queue Delay (d_3), s/veh	0.0		0.0	0.0		0.0		0.0			0.0	
Control Delay (*d*), s/veh	22.7		21.1	20.1		21.1		13.2			18.2	
Level of Service (LOS)	C		C	C		C		B			B	
Approach Delay, s/veh / LOS	21.9		C	20.6		C	13.2		B	18.2		B
Intersection Delay, s/veh / LOS	18.6						B					

During Construction

- Compute WZ adjustment factor

$$f_{wid} = \frac{1}{1-0.0057(a_w-12)} = \frac{1}{1-0.0057(12-12)} = 1$$

$$f_{reduce} = \frac{1}{1+0.0404(n_o - n_{wz})} = \frac{1}{1+0.0404(2-1)} = 0.961$$

$$f_{wz} = 0.858 \times f_{wid} \times f_{reduce} = f_{wz} = 0.858 \times 1 \times 0.961 = 0.8245$$

- Modify base sat. flow rate for WZ:

1900× f_{wz}=1900 × 0.8245=1567 pcphpl

- Enter the modified sat. flow rate for the closed direction

Sat. flow rate →

	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Demand, veh/h	65	350	35	30	450	20	30	370	20	40	510	50
Lane Width, ft	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Storage Length, ft	0	0	0	0	0	0	0	0	0	0	0	0
Saturation, pc/h/ln	1567	1567	1567	1900	1900	1900	1900	1900	1900	1900	1900	1900
Heavy Vehicles, %	0	5	0	0	5	0	0	8	0	0	8	0

During Construction

- Enter the remaining input data as specified in the problem description
- Highlighted outputs in the "Movement Group Results" form HCS:

Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement	5	2	12	1	6	16	3	8	18	7	4	14
Adjusted Flow Rate (*v*), veh/h		489		277		267		457			652	
Adjusted Saturation Flow Rate (*s*), veh/h/ln		1177		1603		1590		1653			1655	
Queue Service Time (g_s), s		14.7		0.0		9.3		0.0			6.9	
Cycle Queue Clearance Time (g_c), s		24.0		8.3		9.3		12.2			21.5	
Green Ratio (*g/C*)		0.34		0.34		0.34		0.51			0.51	
Capacity (*c*), veh/h		462		607		545		905			906	
Volume-to-Capacity Ratio (*X*)		1.058		0.455		0.490		0.504			0.720	
Back of Queue (*Q*), ft/ln (50 th percentile)		385		89.3		89.3		117.6			209.7	
Back of Queue (*Q*), veh/ln (50 th percentile)		14.8		3.6		3.6		4.4			7.9	
Queue Storage Ratio (*RQ*) (50 th percentile)		0.00		0.00		0.00		0.00			0.00	
Uniform Delay (d_1), s/veh		24.7		17.8		18.2		11.2			13.4	
Incremental Delay (d_2), s/veh		58.0		2.5		3.1		2.0			4.9	
Initial Queue Delay (d_3), s/veh		0.0		0.0		0.0		0.0			0.0	
Control Delay (*d*), s/veh		82.7		20.3		21.3		13.2			18.3	
Level of Service (LOS)		F		C		C		B			B	
Approach Delay, s/veh / LOS	82.7	F		20.8	C		13.2	B		18.3	B	
Intersection Delay, s/veh / LOS			32.6					C				

Adjusted flow rate →

Capacity →

Back of queue →

Intersection delay →

Open "UI Intersection Spreadsheet" for Calculation of Users' Costs-V1.22

- Enter hourly cost figures; for this problem they are default values.

Users' costs figures	
Analysis duration	1
Average number of occupants in a passenger car. (Default is 1.25)	1.25
Hourly delay cost for a combination truck ($/hr) (Default is 90 $/hr)	90.00
Hourly delay cost for a passenger car ($/hr) (Default is 20 $/hr)	20.00

- Enter demand, heavy vehicle %, and intersection delay computed by HCS for before and during construction

HCS outputs for before construction	
Total "Adjusted flow rate" for all approaches (veh/h)	2142
Weighted heavy vehicles %	6.55
Intersection delay (s/veh)	18.6

HCS outputs for during construction	
Total "Adjusted flow rate" for all approaches (veh/h)	2142
Weighted heavy vehicles %	6.55
Intersection delay (s/veh)	32.6

- Users cost

Users' cost for all approaches ($)	409.605

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Module 5

Traffic Management Strategies using the Tools

Example Problems

Traffic Management Strategies (TMS)

The tools may be used to evaluate various traffic management strategies

For example, for managing back-of-queue-reach or delay, the tools may be used to assess the effects of the following strategies:

A. What are the effects **closing 1 lane vs 2** lanes?

B. What are the effects of changing the **lane closure time**?

C. What are the effects of **diverting traffic** to alternate routes?

D. What are the effects of **daytime vs nighttime** operation?

E. How may I assess the effects of **implementing ITS in WZ**?

How/What Tools to Use to Evaluate TMS

A. Number of Lanes Closed (1 to 2 Lanes)

(This corresponds to the TTC Strategy IA3)

- Do the analysis when one lane is closed and compare the queue length when two lanes are closed
- May use any of the tools

B. Hours of Lane Closure and Construction

(This corresponds to the TTC Strategy IA11)

- **If capacity is constant** during the analysis period, may use any of the tools
- **If capacity varies** during the analysis period, may use WorkZoneQ-Pro

How/What Tools to Use to Evaluate TMS

C. Diverting to Alternate Routes

(This corresponds to the TTC Strategy IA14)

- May use any of the tools to compute queue length with and without any diversion
- Enter the non-diverted volume as the arrival volume, when there is diversion
- But, the tools do no provide guidance on how to estimate diversion amount.

  NCHRP Scan 08-04 says that "…few agencies noted the difficulties associated with predicting diversion as part of the impact assessment process".
- Max diversion should not exceed the detour routes' "unused" capacity

D. Daytime / Nighttime Operation

(This corresponds to the TTC Strategy IA9)

- May use any of the tools to compute queue length for day and night
  - For QDAT or MoDOT, may use capacity values from the updated HCM
  - For WZQ-Pro, the program computes capacity values for day and night.

How/What Tools to Use to Evaluate TMS

E. ITS Implementations*

(This corresponds to the Transp. Op. Strategy IIID1)

- ITS may affect WZ speed, capacity, or both

- **If ITS effect on capacity is "known"/estimated**, may use any of the tools:
  - In QDAT and MoDOT, enter the "known" capacity
    - HCM does **NOT** provide capacity for WZ with ITS
  - In WZQ-Pro, use an R_T value that yields capacity for WZ with ITS

- **If ITS effect on speed is "known"/estimated**, may use WorkZoneQ-Pro:
  - Enter the change in speed due to ITS (positive or negative)

** An example on how to use the tools for this situation is discussed later*

TMS-Related Example Problems

1. Example Problem #1T:
   Comparing the Results from the Three Tools
2. Example Problem #2T:
   Effects of buffer space on queue
3. Example Problem #3T:
   Variations in Work Zone Capacity within Analysis Period
4. Example Problem #4T:
   Determine Hours of Construction
5. Example Problem #5T:
   Determine the Effects of ITS

- Appendix J (capacity look-up tables) and K (users' cost)
- Discuss Real-World examples

There are more example problems in the Appendix

Example Problem #1T
Comparing the results from the three tools

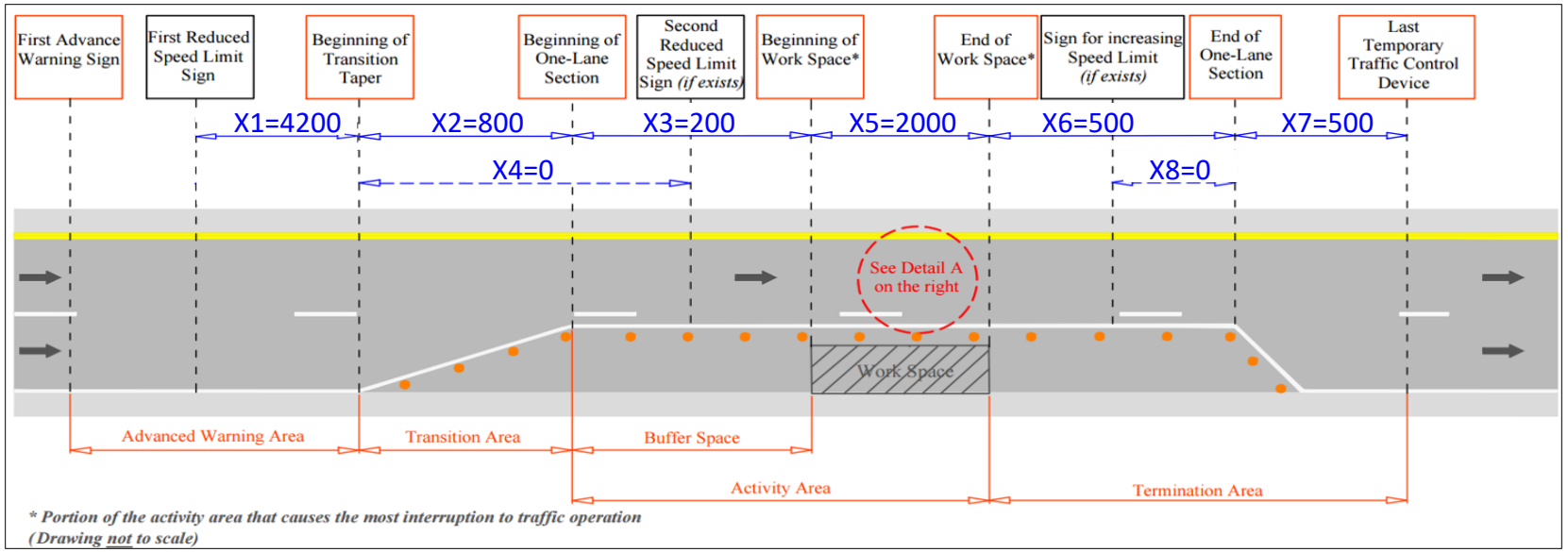
The goal of this example is to compare the outputs of the tools when using the **same capacity**

Description:

A 2-to-1 freeway work zone, daytime, clear weather condition

Geometric data: Longitudinal distances in the sketch below

Lane width = 11.5 ft, Right shoulder width = 4 ft, Left shoulder width = 2 ft



Description of Example Problem #1T (Continued…)

WZ conditions:

- Both first and second speed limit inside WZ are 55 mph
- Moderate work activity due to 5 workers working with lateral distance of 7 ft
- Work activity area is separated from the travel lane by means of barrels.
- Speed limit outside of the WZ is 65 mph
- Use Passenger Car Equivalency (PCE=1.5) factor
- Assume work zone capacity is 1475 pcphpl.
- Traffic volume data:

Interval	% single-unit Trucks	% combination trucks	% recreational vehicles	Volume (veh)
9:00 AM-10:00 AM	1.0	15.0	0.0	900
10:00 AM-11:00 AM	1.0	15.0	0.0	1,150
11:00 AM-12:00 PM	1.0	15.0	0.0	1,400
12:00 PM-1:00 PM	1.0	15.0	0.0	1,500
1:00 PM-2:00 PM	1.0	15.0	0.0	1,300
2:00 PM-3:00 PM	1.0	15.0	0.0	1,050
3:00 PM-4:00 PM	1.0	15.0	0.0	900

Compute queue lengths and number of vehicles in queue from the three tools and compare them

Capacity Input (PCE=1.5)

- First, convert the given capacity (V_{PC}) which is in pcphpl to capacity in vphpl (V) using PCE value of 1.5.

$$V_{PC} = \frac{V}{f_{HV}} \quad , \quad V = V_{PC} * f_{HV}$$

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

$$f_{HV} = \frac{1}{1 + 0.16(1.5 - 1)}$$

$$f_{HV} = 0.9259$$

Thus, $V = 1475 * 0.9259 = 1366\ vphpl$

Input in QDAT (PCE=1.5)

- Enter 1366 as capacity:

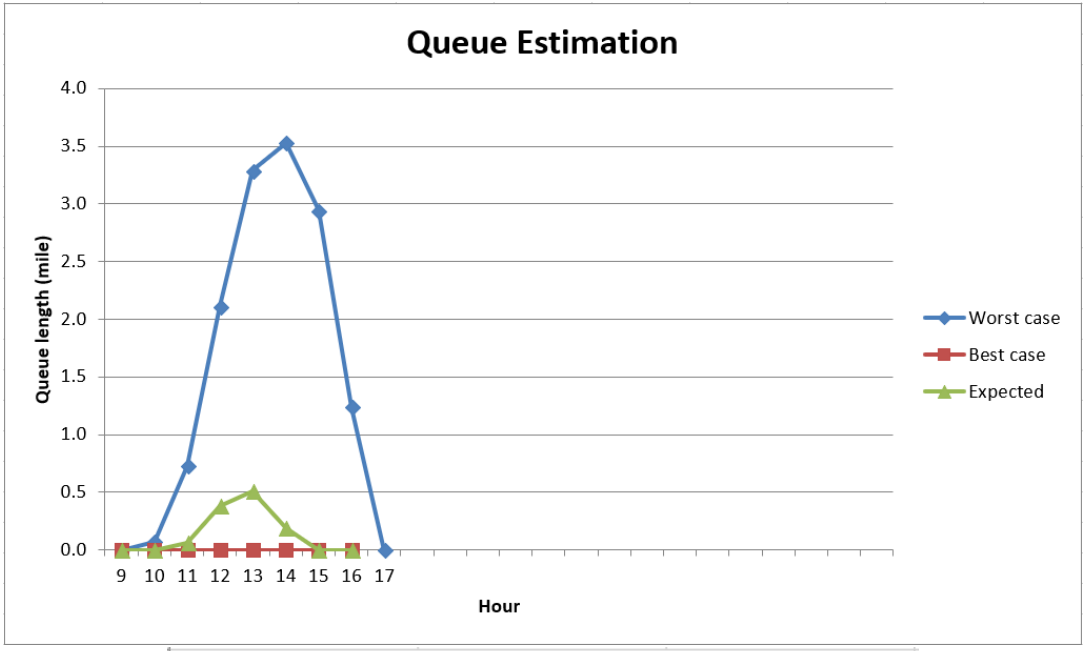
Step 2: Input Variables	?	
Speed		
free flow speed(mph)		65
Lane closure configuration		
normal number of lanes per direction		2
Length of the lane closure(miles)		0.66
Work zone capacity		
Capacity (vphpl)	?	1366 change C value
Work intensity adjustment (I)	?	0
Ramp adjustment (R)	?	0
Percentage of trucks (P)	?	16
Passenger car Equivalent (E)	?	1.5

- Select “Delay and Queue Estimation” in Step 1 and specify:

"Delay & Queue Estimation" output option only		
Schedule of Work Activity	?	
Number of Closed Lanes		1
Hour lane closure begins	?	9
Hour lane closure ends	?	16

QDAT output (PCE=1.5)

- The following output is obtained:



Expected: Estimated Queue(mile)		
start hour	9	0.0
	10	0.0
	11	0.1
	12	0.4
	13	0.5
	14	0.2
	15	0.0
end hour	16	0.0

Input in MoDOT (PCE=1.5)

- Enter 1366 as capacity and select proper values for Work Location, Lane Width, No of Lanes Open

BASE CONDITIONS

Open Lane Capacity (veh/h/lane):	1900

Base Conditions Capacity (Total for ALL Lanes): 3800 veh/h

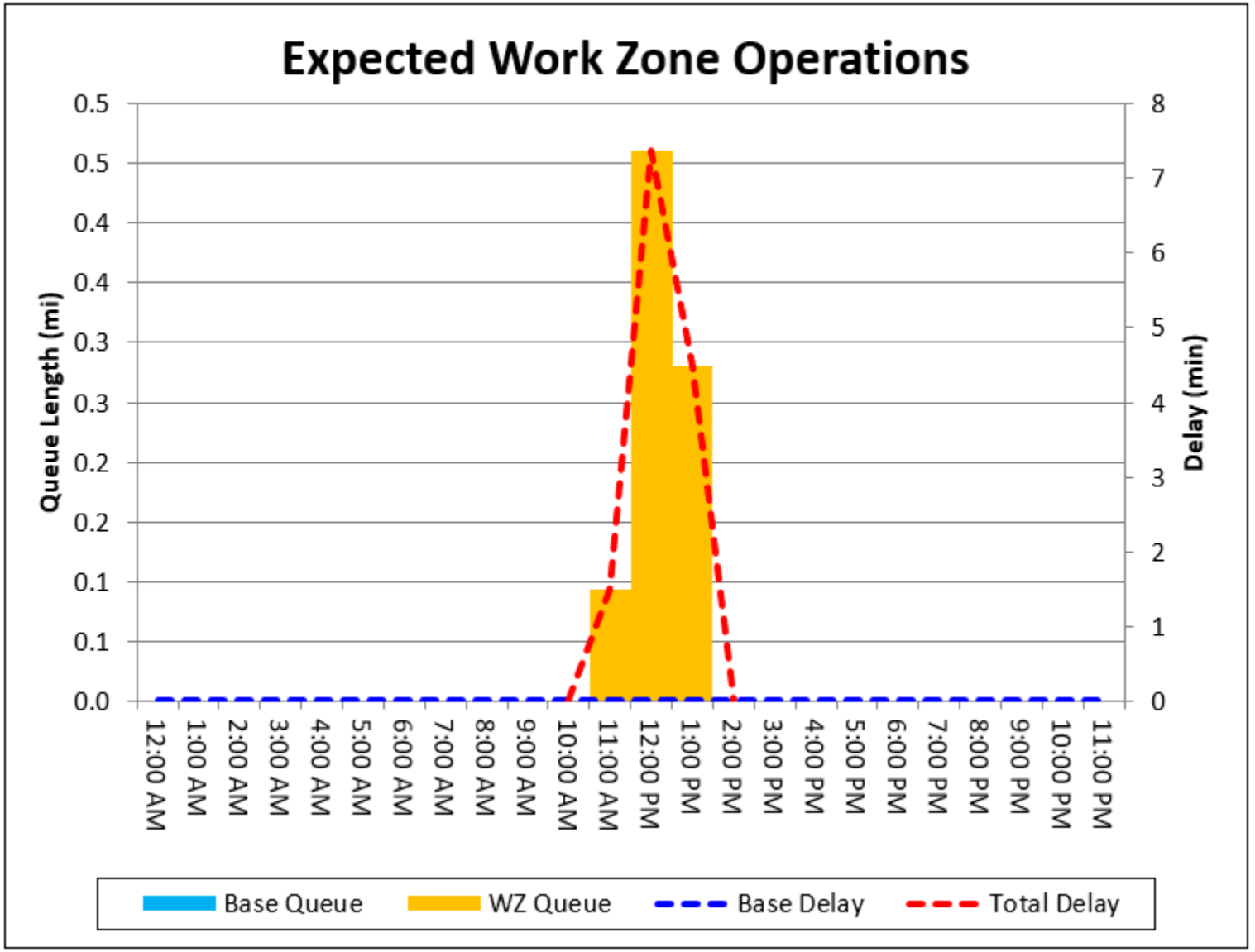
WORKZONE DETAILS

Work Description:	Example #1
Work Location:	Workers & equipment less than 4 feet from travel lane
Travel Lane Width (ft):	10 - 11.5
Number of Lanes Open:	1
ESTIMATED Work Zone Capacity (veh/h):	1213
USER DEFINED Work Zone Capacity (veh/h):	1366
Start Time:	9:00 AM
End Time:	4:00 PM
Duration of Closure (hrs):	7

RESULTS

Measure of Effectiveness	Base Conditions	Work Zone	Total
Max Queue Length (mi):	0.0	0.5	0.5
Max Delay (minutes):	0	7	7
Cost ($):	$0	$360	$360

MoDOT output (PCE=1.5)



Capacity Input (PCE value = 2.0)

- First, convert the given capacity (V_{PC}) which is in pcphpl to capacity in vphpl (V) using PCE value of 2.0.

$$V_{PC} = \frac{V}{f_{HV}} \quad , \quad V = V_{PC} * f_{HV}$$

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

$$f_{HV} = \frac{1}{1 + 0.16(2.0 - 1)}$$

$$f_{HV} = 0.8621$$

Thus, $V = 1475 * 0.8621 = 1272\ vphpl$

Input in QDAT (PCE value = 2.0)

- Enter 1272 as capacity:

Step 2: Input Variables	?	
Speed		
free flow speed(mph)		65
Lane closure configuration		
normal number of lanes per direction		2
Length of the lane closure(miles)		0.66
Work zone capacity		
Capacity (vphpl)	?	1272
Work intensity adjustment (I)	?	0
Ramp adjustment (R)	?	0
Percentage of trucks (P)	?	16
Passenger car Equivalent (E)	?	2

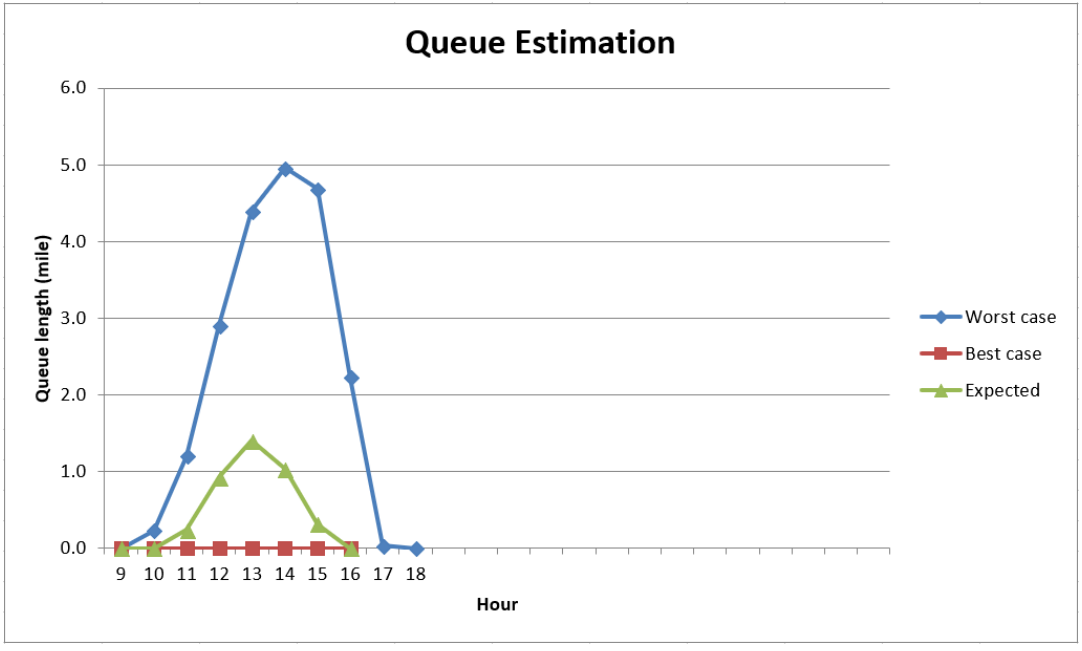
change C value

- Select “Delay and Queue Estimation” in Step 1 and specify:

"Delay & Queue Estimation" output option only		
Schedule of Work Activity	?	
Number of Closed Lanes		1
Hour lane closure begins	?	9
Hour lane closure ends	?	16

QDAT output (PCE value = 2.0)

- The following output is obtained:



Expected: Estimated Queue(mile)		
start hour	9	0.0
	10	0.0
	11	0.2
	12	0.9
	13	1.4
	14	1.0
	15	0.3
end hour	16	0.0

Input in MoDOT (PCE value = 2.0)

- Enter 1272 as capacity and select proper values for Work Location, Lane Width, No of Lanes Open

BASE CONDITIONS

Open Lane Capacity (veh/h/lane):	1900

Base Conditions Capacity (Total for ALL Lanes): 3800 veh/h

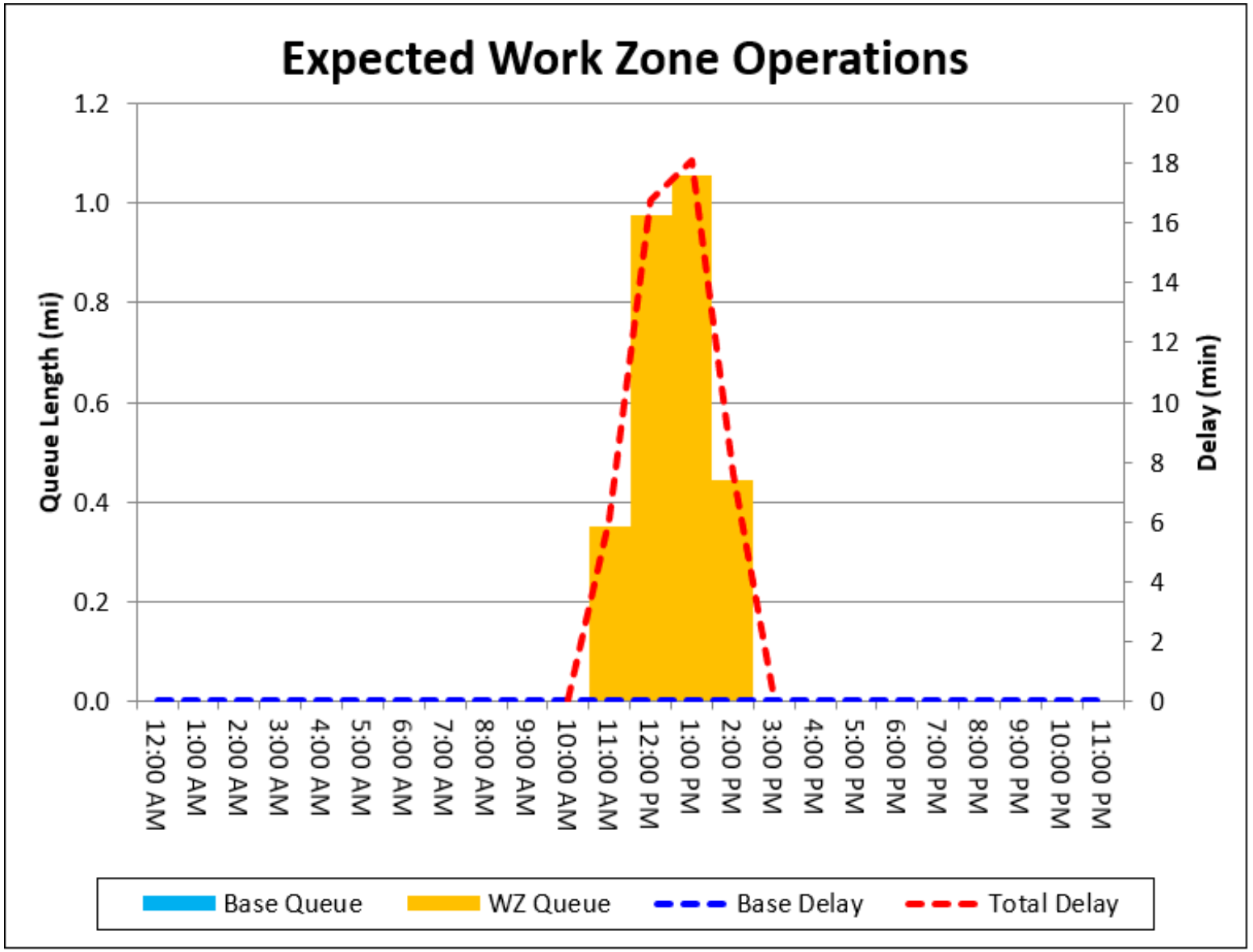
WORKZONE DETAILS

Work Description:	Example #1
Work Location:	Workers & equipment less than 4 feet from travel lane
Travel Lane Width (ft):	10 - 11.5
Number of Lanes Open:	1
ESTIMATED Work Zone Capacity (veh/h):	1213
USER DEFINED Work Zone Capacity (veh/h):	1272
Start Time:	9:00 AM
End Time:	4:00 PM
Duration of Closure (hrs):	7

RESULTS

Measure of Effectiveness	Base Conditions	Work Zone	Total
Max Queue Length (mi):	0.0	1.1	1.1
Max Delay (minutes):	0	18	18
Cost ($):	$0	$3,100	$3,100

MoDOT output (PCE value = 2.0)



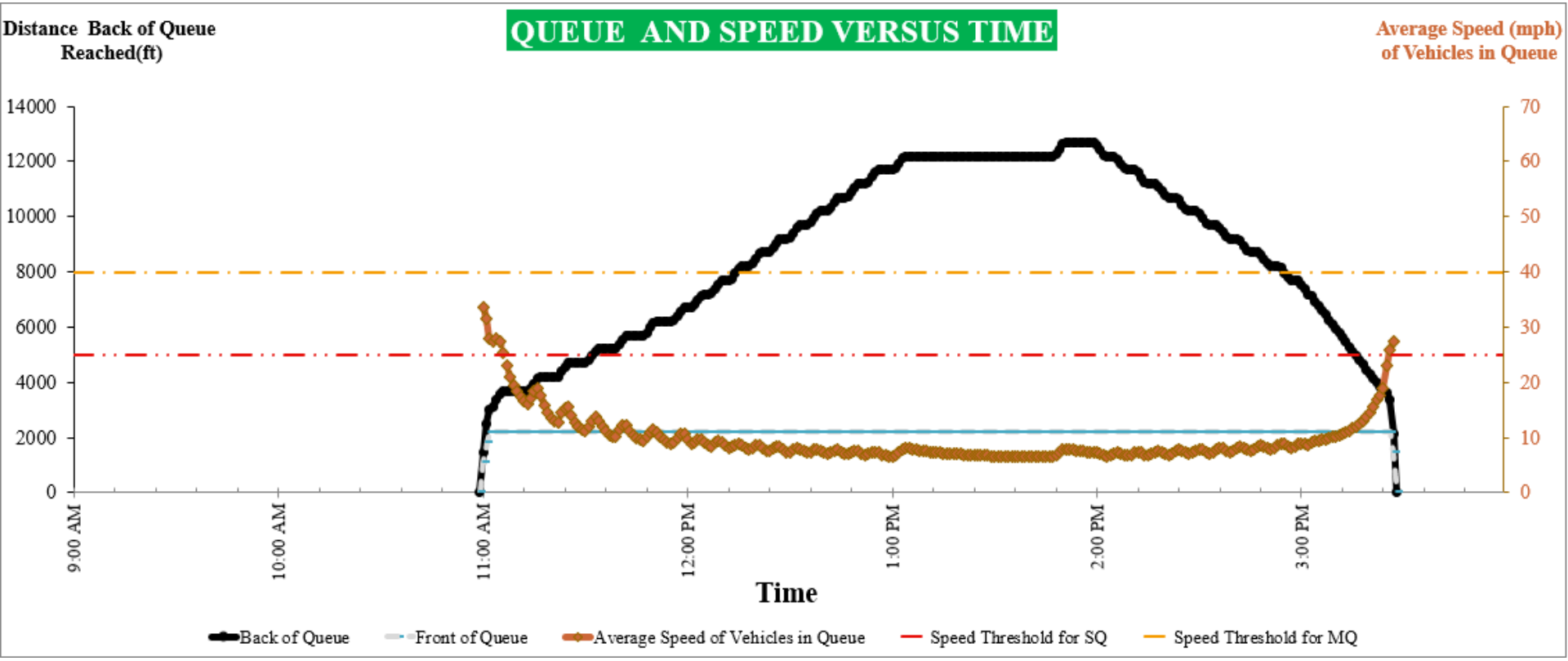
Queue length comparison with PCE values of 1.5 and 2.0

Interval	Volume (vphpl)	QDAT						MoDOT				
		PCE 1.5				PCE 2.0		PCE 1.5			PCE 2.0	
		Average excess vehicles QDAT would normally use	Excess vehicles at the end of interval *	Average spacing (ft)	Queue length (ft)	Excess vehicles at the end of interval *	Queue length (ft)	Excess vehicles	Average spacing (ft)	Queue length (ft)	Excess vehicles	Queue length (ft)
9:00 AM-10:00 AM	900	0	0	-	-	0	-	0	-	-	0	-
10:00 AM-11:00 AM	1150	0	0	-	-	0	-	0	-	-	0	-
11:00 AM-12:00 PM	1400	17	34	40	**680**	128	**2560**	34	29	**493**	128	**1856**
12:00 PM-1:00 PM	1500	101	168	40	**3360**	356	**7120**	168	29	**2436**	356	**5162**
1:00 PM-2:00 PM	1300	135	102	40	**2040**	384	**7680**	102	29	**1479**	384	**5568**
2:00 PM-3:00 PM	1050	51	0	-	-	162	**3240**	0	-	-	162	**2349**
3:00 PM-4:00 PM	900	0	0	-	-	0	-	0	-	-	0	-

- For a more meaningful comparison of QDAT to others, the excess vehicles at end of interval should be used, but QDAT gives excess vehicles in the middle of interval
- Note: MoDOT gives the excess vehicles at the end of the interval

Input and Output in WorkZoneQ-Pro

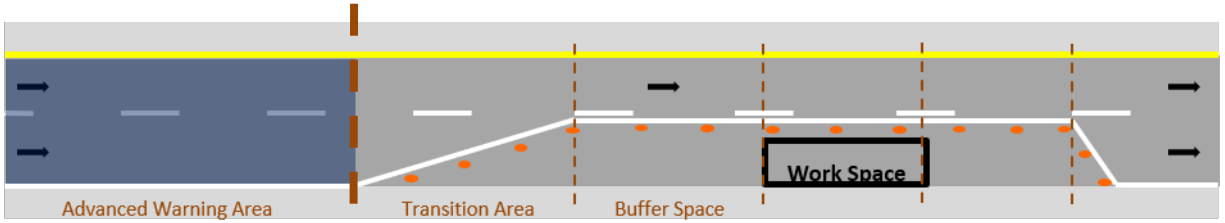
To get a capacity of 1,475 pcphpl, enter -9.9% in Column R in "GeoCond" worksheet (Overriding the computed value of 1,343 pcphpl).



NOTE: **Different reference points for start of queue**:

QDAT and MoDOT:

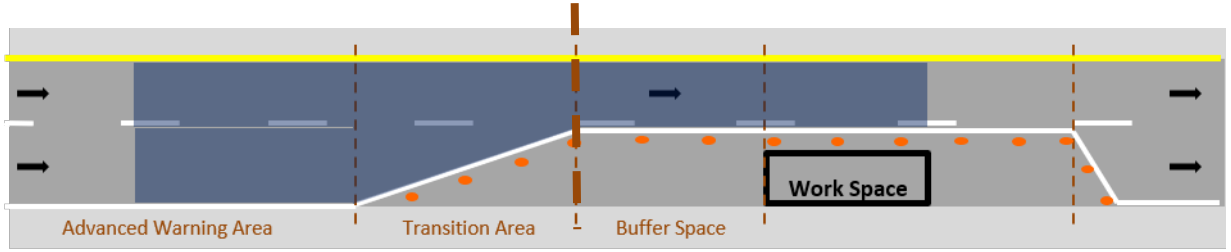
Queue length is measured from the beginning of taper



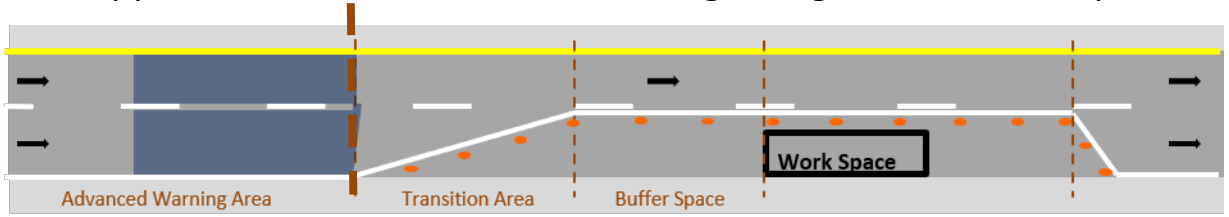
WorkZoneQ:

Bottleneck can be at any point between the beginning of taper and end of work area

In Example Problem 1T, beginning of queue starts from the buffer space



In the Example Problem given in Appendix G, bottleneck is at the beginning of transition taper



Queue length from the three tools using PCE 2.0

Interval	Volume (vphpl)	Capacity	QDAT				MoDOT			WorkZoneQ-Pro			
			Average excess vehicles QDAT would normally use	Excess vehicles at the end of interval *	Average spacing (ft)	Queue length (ft)	Excess vehicles	Average spacing (ft)	Queue length (ft)	Veh. in queue	Average spacing (ft)	Queue length starting from work space (ft)	Queue length extended to two-lane section (ft)
9:00 AM-10:00 AM	900	1272 (vphpl)	0	0	-	-	0	-	-	0	-	-	-
10:00 AM-11:00 AM	1150		0	0	-	-	0	-	-	0	-	-	-
11:00 AM-12:00 PM	1400		64	128	40	**2560**	128	29	**1856**	148	55	6700	**3700**
12:00 PM-1:00 PM	1500		242	356	40	**7120**	356	29	**5162**	391	47	11700	**8700**
1:00 PM-2:00 PM	1300		370	384	40	**7680**	384	29	**5568**	429	47	12700	**9700**
2:00 PM-3:00 PM	1050		273	162	40	**3240**	162	29	**2349**	193	53	7700	**4700**
3:00 PM-4:00 PM	900		81	0	-	-	0	-	-	0	53	-	-

Spacing is constant

Spacing depends on truck %

Spacing is a function of speed

Comparison of queue lengths

- Using the same capacity in all tools, there are differences in queue length mainly due to using different methodologies

- **Queues** started at different locations:
  - WorkZoneQ-Pro: Beginning of queue starts from buffer and moves to end of work space, and propagated to two-lane section
  - QDAT and MoDOT : Queue started at the beginning of the transition taper

- **Spacing** is computed differently:
  - In WorkZoneQ-Pro: Function of the speed (higher speed → greater spacing)
  - QDAT: Fixed (40 ft)
  - MoDOT: Depends on veh. mix (Weighted average of cars (25ft) and trucks (50ft)

- **Number of vehicles in queue**:
  - WorkZoneQ-Pro: Uses the speed of vehicles to determine if they are in queue (either in severe queue or moderate queue)
  - QDAT and MoDOT: Equal to the demand in excess of capacity.

For comparison of the **delays** from the three tools refer to Appendix A

Users' Costs

MoDOT:

Recall that costs are specified in Step 2 - Facility Data Inputs:

USER COST ($ / hr)	
TRUCKS	$22.70
CARS	$10.30

The total costs found are:

RESULTS

Measure of Effectiveness	Base Conditions	Work Zone	Total
Max Queue Length (mi):	0.0	1.1	1.1
Max Delay (minutes):	0	18	18
Cost ($):	$0	$3,100	$3,100

QDAT:

Does not compute users' costs

Users' Costs

WorkZoneQ:

- Default values of users' costs figures in the "UserComp" worksheet

	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 25 $/hr)	Hourly delay cost for a combination truck ($/hr) (Default is 30 $/hr)	Hourly delay cost for a recreational vehicle ($/hr) (Default is 21 $/hr)	Hourly delay cost for a passenger car ($/hr) (Default is 21 $/hr)
3						
4	1.25	2.00	$25	$30	$21	$21

- Users' costs for three types of queue

Start of Interval	End of Interval	Users' costs ($)						Summary of Users' Costs ($)	
		Severe Queue (SQ)		Moderate Queue (MQ)		Slower Moving Vehicles (SMV)		All (SQ+MQ+SMV)	
		Based on WZ speed limit	Based on speed limit outside of the WZ	Based on WZ speed limit	Based on speed limit outside of the WZ	Based on WZ speed limit	Based on speed limit outside of the WZ	Based on WZ speed limit	Based on speed limit outside of the WZ
9:00 AM	10:00 AM	-	-	-	-	$45.98	$104.99	$45.98	$104.99
10:00 AM	11:00 AM	-	-	-	-	$91.55	$166.94	$91.55	$166.94
11:00 AM	12:00 PM	$1,723.74	$1,834.17	-	-	-	-	$1,723.74	$1,834.17
12:00 PM	1:00 PM	$6,474.93	$6,613.84	-	-	-	-	$6,474.93	$6,613.84
1:00 PM	2:00 PM	$9,920.12	$10,059.17	-	-	-	-	$9,920.12	$10,059.17
2:00 PM	3:00 PM	$7,385.27	$7,524.32	-	-	-	-	$7,385.27	$7,524.32
3:00 PM	4:00 PM	$1,089.94	$1,174.72	-	-	-	-	$1,089.94	$1,174.72
		SUM SQ	SUM SQ	SUM MQ	SUM MQ	SUM SMV	SUM SMV	SUM All	SUM All
*: At the end of the corresponding interval		$26,593.99	$27,206.22	$0.00	$0.00	$137.53	$271.93	$26,731.52	$27,478.15

Example Problem #2T
Effects of buffer space on queue

Example Problem # 2T is moved to Appendix N

Example Problem #3T
Variations in Work Zone Capacity within Analysis Period

Example Problem # 3T is moved to Appendix R

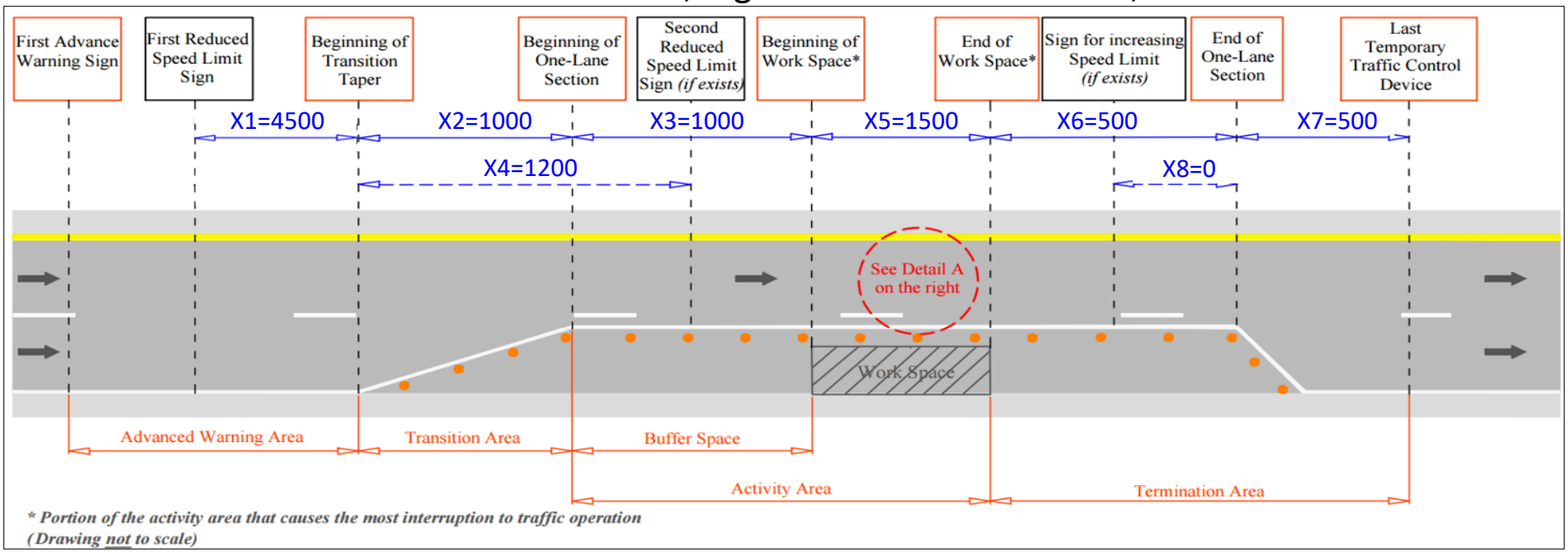
Example Problem #4T
Determine Hours of Construction

The goal of this example is to illustrate how to determine the hours of work activity while maintaining a mobility criteria

Description: A 2-to-1 freeway work zone, daytime, clear weather condition

Geometric data: Longitudinal distances in the sketch below

Lane width = 11.5 ft, Right shoulder width = 4 ft, Left shoulder width = 2 ft



Description (Continued…)

Work Zone Conditions:

- Speed limit outside the work zone is 65 mph
- First speed limit in the work zone =55 mph
- Second speed limit in the work zone = 45 mph for entire time period
- Moderate work activity starts at 3 PM (no work activity between 2 and 3)
- Work activity area is separated from the travel lane by barrels
- 2% single unit truck, 10% combination truck, 0% recreational vehicle
- Work zone is on level terrain
- Traffic volume data:

Interval	Volume (veh)		Interval	Volume (veh)
2:00 PM-3:00 PM	900		7:00 PM-8:00 PM	900
3:00 PM-4:00 PM	1100		8:00 PM-9:00 PM	800
4:00 PM-5:00 PM	1250		9:00 PM-10:00 PM	700
5:00 PM-6:00 PM	1350		10:00 PM-11:00 PM	600
6:00 PM-7:00 PM	1200		-	-

Use the three tools to find hours of construction (activity) such that back of queue does not exceed 1.5 miles

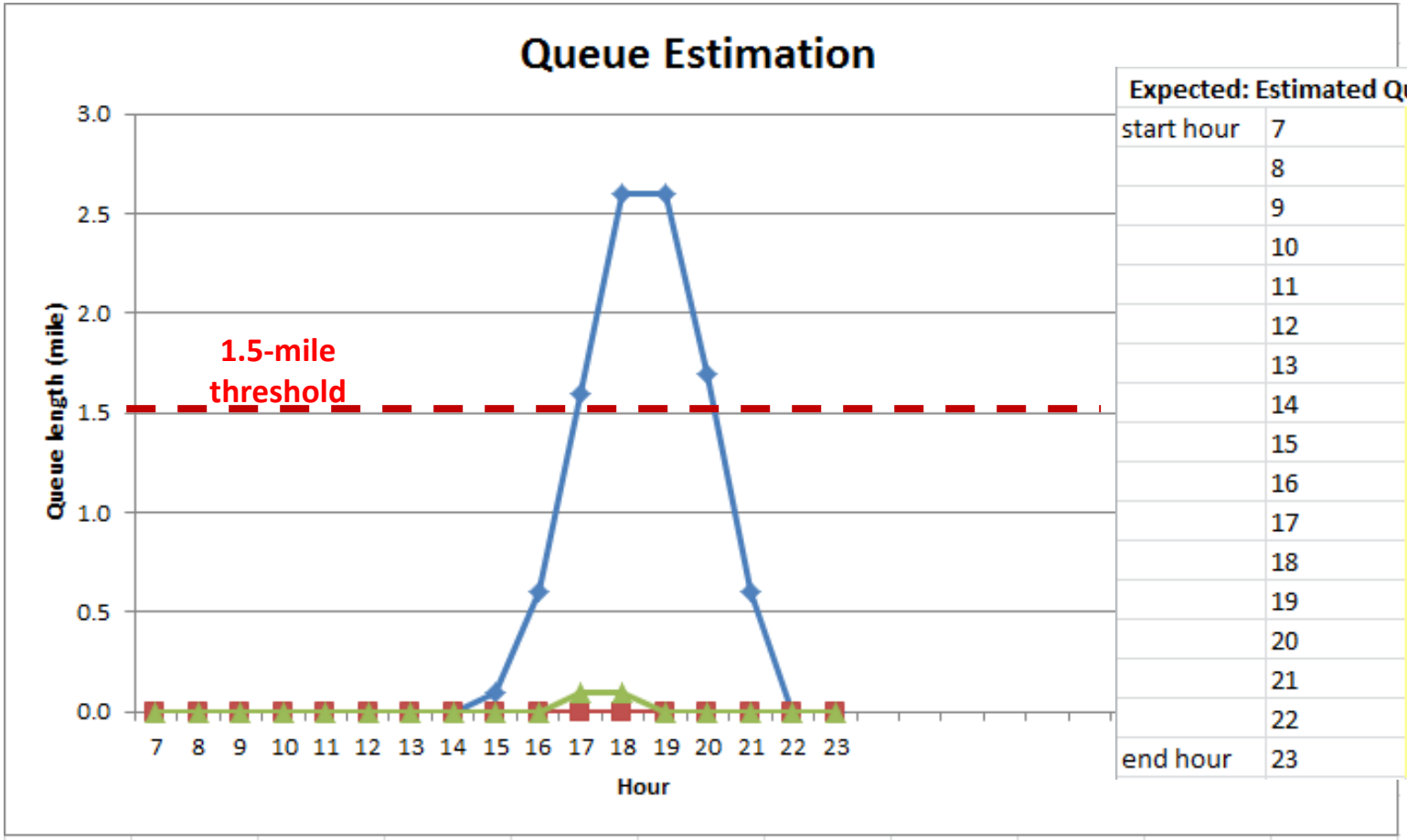
QDAT

- Using QDAT, input the data and select the “Lane Closure Schedule” output:

Step 2: Input Variables	?	
Speed		
free flow speed(mph)		65
Lane closure configuration		
normal number of lanes per direction		2
Length of the lane closure(miles)		0.76
Work zone capacity		
Capacity (vphpl)	?	1285
Work intensity adjustment (I)	?	160
Ramp adjustment (R)	?	0
Percentage of trucks (P)	?	12
Passenger car Equivalent (E)	?	2

change C value

QDAT



Expected: Estimated Queue(mile)		
start hour	7	0.0
	8	0.0
	9	0.0
	10	0.0
	11	0.0
	12	0.0
	13	0.0
	14	0.0
	15	0.0
	16	0.0
	17	0.1
	18	0.1
	19	0.0
	20	0.0
	21	0.0
	22	0.0
end hour	23	0.0

Queue only exists in the interval 4pm-7pm, and it reaches 0.1 mile. Queue does not exceed 1.5 mile limit. So, there is no time period that the queue length will be longer than the 1.5 mile limit.

MoDOT

BASE CONDITIONS

Open Lane Capacity (veh/h/lane):	1900

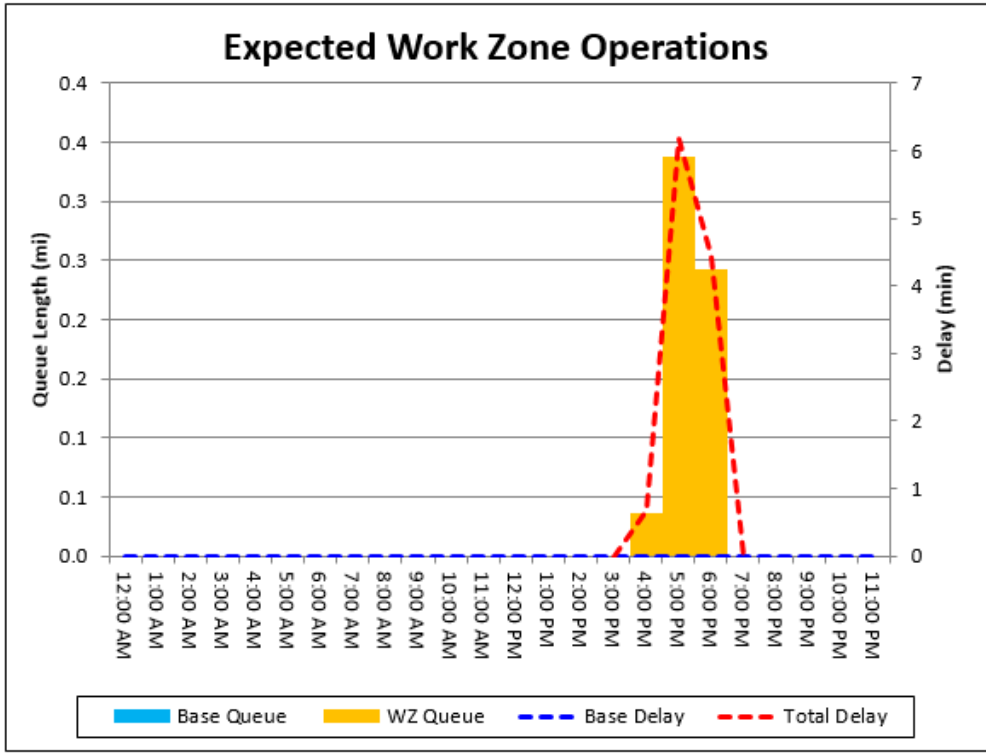
Base Conditions Capacity (Total for ALL Lanes): 3800 veh/h

WORKZONE DETAILS

Work Description:	Example #6 - Diversion
Work Location:	Workers & equipment less than 4 feet from travel lane
Travel Lane Width (ft):	10 - 11.5
Number of Lanes Open:	1
ESTIMATED Work Zone Capacity (veh/h):	1236
USER DEFINED Work Zone Capacity (veh/h):	
Start Time:	7:00 AM
End Time:	11:00 PM
Duration of Closure (hrs):	16

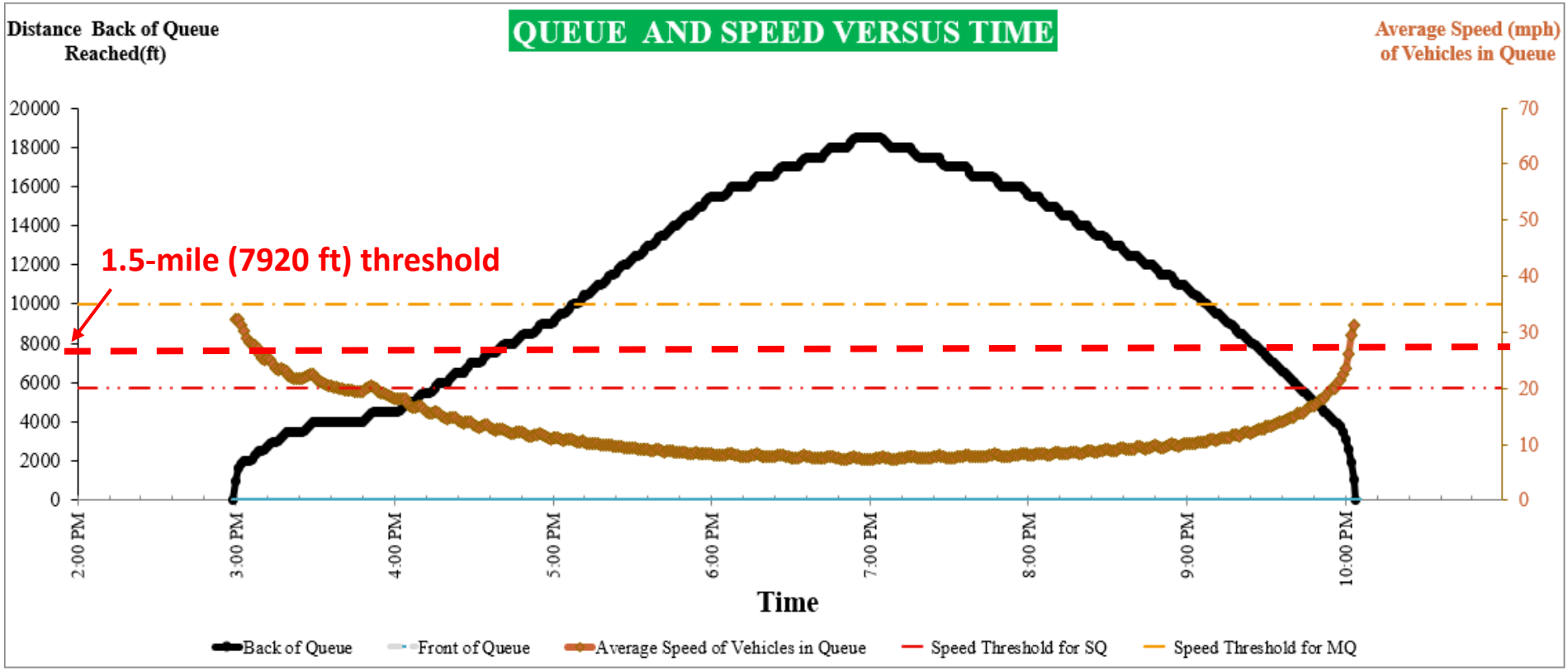
RESULTS

Measure of Effectiveness	Base Conditions	Work Zone	Total
Max Queue Length (mi):	0.0	0.3	0.3
Max Delay (minutes):	0	6	6
Cost ($):	$0	$240	$240



At no time period queue length exceeded the 1.5 mile limit.

WorkZoneQ-Pro Plot



- Queue length exceeds 1.5 mile from 4:41 PM to 9:26 PM.

Determine Hours of Construction

- Queue length exceeded 1.5 mile limit in WorkZoneQ , but did not in MoDOT and QDAT
- For WZQ-Pro, the queue exceeded 1.5 mile limit from 4:41 pm to 9:26 pm.
- For QDAT the queue length was 0.1 miles and for MoDOT it was 0.34 miles
- Effects of speed limit change inside is considered in WZQ-Pro, but not in QDAT and MoDOT.
  - This is one of the factors that affects queue length.

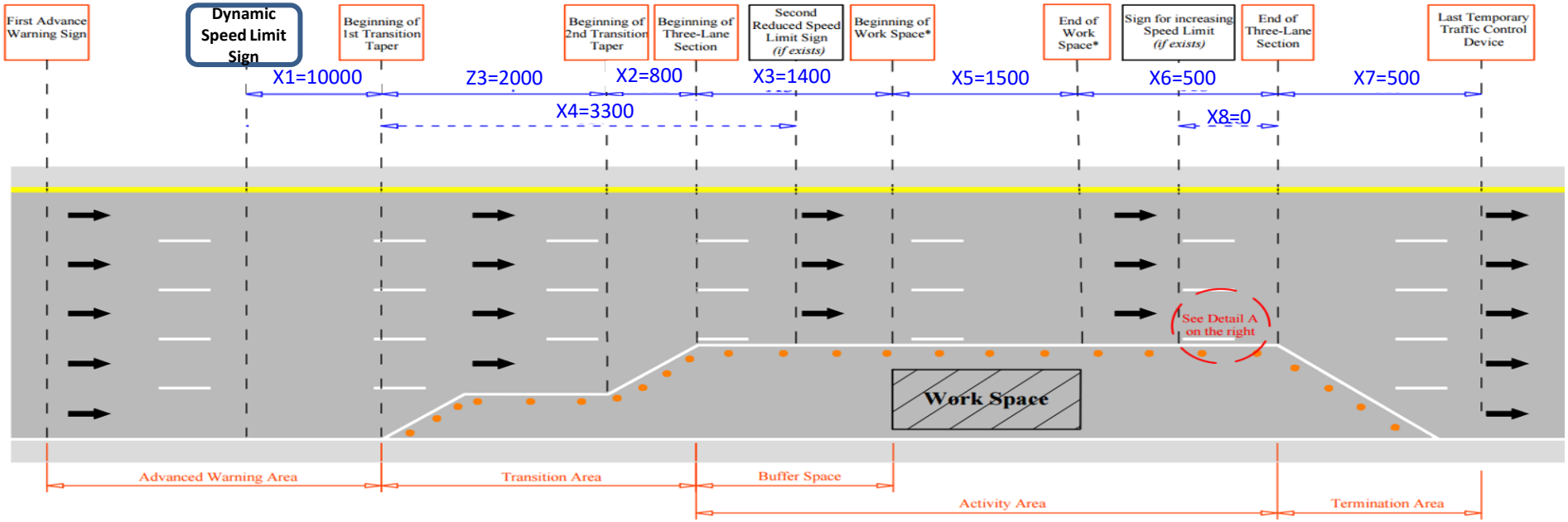
Example Problem #5T
Determine the Effect of ITS

The goal of this example is to illustrate how to determine the effects of ITS in WZ

Work Zone Conditions:

On a 5-to-3 WZ, A dynamic speed limit sign is deployed 10,000 ft before the beginning of the buffer space. The sign displays the following messages:

- If there is no queue or back of queue < 1 mile, the sign displays “Speed Limit 55 mph”
- If back of queue exceeds 1 mile, the sign displays “Speed Limit 45 mph”.



** Portion of the activity area that causes the most interruption to traffic operation*

(Drawing not to scale)

Work Zone Conditions

Work Zone Conditions:

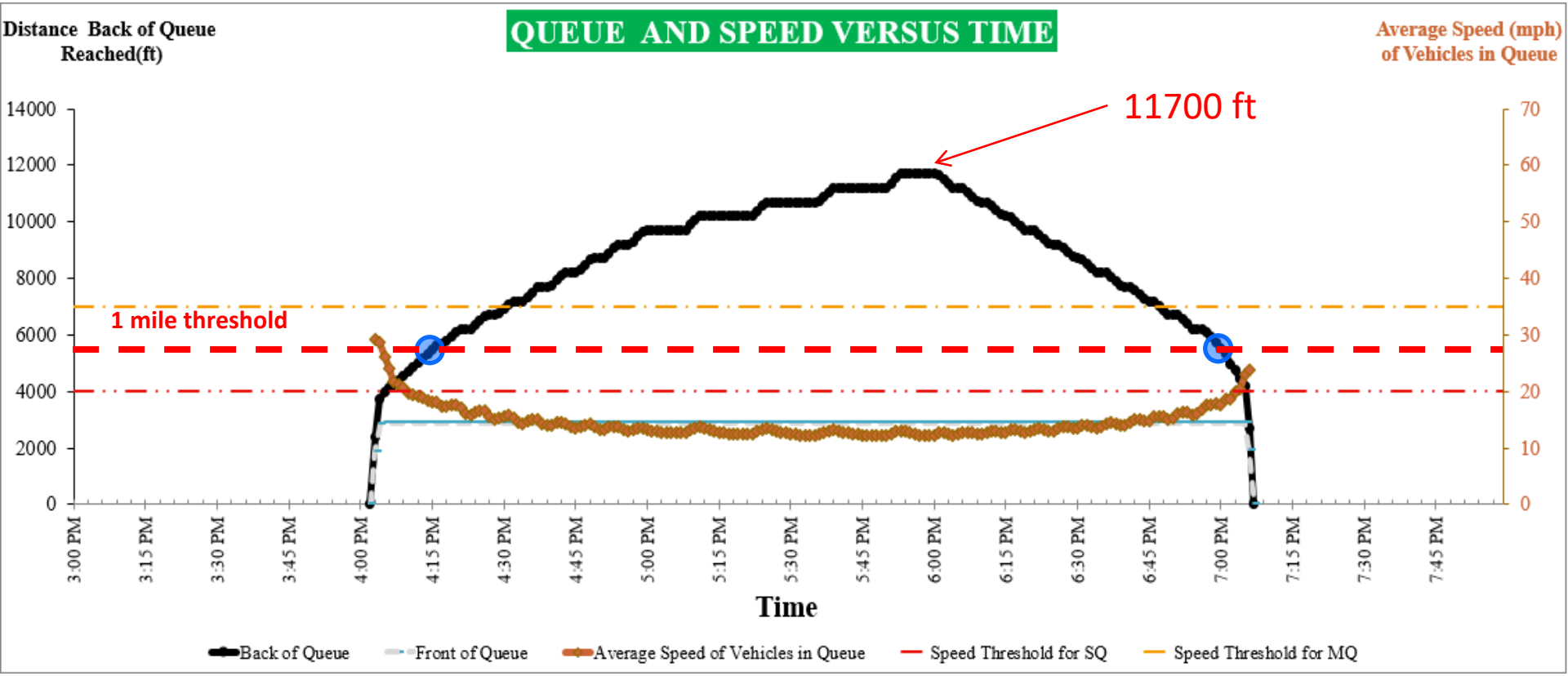
- Speed limit outside the work zone is static and 65 mph.
- First speed limit sign is 55 mph and second speed limit sign in the work zone is 45 mph
- Daytime, clear weather condition
- Lane width = 12 ft, Right shoulder width = 2 ft, Left shoulder width = 1 ft
- Low work activity
- Work activity area separated from the travel lane by barrels.
- Level terrain
- Traffic volume data:

Interval	% single-unit Trucks	% combination trucks	% recreational vehicles	Volume (veh)
3:00 PM-4:00 PM	2	10	0	3850
4:00 PM-5:00 PM	2	10	0	4300
5:00 PM-6:00 PM	2	10	0	4100
6:00 PM-7:00 PM	2	10	0	3600
7:00 PM-8:00 PM	2	10	0	3300

Use the three tools to find the time the sign should be turned on/off

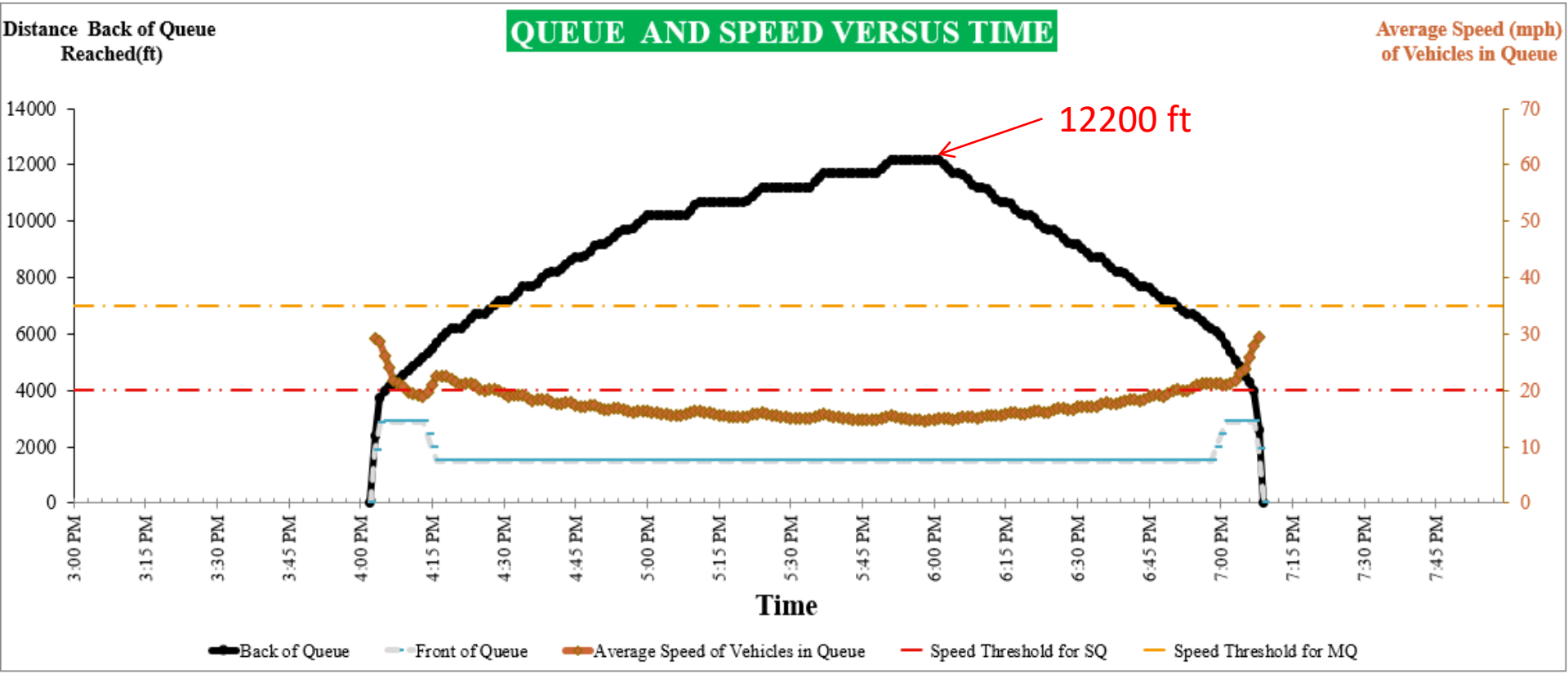
WorkZoneQ-Pro Plot

- To determine the time to trigger the dynamic speed limit sign, find the interval the queue length exceeds 1 mile.
- Back of queue exceeds 1 miles (5280 ft) from 4:14 PM to 7:01 PM.
- So, the dynamic speed limit sign should show 45 mph speed from 4:15 to 7:00 PM.



WorkZoneQ-Pro Plot with ITS

- To determine effects of ITS, changed SL to 45 mph from 4:15 to 6:45 PM



- Back of queue reached 12,200 ft which was 11,700 ft without ITS
- Speed in queue increased to 17.8 mph which was 14.8 mph without ITS
- Users cost went up by 6.4% ($1687)

Determine the Effect of ITS with MoDOT and QDAT

- One needs to know the effect of ITS on BOTH speed and capacity of WZ.
- MoDOT and QDAT do not determine effects of ITS on speed or capacity
- MoDOT and QDAT do NOT say how to evaluate the effects of ITS in WZ even if speed and capacity are known

Appendix J

Look-up tables for capacity used in WorkZoneQ-Pro

Table J1: Suggested capacities for 2-to-1 WZs based on field data

Table J2: Suggested capacities for 2-to-1 WZs with concrete barriers

Table J3: Suggested capacities for 2-to-1 WZs without concrete barriers

Table J4: Suggested capacities for 2-to-1 WZs with flagger

Table J5: Capacity adjustment factors due to lane configuration

Table J1: Suggested capacities for 2-to-1 WZs based on field data

Speed Limit	WZ conditions	No. of data sets	Computed values form field data		Suggested values*	
			Average speed (mph)	Capacity (pcphpl)	Speed (mph) at capacity	Capacity (pcphpl)
45	Flagger, queue	5	15.9-36	1131-1367	27	1200
	Low work activity, flagger, dynamic speed feedback sign, no queue	1	35.3	1476	35	1400
	No work activity, with police, no queue	1	41.9	1485	42	1450
	No work activity, no queue, off peak	2	42.2-46.5	1502-1696	44	1550
55	No work activity, dynamic speed feedback sign, no queue	1	45.5	1495	46	1600
	No work activity, no queue, short distance work zone	2	51.7-52.4	1760-1777	52	1800

**Suggested based on the computed values and comparison between WZ conditions*

Table J2: Suggested capacities for 2-to-1 WZs with concrete barriers

(based on data from 55 mph speed limit in WZ)

WZ Free Flow Speed (mph)	Capacity (pcphpl)	Speed at capacity (mph)
86	2411	71.0
84	2360	69.5
82	2309	68.0
80	2258	66.5
78	2208	65.0
76	2157	63.5
74	2106	62.0
72	2055	60.5
70	2004	59.0
68	1953	57.5
66	1902	56.0
64	1851	54.5
62	1800	53.0
60	1749	51.5

WZ Free Flow Speed (mph)	Capacity (pcphpl)	Speed at capacity (mph)
58	1698	50.0
56	1647	48.5
54	1596	47.0
52	1545	45.5
50	1494	44.0
48	1443	42.5
46	1392	41.0
44	1342	39.5
42	1291	38.0
40	1240	36.5
38	1189	35.0
36	1138	33.5
34	1087	32.0
32	1036	30.5

Table J3: Suggested capacities for 2-to-1 WZs without concrete barriers

(based on data from 45 mph speed limit WITHOUT flagger in WZ)

WZ Free Flow Speed (mph)	Capacity (pcphpl)	Speed at capacity (mph)
71	1781	49.4
69	1752	48.6
67	1723	47.8
65	1694	47.0
63	1665	46.2
61	1637	45.4
59	1608	44.6
57	1579	43.8
55	1550	43.0
53	1500	41.6
51	1450	40.2
49	1400	38.8
47	1350	37.5
45	1300	36.1

WZ Free Flow Speed (mph)	Capacity (pcphpl)	Speed at capacity (mph)
43	1250	34.7
41	1200	33.3
39	1150	31.9
37	1100	30.5
35	1050	29.1
33	1000	27.7
31	950	26.4
29	900	25.0
27	850	23.6
25	800	22.2
23	750	20.8
21	700	19.4
19	650	18.0
17	600	16.6

Table J4: Suggested capacities for 2-to-1 WZs with flagger

(based on data from 45 mph speed limit WITH flagger in WZ)

WZ Free Flow Speed (mph)	Capacity (pcphpl)	Speed at capacity (mph)
53	1600	38.9
51	1600	38.9
49	1600	38.9
47	1546	37.6
45	1476	35.9
43	1407	34.2
41	1337	32.5
39	1267	30.8
37	1197	29.1
35	1127	27.4
33	1057	25.7
31	987	24.0
29	918	22.3
27	848	20.6
25	778	18.9
23	708	17.2
21	638	15.5

Note1: Capacity values for with flagger and without flagger are not comparable.
Note2: Arterial midblock capacity is based on Table J3 or Table J4.

Table J5: Capacity adjustment factors due to lane configuration

Capacities in Tables J2-J4 are based on field data collected from 2-to-1 WZs. For other lane configurations the capacities should be multiplied by the following adjustment factor.

		No. of lanes inside WZ					
		1	**2**	**3**	**4**	**5**	**6**
No. of open lanes outside WZ	**2**	1	1.04	_	_	_	_
	3	0.98	1.03	1.06	_	_	_
	4	0.96	1.02	1.05	1.07	_	_
	5	_	1.01	1.03	1.05	1.07	_
	6	_	1.00	1.01	1.03	1.05	1.07

Appendix K

Sources for users' costs figures

Source 1: FHWA Report: "Work Zone Road User Costs - Concepts and Applications"*

- Users' Costs have 4 components

Component 1) Travel delay cost

1.1) Dollar value of personal travel time (only passenger cars).

Local travel: $11.89/person –hr** Intercity travel:$16.64/person –hr**

1.2) Dollar value of business travel time (only passenger cars).

For both local and intercity travel: $29.75/person –hr**

1.3) Value of truck travel time (only trucks).

See section 2.2.2.3 for detailed computations

1.4) Cost of freight inventory delay (only trucks).

See section 2.2.2.3 for detailed computations

1.5) Cost of vehicle depreciation (all vehicles).

See section 2.2.2.3 for detailed computations

*Single-unit trucks = 1.025 * ($14.90 + $7.60) = $23.06/hr (May 2009)*
*Combination-unit trucks = 1.12 * ($18.87 + $7.60) = $29.65/hr (May 2009)*

**URL:http://www.ops.fhwa.dot.gov/wz/resources/publications/fhwahop12005/index.htm*

***computed for 2010.*

Source 1: FHWA Report: "Work Zone Road User Costs - Concepts and Applications" (cont.)

Component 2) Vehicle operating cost

2.1) Fuel consumption.

2.2) Engine oil consumption.

2.3) Tire-wear.

2.4) Repair and maintenance.

2.5) Mileage-related depreciation.

Section 2.3 discusses three different methods to compute VOC

Component 3) Crash Cost

See Section 2.4 for detailed computations

Component 4) Emission cost

See Section 2.5 for detailed computations

Source 2: American Transportation Research Institute (ATRI) Report: "An Analysis of the Operational Costs of Trucking: A 2014 Update"*

Average Marginal Costs per Hour, 2008-2013

Motor Carrier Costs	2008	2009	2010	2011	2012	2013
Vehicle-based						
Fuel Costs	$25.30	$16.17	$19.41	$23.58	$25.63	$25.78
Truck/Trailer Lease or Purchase Payments	$8.52	$10.28	$7.37	$7.55	$6.94	$6.52
Repair & Maintenance	$4.11	$4.90	$4.97	$6.07	$5.52	$5.92
Truck Insurance Premiums	$2.22	$2.15	$2.35	$2.67	$2.51	$2.57
Permits and Licenses	$0.62	$1.15	$1.60	$1.53	$0.88	$1.04
Tires	$1.20	$1.14	$1.42	$1.67	$1.76	$1.65
Tolls	$0.95	$0.98	$0.49	$0.69	$0.74	$0.77
Driver-based						
Driver Wages	$17.38	$16.12	$17.83	$18.39	$16.67	$17.60
Driver Benefits	$5.77	$5.11	$6.47	$6.05	$4.64	$5.16
TOTAL	**$66.07**	**$58.00**	**$61.90**	**$68.21**	**$65.29**	**$67.00**

**URL: http://www.atri-online.org/wp-content/uploads/2014/09/ATRI-Operational-Costs-of-Trucking-2014-FINAL.pdf*

Source 3: DOT Default Values

- Missouri DOT:
  - $10.30/person-hr for passenger cars
  - $22.70/person-hr for trucks

- Illinois DOT:
  - $0.22/mile per diversion for passenger cars
  - $0.99/mile per diversion for single-unit trucks
  - $1.21/mile per diversion for combination trucks

- Delaware DOT:
  - $20.19/person-hr for passenger cars
  - $29.16/person-hr for trucks

- Arkansas DOT: (some crash and operating costs are included here)
  - $20.7/person-hr for passenger cars
  - $32.7/person-hr for single-unit trucks
  - $48.3/person-hr for combination trucks

- Your State?

Wrap-up

1. Which package should I use?
2. What is covered in appendices
3. Additional Resources
4. Q &A and Discussions
5. Course Evaluation
6. PDH Certificate Distribution

Questions related to Module 2 - 5

Performance Measure	Tools				
	QDAT spread sheet	MoDOT spreads heet	HCM 2016 WZ capacity method	WZQ-Pro	None
1) Computing delay in stopped queue.					
2) Computing delay in moving queue.					
3) Determining the times queue begins and ends.					
4) Determining location of front and back of queue.					
5) Determining effect of work space location on queue length.					
6) Determining volume of diversion.					
7) Determining queue length when volume of diversion is known.					
8) Determining queue length when WZ capacity varies during the construction hours.					
9) It can be used for freeways					
10) It can be used for arterials					

What are practical things to reduce queue length

1. Night time construction
2. Limit construction to off-peak hours
3. Do not allow worker to be near the travel lane during peak hours
4. Divert traffic to other routes
5. Increase lane width to 12 ft
6. Do not allow TCD to intrude into travel lane
7. Widen left and/or right shoulders
8. Use concrete barriers instead of non-concrete barriers
9. Do not reduce speed limit when it is not needed
10. Shorten the length of work space, if possible
11. Avoid merge/diverge or make them as gradual as possible,
12. Avoid sharp curves and abrupt changes in geometry
13. Avoid rough pavement and bumps on the road
14. Be prepared to quickly remove disabled vehicles
15. Ask police to stop the violators once they left the WZ
16. ….

Appendices – Additional Examples

Appendix A:

Delay from the three tools for Example Problem #1T

Appendix B:

Computation of no of vehicles in queue in QDAT and MoDOT for Example 1T

Appendix C:

Effects of variable vehicle composition

Appendix D:

QDAT and MoDOT approx. methods when WZ capacity changes

Appendix E:

Modeling a long work space in WorkZoneQ-Pro 1.5

Appendix F:

Determine location of sensors

Appendix G:

A WZQ-Pro example when transition area is the bottleneck

Appendix H:

Cell Transmission Model in WorkZoneQ-Pro 1.5

Appendix I:

Developing speed-flow curves in WorkZoneQ-Pro 1.5

Appendices – Additional Examples (Cont.)

Appendix J:
Look-up tables for capacity used in WorkZoneQ-Pro 1.5

Appendix K:
Sources for users' costs figures

Appendix L:
Flow rate and Peak Hour Factor (PHF)

Appendix M:
Typical values for the longitudinal distances in In WZQ-Pro for Freeway WZs

Appendix N:
Effects of buffer space on queue

Appendix O:
Effect of Diversion

Appendix P:
Lane Closure Schedule Analysis in QDAT

Appendix Q:
HCM 2016 detailed calculations for one-lane two way operation on two-lane highways

Appendix R:
Variations in Work Zone Capacity within Analysis Period

Appendices – Additional Examples (Cont.)

Appendix S:

Implementing Speed Control Technique in the work zone

Appendix T:

Approximating Multilane Highway

Appendix U:

Real-World Examples

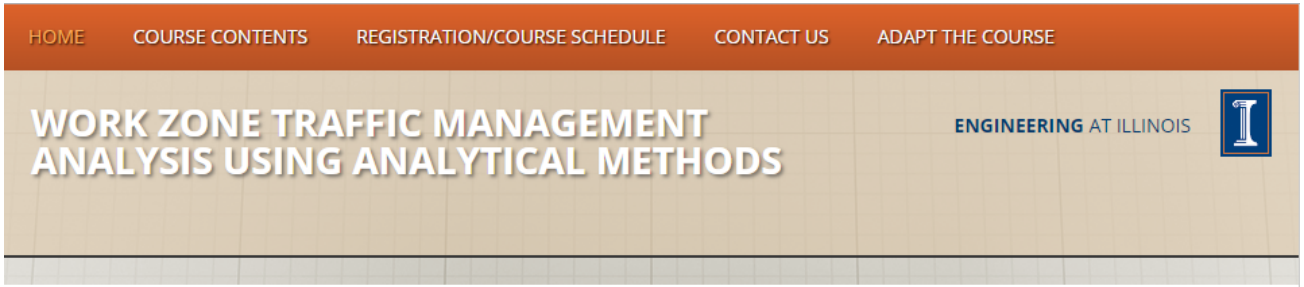
Appendix V:

Troubleshooting and FAQs

Note: Appendices A-I & L-U are in the electronic version of the Participants Handout.
Appendix J and K was presented in printed version right after Module 5

Course website

https://publish.illinois.edu/workzone-traffic-management/



Course Description

This course has been developed and is being delivered under FHWA Work Zone Safety Grant program. The course provides hands-on training on basic analytical methods (sketch planning methods) to compute work zone performance measures (WZPM). The WZPM includes to the following factors: capacity, speed, queue length, delay, and users' costs. The capabilities and limitations of the analytical tools are discussed and basic guidance on how to use them is presented. The course is composed of 5 main modules. It covers stopped and moving queues in work zones(WZ). Module 1 briefly reviews the necessary background material for this course. It presents basic principles of traffic flow in work zones, transportation management plans (The Rule), and other topics. Module 3 discuss the WZ capacity estimation procedures in the recently published Highway Capacity Manual (HCM 2016). Module 2 and 4 cover two (or three) different analytical methods and step-by-step procedure for computing WZPM. These modules complement each other enabling the participants to analyze more complex WZ conditions. Module 5 discusses how to select and use the appropriate methods to evaluate various traffic management strategies in their impacts WZPM.

The course is offered free (no instructional fee).

Course Objectives:

To learn:

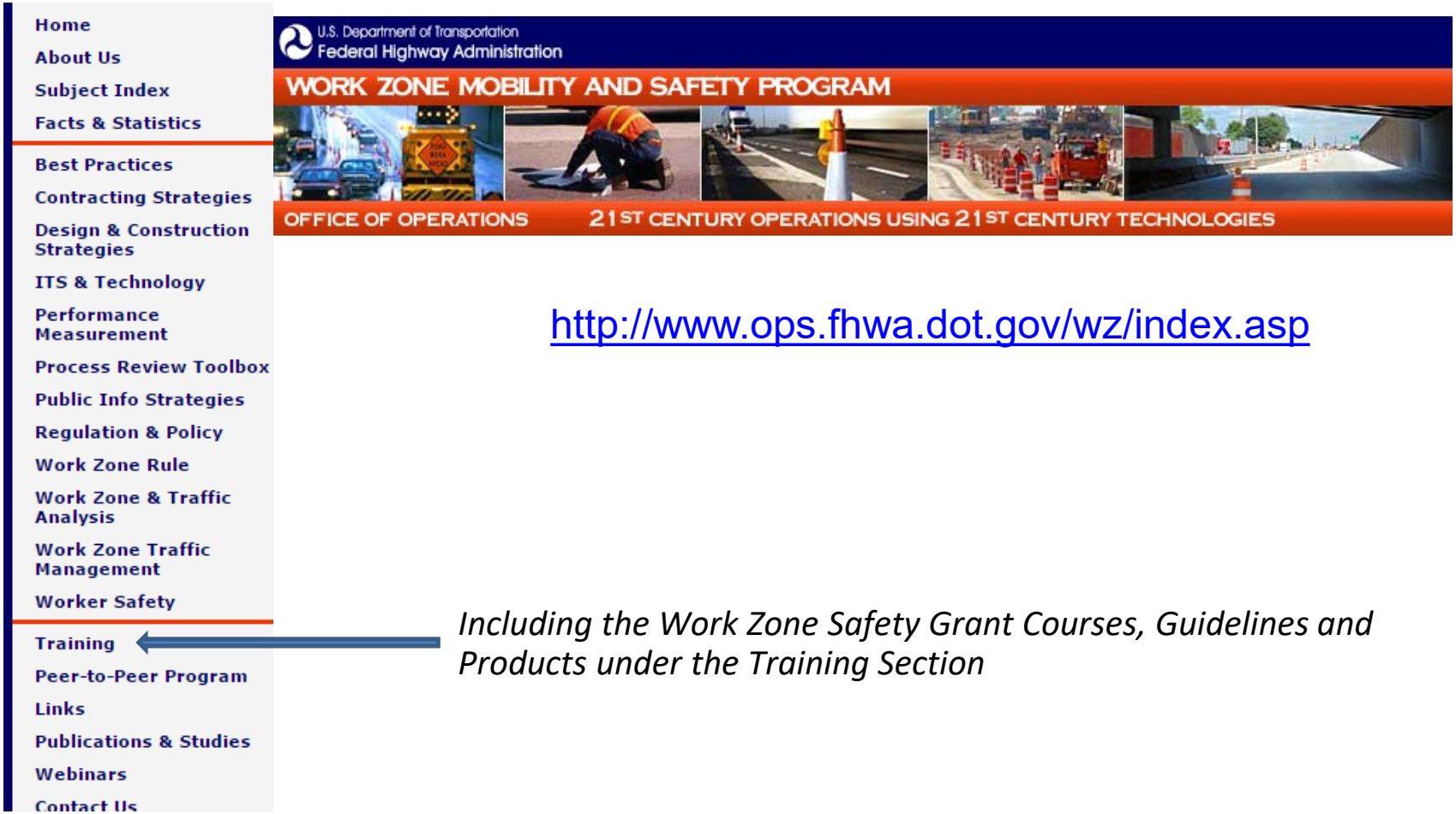
1. Work zone traffic management analysis using analytical methods.
2. Work zone performance measures computations (capacity, speed, queue length, delay, and users' costs).
3. Hands-on experience on solving examples problems that demonstrate how the tools can be used for evaluation of traffic management strategies or implementation of ITS in managing back-of-queue and delay.

Additional Details:

- **PRIMARY AUDIENCE:**
  Technical personnel who make decisions about planning, design, operation, or management of traffic in work zones.

Additional Resources

FHWA maintains a key website with plenty of material related to WZ traffic management as well as links to other sites:



http://www.ops.fhwa.dot.gov/wz/index.asp

Including the Work Zone Safety Grant Courses, Guidelines and Products under the Training Section

Appendices

(Not Printed)

They are on the USB Drive

Appendix A

Delay from the three tools for Example Problem #1T

In a similar way that queues from the three tools were compared in Example 1T, we can also compare their delays:

Interval	Volume (vphpl)	Capacity	QDAT		MoDOT		WorkZoneQ		
			Excess vehicles *	Delay (min/veh)	Excess vehicles	Delay (min/veh)	Veh. in queue	Average Delay per vehicle	
								Based on WZ speed limit	Based on speed limit outside WZ
9:00 AM-10:00 AM	900	1272 (vphpl)	0	0.1	0	0	0	0.00	0.00
10:00 AM-11:00 AM	1150		0	0.2	0	0	0	0.00	0.01
11:00 AM-12:00 PM	1400		128	3.0	128	6.0	146	0.04	0.04
12:00 PM-1:00 PM	1500		356	9.5	356	16.8	395	0.14	0.14
1:00 PM-2:00 PM	1300		384	14.2	384	18.1	425	0.25	0.25
2:00 PM-3:00 PM	1050		162	10.7	162	7.6	188	0.23	0.23
3:00 PM-4:00 PM	900		0	3.2	0	0	0	0.04	0.04

* To reflect that QDAT and MoDOT use the same method to estimate the number of vehicles in queue, the excess vehicles shown for QDAT and MoDOT correspond to those at the end of each interval. QDAT would normally use the queues at the middle of the interval for queue length. **However, the delay calculation in QDAT is not directly related to the number of vehicles in queue, but rather on speed flow curves (as described in Module 2)**

Appendix B

Computation of no of vehicles in queue in QDAT and MoDOT for Example 1T

The calculation for the accumulated number of vehicles in excess of demand (i.e. the vehicles used for calculating queue length) in MoDOT and QDAT follow the same procedure described in Module 1 – Discussion 5

Interval	Demand (vphpl)	Capacity (vphpl)	Excess Demand in MoDOT (veh)	Average Excess Vehicles used in QDAT for Queue * (veh)
9:00 AM-10:00 AM	900	1272	0	0
10:00 AM-11:00 AM	1150	1272	0	0
11:00 AM-12:00 PM	1400	1272	128	128
12:00 PM-1:00 PM	1500	1272	356	356
1:00 PM-2:00 PM	1300	1272	384	384
2:00 PM-3:00 PM	1050	1272	162	162
3:00 PM-4:00 PM	900	1272	0	0

* Even though the excess vehicles are calculated using the same procedure in both tools, QDAT calculates the queue length based on the queue in the middle of each interval (or the average queue). For example, for the interval between 1:00pm and 2:00pm, the queue reported by QDAT would correspond to the queue at 1:30pm

Appendix C

Effects of vehicle composition

In the WZ from Example Problem #1T, assume that everything stays the same except that the percentage of heavy vehicles is not constant at 16%, but it changes as follows:

Interval	% single-unit Trucks	% combination trucks	% recreational vehicles	Volume (veh)
9:00 AM-10:00 AM	1	19	0.0	900
10:00 AM-11:00 AM	2	14	0.0	1150
11:00 AM-12:00 PM	3	10	0.0	1400
12:00 PM-1:00 PM	3	11	0.0	1500
1:00 PM-2:00 PM	2	19	0.0	1300
2:00 PM-3:00 PM	2	22	0.0	1050
3:00 PM-4:00 PM	2	24	0.0	900

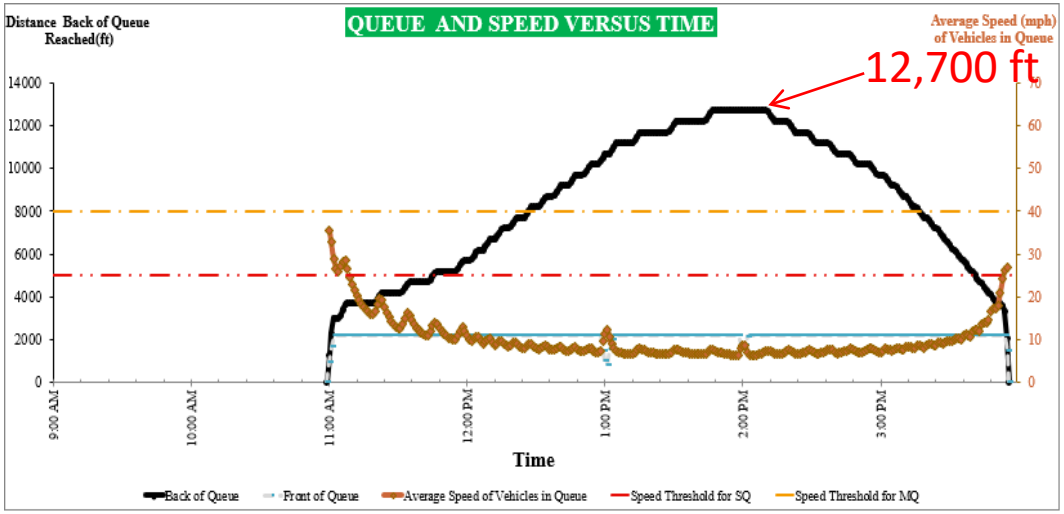
Find queue and delay.

How much does the variation in heavy vehicles affect the results?

WorkZoneQ-Pro

Queue:

- Back of queue reached 12,700 ft (it was 12,700 ft)
- Number of vehicles in queue decreased from 429 to 420



Delay:

- Total delay increased from 1,025.3 hr to 1,053.3 hr (not shown in this table)
- Maximum delay (based on WZ speed limit) decreased from 0.25 hr to 0.24 hr.

Start of Interval	End of Interval	No. of vehicles in queue*	Average speed in queue (mph)	Average delay per vehicle (hr)	
				Based on WZ speed limit	Based on speed limit outside of the WZ
9:00 AM	10:00 AM	0	-	0.00	0.00
10:00 AM	11:00 AM	0	-	0.00	0.00
11:00 AM	12:00 PM	110	14.6	0.03	0.03
12:00 PM	1:00 PM	337	8.3	0.12	0.12
1:00 PM	2:00 PM	420	7.2	0.22	0.22
2:00 PM	3:00 PM	277	7.2	0.24	0.25
3:00 PM	4:00 PM	0	9.3	0.10	0.11

WorkZoneQ-Pro

Output **without** variation in % HV (as shown in Example 1T)

Start of Interval	End of Interval	No. of vehicles in queue*	Average spacing between vehicles in queue (ft)	Distance queue occupied (ft)	Average speed in queue (mph)	Average delay per vehicle (hr)	
						Based on WZ speed limit	Based on speed limit outside of the WZ
9:00 AM	10:00 AM	0	0	0	-	0.00	0.00
10:00 AM	11:00 AM	0	-	-	-	0.00	0.00
11:00 AM	12:00 PM	148	55	4,500	12.6	0.04	0.04
12:00 PM	1:00 PM	391	47	9,500	7.8	0.14	0.14
1:00 PM	2:00 PM	429	47	10,500	7.1	0.25	0.25
2:00 PM	3:00 PM	193	53	5,500	7.5	0.23	0.23
3:00 PM	4:00 PM	0	53	0	11.2	0.04	0.04

WorkZoneQ-Pro

Outputs **with** variation in %HV

Start of Interval	End of Interval	No. of vehicles in queue*	Average spacing between vehicles in queue (ft)	Distance queue occupied (ft)	Average speed in queue (mph)	Average delay per vehicle (hr)	
						Based on WZ speed limit	Based on speed limit outside of the WZ
9:00 AM	10:00 AM	0	0	0	-	0.00	0.00
10:00 AM	11:00 AM	0	-	-	-	0.00	0.00
11:00 AM	12:00 PM	110	56	3,500	14.6	0.03	0.03
12:00 PM	1:00 PM	337	48	8,400	8.3	0.12	0.12
1:00 PM	2:00 PM	420	48	10,500	7.2	0.22	0.22
2:00 PM	3:00 PM	277	51	7,500	7.2	0.24	0.25
3:00 PM	4:00 PM	0	51	0	9.3	0.10	0.11

Appendix D

QDAT and MoDOT approx. methods when WZ capacity changes

This is an extension to Example #3, where the WZ intensity and the speed limit changed in the middle of the analysis period.

One suggested approach for MoDOT and QDAT is to make thee separate runs, one for each time period of constant capacity. This approach has its own issues, but is an approximate way of getting some results.

Analysis	Time duration	WZ characteristics	Capacity
1	7:00 AM-9:00 AM	Speed limit=55 mph	Capacity 1
2	9:00 AM-11:00 AM	Moderate work activity, Speed limit=45 mph	Capacity 2
3	11:00 AM-1:00 PM	Speed limit=55 mph	Capacity 1

MoDOT

Run for Analysis 1

6:00am – 9:00am
Capacity 1 = 1400 veh/h

		Excess demand (7am – 9am)
6:00 - 7:00 AM	950	0
7:00 - 8:00 AM	1400	0
8:00 - 9:00 AM	1357	0
9:00 - 10:00 AM	1250	
10:00 - 11:00 AM	1135	
11:00 - 12:00 NOON	1200	
12 NOON - 1:00 PM	1250	

A total of 0 vehicles will need to be carried over to the next analysis period

BASE CONDITIONS

Open Lane Capacity (veh/h/lane):	1900

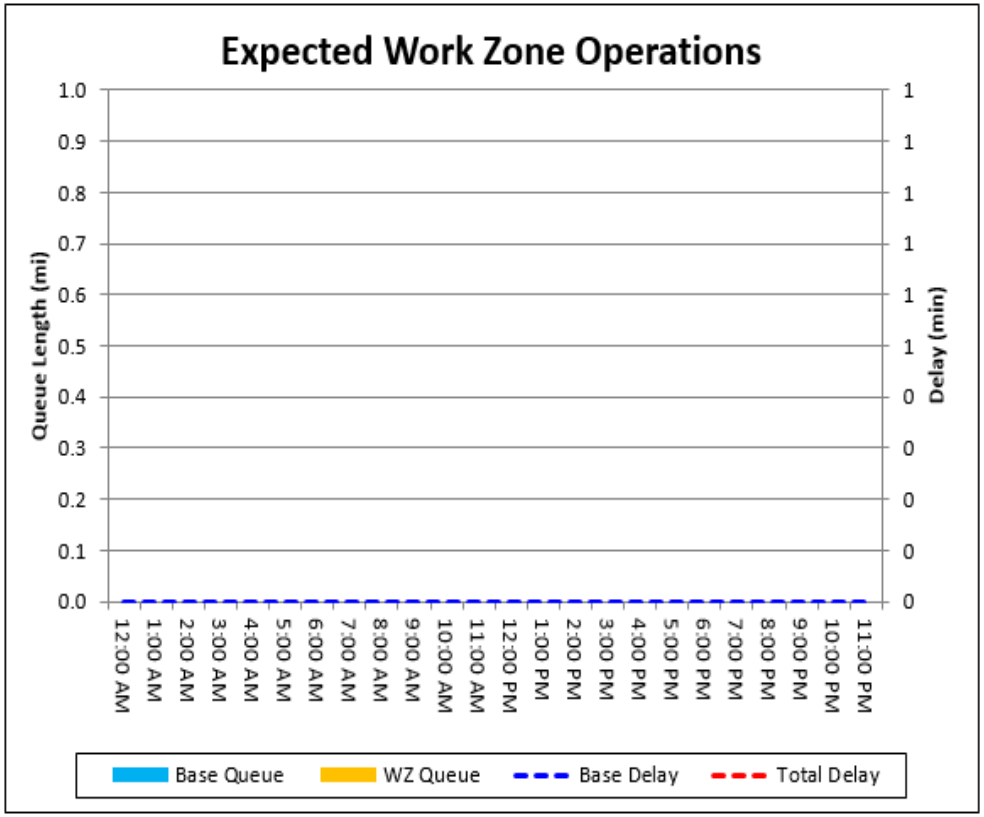
Base Conditions Capacity (Total for ALL Lanes): 3800 veh/h

WORKZONE DETAILS

Work Description:	Example #2
Work Location:	Workers & equipment greater than 4-feet from travel lane
Travel Lane Width (ft):	10 - 11.5
Number of Lanes Open:	1
ESTIMATED Work Zone Capacity (veh/h):	1400
USER DEFINED Work Zone Capacity (veh/h):	
Start Time:	6:00 AM
End Time:	9:00 AM
Duration of Closure (hrs):	3

RESULTS

Measure of Effectiveness	Base Conditions	Work Zone	Total
Max Queue Length (mi):	0.0	0.0	0.0
Max Delay (minutes):	0	0	0
Cost ($):	$0	$0	$0



MoDOT

Run for Analysis 2

9:00am – 11:00am

Capacity 2 = 1260 veh/h

9:00 - 10:00 AM	1250
10:00 - 11:00 AM	1135
11:00 - 12:00 NOON	1200
12 NOON - 1:00 PM	1250

Excess demand (9am – 11am)

0

0

A total of 0 vehicles will need to be carried over to the next analysis period

BASE CONDITIONS

Open Lane Capacity (veh/h/lane):	1900

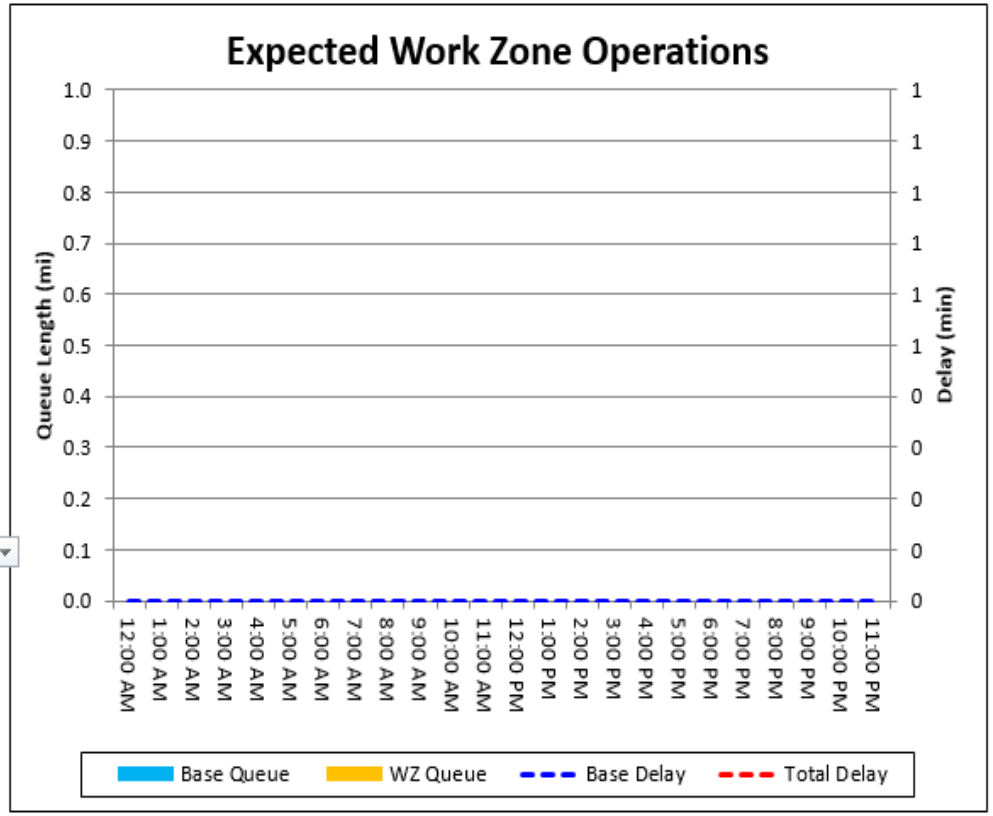
Base Conditions Capacity (Total for ALL Lanes): 3800 veh/h

WORKZONE DETAILS

Work Description:	Example #2
Work Location:	Workers & equipment less than 4 feet from travel lane
Travel Lane Width (ft):	10 - 11.5
Number of Lanes Open:	1
ESTIMATED Work Zone Capacity (veh/h):	1260
USER DEFINED Work Zone Capacity (veh/h):	
Start Time:	9:00 AM
End Time:	11:00 AM
Duration of Closure (hrs):	2

RESULTS

Measure of Effectiveness	Base Conditions	Work Zone	Total
Max Queue Length (mi):	0.0	0.0	0.0
Max Delay (minutes):	0	0	0
Cost ($):	$0	$0	$0



MoDOT

Run for Analysis 3

11:00am – 1:00pm

Capacity 1 = 1400 veh/h

		Excess demand (11am – 1pm)
11:00 - 12:00 NOON	1200	0
12 NOON - 1:00 PM	1250	0

A total of 0 vehicles remain in queue at the end of the analysis period

BASE CONDITIONS

Open Lane Capacity (veh/h/lane):	1900

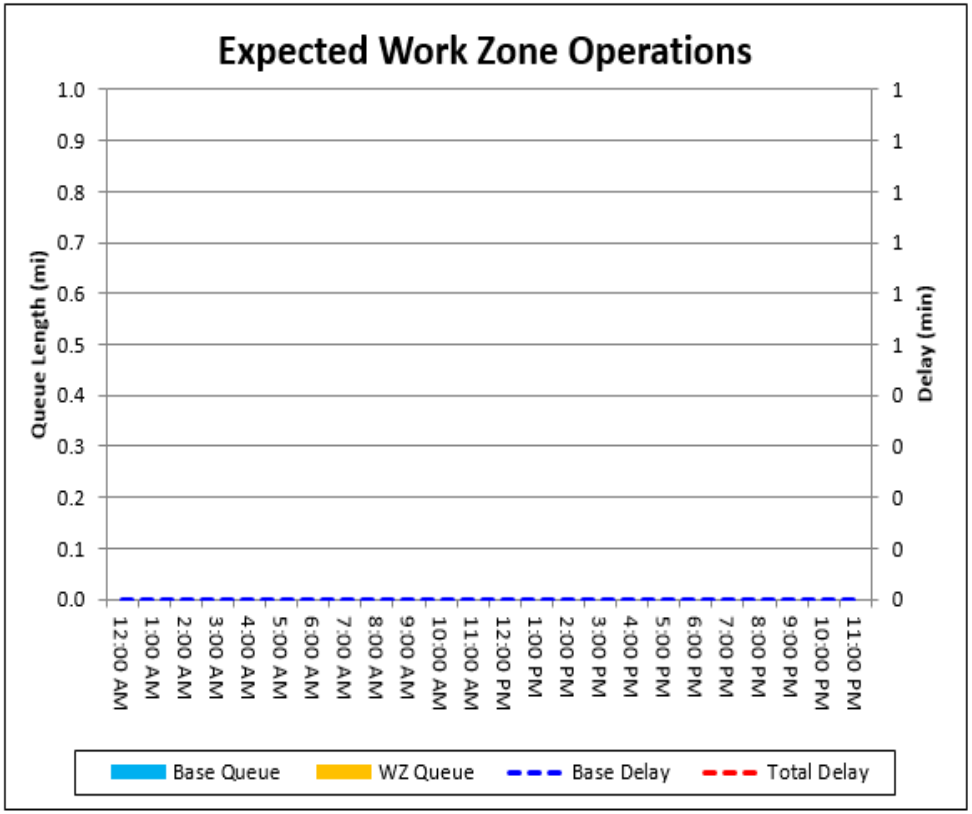
Base Conditions Capacity (Total for ALL Lanes): 3800 veh/h

WORKZONE DETAILS

Work Description:	Example #2
Work Location:	Workers & equipment greater than 4-feet from travel lane
Travel Lane Width (ft):	10 - 11.5
Number of Lanes Open:	1
ESTIMATED Work Zone Capacity (veh/h):	1400
USER DEFINED Work Zone Capacity (veh/h):	
Start Time:	11:00 AM
End Time:	1:00 PM
Duration of Closure (hrs):	2

RESULTS

Measure of Effectiveness	Base Conditions	Work Zone	Total
Max Queue Length (mi):	0.0	0.0	0.0
Max Delay (minutes):	0	0	0
Cost ($):	$0	$0	$0



MoDOT

After the analysis, we can look at the big picture again to observe the maximum queue for all three periods:

Analysis	Time duration	WZ characteristics	Capacity	Max Queue Length (Miles)	Max Delay (minutes)
1	7:00 AM-9:00 AM	Speed limit=55 mph	1400 vphpl	0	0
2	9:00 AM-11:00 AM	Moderate work activity, Speed limit=45 mph	1260 vphpl	0	0
3	11:00 AM-1:00 PM	Speed limit=55 mph	1400 vphpl	0	0

QDAT

A slightly modified approach can be followed with QDAT. We have to consider that the queue is the average of the beginning and end of the period

To do this, the first period of each analysis needs an initial queue equal to the last queue of the previous analysis.

For example, at the end of Analysis 1 (from 6am to 9am) we have an accumulation of 0 vehicle (as shown for MoDOT), so the beginning of Analysis 2 should have an initial queue of 0 vehicles.

We solve the whole example in the following slides to illustrate the approximated method

QDAT

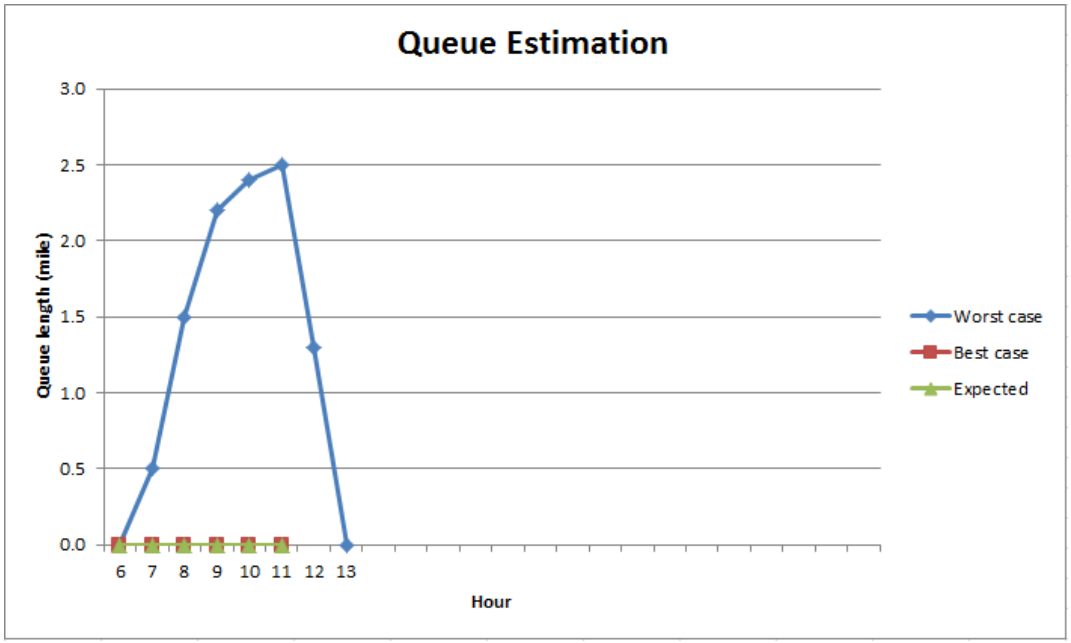
Run for Analysis 1

6:00am – 9:00am
Capacity 1 = 1400 veh/h

6: 6AM-7AM	950
7: 7AM-8AM	1400
8: 8AM-9AM	1357
9: 9AM-10AM	1250
10: 10AM-11AM	1135
11: 11AM-12PM	1200
12: 12PM-1PM	1250

Similar to MoDOT, a total of 0 vehicles will need to be carried over to the next analysis period

Expected: Estimated Queue(mile)		
start hour	6	0.0
	7	0.0
	8	0.0
	9	0.0
	10	0.0
end hour	11	0.0



QDAT

Run for Analysis 2

9:00am – 11:00am

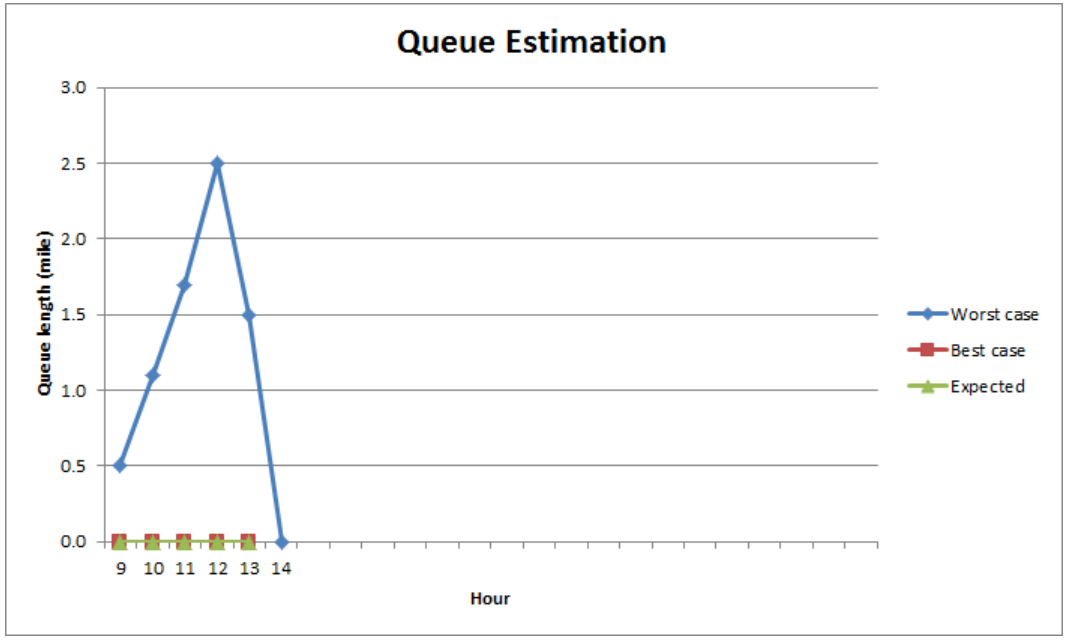
Capacity 2 = 1260 veh/h

We generated this volume in the hour before the beginning of Analysis 2 to generate an initial queue of 0 (carried over from Analysis 1)

8: 8AM-9AM	1357
9: 9AM-10AM	1250
10: 10AM-11AM	1135
11: 11AM-12PM	1200
12: 12PM-1PM	1250

Similar to MoDOT, a total of 0 vehicles will need to be carried over to the next analysis period

Expected: Estimated Queue(mile)		
start hour	9	0.0
	10	0.0
	11	0.0
	12	0.0
end hour	13	0.0



QDAT

Run for Analysis 3

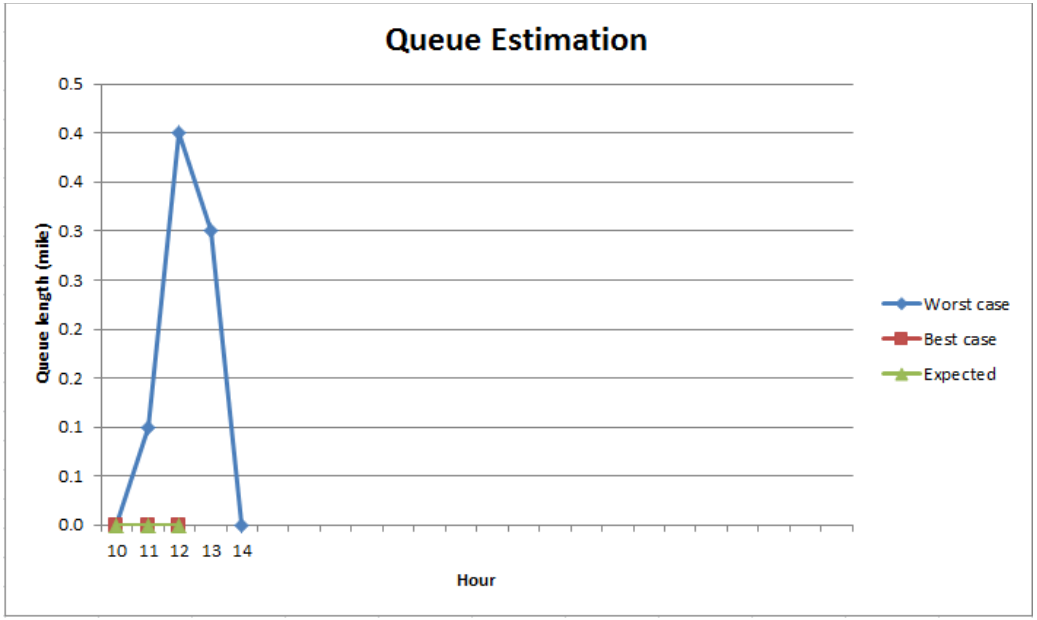
11:00am – 1:00pm

Capacity 1 = 1400 veh/h

We generated this volume in the hour before the beginning of Analysis 3 to generate an initial queue of 0 (carried over from Analysis 2)

10: 10AM-11AM	1135
11: 11AM-12PM	1200
12: 12PM-1PM	1250

Expected: Estimated Queue(mile)		
start hour	10	0.0
	11	0.0
end hour	12	0.0



QDAT

After the analysis, we can look at the big picture again to observe the maximum queue for all three periods:

Analysis	Time duration	WZ characteristics	Capacity	Max Queue Length (Miles)
1	7:00 AM-9:00 AM	Speed limit=55 mph	1400 vphpl	0
2	9:00 AM-11:00 AM	Moderate work activity, Speed limit=45 mph	1260 vphpl	0
3	11:00 AM-1:00 PM	Speed limit=55 mph	1400 vphpl	0

The approximated method for QDAT when the capacity of the work zone is not constant was more elaborated than for MoDOT, given that an initial queue had to be generated at the beginning of each analysis period

Notes:

- This method provides approximated queues, but it **does not provide reliable delays**
- For this example, capacities used in QDAT were taken from MoDOT given that QDAT does not provide a correction for lane width

Appendix E

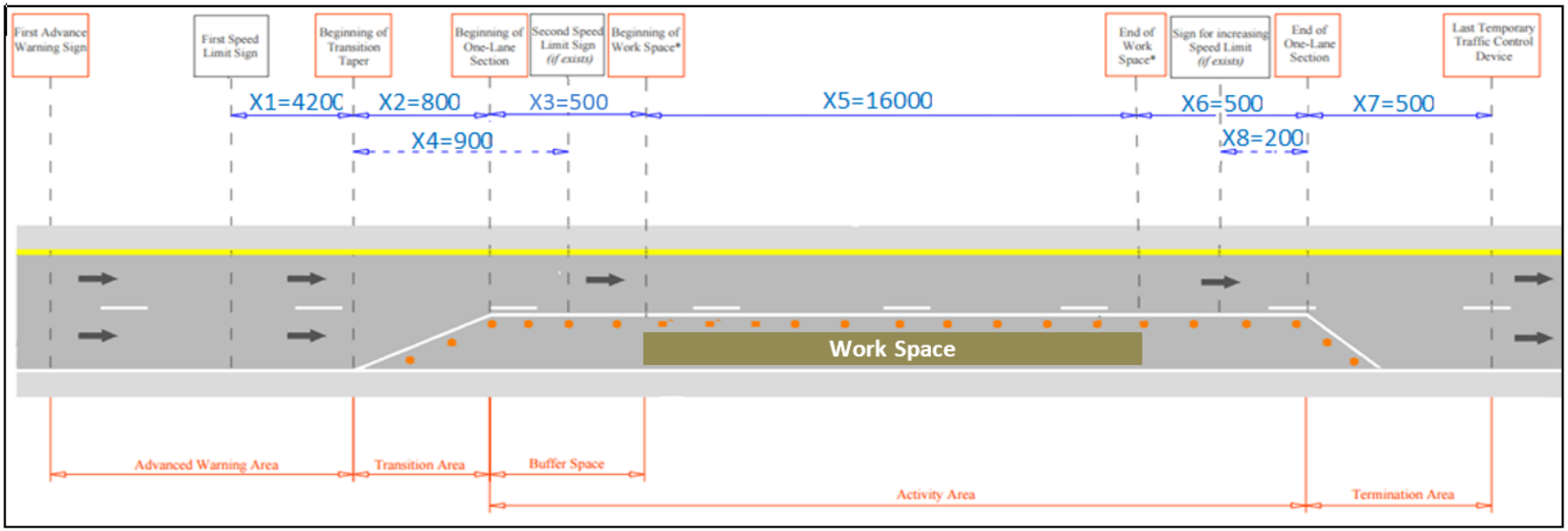
Modeling a long work space in WorkZoneQ-Pro 1.56

The goal of this problem is to show how a long work space should be coded in the WorkZoneQ-Pro

Assume there is a 16000-ft work space specified in the construction plan as shown in the sketch below, but work activity occurs only within 2000 ft of that. The rest of the required data is the same as Example 2T.

Find back of queue when location of work activity is

a) **in the beginning,**
b) **in the middle, and**
c) **at the end of the work space**



Case a) Work activity is in the BEGINNING of work space

Do the following modifications:

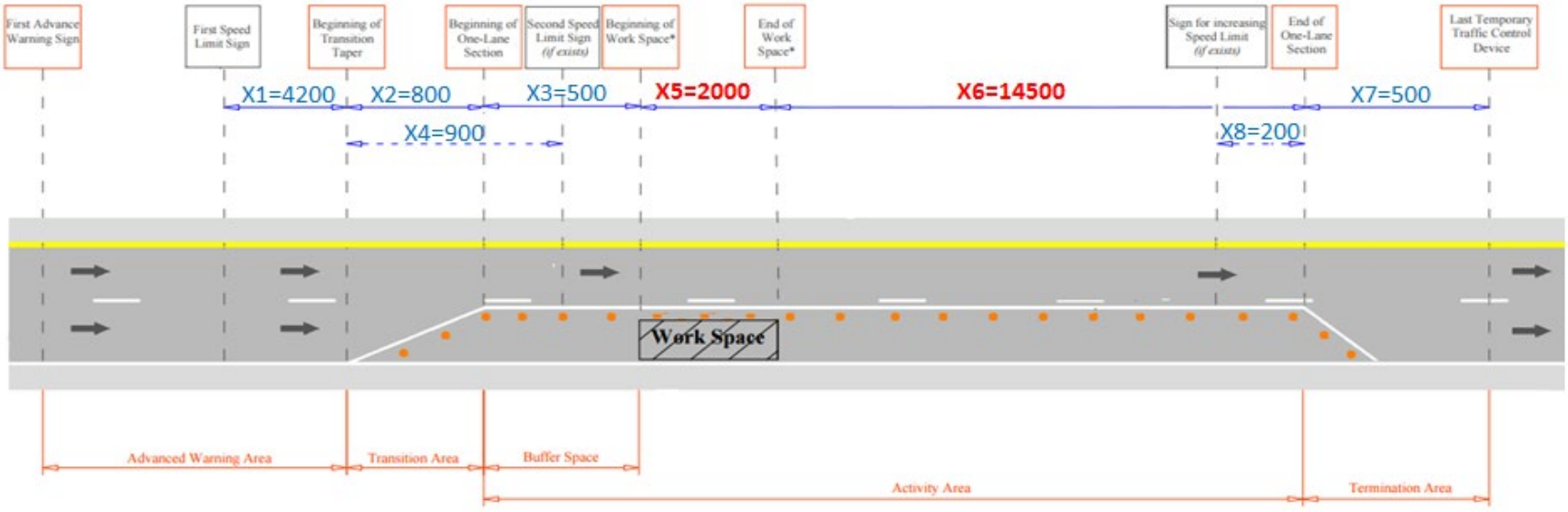
- X5=2000 ft

Note: The WZQ-Pro restricts the maximum values of X5 to 1 mile

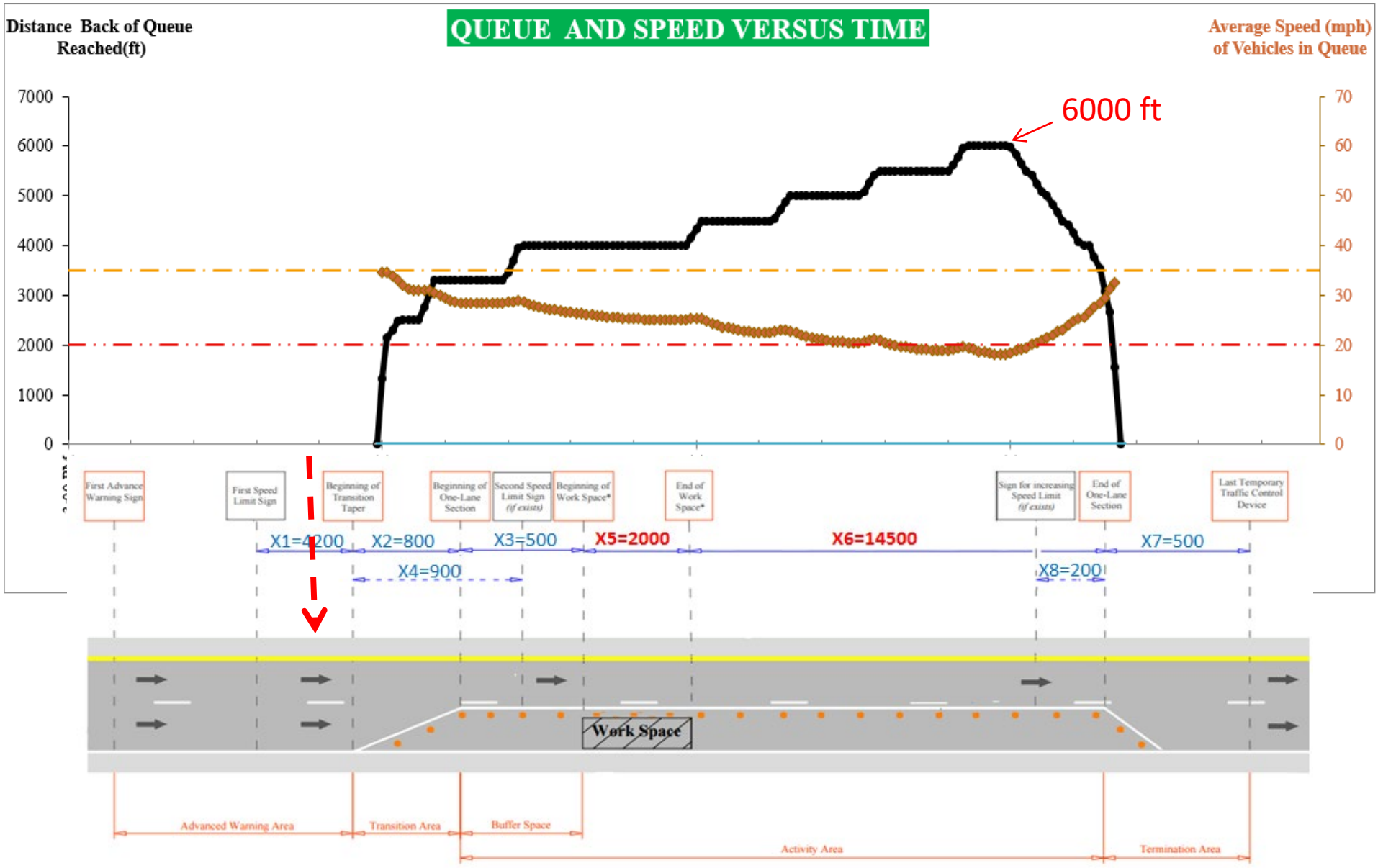
- Add the rest of the work space to X6, so

X6=500+(16000-2000)=14500 ft

Then the sketch becomes:



Case a) Work activity is in the BEGINNING of work space



Case b) Work activity is in the MIDDLE of work space

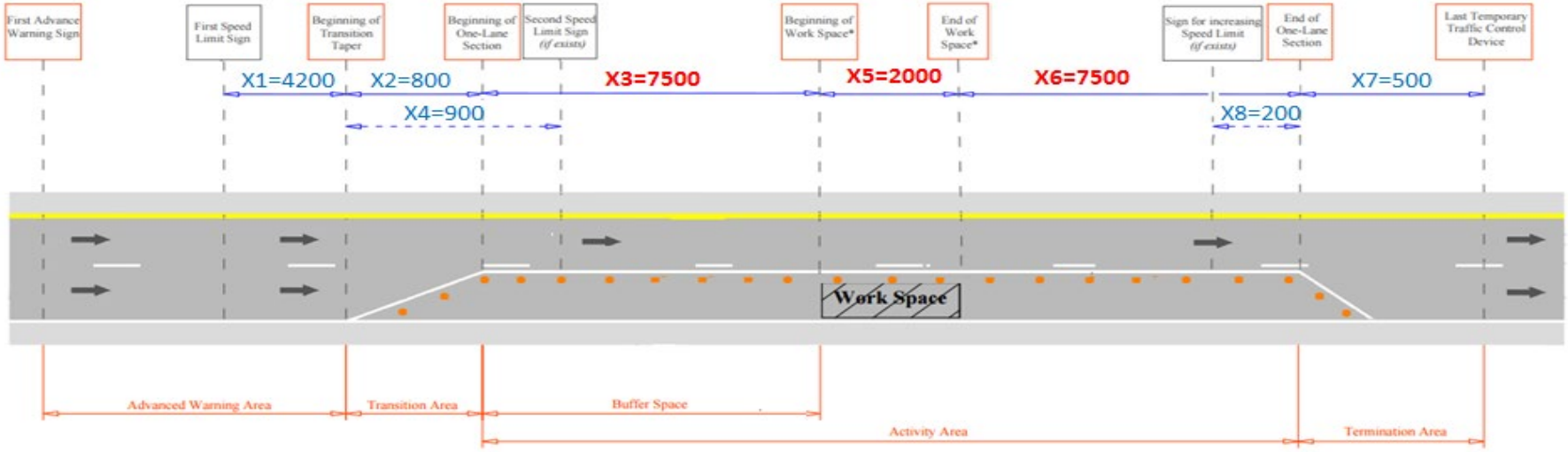
Do the following modifications:

- X5=2000 ft
- Add half the remaining length to X3, so

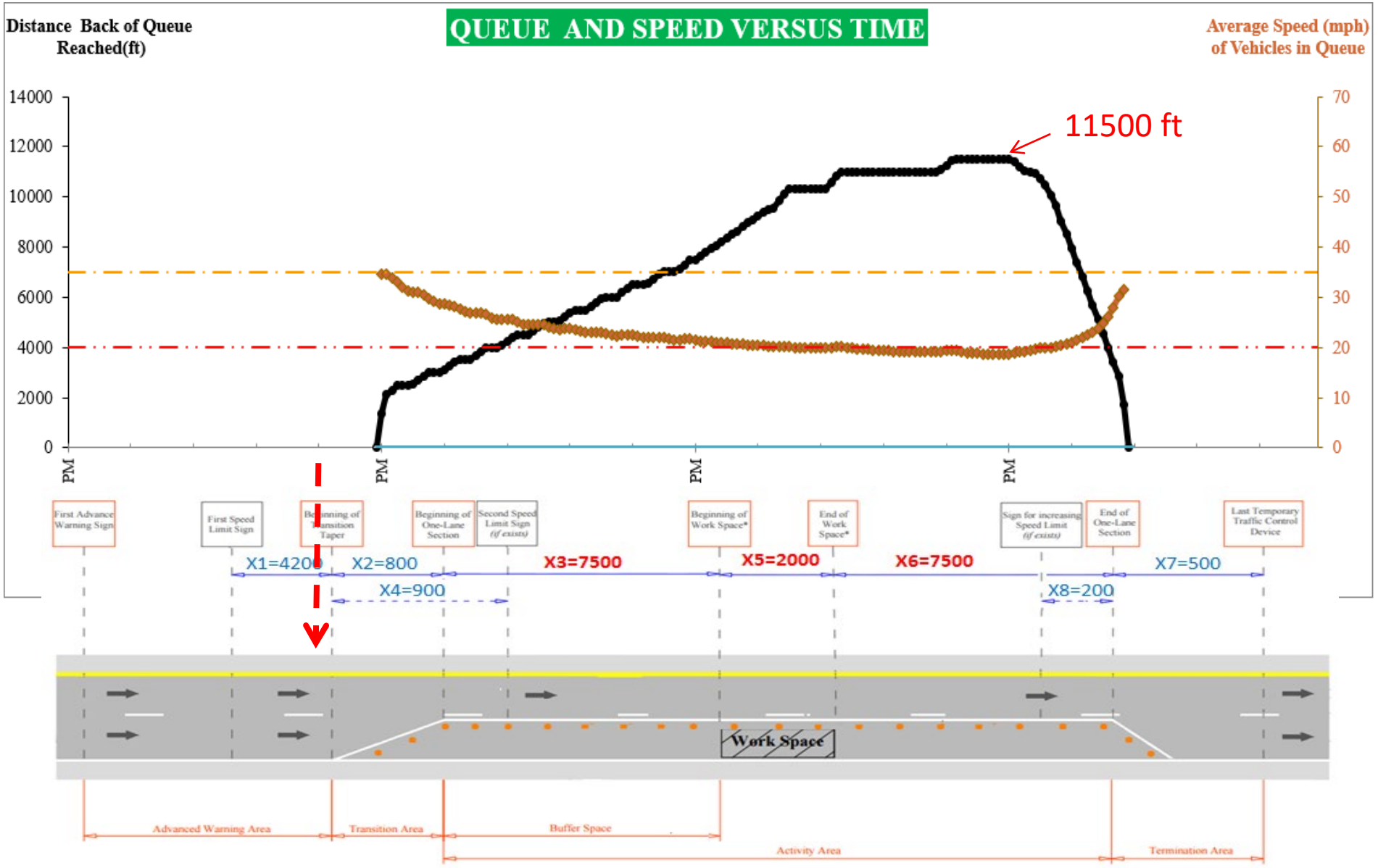
  X3=500+(16000-2000)/2=7500 ft
- Add half the remaining length to X6, so

  X6=500+(16000-2000)/2=7500 ft

Then the sketch becomes:



Case b) Work activity is in the MIDDLE of work space



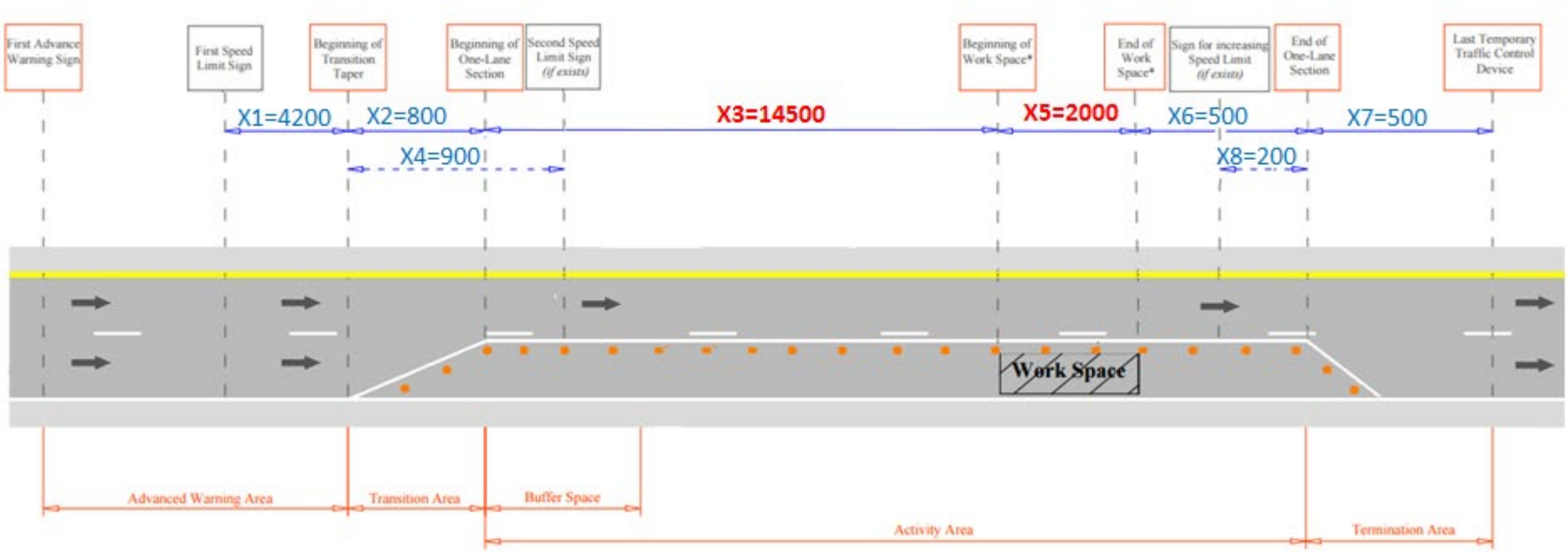
Case c) Work activity is at the END of work space

Do the following modifications:

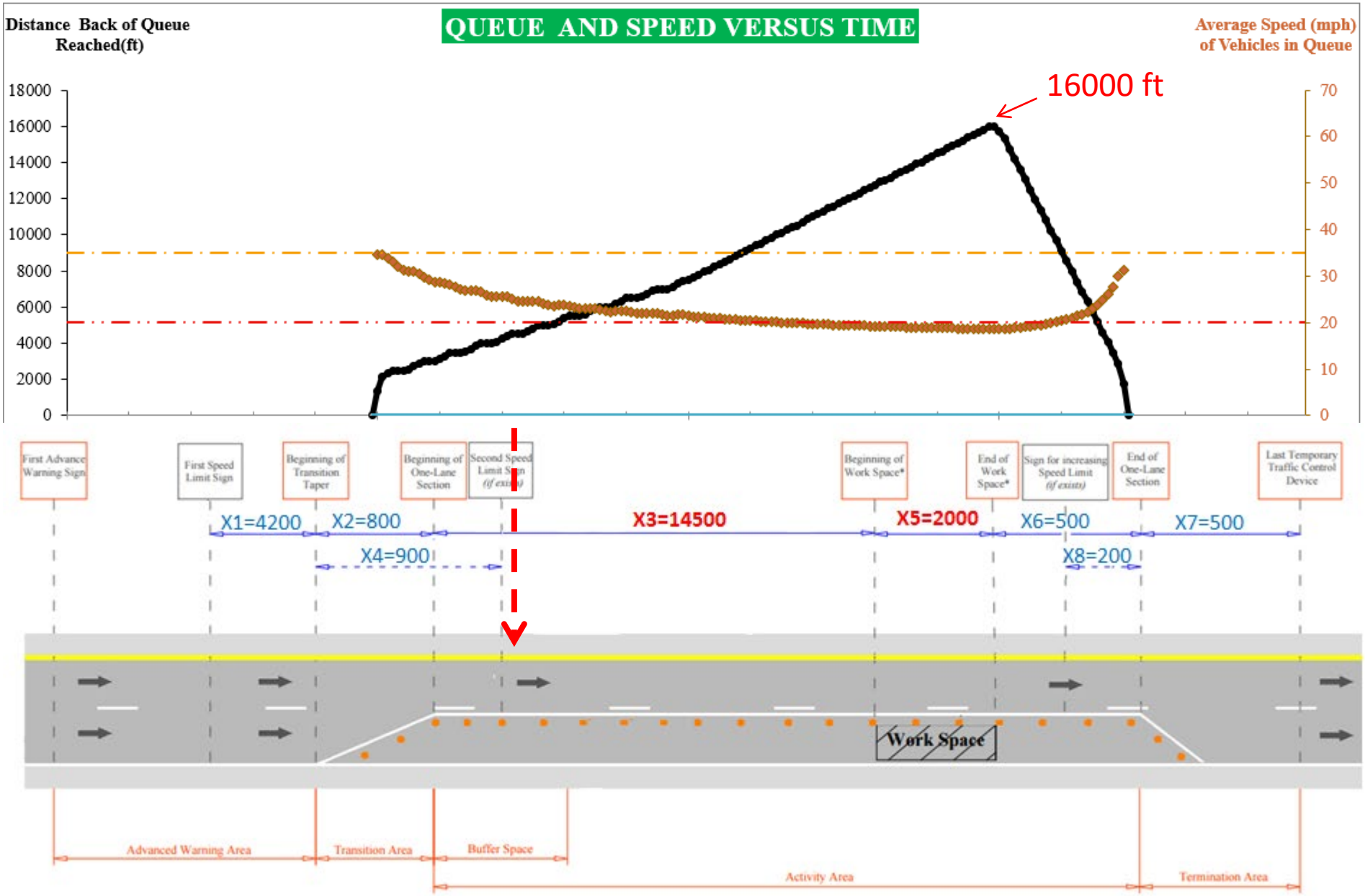
- X5=2000 ft
- Add the rest of the work space to X3, so

X3=500+(16000-2000)=14500 ft

Then the sketch becomes:



Case c) Work activity is at the END of work space



Appendix F
Determine locations of sensors

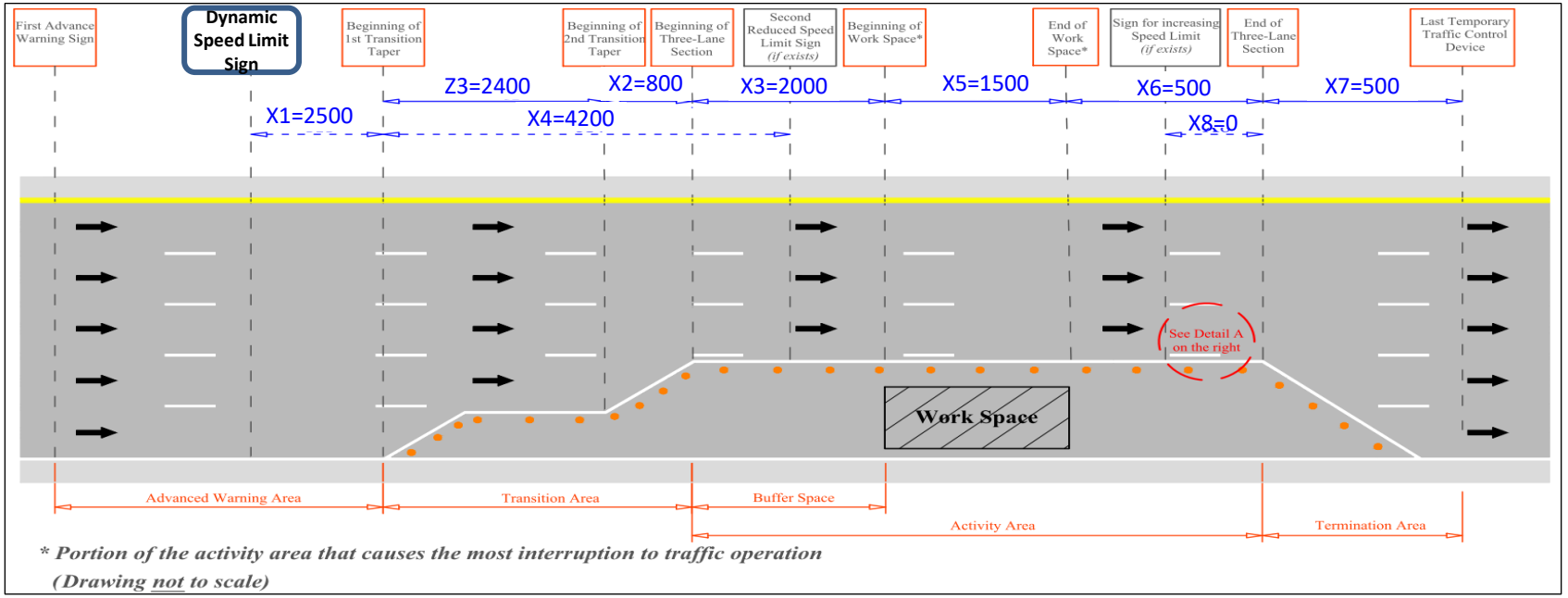
In Example problem 5T, there were three Changeable Message Signs (CMS) as follows:

CMS 1: To inform drivers about the downstream queue in the reduced-lane section ,
Installed at 6700 ft upstream of the end of the work space

CMS 2: To display dynamic speed limit sign when queue length exceeds 1 mile
Installed at 16700 ft upstream of the end of the work space

CMS 3: To Inform drivers about the downstream queue when queue passes CMS2
Installed at 26700 ft upstream of the end of the work space

Find the locations of sensors



Appendix F

Determine locations of sensors

- Sensor1 is installed 2500 ft (work space length+1000 ft) from the end of work space to activate CMS 1.
- Sensor 2 is installed 6780 ft (work space length + 1 mile) from the end of the work space to activate CMS 2
- Sensor 3 is installed 16700 ft (the location of CMS 2) from the end of the work space to activate CMS 3

Note: When sensors data show that traffic speed is below severe queue threshold for 3 minutes, it is assumed that the back of queue has reached the sensor location.

Appendix G

A WZQ-Pro example when transition area is the bottleneck

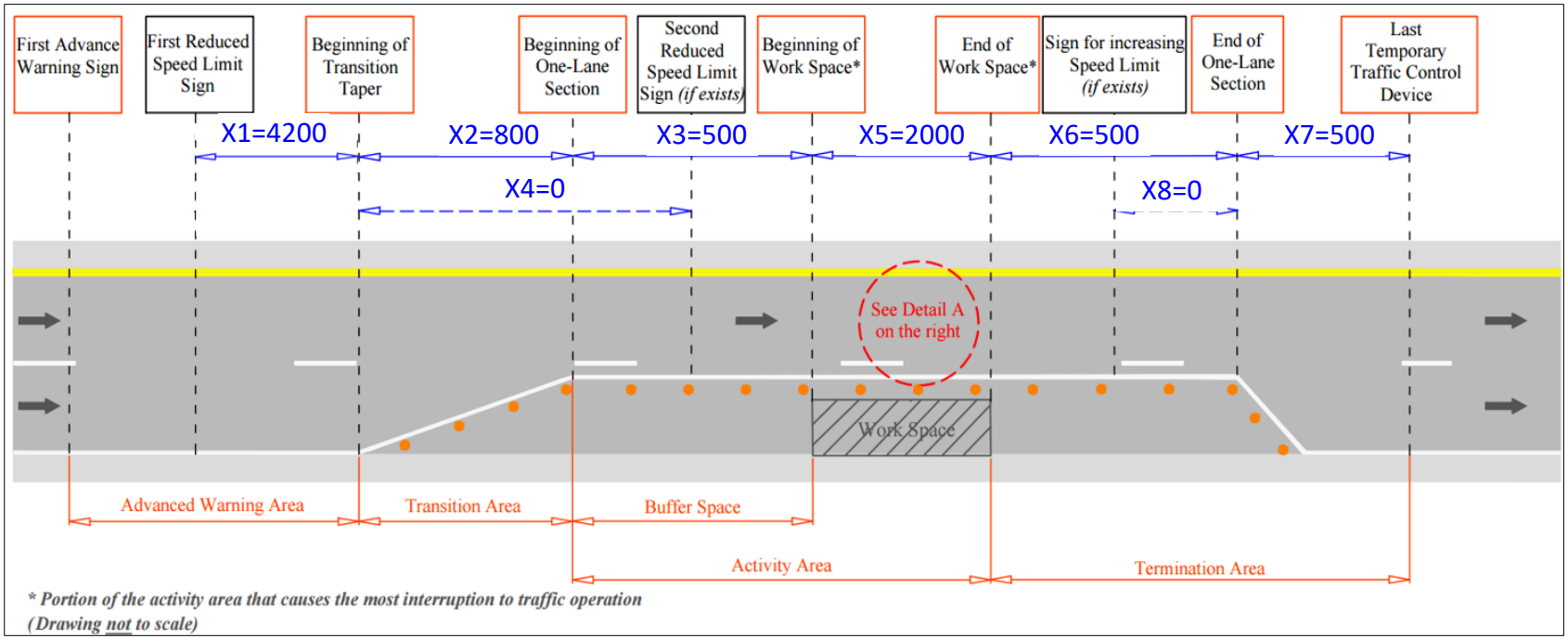
The goal of this example is to analyze a work zone when transition area is the choke point.

Description:

A 2-to-1 freeway work zone, daytime, clear weather condition

Geometric data: Longitudinal distances in the sketch below

Lane width = 12 ft, Right shoulder width = 6 ft, Left shoulder width = 2 ft



Description (Continued…)

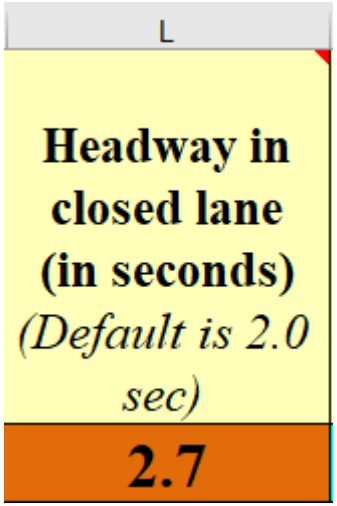
WZ conditions:

- First speed limit = 55 mph, Second speed limit=55 mph
- No work activity
- Speed limit outside of the WZ is 65 mph
- Use default Passenger Car Equivalency (PCE) factors
- Traffic volume data:

Interval	% single-unit Trucks	% combination trucks	% recreational vehicles	Volume (veh)
3:00 PM-4:00 PM	1.0	4.0	0.0	1,550
4:00 PM-5:00 PM	1.0	4.0	0.0	1,700
5:00 PM-6:00 PM	1.0	4.0	0.0	1,650
6:00 PM-7:00 PM	1.0	4.0	0.0	1,500
7:00 PM-8:00 PM	1.0	4.0	0.0	1,400
8:00 PM-9:00 PM	1.0	4.0	0.0	1,300

WorkZoneQ-Pro Input

- Input 2.7 seconds in headway in closed lane in Cell L3:



Headway is used to compute capacity in the transition area

WorkZoneQ-Pro output

- Capacity and corresponding speed:

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		62.0	1,644	45.9	1,644
62.0		62.0	1,644	45.9	1,644
62.0		62.0	1,644	45.9	1,644
62.0		62.0	1,644	45.9	1,644
62.0		62.0	1,644	45.9	1,644
62.0		62.0	1,644	45.9	1,644

When the transition area is the choke point, the color of the cells in column Y changes to light blue and the following message is displayed as the bottom of the table.

TRANSITION AREA IS THE CHOKE POINT FOR THE INDICATED INTERVALS

WorkZoneQ-Pro output

- No of vehicles in queue and distance queue reached:

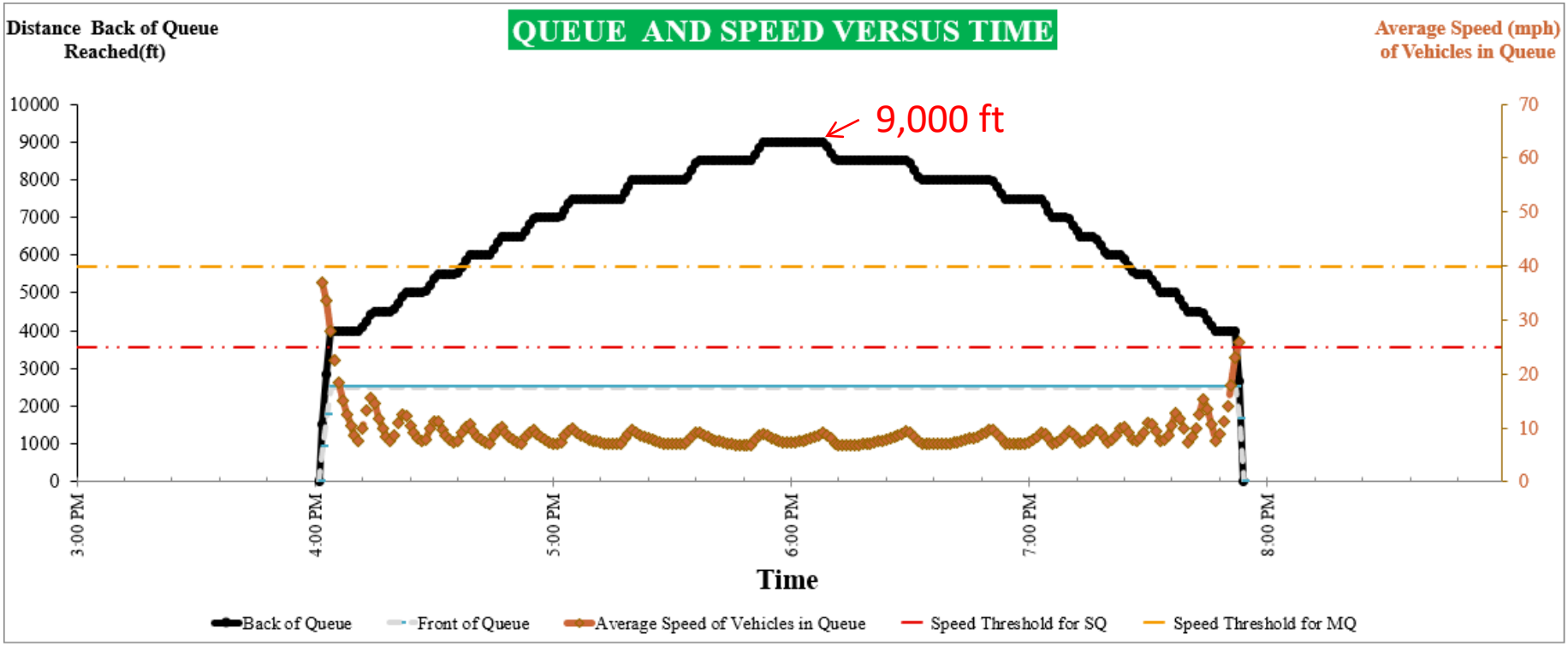
Start of Interval	End of Interval	No. of vehicles in queue*	Average spacing between vehicles in queue (ft)	Front-of-queue (ft)	Back-of-queue (ft)	Distance queue occupied (ft)	Average speed in queue (mph)
3:00 PM	4:00 PM	0	0	0	0	0	-
4:00 PM	5:00 PM	160	51	2,500	7,000	4,500	9.4
5:00 PM	6:00 PM	253	48	2,500	9,000	6,500	7.8
6:00 PM	7:00 PM	161	51	2,500	7,500	5,000	7.7
7:00 PM	8:00 PM	0	51	0	0	0	9.1
8:00 PM	9:00 PM	0	-	-	-	-	-

Max excess demand (Number of vehicles in queue for the back-of-queue calculation)

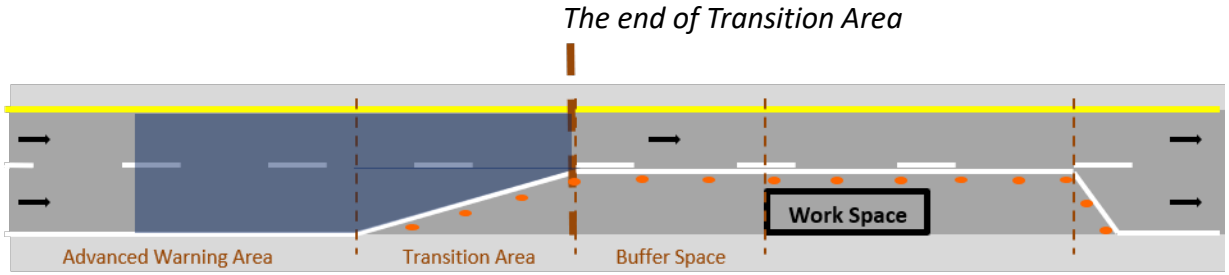
Maximum distance back-of-queue reached (ft)	Maximum distance queue occupied (ft)
9,000	*6,500*

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

WorkZoneQ-Pro output



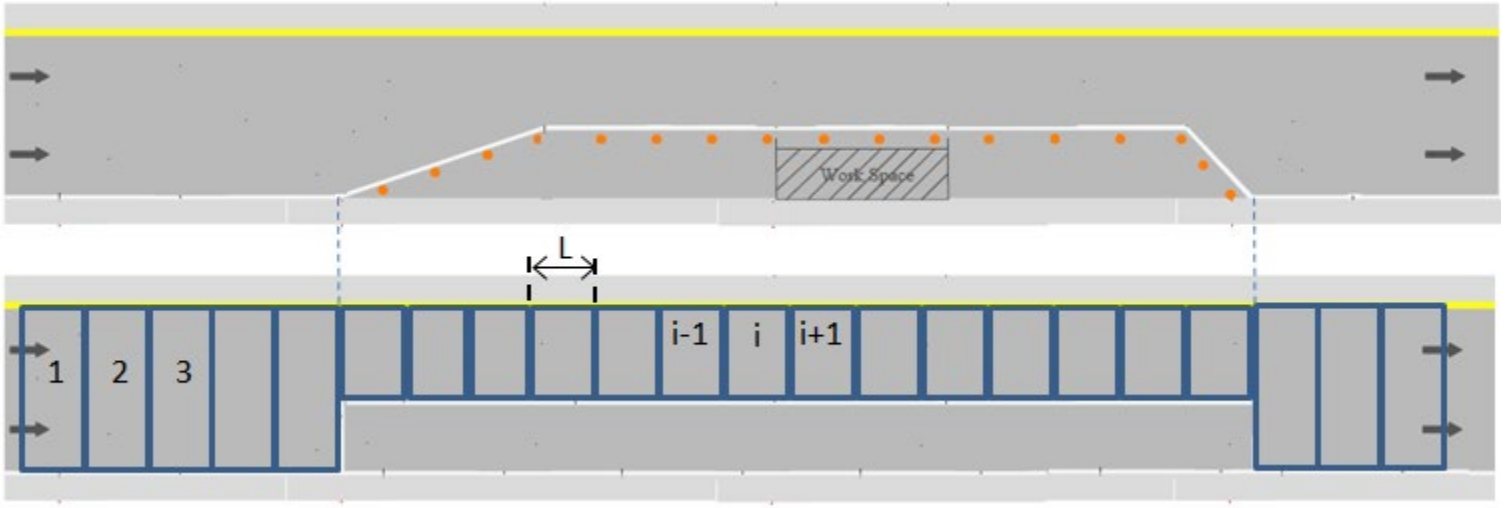
Queue is measured from the end of the Transition Area:



Appendix H
Cell Transmission Method (CTM) in WZQ-Pro 1.5

Settings

- Assume the length of the roadway is 10 miles and ends at the end of the termination area (far right on the figure)
- It is assumed that lane drop happens at the beginning of the transition area
- Roadway is divided into cells of length **L** (default: **L** = 500 ft)
- Traffic variables are computed every **T** sec (default **T** = 4 sec)
- Cells are numbered in the direction of traffic



Definitions

- $V_{i,t}$: Average travel speed (mph) for Cell i at the beginning of time increment t (The length of each time increment is T sec)
- $D_{i,t}$: Density (veh/mi/ln) for Cell i at the beginning of time increment t
- $F_{i,t}$: Flow rate (vphpl) exiting from Cell i at the beginning of time increment t
- λ_i: Number of open lanes for Cell i

Compute Traffic Parameters

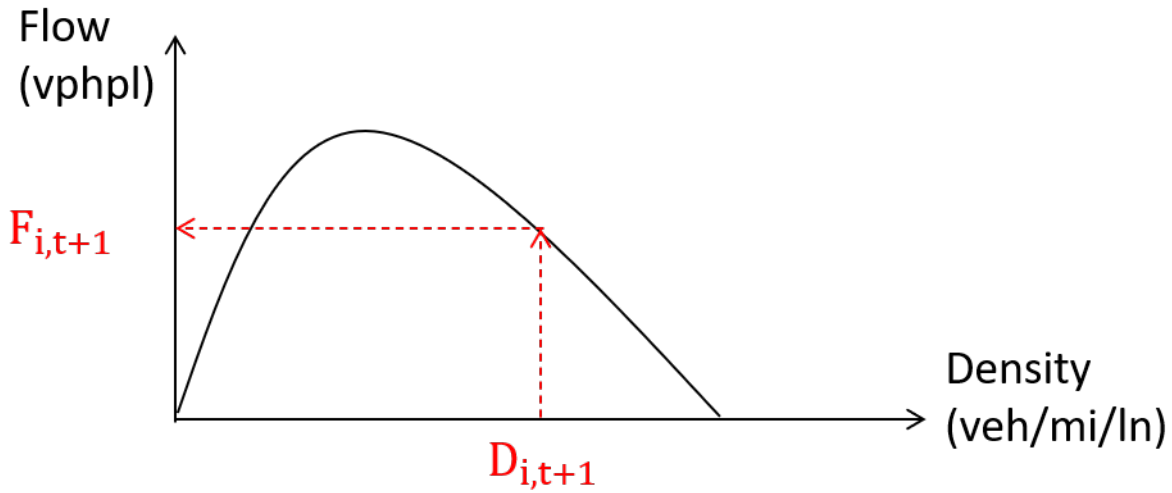
Goal: Compute the traffic parameters at the beginning of time increment t+1 when traffic parameters at the beginning of time increment t are given

For all sections and all time increments:

1) Compute density:

$$D_{i,t+1} = \frac{\left[D_{i,t} * L + \left(F_{i+1,t} * \lambda_{i+1} - F_{i,t} * \lambda_i\right) * T\right]}{L}$$

2) Determine exit flow rate ($F_{i,t+1}$) from the density-flow curve:



Compute Traffic Parameters

3) Compute speed:

$$V_{i,t+1} = \frac{F_{i,t+1}}{D_{i,t+1}}$$

Note: Traffic stream models used in CTM are based on speed-flow curves developed using work zone field data (See Appendix H)

Appendix I

Developing speed-flow curves in WorkZoneQ-Pro 1.5

- ***Step 1:*** Find the speed reductions due to less-than-ideal lane width (R_{LW}) and lateral clearance (R_{LC}) from the following tables.

Adjustment for lane width	
Lane width (ft)	**Reduction in speed (mph)**
12 ft or more	0.0
11.5	2.1
11	4.4
10.5	7.0
10	10.0
Adjustment for left shoulder	
Left shoulder (ft) width	**Reduction in speed (mph)**
2 ft or more	0.0
1	1.0
0	2.0

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	0.0
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	3.0	2.0	1.0	0.5
0	3.6	2.4	1.2	0.6

- ***Step 2:*** Determine the level of work intensity from the following tables:

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

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

- ***Step 3:*** Find the speed reduction corresponding to the work intensity (R_{WI})

Work intensity	Long-term work zone*		Short-term work zone**	
	Estimated speed reduction range (mph)	Suggested speed reduction (mph)	Estimated speed reduction range (mph)	Suggested speed reduction (mph)
Low	0.01 – 2.65	2	6.04 – 10.80	8
Moderate	2.66 – 3.80	3	10.81 – 14.40	12
High	3.81 – 5.93	5	14.41 – 19.16	16

- ***Step 4:*** Find the speed reduction (mph) due to any treatment (R_T)

Speed Control Technique	Observed * Range of Speed Reduction (mph)	Typical * Speed Reduction (mph)
Drone Radar	1.2 – 9.8	2.5
Changeable Message Signs(CMS)	1.4 – 4.7	3.0
Speed Monitoring Display	4.0 – 5.0	4.0
Police Presence	4.3 – 5.0	4.5
Speed Photo Enforcement(SPE)	3.4 – 7.8	5.0
Changeable Message Signs with Radar	4.0 – 8.0	5.0

Step 5: Compute adjusted free flow speed

$$AFFS = FFS - R_{LW} - R_{LC} - R_{WI} - R_T - R_O$$

$\boldsymbol{AFFS}$ =Adjusted free-flow speed (mph)

$\boldsymbol{FFS}$ = Free-flow speed

when there are no field data, use

62 mph for speed limit of 55 mph,

55 mph for speed limit of 45 mph, without a flagger

43 mph for speed limit of 45 mph, with a flagger

$\boldsymbol{R_{LW}}$ = Speed reduction due to **lane width**

$\boldsymbol{R_{LC}}$ = Speed reduction due to **left and right lateral clearances**

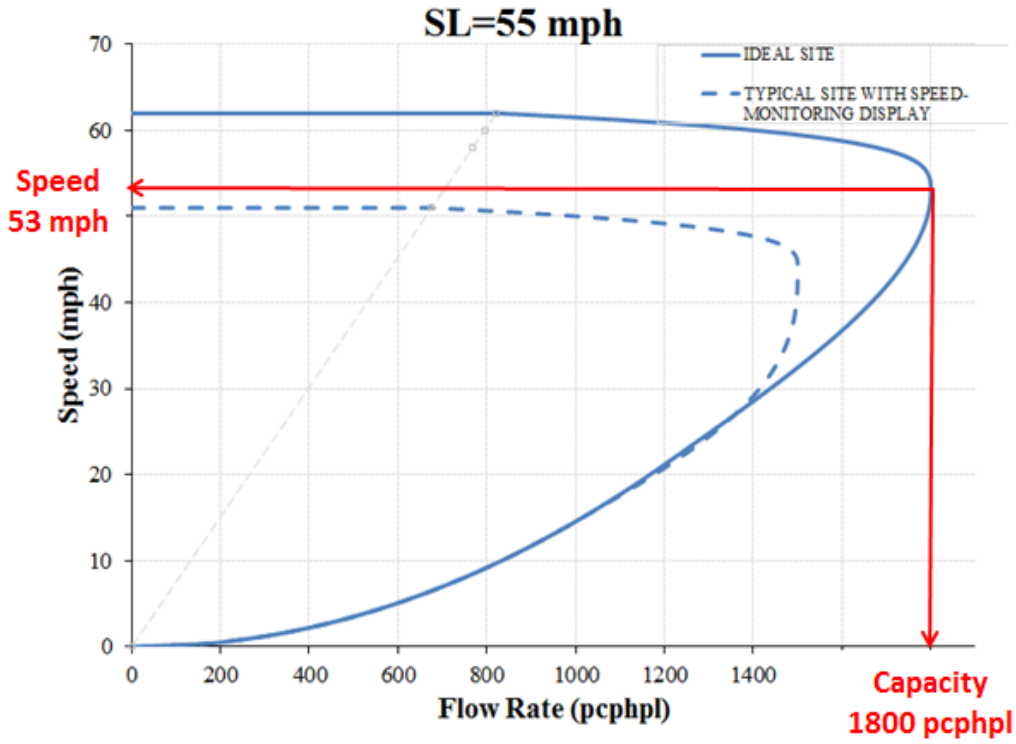
$\boldsymbol{R_{WI}}$ = Speed reduction due to **work intensity**

$\boldsymbol{R_T}$ = Speed reduction due to **treatment**

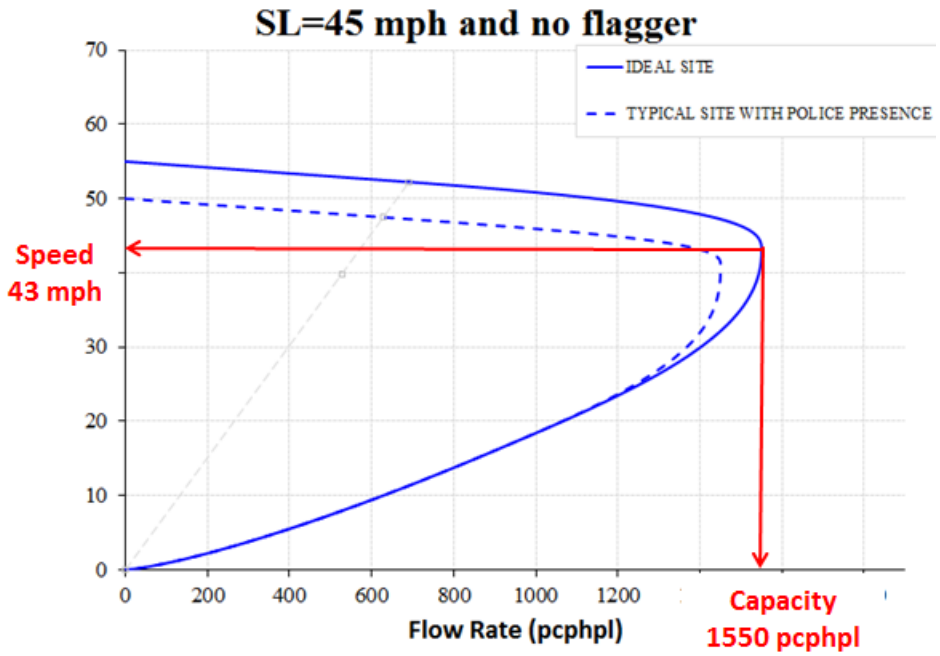
$\boldsymbol{R_O}$ = Speed reduction due to all **other factors** (e.g. flow breakdown)

Step 6: Depending on the speed limit and presence of flagger, WZQ-Pro uses a curve from the following three sets:

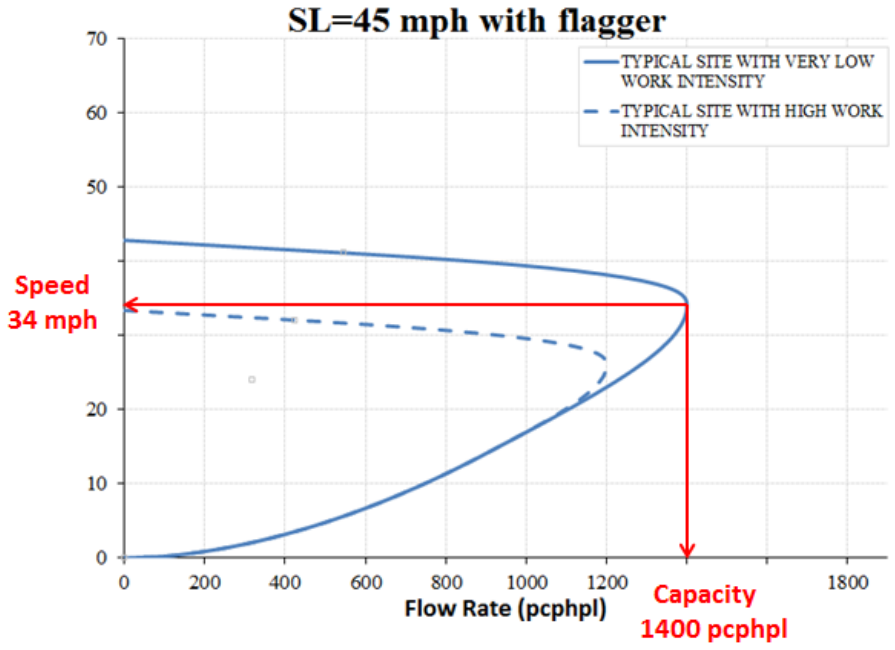
Set a) Speed limit=55 mph



Set b) Speed limit=45 mph and no flagger



Set c) Speed limit=45 mph with flagger



Appendix J is presented right after Module 5

Appendix L
Flow rate and Peak Hour Factor (PHF)

Flow (or volume): No. of vehicles passing a point during a given time interval.

Flow rate:

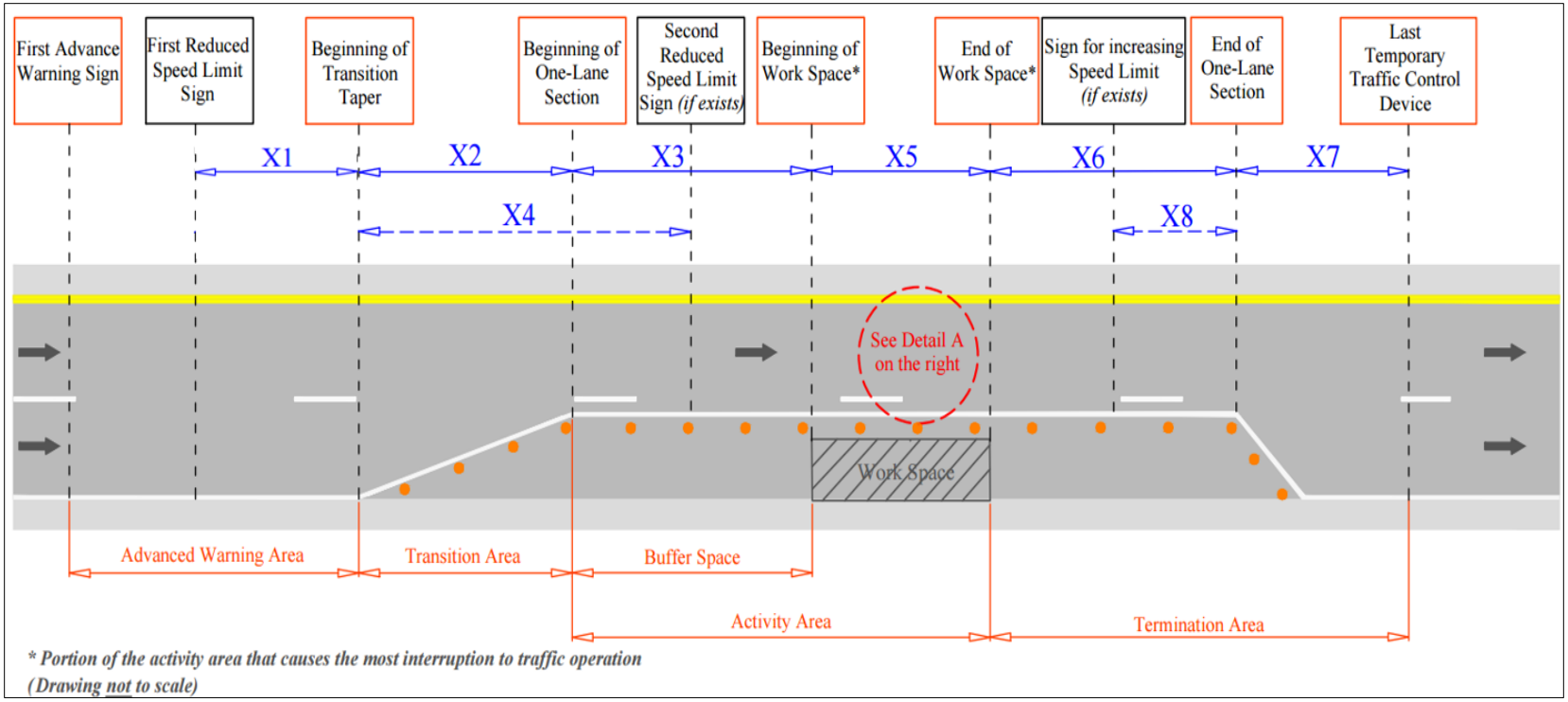
Time (hourly)	Volume (veh)	Multiply		Flow rate (veh)
5:00-5:15	500	4	=	2000
5:15-5:30	600	4	=	2400
5:30-5:45	550	4	=	2200
5:45-6:00	510	4	=	2040
Total	2160			

Peak Hour Factor (PHF): $\frac{Hourly\ Volume}{Highest\ hourly\ Flow\ Rate} = \frac{2160}{2400} = 0.90$

Appendix M

Typical values for some of the longitudinal distances in In WZQ-Pro for Freeway WZs

- Typical values for X2, and X3 are proposed based on MUTCD, and other distances should be determined as indicated in the construction plan.



Transition Taper Length (X2)

Use Tables 6C-3 and 6C-4

Table 6C-3. Taper Length Criteria for Temporary Traffic Control Zones

Type of Taper	Taper Length
Merging Taper	at least L
Shifting Taper	at least 0.5 L
Shoulder Taper	at least 0.33 L
One-Lane, Two-Way Traffic Taper	50 feet minimum, 100 feet maximum
Downstream Taper	100 feet per lane

Note: Use Table 6C-4 to calculate L

Table 6C-4. Formulas for Determining Taper Length

Speed (S)	Taper Length (L) in feet
40 mph or less	$L = WS^2 / 60$
45 mph or more	$L = WS$

Where:
L = Taper length (ft)
W = Width of offset (ft)
S = Posted speed limit, or off-peak 85th-percentile speed prior to work starting, or the anticipated operating speed (mph)

Longitudinal Buffer Space (X3)

Are given in Table 6C-2
- Equal to Stopping Sight Distance (SSD)

Table 6C-2. Stopping Sight Distance as a Function of Speed

Speed*	Distance
20 mph	115 feet
25 mph	155 feet
30 mph	200 feet
35 mph	250 feet
40 mph	305 feet
45 mph	360 feet
50 mph	425 feet
55 mph	495 feet
60 mph	570 feet
65 mph	645 feet
70 mph	730 feet
75 mph	820 feet

** Posted speed, off-peak 85th-percentile speed prior to work starting, or the anticipated operating speed*

Appendix N: Effects of buffer space on queue

Example 2T of Module 5

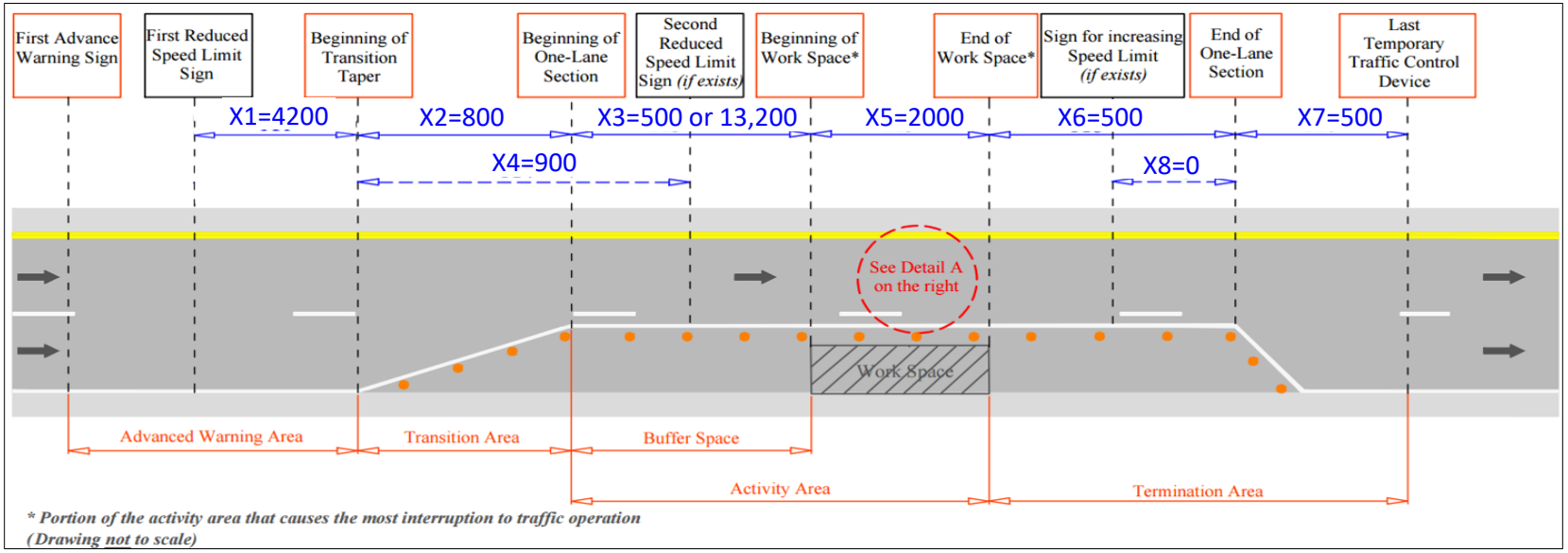
The goal of this example is to illustrate the effects of buffer space on queue growth.

We first assume buffer space is 500 ft, then change it to 2.5 miles to see its effects on queue

Description: A 2-to-1 freeway work zone, daytime, clear weather condition

Geometric data: Longitudinal distances in the sketch below

Lane width = 11 ft, Right shoulder width = 6 ft, Left shoulder width = 2 ft



Description (Continued…)

WZ conditions:

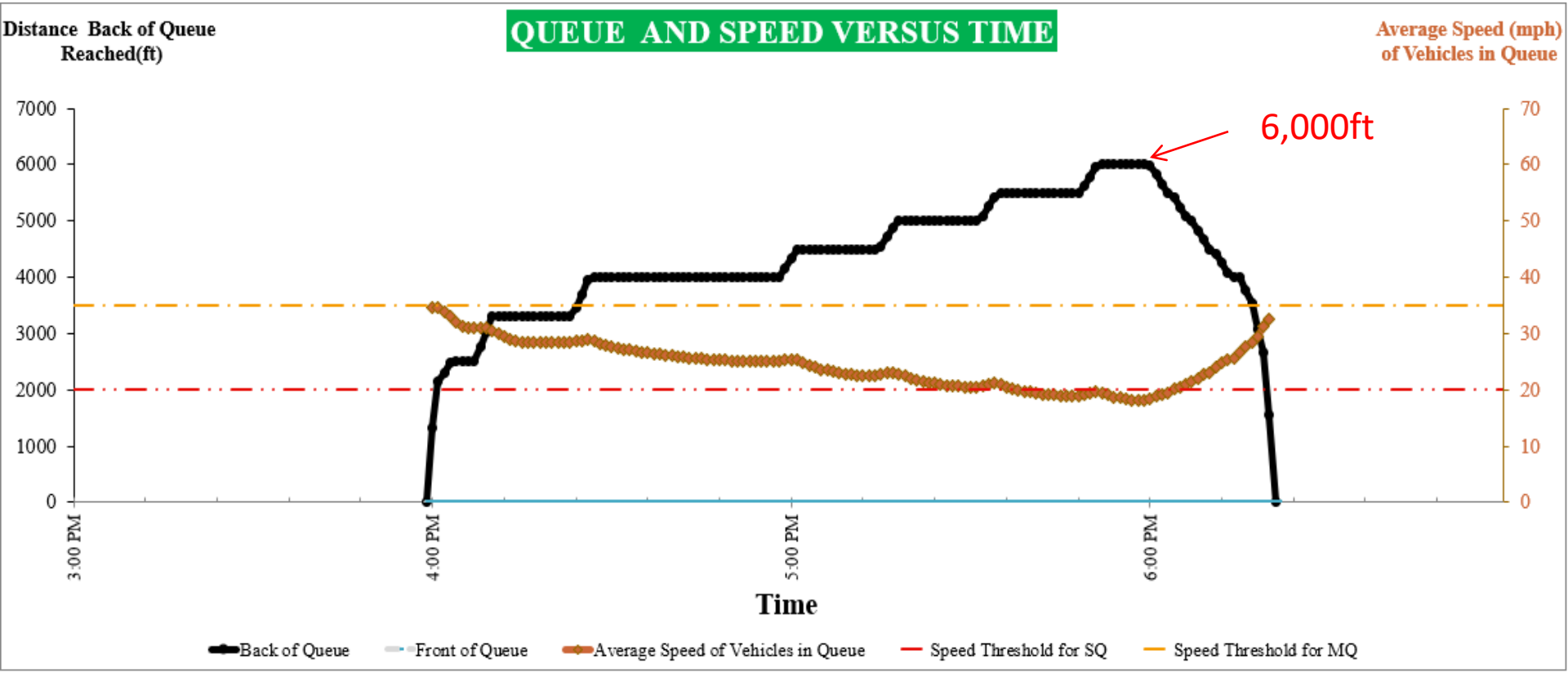
- First speed limit = 55 mph, Second speed limit=45 mph
- Moderate work activity due to 5 workers working with lateral distance of 7 ft
- Work activity area is separated from the travel lane by means of barrels.
- Speed limit outside of the WZ is 65 mph
- Use default Passenger Car Equivalency (PCE) factors
- Assume work zone capacity is 1250 pcphpl
- Traffic volume data:

Interval	% single-unit Trucks	% combination trucks	% recreational vehicles	Volume (veh)
3:00 PM-4:00 PM	1.0	4.0	0.0	800
4:00 PM-5:00 PM	1.0	4.0	0.0	1,240
5:00 PM-6:00 PM	1.0	4.0	0.0	1,270
6:00 PM-7:00 PM	1.0	4.0	0.0	800

Find back of queue when buffer space length is 500 ft and 2.5 miles using the three tools

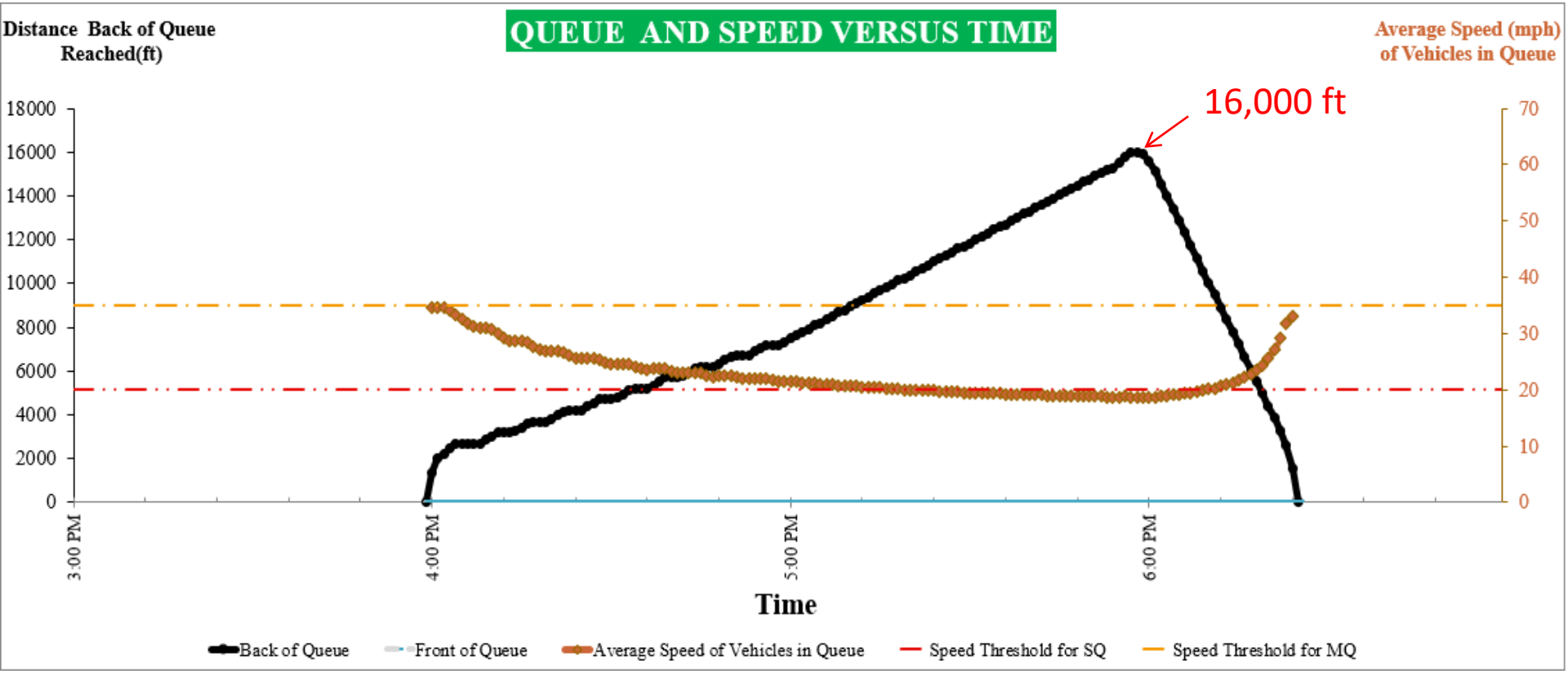
WorkZoneQ-Pro, when buffer space=500 ft

To get a capacity of 1250 pcphpl , enter -9.65% in Column Q in “GeoCond” worksheet (Override the computed value of 1140 pcphpl).



WorkZoneQ-Pro, when buffer space 2.5 miles

Enter -9.65% in Column Q in “GeoCond” worksheet to reduce capacity from 1350 pcphpl to 1250 pcphpl



Capacity Input

- First, convert the given capacity (V_{PC}) which is in pcphpl to capacity in vphpl (V) for PCE value of 1.5.

$$V_{PC} = \frac{V}{f_{HV}} \quad , \quad V = V_{PC} * f_{HV}$$

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

$$f_{HV} = \frac{1}{1 + \mathbf{0.05}(1.5 - 1)}$$

$$f_{HV} = 0.9756$$

Thus, $V = 1250 * 0.9756 = 1220\ vphpl$

MoDOT

When buffer space is 500ft or 2.5 miles, MoDOT yields a max queue of 0.17 miles

BASE CONDITIONS

Open Lane Capacity (veh/h/lane):	1900

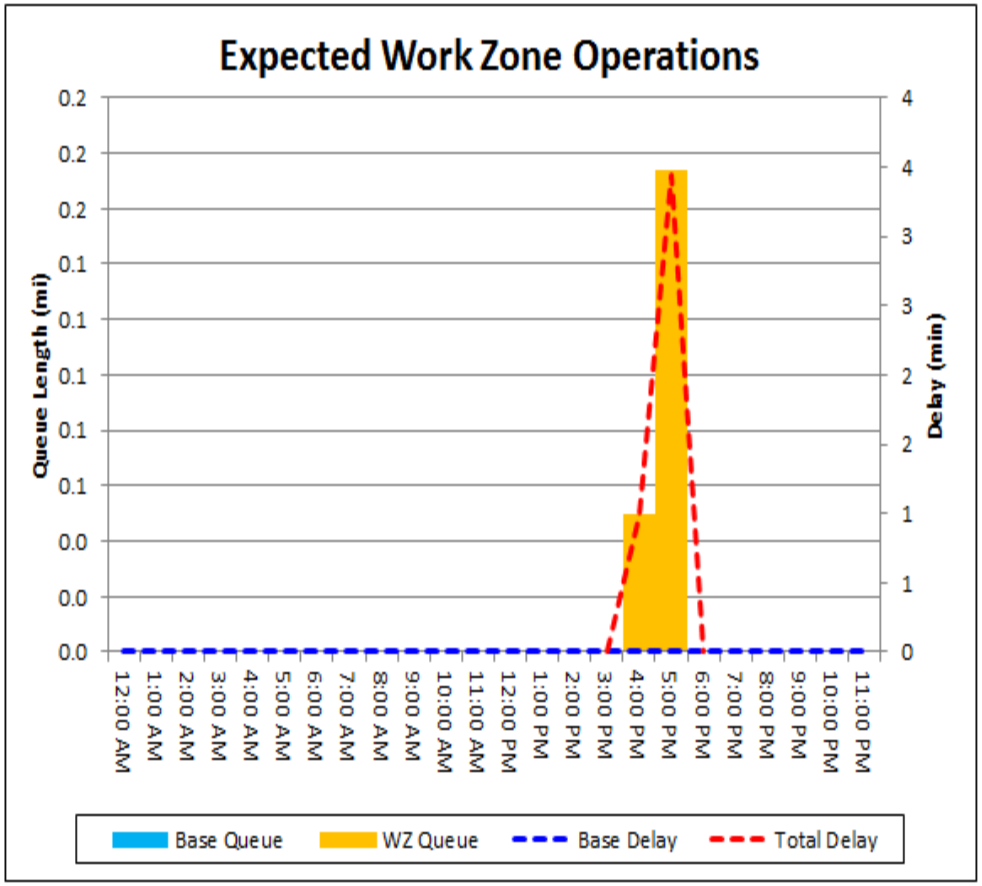
Base Conditions Capacity (Total for ALL Lanes): 3800 veh/h

WORKZONE DETAILS

Work Description:	Example #2
Work Location:	Workers & equipment less than 4 feet from travel lane
Travel Lane Width (ft):	10 - 11.5
Number of Lanes Open:	1
ESTIMATED Work Zone Capacity (veh/h):	1278
USER DEFINED Work Zone Capacity (veh/h):	1220
Start Time:	3:00 PM
End Time:	7:00 PM
Duration of Closure (hrs):	4

RESULTS

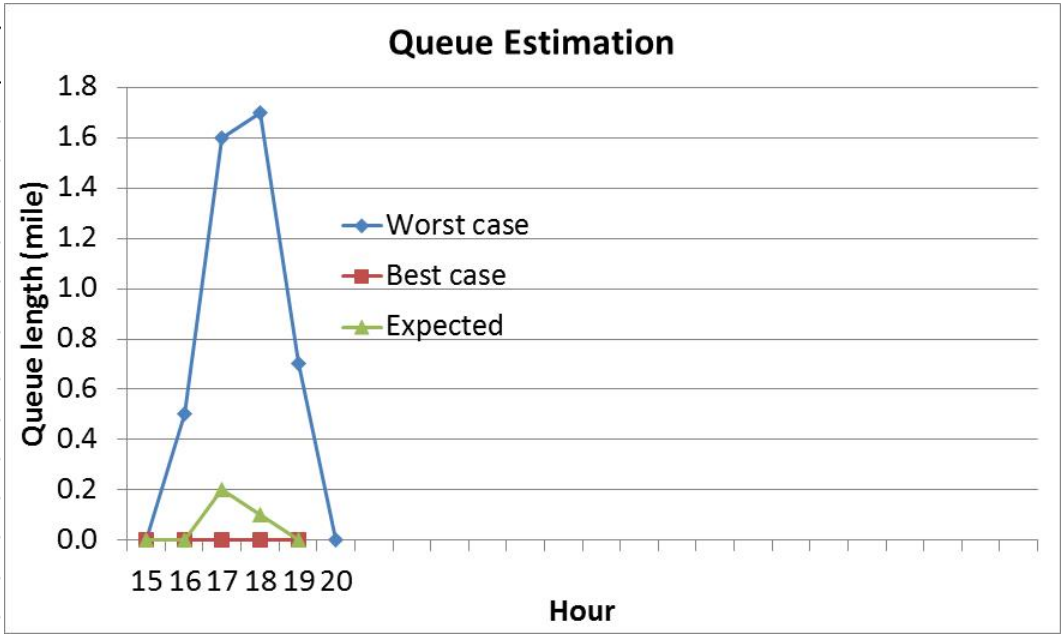
Measure of Effectiveness	Base Conditions	Work Zone	Total
Max Queue Length (mi):	0.0	0.2	0.2
Max Delay (minutes):	0	3	3
Cost ($):	$0	$47	$47



QDAT

When buffer space is 500ft or 2.5 miles, QDAT yields a max queue of 0.2 miles

Step 2: Input Variables	?	
Speed		
free flow speed(mph)		65
Lane closure configuration		
normal number of lanes per direction		2
Length of the lane closure(miles)		0.66
Work zone capacity		
Capacity (vphpl)	?	1220 change C value
Work intensity adjustment (I)	?	0
Ramp adjustment (R)	?	0
Percentage of trucks (P)	?	5
Passenger car Equivalent (E)	?	1.5



Expected: Estimated Queue(mile)		
start hour	15	0.0
	16	0.0
	17	0.2
	18	0.1
end hour	19	0.0

Capacity Input (PCE value = 2.0)

- First, convert the given capacity (V_{PC}) which is in pcphpl to capacity in vphpl (V) for PCE value of 2.0.

$$V_{PC} = \frac{V}{f_{HV}} \quad , \quad V = V_{PC} * f_{HV}$$

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

$$f_{HV} = \frac{1}{1 + \mathbf{0.05}(2.0 - 1)}$$

$$f_{HV} = 0.9524$$

Thus, $V = 1250 * 0.9524 = 1191\ vphpl$

MoDOT (PCE value = 2.0)

When buffer space is 500ft or 2.5 miles, MoDOT yields a max queue of 0.32 miles

BASE CONDITIONS

Open Lane Capacity (veh/h/lane):	1900

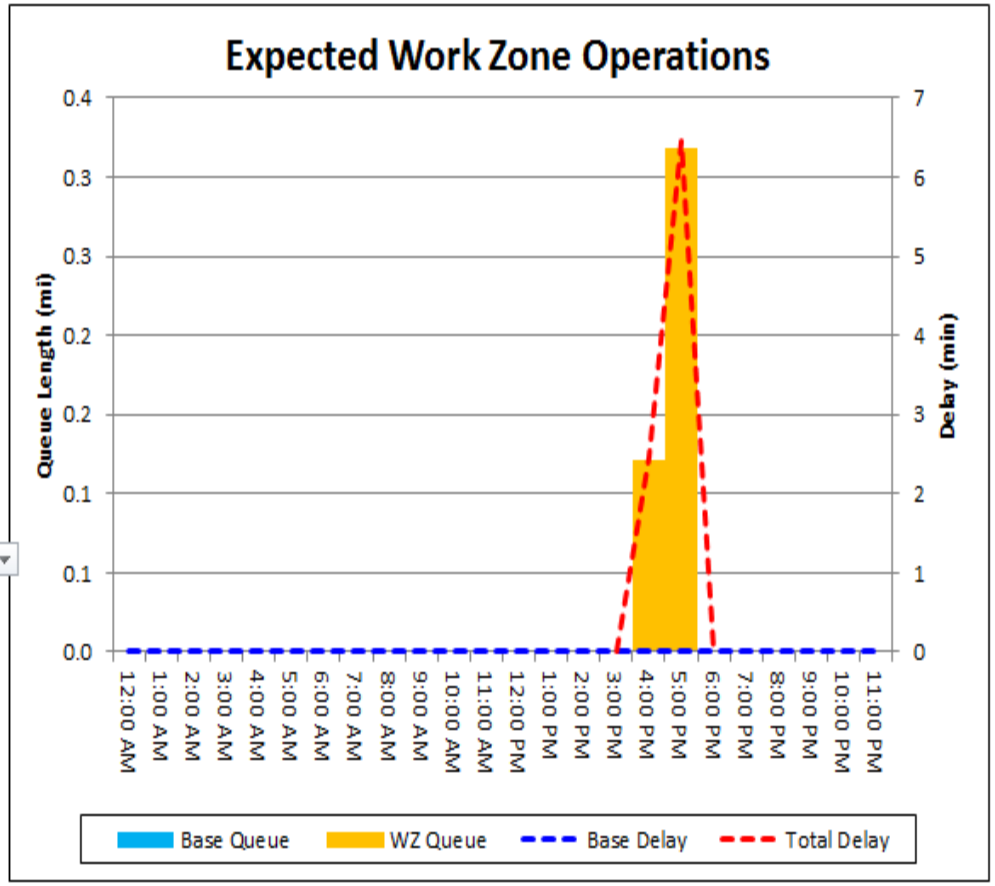
Base Conditions Capacity (Total for ALL Lanes): 3800 veh/h

WORKZONE DETAILS

Work Description:	Example #2
Work Location:	Workers & equipment less than 4 feet from travel lane
Travel Lane Width (ft):	10 - 11.5
Number of Lanes Open:	1
ESTIMATED Work Zone Capacity (veh/h):	1278
USER DEFINED Work Zone Capacity (veh/h):	1191
Start Time:	3:00 PM
End Time:	7:00 PM
Duration of Closure (hrs):	4

RESULTS

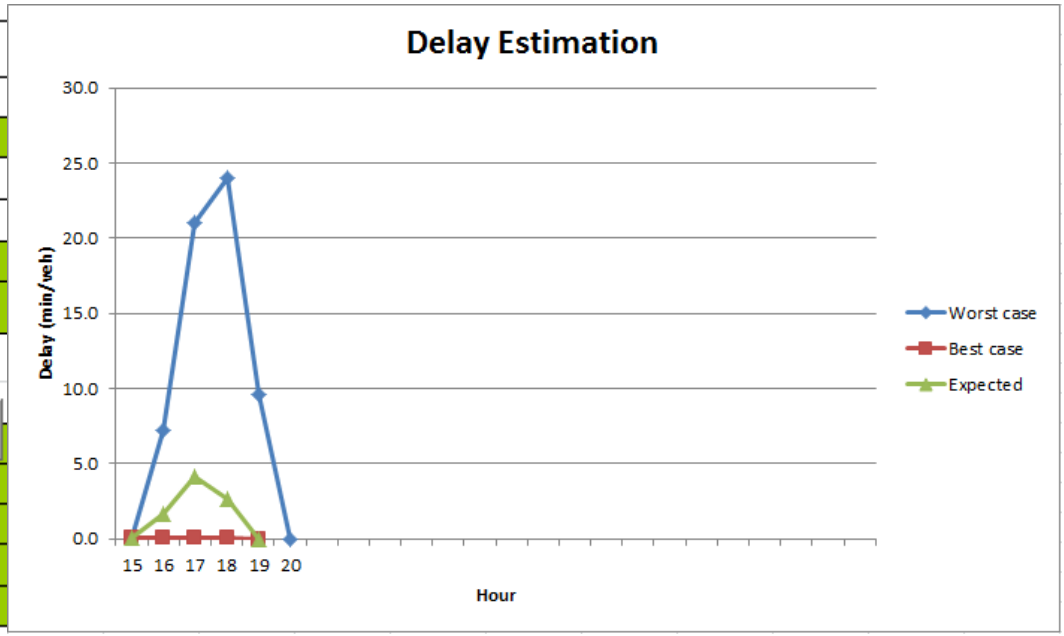
Measure of Effectiveness	Base Conditions	Work Zone	Total
Max Queue Length (mi):	0.0	0.3	0.3
Max Delay (minutes):	0	6	6
Cost ($):	$0	$170	$170



QDAT (PCE value = 2.0)

When buffer space is 500ft or 2.5 miles, QDAT yields a max queue of 0.3 miles

Step 2: Input Variables	?	
Speed		
free flow speed(mph)		65
Lane closure configuration		
normal number of lanes per direction		2
Length of the lane closure(miles)		0.66
Work zone capacity		
Capacity (vphpl)	?	1191 change C value
Work intensity adjustment (I)	?	0
Ramp adjustment (R)	?	0
Percentage of trucks (P)	?	5
Passenger car Equivalent (E)	?	2



Expected: Estimated Queue(mile)		
start hour	15	0.0
	16	0.1
	17	0.3
	18	0.2
end hour	19	0.0

Effects buffer space on queue length

1. In QDAT and MoDOT,
   a. Whether buffer space is 500 ft or 2.5 miles, there is no queue
   b. The length of buffer space is **not** considered in computing queue length

2. In WZQ-Pro,
   a. When buffer space is 500 ft, queue extends 2200 ft into the two-lane section (5500-3300=2200)
   b. However, when buffer space is 2.5 miles, queue does NOT extend into the two-lane section

      (One-lane section is 16,000 ft and back of queue is only at 14,333 ft)

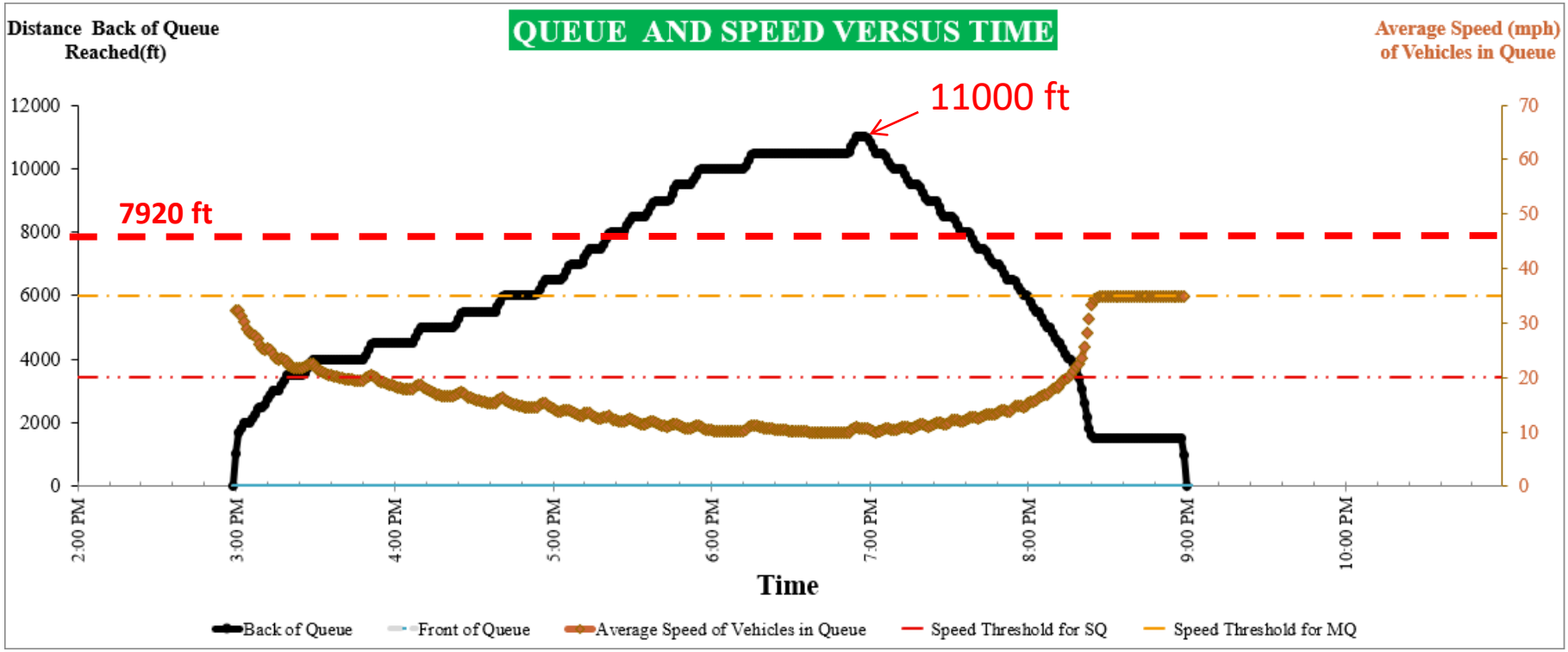
Appendix O: Effect of Diversion

The goal of this example is to illustrate the effects of traffic diversion on queue

In Example Problem 4T, assume a Changeable Message Sign is installed 5 miles upstream of the transition taper. When queue reaches 1.5 miles, the CMS is triggered to display a diversion message for certain time period

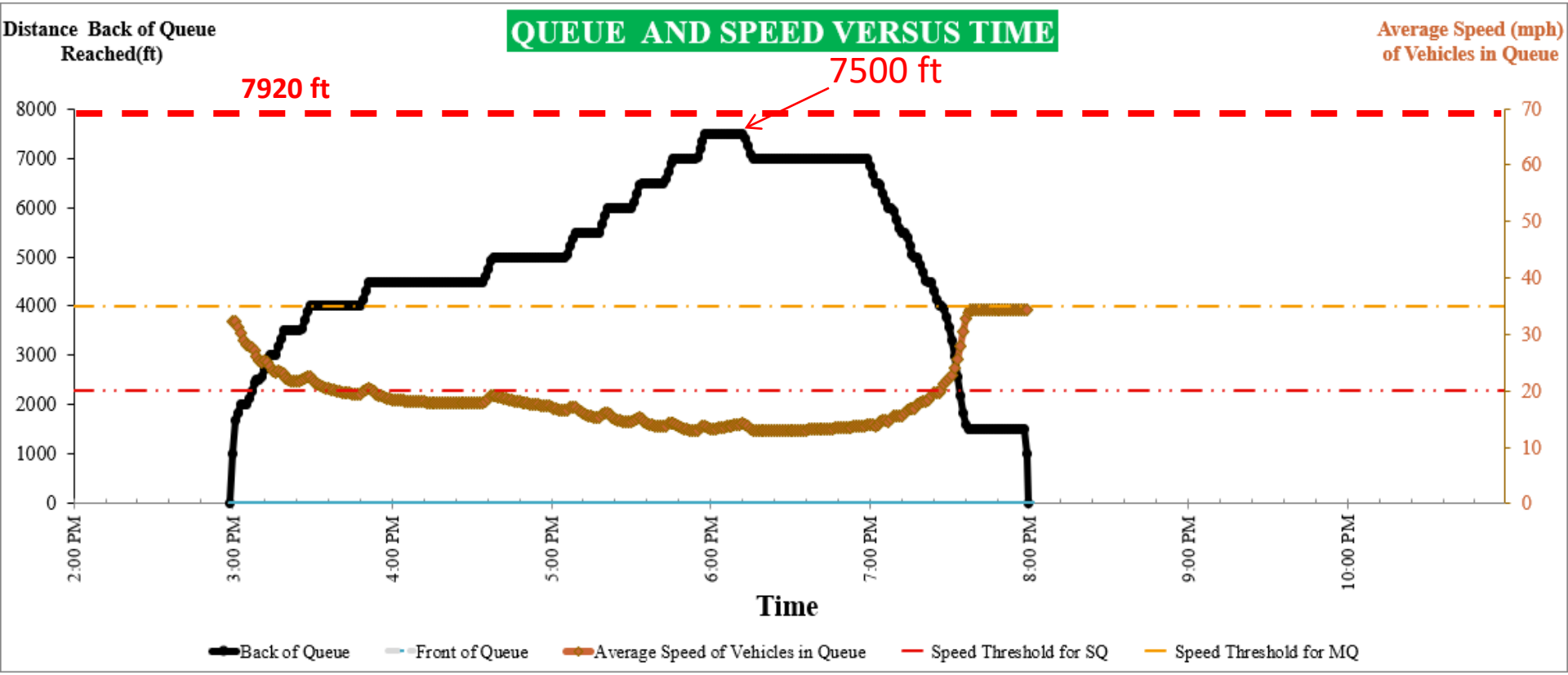
WorkZoneQ:

Part a) A diversion rate of **10%** from 4:00 PM to 10:00 PM, gives following results



Effect of diversion WorkZoneQ-Pro

Part b) A diversion rate of **15%** from 4:00 PM to 10:00 PM, gives following results

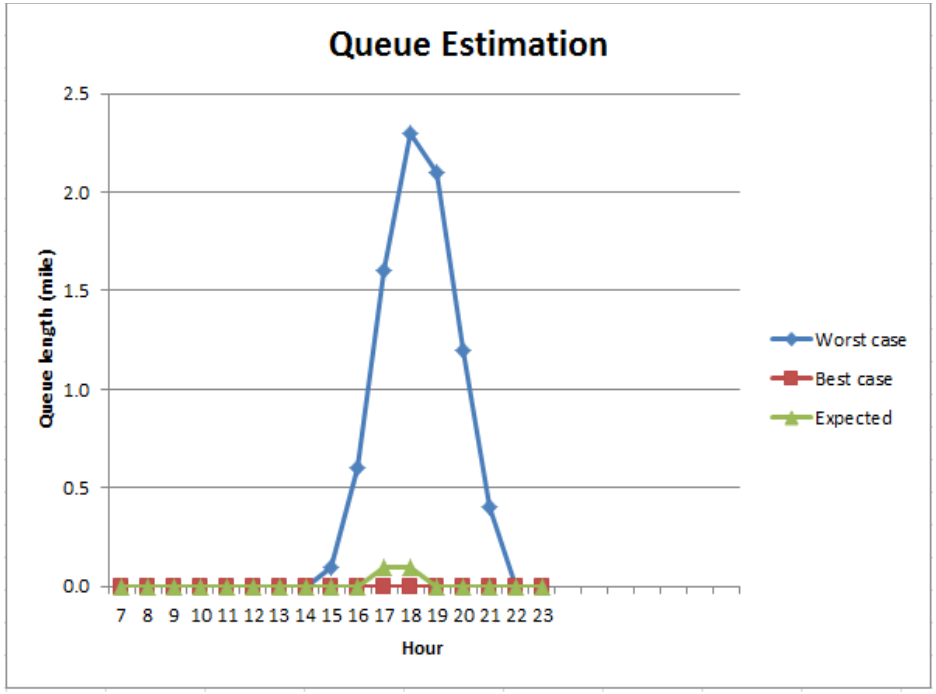


Effect of diversion
QDAT

QDAT:

A diversion rate of 10% from 6:00 PM to 7:00 PM gives the following results.

With Diversion

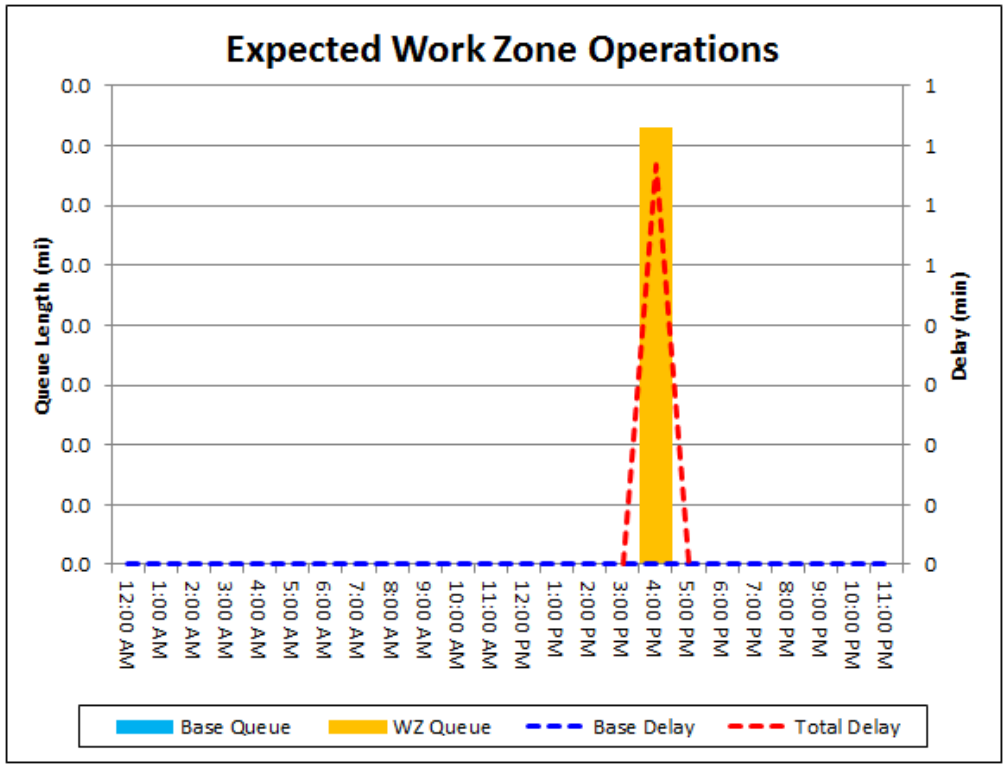


Expected: Estimated Queue(mile)			Without Diversion
start hour	7	0.0	0.1
	8	0.0	0.1
	9	0.0	0.0
	10	0.0	0.0
	11	0.0	0.0
	12	0.0	0.0
	13	0.0	0.0
	14	0.0	0.0
	15	0.0	0.0
	16	0.0	0.0
	17	0.1	
	18	0.1	
	19	0.0	
	20	0.0	
	21	0.0	
	22	0.0	
end hour	23	0.0	

Effect of diversion
MoDOT

MoDOT:

A diversion rate of 10% from 5:00 PM to 7:00 PM gives the following results.



With Diversion

Measure of Effectiveness	Work Zone
Max Queue Length (mi):	0.0
Max Delay (minutes):	1
Cost ($):	$2

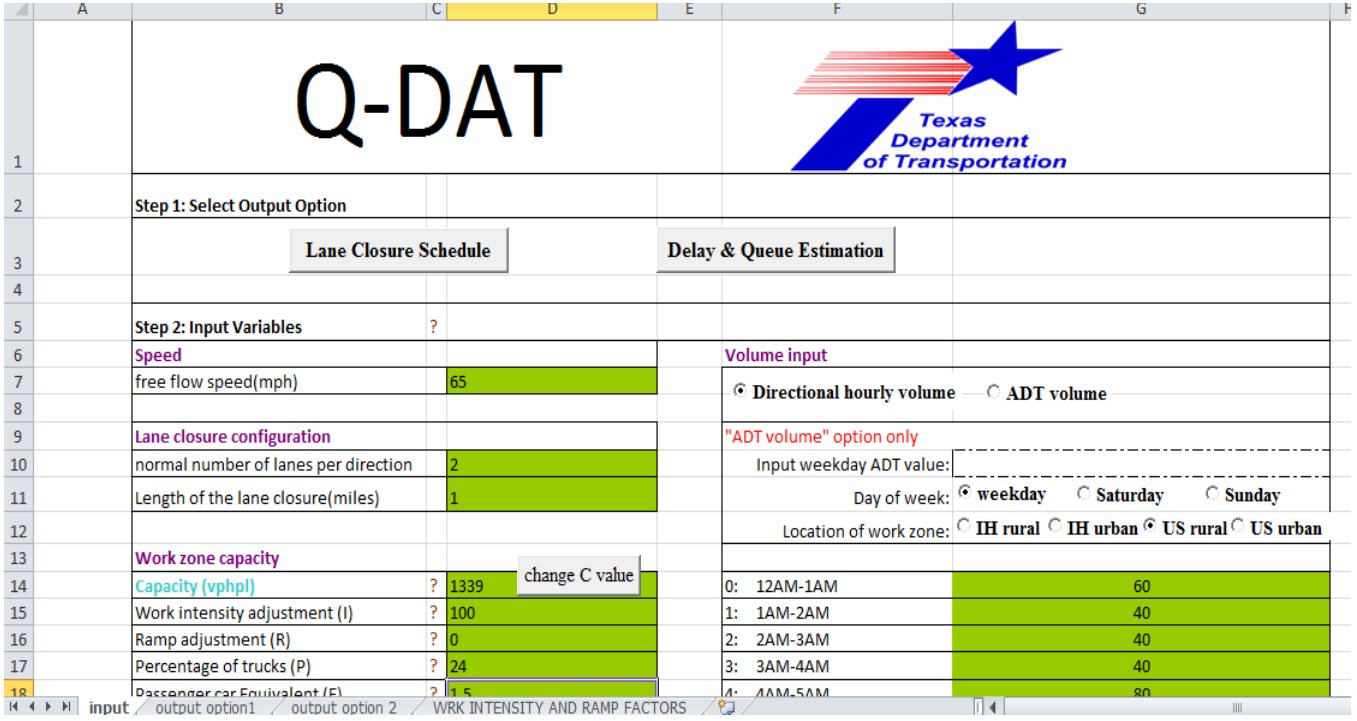
Without Diversion

Measure of Effectiveness	Work Zone
Max Queue Length (mi):	0.3
Max Delay (minutes):	6
Cost ($):	$240

Appendix P

Lane Closure Schedule Analysis in QDAT

Open a new QDAT spreadsheet to start the example



Lane Closure Schedule Analysis

- For the same WZ in Example 1, and assuming the queue length should not exceed 1 mile (critical queue length = 1 mile):

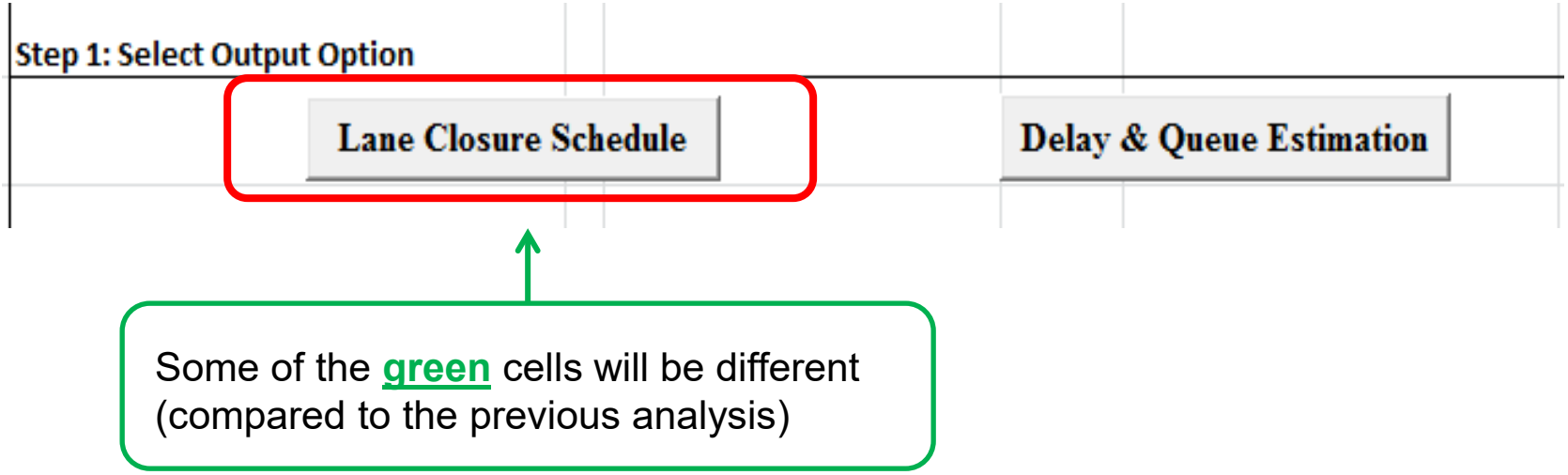
Can we have the lane closure at the scheduled time (4-7pm) without exceeding the critical queue?

a) Assuming the "expected" case

b) Assuming the "worst" case

Input

Step 1/3: Select the type of analysis



Input

Step 2/3: Input Variables

Same procedure used in Example Problem #1

Step 2: Input Variables	?	
Speed		
free flow speed(mph)		65
Lane closure configuration		
normal number of lanes per direction		2
Length of the lane closure(miles)		1.5
Work zone capacity		
Capacity (vphpl)	?	1428
Work intensity adjustment (I)	?	100
Ramp adjustment (R)	?	0
Percentage of trucks (P)	?	10
Passenger car Equivalent (E)	?	1.5

change C value

First, Input values as given in the example problem

Second, input values to calculate capacity

Third, click this button to update capacity

Input

Step 2/3: Input Variables

Select the Analysis Type

(Note: only one can be analyzed at a time)

"Lane Closure Schedule" output option only		
Excessive Queuing	?	
◉ Critical length of Queue ○ Maximum acceptable delay		
Critical length of queue (miles)	?	1
Maximum acceptable delay(minutes)	?	20

Input 1 for the critical queue length

When one criteria is selected, the other one has no effect

"Delay & Queue Estimation" output option only		
Schedule of Work Activity	?	
Number of Closed Lanes		1
Hour lane closure begins	?	16
Hour lane closure ends	?	19

Input

Step 2/3: Volume Input

Same procedure and same values used in Example Problem #1

Step 3/3: Run the Program

Step 3: Run the Program	!			
		RUN		

Example Problem #2
Effects of Reducing Capacity

- For the WZ in the example problem #1, the resident engineer wants to know the effect of construction trucks entering and exiting the WZ. In this WZ, it was estimated that trucks would reduce the capacity by about 200 veh/h/lane for the traffic mix in the previous example

If trucks enter and exit for the duration of the lane closure:

  - **What would be the maximum queue length in this case?**
  - **What would be the increase in the total users' costs?**

Step 2: Facility Data Inputs

- Use the same information entered for the previous example

Step 3: WZ Analysis

- We know that the Estimated WZ capacity during the lane closure was: 1248 vphpl

  Reducing capacity by 200 vphpl (about 15% of 1248), the results are:

Measure of Effectiveness	Base Conditions	Work Zone	Total
Max Queue Length (mi):	0.0	3.0	3.0
Max Delay (minutes):	0	66	66
Cost ($):	$0	$33,500	$33,500

Compared to the previous example, the increase in the maximum queue length was 3.0 - 1.6 = **1.4 miles** (an increase in **88%** in the maximum queue length)

- The delay and total users' costs without the trucks were estimated at:

Measure of Effectiveness	Base Conditions	Work Zone	Total
Max Queue Length (mi):	0.0	1.6	1.6
Max Delay (minutes):	0	29	29
Cost ($):	$0	$8,100	$8,100

- With the capacity reduction, they increased to:

Measure of Effectiveness	Base Conditions	Work Zone	Total
Max Queue Length (mi):	0.0	3.0	3.0
Max Delay (minutes):	0	66	66
Cost ($):	$0	$33,500	$33,500

The increase in the total users' costs was $25,400

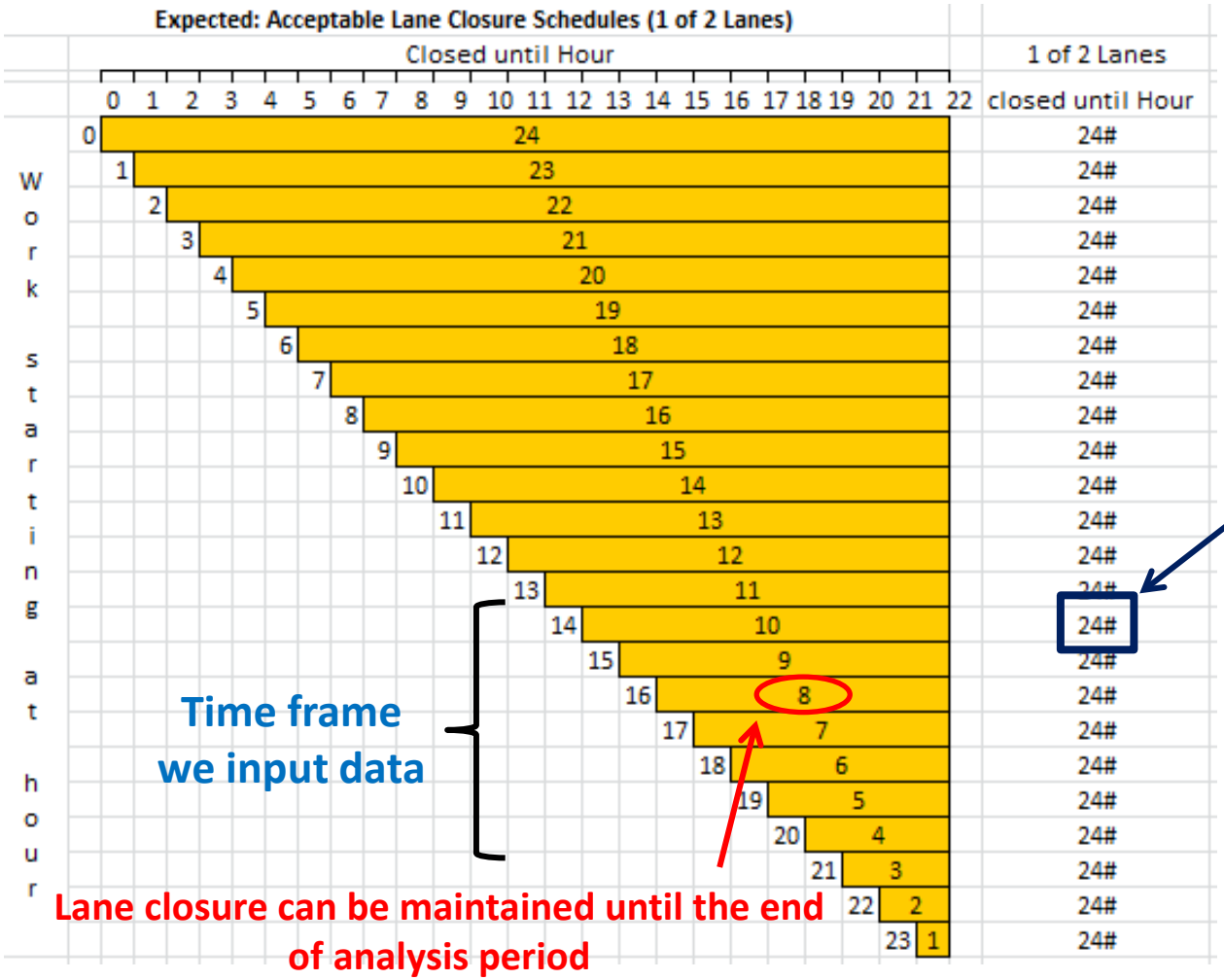
Users' costs with the construction trucks in the WZ were 4 times the cost without the trucks

Compare the magnitude of the increase of users' cost Vs. max queue length. Was that expected? Why does that happen? Think of the formulation

Output

Go to "Output option 1" (the second worksheet)

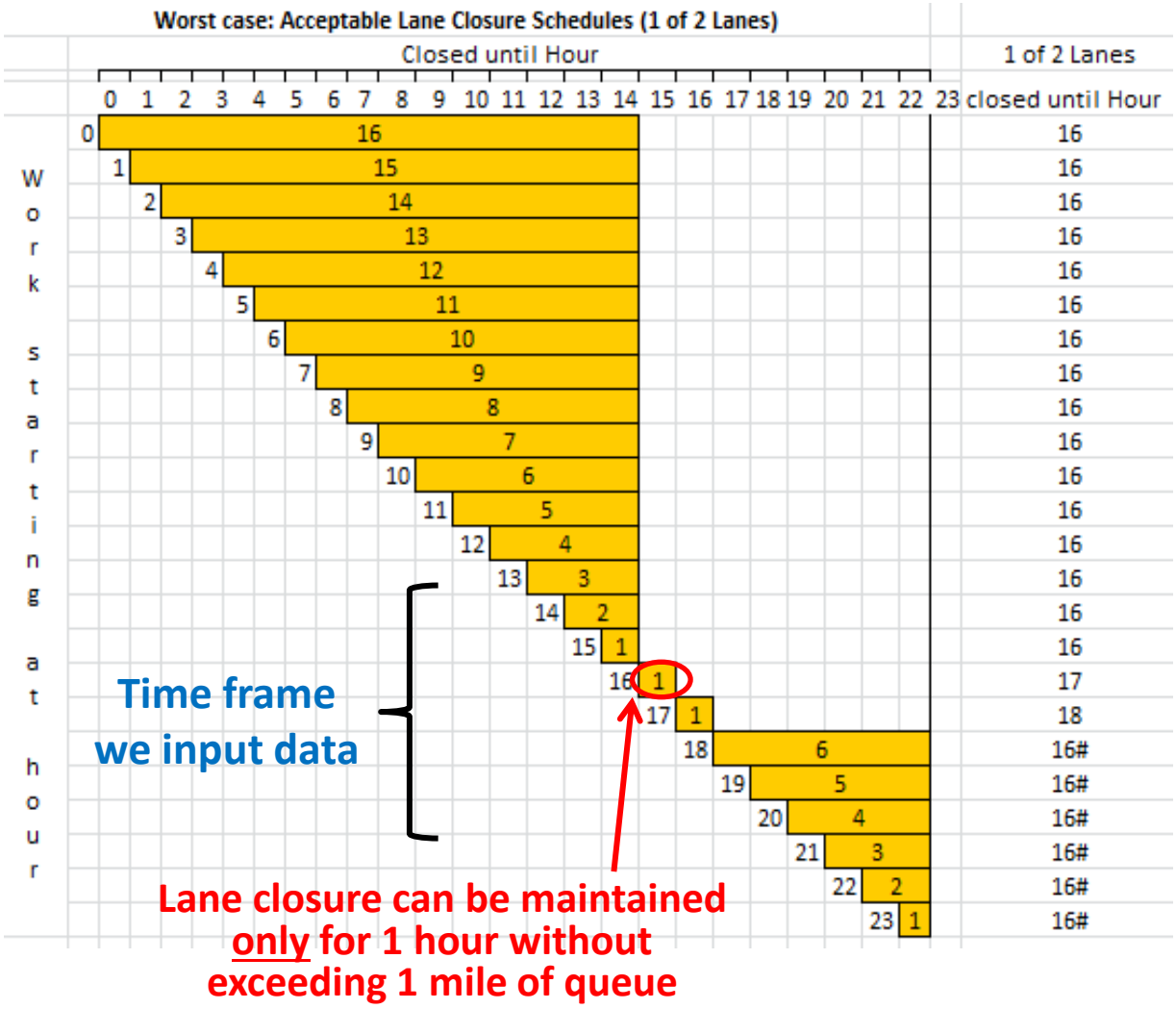
"Expected" case



means lane closure could continue through the rest of the day and to that hour of the following day

Output

“Worst” case



Appendix Q

HCM 2016 detailed calculations for one-lane two way operation on two-lane highways

Estimating Average Travel Speed

$$V_1 = 0.615 \times SL - f_{LS} - f_A - f_{np,ATS}$$

$$V_2 = 0.692 \times SL - f_{LS} - f_A - f_{np,ATS}$$

V_i = average travel speed (ATS) in the analysis direction i, mi/h;
SL = speed limit of the two lane highway segment, mi/h;
f_{LS} = adjustment for lane and shoulder width, mi/h;
f_A = adjustment for access-point density, mi/h;
$f_{np,ATS}$ = adjustment factor for ATS determination for the percentage of no-passing zones in the analysis direction, mi/h

Tables from two-lane highways analysis (HCM Chapter 15)

$f_{np,ATS} = 2.4\ mph$ for all conditions

Estimating Average Travel Speed

Adjustment Factor for Lane and Shoulder Width (f_{LS})

Lane Width (ft)	Shoulder Width (ft)			
	$\geq 0, < 2$	$\geq 2, < 4$	$\geq 4, < 6$	≥ 6
$\geq 9, < 10$	6.4	4.8	3.5	2.2
$\geq 10, < 11$	5.3	3.7	2.4	1.1
$\geq 11, < 12$	4.7	3.0	1.7	0.4
≥ 12	4.2	2.6	1.3	0.0

From HCM 2016, Exhibit 15-7

Estimating Average Travel Speed

Adjustment Factor for Access Point Density (f_A)

Access Points per Mile (Both Sides)	Reduction in FFS (mi/h)
0	0.0
10	2.5
20	5.0
30	7.5
40	10.0

From HCM 2016, Exhibit 15-8

Estimating Saturation Flow Rate

The directional saturation flow rate (s_i) is based on the adjusted time headway ($\hat{h}_i$) :

$$s_i = \frac{3600}{\hat{h}_i}$$

$$\hat{h}_i = h_0 \times f_{speed\ i}$$

Base headway

$$\boldsymbol{h_0 = \frac{3600}{1900} = 1.89\ s}$$

(base saturation rate is 1900 pcphpl)

Travel speed adjustment for direction *i*:

$$\boldsymbol{f_{speed\ i} = 1 - 0.005[min(V_i, 45) - 45]}$$

(Speed $\boldsymbol{V_i}$ is in mph)

Estimating Green Times

Green times are an input and should be determined (and optimized) by the user

If fixed time signals → collect green times from field

If flagger control plan → if directional demands are similar, efficient green times can be found by:

$$G_{opt} = \begin{cases} 20 & if\ 0.0375l < 20 \\ 0.0375l & if\ 20 \leq 0.0375l \leq 60 \\ 60 & if\ 0.0375l > 60 \end{cases}$$

G_{opt} = optimal effective green signal length for one direction (s)

l = work zone length (ft)

Estimating Green Times

A quick check to determine if the user-specified green times (G_i) can fully discharge the vehicles waiting in queue at each cycle.

$$G_i \geq G_{i,min} = \frac{q_i}{s_i - q_i}(C - G_i)$$

If the green time is not enough, queues will grow cycle after cycle until vehicle arrivals decrease

Calculate Capacity

Capacity for direction *i* (c_i) is computed as:

Sat. flow rate in direction (pc/h)

$$c_i = s_i\left(\frac{G_i}{C}\right)$$

← Effective green time for direction *i* (*s*)

← Cycle length (*s*)

Where Cycle length is :

$$C = \frac{l}{V_1} + \frac{l}{V_2} + G_1 + G_2 + 2L_S$$

Clearance times (s)

Effective greens (s)

Start-up lost time (2 sec per direction)

Note: the WZ length (l) is in feet and the travel speeds (V_i) is in *ft/s*

Calculate Capacity

Capacity in directions 1 and 2 are:

$$c_1 = \frac{s_1 G_1}{\frac{l}{V_1} + \frac{l}{V_2} + G_1 + G_2 + 2L_S}$$

$$c_2 = \frac{s_2 G_2}{\frac{l}{V_1} + \frac{l}{V_2} + G_1 + G_2 + 2L_S}$$

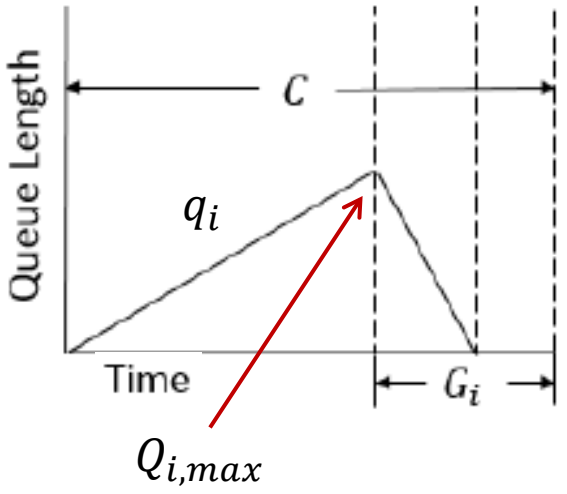
The total capacity is:

$$c_{total} = c_1 + c_2$$

$$c_{total} = \frac{s_1 G_1 + s_2 G_2}{\frac{l}{V_1} + \frac{l}{V_2} + G_1 + G_2 + 2L_S}$$

Queue Analysis

Directional queueing diagram



For each direction the maximum queues are:

$$Q_{1,max} = q_1(C - G_1) = q_1\left(\frac{l}{V_1} + \frac{l}{V_2} + G_2 + 2L_S\right)$$

$$Q_{2,max} = q_2(C - G_2) = q_2\left(\frac{l}{V_1} + \frac{l}{V_2} + G_1 + 2L_S\right)$$

q_i = Traffic flow rate (pc/s) in direction *i*

$Q_{i,max}$ = Maximum queue length in direction *i* (***Note:*** Queue is given in passenger cars)

Delay Analysis

For undersaturated conditions, delay is computed as:

$$d = d_1 + d_2$$

Control delay per passenger car (*s/pc*)

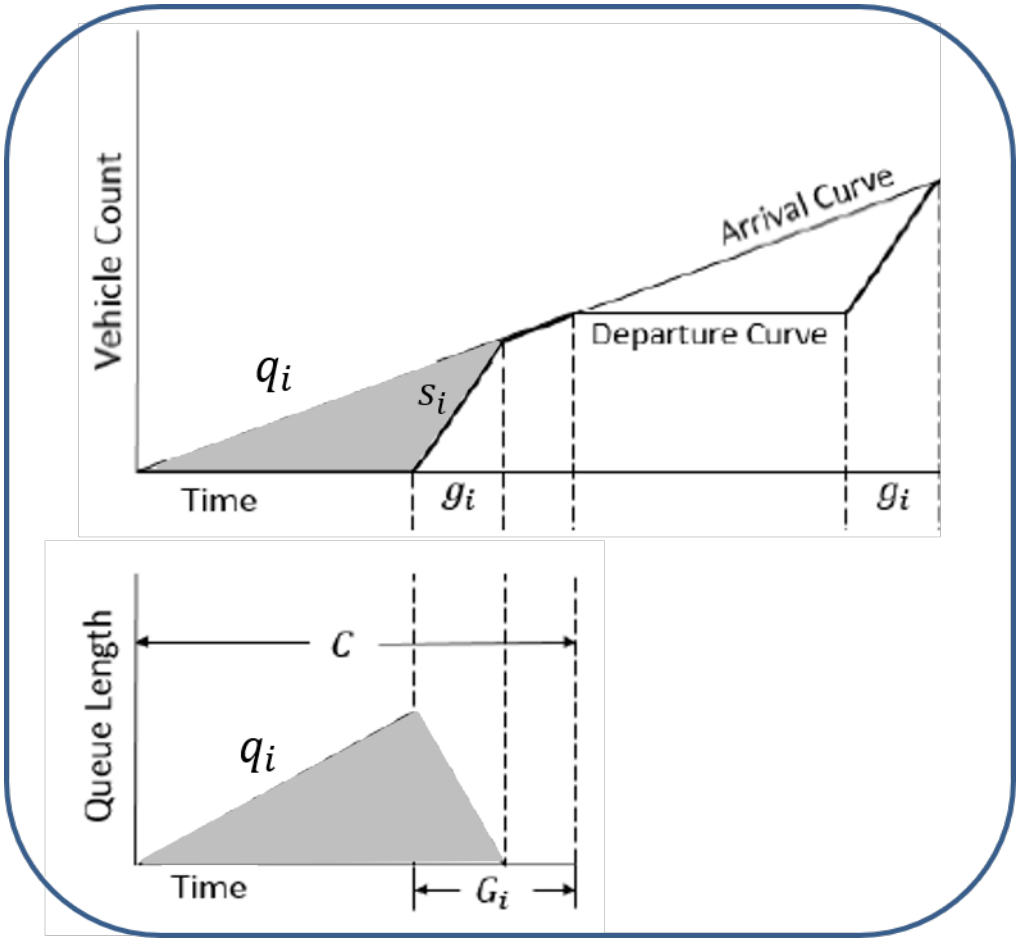
Uniform control delay assuming uniform arrival rate (*s/pc*)

Incremental delay resulted from random arrivals and oversaturation queues (*s/pc*)

This formulation assumes deterministic traffic flows for both directions

Delay Analysis

The Uniform Control Delay is obtained from the shaded area in the arrival-departure diagram or the queueing diagram (they are the same):



For each direction the uniform control delay per cycle is:

$$D_{1,i} = \frac{1}{2}\frac{s_i q_i}{s_i - q_i}(C - G_i)^2$$

…and per vehicle is:

$$d_{1,i} = \frac{D_{1,i}}{q_i C} = \frac{1}{2}\frac{s_i}{s_i - q_i}\frac{(C - G_i)^2}{C}$$

Delay Analysis

The incremental delay (d_2) is obtained from the HCM 2010 equation for signalized intersections:

$$d_{2,i} = 900T\left[(X_i - 1) + \sqrt{(X_i - 1)^2 + \frac{8kIX_i}{c_i T}}\right]$$

Where:

T = duration of the analysis period (*hr*) – Recomm. 30 min (0.5hr) or longer
k = incremental delay factor that depends on controller settings – Recomm. 0.5
I = upstream filtering/metering adj. factor – Recomm. 1.0
$X_i = {}^{q_i}/_{c_i}$ ratio (or degree of saturation) for direction *i*

Delay Analysis

Finally, the average delay per passenger car (*s/pc*) for the two directions combined can be found using a weighted average of the directional delays:

$$d = \frac{(d_{1,1} + d_{2,1})q_1 + (d_{1,2} + d_{2,2})q_2}{q_1 + q_2}$$

Example one-lane two way Operations

Step 1. Transform demand observed (vph) to traffic flow rate (pc/h):

From HCM Chapter 15 find the effect of trucks and RVs on rolling terrain for 300 vph

- Passenger car equivalents for trucks (E_T) = 2.1 (Exhibit 15-11)
- Passenger car equivalents for RVs (E_R) = 1.1 (Exhibit 15-11)

The vehicle flow rate is calculated as:

$$q_1 = q_2 = 300 \times [0.8(1.0) + 0.1(2.1) + 0.1(1.1)] = \textbf{336 pc/h}$$

Passenger cars **Trucks** **RVs**

Example one-lane two way Operations

Step 2. Calculate average travel speeds using equations for V_1 and V_2:

$$V_1 = 0.615 \times SL - f_{LS} - f_A - f_{np,ATS}$$

$$V_2 = 0.692 \times SL - f_{LS} - f_A - f_{np,ATS}$$

With the following parameters:

$f_{LS} = 2.6\ mph$ (Exhibit 15-7), $f_A = 0$, $f_{np,ATS} = 2.4\ mph$

Therefore:

$$V_1 = 22.7\ mph = 33.3\ ft/s$$

$$V_2 = 26.1\ mph = 38.3\ ft/s$$

Example one-lane two way Operations

Step 3. Calculate saturation flow rate: $s_i = \frac{3600}{h_0 \times 1 - 0.005(min(V_i, 45) - 45)}$

$$s_1 = \frac{3600}{1.89 \times 1 - 0.005(22.7 - 45)} = 1713\ pc/h$$

$$s_2 = \frac{3600}{1.89 \times 1 - 0.005(26.1 - 45)} = 1740\ pc/h$$

Step 4. Estimate green times (we will use the recommended values first):

$$G_{opt} = 0.0375l = 37.5\ s$$

We have to check if it meets the requirement:

$$G_{opt} \geq G_{1,min} = \frac{336}{1713 - 336}\left(\frac{1000}{33.3} + \frac{1000}{38.3} + 37.5 + 4\right) = 23.8\ s$$ ✓

$$G_{opt} \geq G_{2,min} = \frac{336}{1740 - 336}\left(\frac{1000}{33.3} + \frac{1000}{38.3} + 37.5 + 4\right) = 23.4\ s$$ ✓

Example one-lane two way Operations

Step 5. Estimate the cycle length:

$$C = \frac{l}{V_1} + \frac{l}{V_2} + G_1 + G_2 + 2L_S = \frac{1000}{33.3} + \frac{1000}{38.3} + 37.5 + 37.5 + 4 = 135.1 \text{ s}$$

Step 6. Calculate the directional capacity: $c_i = s_i\left(\frac{G_i}{C}\right)$

$c_1 = 1713\left(\frac{37.5}{135.1}\right)$=475 pc/h $c_2 = 1740\left(\frac{37.5}{135.1}\right)$=483 pc/h

Note: The capacities are greater than the traffic flow rate (336 pc/h), indicating that the WZ can serve the traffic without accumulating vehicles

Example one-lane two way Operations

Step 7. Queue length analysis:

$$Q_{1,max} = q_1(C - G_1) = \frac{336}{3600}(135.1 - 37.5) = 9.1\ pc$$

$$Q_{2,max} = q_2(C - G_2) = \frac{336}{3600}(135.1 - 37.5) = 9.1\ pc$$

Step 8. Delay analysis:

Uniform control delay $(d_{1,i})$

$$d_{1,1} = \frac{1}{2}\frac{s_1}{s_1 - q_1}\frac{(C-G_1)^2}{C} = \frac{1}{2} \times \frac{1713}{1713-336} \times \frac{(135.1-37.5)^2}{135.1} = 43.86\ s/pc$$

$$d_{1,2} = \frac{1}{2}\frac{s_2}{s_2 - q_2}\frac{(C-G_2)^2}{C} = \frac{1}{2} \times \frac{1740}{1740-336} \times \frac{(135.1-37.5)^2}{135.1} = 43.69\ s/pc$$

Example one-lane two way Operations

Step 8. Delay analysis:

Incremental delay ($d_{2,i}$)

$$d_{2,i} = 900T\left[(X_i - 1) + \sqrt{(X_i - 1)^2 + \frac{8kIX_i}{c_i T}}\right]$$

$$X_i = {}^{q_i}/_{c_i}$$

$$X_1 = \frac{336}{475} = 0.707$$

$$X_2 = \frac{336}{483} = 0.696$$

$$d_{2,1} = 900 \times 1\left[(0.707 - 1) + \sqrt{(0.707 - 1)^2 + \frac{4 \times 0.707}{475 \times 1}}\right] = 8.99\ s/pc$$

$$d_{2,2} = 900 \times 1\left[(0.696 - 1) + \sqrt{(0.696 - 1)^2 + \frac{4 \times 0.696}{483 \times 1}}\right] = 8.54\ s/pc$$

Example one-lane two way Operations

Step 8. Delay analysis:

Thus, the average delay per direction is: $d = d_1 + d_2$

$d_1 = 43.86 + 8.99 = 52.85\ s/pc$ $d_2 = 43.69 + 8.54 = 52.23\ s/pc$

And the average delay for the two directions would be:

$$d = \frac{(d_{1,1} + d_{2,1})q_1 + (d_{1,2} + d_{2,2})q_2}{q_1 + q_2}$$

$$d = \frac{(43.86 + 8.99)336 + (43.69 + 8.54)336}{336 + 336}$$

$$d = 52.54\ s/pc$$

Appendix R

Variations in Work Zone Capacity within Analysis Period

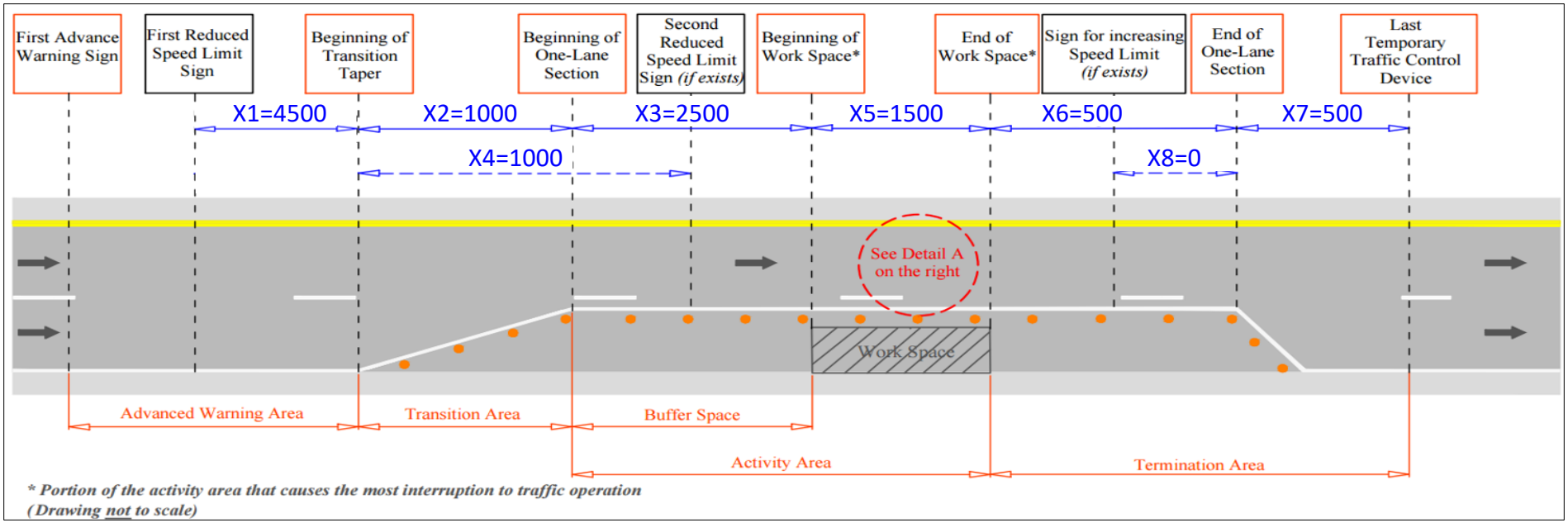
This goal of this example is to show the effect of capacity reduction on distance back of queue reached. An example for capacity reduction is when the work activity increases

Description:

A 2-to-1 freeway work zone, daytime, clear weather condition

Geometric data: Longitudinal distances in the sketch below

Lane width = 11.5 ft, Right shoulder width = 1 ft, Left shoulder width = 1 ft



Description (Continued…)

WZ conditions:

- Speed limit and work activity

Time duration	WZ characteristics
6:00 AM-9:00 AM	First and second speed limit=55 mph
9:00 AM-11:00 AM	Moderate work activity, First speed limit=55mph , Second speed limit=45 mph
11:00 AM-1:00 PM	First and second speed limit=55 mph

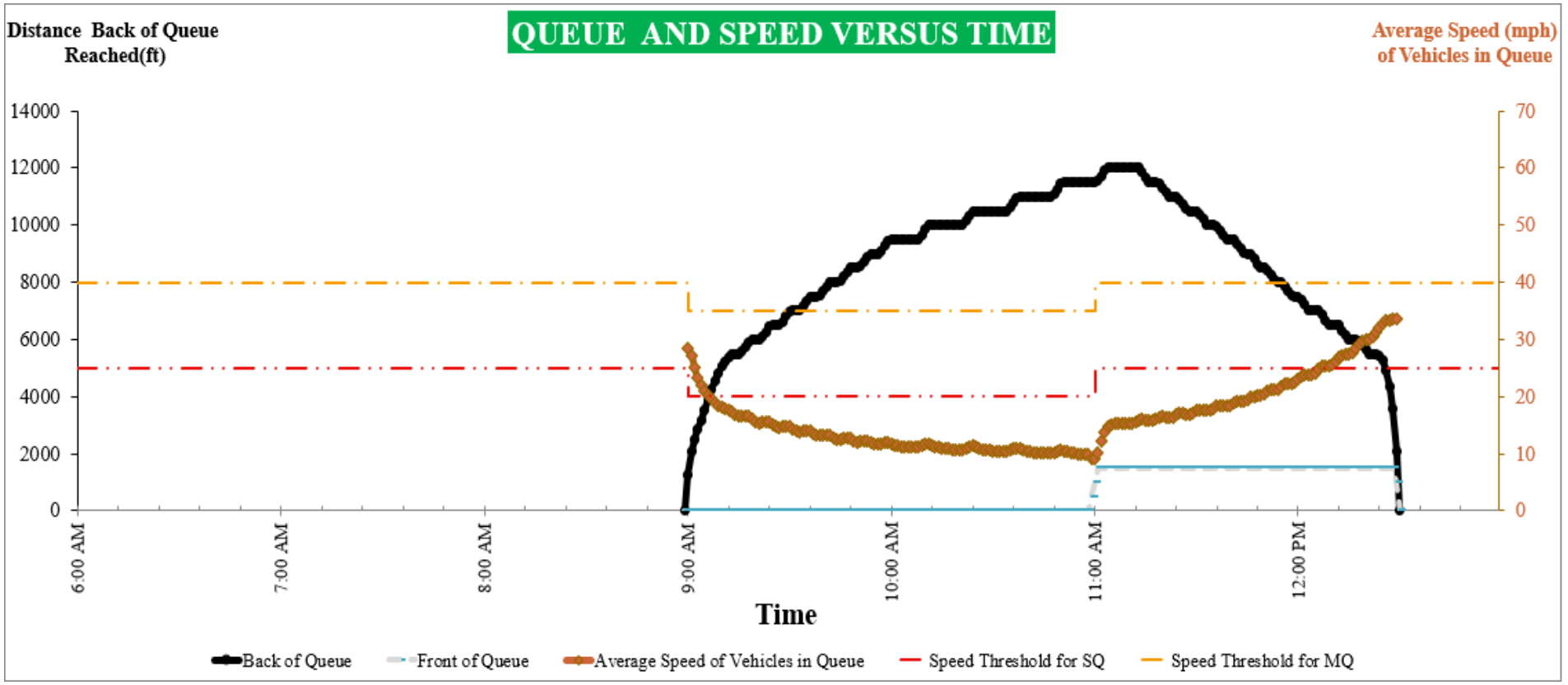
- Work activity area is separated from the travel lane by means of barrels
- Speed limit outside of the WZ is 65 mph
- Use default Passenger Car Equivalency (PCE) factors
- Traffic volume data:

Interval	% single-unit Trucks	% combination trucks	% recreational vehicles	Volume (veh)
6:00 AM – 7:00 AM	2.0	6.0	0.0	950
7:00 AM-8:00 AM	2.0	6.0	0.0	1,400
8:00 AM-9:00 AM	2.0	6.0	0.0	1,357
9:00 AM-10:00 AM	2.0	6.0	0.0	1,250
10:00 AM-11:00 AM	2.0	6.0	0.0	1,135
11:00 AM-12:00 PM	2.0	6.0	0.0	1,200
12:00 PM-1:00 PM	2.0	6.0	0.0	1,250

Compute back of queue from the three tools

WorkZoneQ-Pro Plot

- Input data as demonstrated in Module 4
- Make sure to input variations in speed limit, and work activity in Columns E to I in the “GeoCond” worksheet



MoDOT and QDAT

Instructions of these tools do not provide recommendations on how to analyze work zones when the capacity changes within the analysis period.

They may underestimate or overestimated queue length

Decision	Result
If capacity when the work intensity is low is used	Underestimation of WZ effects
If capacity when the work intensity is moderate is used	Overestimation of WZ effects

In the Appendix D, we used an approximation approach to find queue length in MoDOT and QDAT for this example problem

Variations in Work Zone Capacity within Analysis Period

- In QDAT and MoDOT, capacity is fixed during the entire analysis period, while in WorkZoneQ-Pro, capacity can change for every time interval (e.g. every hour).

- When there are variations in capacity, MoDOT and QDAT an approximation approach is suggested in the Appendix D to find the queue length.

- WorkZoneQ-Pro can take into account changes in capacity, speed limit, hours of construction, work intensity, and hours of deployment a traffic management strategy.

Appendix S

Implementing Speed Control Technique in the work zone

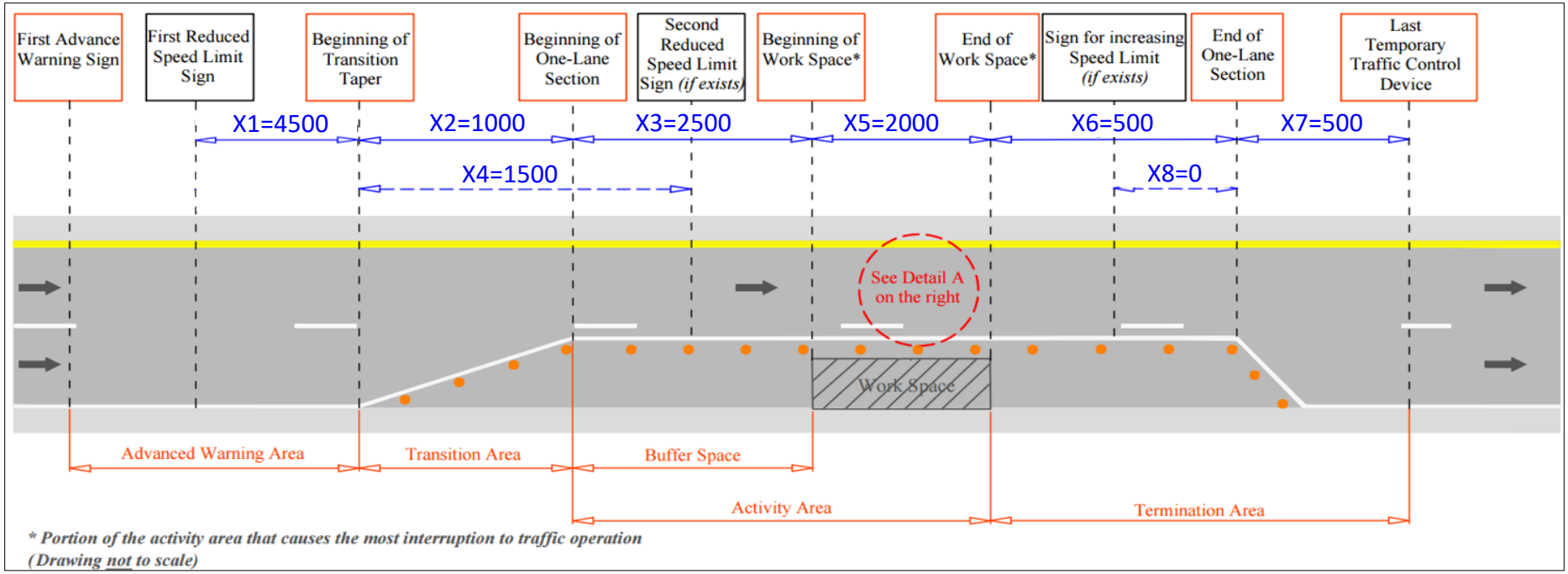
The goal of this example is to find the delay and users' costs of a 2-1 freeway work zone

Description:

Freeway, rural area, daytime, clear weather condition

Geometric data: Longitudinal distances in the sketch below

Lane width = 11 ft, Right shoulder width = 1 ft, Left shoulder width = 2 ft



Description (Continued…)

- Speed limit outside of the WZ is 65 mph
- Inside the WZ, the first speed limit sign is 55 mph
- WZ conditions and the second speed limit in the WZ:

Time duration	WZ characteristics
3:00 PM-3:30 PM	Speed limit=55 mph
3:30 PM-4:30 PM	Flagger, Low work activity, Police, Speed limit=45 mph
4:30 PM-7:00 PM	Speed limit=55 mph

- Work activity area is separated from the travel lane by means of barrels.
- Traffic volume data:

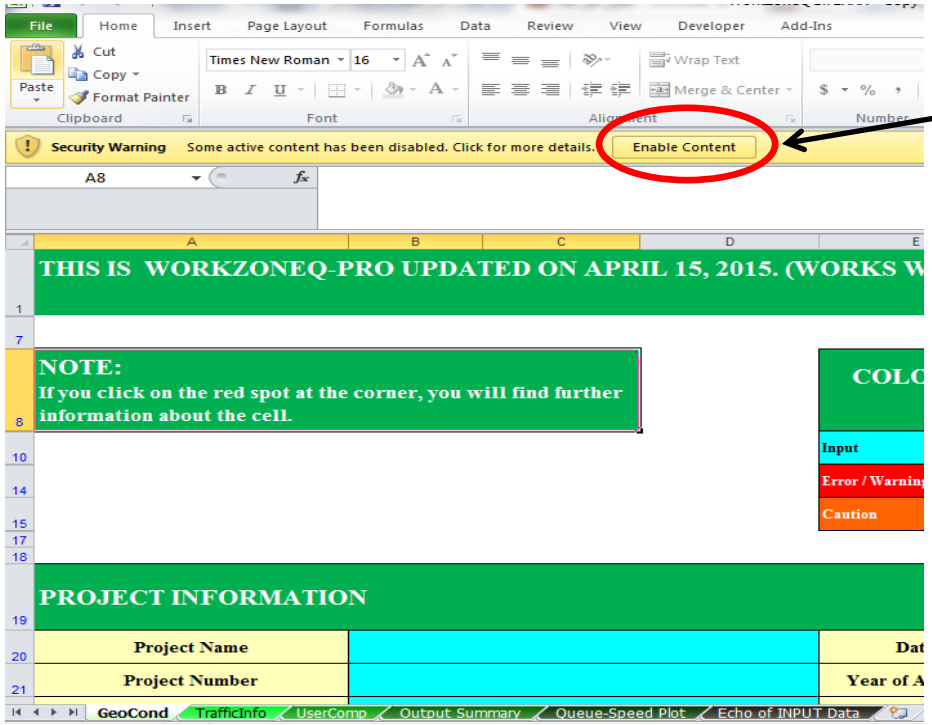
Interval	% single-unit Trucks	% combination trucks	% recreational vehicles	Volume (veh)
3:00 PM-3:30 PM	2	21	0	550
3:30 PM-4:00 PM	2	21	0	550
4:00 PM-4:30 PM	2	21	0	650
4:30 PM-5:00 PM	2	21	0	650
5:00 PM-5:30 PM	2	21	0	450
5:30 PM-6:00 PM	2	21	0	450
6:00 PM-6:30 PM	2	21	0	400
6:30 PM-7:00 PM	2	21	0	400

Use default Passenger Car Equivalency (PCE) factors

Open "WZQ-Pro V 1.56 for Freeway WZ" to start the example

WZQ-Pro User Guide:

- The program automatically opens on the "GeoCond" worksheet by default
- Click the "Enable Content" button to enable macro as shown below:



Note: Enable Content

color codes

COLOR CODING OF THE CELLS	
Input	Output
Error / Warning	Input / output title
Caution	Guidance

"GeoCond" Worksheet

- Input project information on cells from B20 to F22
- Input number of open lanes inside and outside of the WZ

Number of open lanes outside the work zone	Number of open lanes in the work zone
2	1

- Select interval length, start of analysis and speed limit outside of WZ

Select interval length (min) for analysis	Select start of analysis	Speed limit outside of the work zone (mph)
○ 15 min ◉ 30 min ○ 60 min (DEFAULT)	3:00 PM	65

"GeoCond" Worksheet

- Enter the longitudinal distances from problem description

Distance X1 (Write "0" if there is no speed limit reduction) (ft)	Distance Z1 (ft)	Distance Z2 (ft)	Distance Z3 (ft)	Distance X2 (ft)	Distance X3 (ft)	Distance X4 (Write "0" if there is no second speed limit) (ft)
4,500				1,000	2,500	1,500

Distance X5 (ft)	Distance X6 (ft)	Distance X7 (ft)	Distance X8 (Write "0" if there is no speed limit increase sign after Work Space) (ft)
2,000	500	500	0

- Enter lane and shoulder widths

Lane width Y1 (ft)	Right shoulder width Y2 (ft)	Left shoulder width Y3 (ft)
11.0	1.0	2.0

"GeoCond" Worksheet

- Enter the traffic control plan data

Start of Interval	End of Interval	Put "Y" if this interval is analyzed	Put "Y" if crew or construction equipment is closer than 9 ft to edge of travel lane.	Select the first speed limit from the drop down menu	Select the second speed limit from the drop down menu	Put "C" for long term work zones (concrete barriers are used), and "O" for short term work zones (other devices such as cones and drums are used).	Put "L" for low work intensity, "M" for moderate work intensity, "H" for high work intensity.	Put "F" if flagger is present.	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?	Select the Speed Control Technique (if any) from the drop down menu. Otherwise, leave it blank.
3:00 PM	3:30 PM	Y	N	55	55	O		N	N		
3:30 PM	4:00 PM	Y	Y	55	45	O	L	F	N		Police Presence
4:00 PM	4:30 PM	Y	Y	55	45	O	L	F	N		Police Presence
4:30 PM	5:00 PM	Y	N	55	55	O		N	N		
5:00 PM	5:30 PM	Y	N	55	55	O		N	N		
5:30 PM	6:00 PM	Y	N	55	55	O		N	N		
6:00 PM	6:30 PM	Y	N	55	55	O		N	N		
6:30 PM	7:00 PM	Y	N	55	55	O		N	N		

"GeoCond" Worksheet

- Highlighted outputs

Adjusted free flow speed

Capacity

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		54.6	1,540	42.4	1,540
43.0	1.0	34.6	1,113	26.5	1,113
43.0	1.0	34.6	1,113	26.5	1,113
62.0		54.6	1,540	42.4	1,540
62.0		54.6	1,540	42.4	1,540
62.0		54.6	1,540	42.4	1,540
62.0		54.6	1,540	42.4	1,540
62.0		54.6	1,540	42.4	1,540

"TrafficInfo" Worksheet

- Enter default PCE values (HCM values for Level terrain)

Terrain Type and PCE values for Specific Grade	PCE for heavy vehicles
Level	2.0

- Input traffic volume and composition data

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)	Heavy vehicle adjustment factor	Adjusted volume (pcph)	Capacity (vphpl)
3:00 PM	3:30 PM	2.0	21.0	0.0	550	0.81	1,353	1,252
3:30 PM	4:00 PM	2.0	21.0	0.0	550	0.81	1,353	905
4:00 PM	4:30 PM	2.0	21.0	0.0	650	0.81	1,599	905
4:30 PM	5:00 PM	2.0	21.0	0.0	650	0.81	1,599	1,252
5:00 PM	5:30 PM	2.0	21.0	0.0	450	0.81	1,107	1,252
5:30 PM	6:00 PM	2.0	21.0	0.0	450	0.81	1,107	1,252
6:00 PM	6:30 PM	2.0	21.0	0.0	400	0.81	984	1,252
6:30 PM	7:00 PM	2.0	21.0	0.0	400	0.81	984	1,252

"UserComp" Worksheet

- Enter hourly cost figures (for this problem they are default values)

2	STEPS 11-15: VEHICLE OCCUPANCY AND COST FIGURES FOR PROJECT NUMBER					
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 ($/hr)	Hourly delay cost for a combination truck ($/hr)	Hourly delay cost for a recreational vehicle ($/hr)	Hourly delay cost for a passenger car ($/hr)
4	1.25	2.00	$25	$30	$21	$21

"UserComp" Worksheet

Highlighted outputs:

No. of vehicles in queue

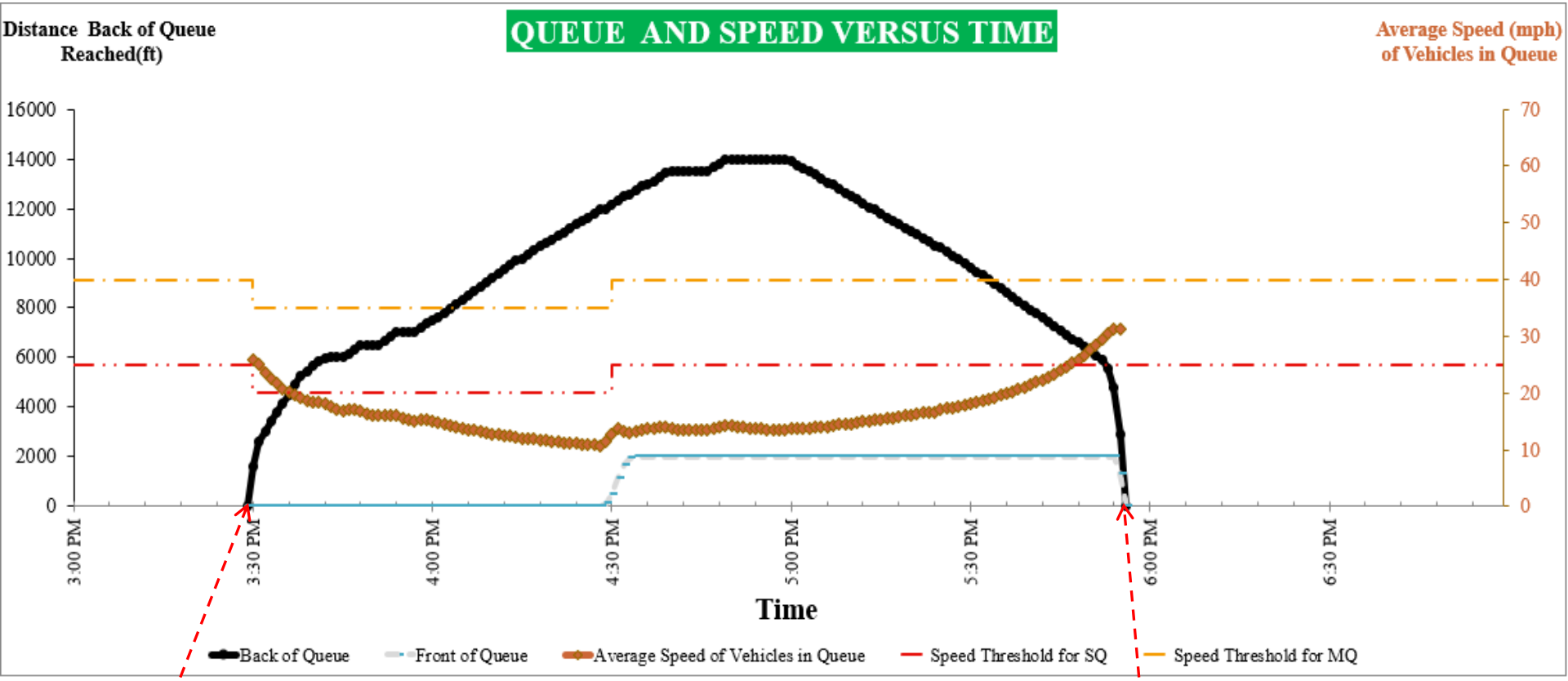
Distance queue occupied

Avg. Speed

Users' costs

Start of Interval	End of Interval	No. of vehicles in queue*	Average spacing between vehicles in queue (ft)	Front-of-queue (ft)	Back-of-queue (ft)	Distance queue occupied (ft)	Average speed in queue (mph)	Summary of Users' Costs ($) All (SQ+MQ+SMV)	
								Based on WZ speed limit	Based on speed limit outside of the WZ
3:00 PM	3:30 PM	0	0	0	0	0	-	$52.97	$109.62
3:30 PM	4:00 PM	134	71	0	7,500	7,500	17.5	$744.14	$855.43
4:00 PM	4:30 PM	347	53	0	12,000	12,000	12.2	$2,764.87	$2,872.00
4:30 PM	5:00 PM	367	56	2,000	14,000	12,000	13.7	$4,142.37	$4,233.85
5:00 PM	5:30 PM	176	65	2,000	9,933	7,933	15.3	$3,110.56	$3,204.62
5:30 PM	6:00 PM	0	65	0	0	0	22.5	$875.03	$948.01
6:00 PM	6:30 PM	0	-	-	-	-	-	$10.94	$50.64
6:30 PM	7:00 PM	0	-	-	-	-	-	$10.94	$50.64
					Maximum distance back-of-queue reached (ft)	Maximum distance queue occupied (ft)		SUM All	SUM All
*: At the end of the corresponding interval or when there is no more vehicle in queue					*14,000*	*12,000*		*$11,711.81*	*$12,324.82*

"Queue-Speed Plot" Worksheet



Queue begins

Queue ends

Appendix T
Approximating Multilane Highways

There is no specific WZQ-Pro spreadsheet for "multilane" highways. Traffic operation on multilane highways may be similar to freeways when speed limit is high (above 55 mph) and at grade access points are very limited. However, when speed limit is lower and there are many access points and median openings, traffic operation may be similar to that of urban arterials. To **approximate** work zone performance on multilane highways, the following steps may be taken with caution:

Step 1. Select either Freeway or Arterial spreadsheet depending on the speed limit outside the WZ:

- Use Freeway WorkZoneQ-Pro for when the outside WZ speed limit is 60 mph or higher.
  - If speed limit outside of the WZ is 65 mph or higher, enter 60 mph; but if it is 60 mph, enter 55 mph in in Cell E27 In Geocond (Speed limit outside of the work zone (mph)).

- Use Midblock Arterial WorkZoneQ-Pro when the outside WZ speed limit is 55 or lower.
  - Enter the speed limit outside the WZ in Cell E27 in GeoCond (Speed limit outside of the work zone (mph)).

Step 2. Input all geometric data such as lane width, shoulder width, etc.

Approximating Multilane Highways (Continued)

Step 3. Depending on the median type, select the speed reduction in FFS value, f_M, from the following table

Exhibit 12-23 Adjustment to FFS for Median Type for Multilane Highways (HCM 2016)

Median Type	Reduction in FFS, f_M (mi/h)
Undivided	1.6
Two way left turn lane (TWLTL)	0.0
Divided	0.0

Step 4. Depending on the number of access points, select the speed reduction in FFS value, from the following table

Exhibit 12-24 Adjustment to FFS for Access Point Density for Multilane Highways (HCM 2016)

Access Point Density (access points / mi)	Reduction in FFS, f_A (mi/h)
0	0.0
10	2.5
20	5.0
30	7.5
≥ 40	10.0

Step 5. Find the speed adjustment factor (sum of f_M and f_A).

Approximating Multilane Highways (Continued)

Step 6. Apply the speed adjustment factor.

- In column N for Freeway WorkZoneQ-Pro

M	N	O	P
Select the Speed Control Technique (if any) from the drop down menu. 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.* (mph)	Select capacity adjustment factors (CAFs) due to inclement weather condition. Otherwise leave it as 100%.	Select percent capacity increase for urban areas, Otherwise leave it as 0%.
	4.1	100.00%	0.00%
	4.1	100.00%	0.00%
	4.1	100.00%	0.00%
	4.1	100.00%	0.00%
	4.1	100.00%	0.00%
	4.1	100.00%	0.00%

- In column M for Midblock Arterial WorkZoneQ-Pro

L	M	N	O
Select the Speed Control Technique (if any) from the drop down menu. Otherwise, leave it blank.	If there is any additional speed reduction due to any other factors, including those in HCM, enter here. Otherwise leave it blank (mph)	Select capacity adjustment factors (CAFs) due to inclement weather condition. Otherwise leave it as 100%.	Select percent capacity increase for urban areas, Otherwise leave it as 0%.
	4.1	100.00%	0.00%
	4.1	100.00%	0.00%
	4.1	100.00%	0.00%

Example for Approximating Multilane Highways

Description:

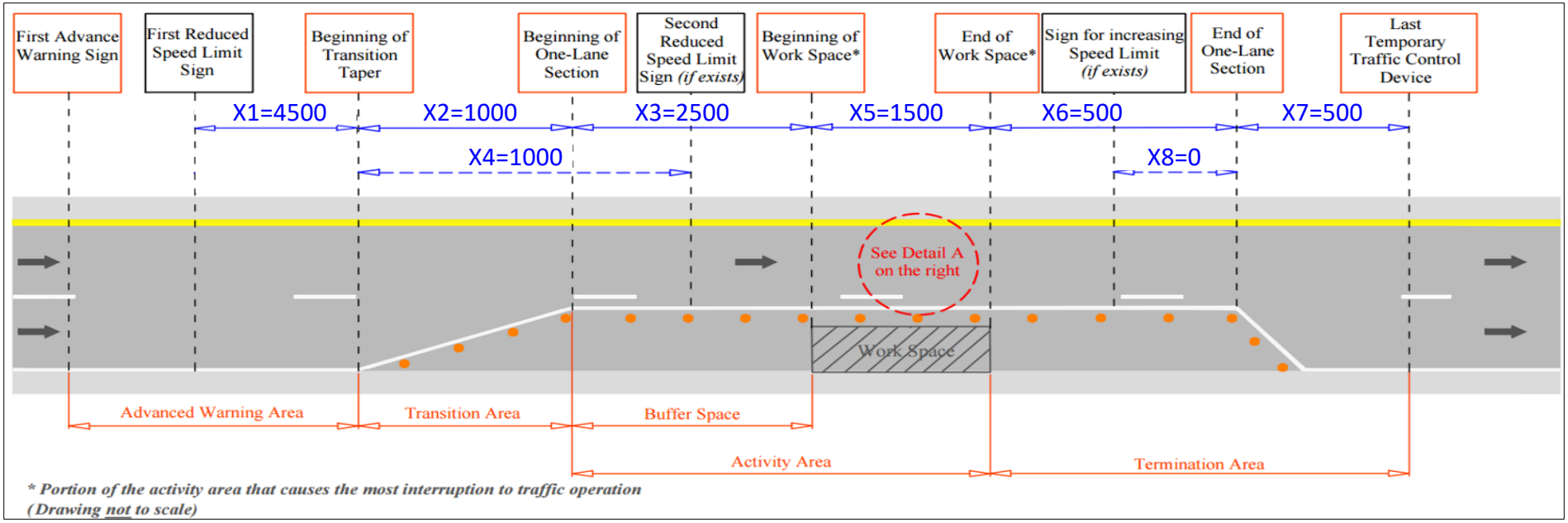
A 2-to-1 multilane highway work zone, daytime, clear weather condition

Geometric data: Longitudinal distances in the sketch below

Undivided multilane highway has 10 access points in mile

Outside speed limit = 65 mph

Lane width = 11.5 ft, Right shoulder width = 1 ft, Left shoulder width = 1 ft



Description (Continued…)

WZ conditions:

- Speed limit and work activity

Time duration	WZ characteristics
6:00 AM-9:00 AM	First and second speed limit=55 mph
9:00 AM-11:00 AM	Moderate work activity, First speed limit=55mph , Second speed limit=45 mph
11:00 AM-1:00 PM	First and second speed limit=55 mph

- Work activity area is separated from the travel lane by means of barrels
- Use default Passenger Car Equivalency (PCE) factors
- Traffic volume data:

Interval	% single-unit Trucks	% combination trucks	% recreational vehicles	Volume (veh)
6:00 AM – 7:00 AM	2.0	6.0	0.0	950
7:00 AM-8:00 AM	2.0	6.0	0.0	1,400
8:00 AM-9:00 AM	2.0	6.0	0.0	1,357
9:00 AM-10:00 AM	2.0	6.0	0.0	1,250
10:00 AM-11:00 AM	2.0	6.0	0.0	1,135
11:00 AM-12:00 PM	2.0	6.0	0.0	1,200
12:00 PM-1:00 PM	2.0	6.0	0.0	1,250
1:00 PM-2:00 PM	2.0	6.0	0.0	1,050
2:00 PM-3:00 PM	2.0	6.0	0.0	950

"GeoCond" Worksheet

- Choose Freeway WorkZoneQ-Pro, since outside speed limit is 65 mph

Select 60 mph for speed limit outside of the work zone

Number of open lanes outside the work zone	Number of open lanes in the work zone	Select interval length (min) for analysis	Select start of analysis	Speed limit outside of the work zone (mph)
2	1	○ 15 min ○ 30 min ◉ 60 min (DEFAULT)	6:00 AM	60

- Input all geometric data such as lane width, shoulder width, etc.
- Select the speed reduction in FFS due to median type, f_M, from the following table

Exhibit 12-23 Adjustment to FFS for Median Type for Multilane Highways (HCM 2016)

Median Type	Reduction in FFS, f_M (mi/h)
Undivided	1.6
Two way left turn lane (TWLTL)	0.0
Divided	0.0

- select the speed reduction in FFS due to no of access points (f_A)

"TrafficInfo" Worksheet

Exhibit 12-24 Adjustment to FFS for Access Point Density for Multilane Highways (HCM 2016)

Access Point Density (access points / mi)	Reduction in FFS, f_A (mi/h)
0	0.0
10	2.5
20	5.0
30	7.5
≥ 40	10.0

- Find the speed adjustment factor (sum of f_M and f_A). 1.6+2.5=4.1
- Apply the speed adjustment factor in column N for Freeway WorkZoneQ-Pro

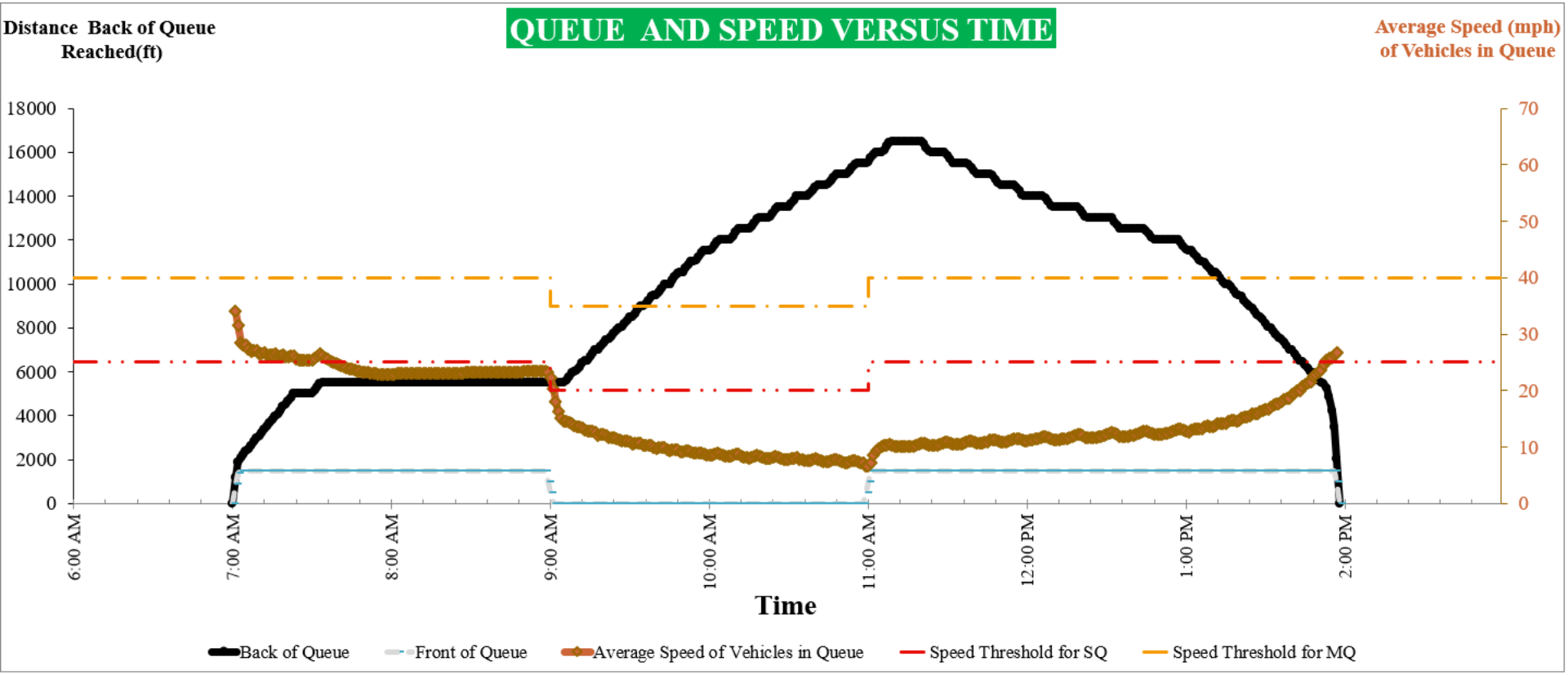
M	N	O	P
Select the Speed Control Technique (if any) from the drop down menu. Otherwise, leave it blank.	**If there is any additional speed reduction due to any other factors not considered so far, enter here.** *Otherwise, leave it blank.* **(mph)**	**Select capacity adjustment factors (CAFs) due to inclement weather condition. Otherwise leave it as 100%.**	**Select percent capacity increase for urban areas, Otherwise leave it as 0%.**
	4.1	**100.00%**	**0.00%**
	4.1	**100.00%**	**0.00%**
	4.1	**100.00%**	**0.00%**
	4.1	**100.00%**	**0.00%**
	4.1	**100.00%**	**0.00%**
	4.1	**100.00%**	**0.00%**

"UserComp" Worksheet

Start of Interval	End of Interval	No. of vehicles in queue*	Average spacing between vehicles in queue (ft)	Front-of-queue (ft)	Back-of-queue (ft)	Distance queue occupied (ft)	Average speed in queue (mph)	Summary of Users' Costs ($) All (SQ+MQ+SMV)	
								Based on WZ speed limit	Based on speed limit outside of the WZ
6:00 AM	7:00 AM	0	0	0	0	0	-	$35.03	$74.69
7:00 AM	8:00 AM	57	79	1,500	5,500	4,000	24.9	$613.57	$673.90
8:00 AM	9:00 AM	53	85	1,500	5,500	4,000	23.2	$967.45	$1,029.44
9:00 AM	10:00 AM	412	44	0	11,500	11,500	11.2	$5,315.56	$5,450.77
10:00 AM	11:00 AM	636	41	0	15,500	15,500	7.9	$12,513.26	$12,657.60
11:00 AM	12:00 PM	460	47	1,500	14,000	12,500	10.5	$12,792.25	$12,893.86
12:00 PM	1:00 PM	333	50	1,500	11,667	10,167	12.0	$9,111.62	$9,214.93
1:00 PM	2:00 PM	0	50	0	0	0	16.3	$3,731.40	$3,817.87
2:00 PM	3:00 PM	0	-	-	-	-	-	$35.03	$74.69
					Maximum distance back-of-queue reached (ft)	Maximum distance queue occupied (ft)		SUM All	SUM All
					15,500	*15,500*		*$45,115.18*	*$45,887.74*

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

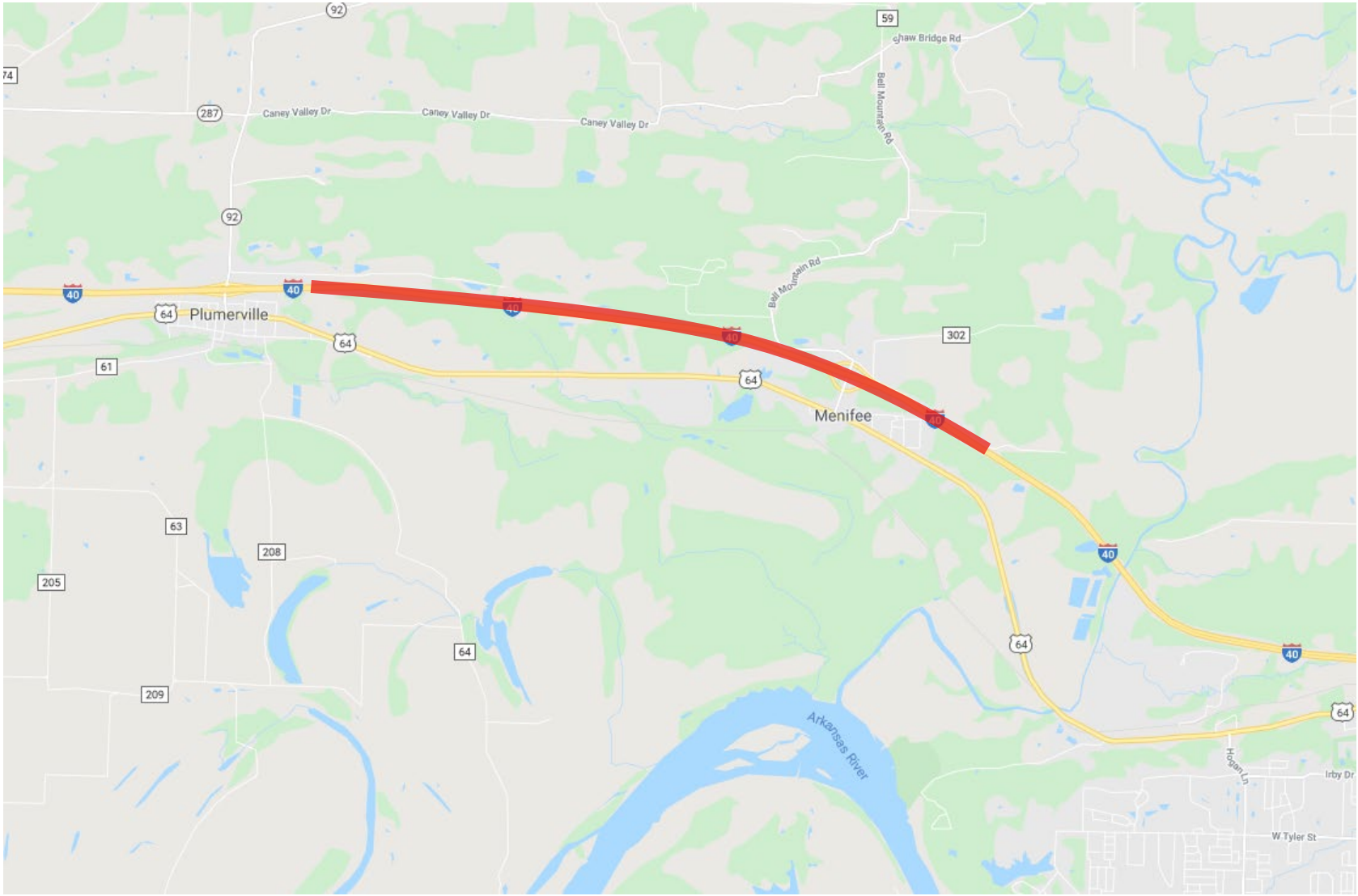
"Queue-Speed Plot" Worksheet



Note: This result is approximation of multilane highway

Appendix U
Real-World Examples

Example 1: I-40 at Plumerville – East (S), Conway County, Arkansas



Description (Continued…)

Description (Continued…)

This project is one lane closure on two lane freeway

Description:

Lane width = 12 ft, left shoulder right = 4 ft, and right shoulder width = 0 ft

Rural area and level terrain

Assumed night-time: 6 PM – 6 AM

WZ conditions:

Speed limit inside work zone is 60 mph and outside is 70 mph

Drum barrier, moderate work intensity (Assumed)

Description (Continued…)

Traffic Demand:

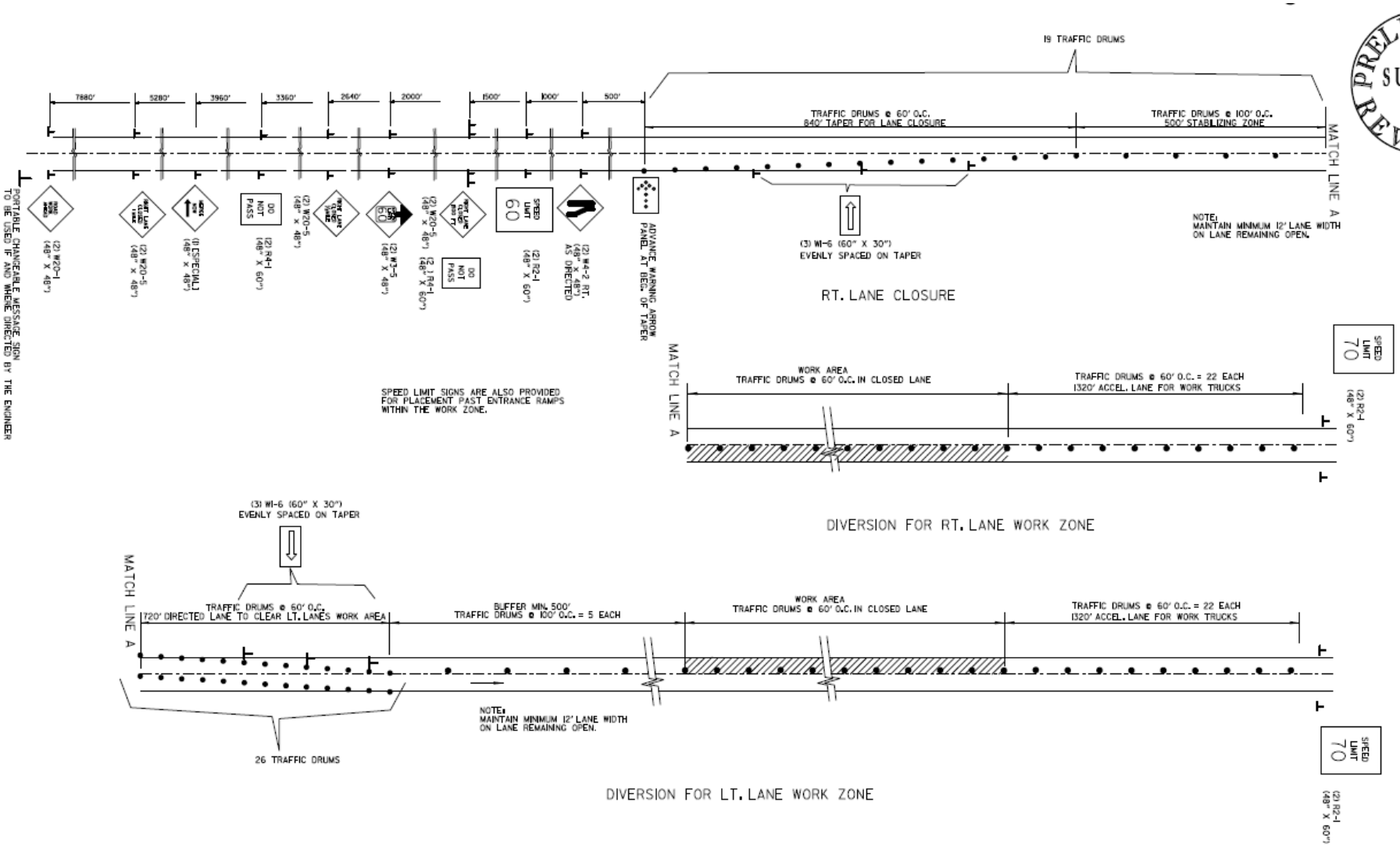
Start of Interval	End of Interval	Percentage of single-unit trucks (%)	Percentage of combination trucks (%)	Percentage of recreational vehicles (%)	Expected traffic volume during the interval (veh)	Heavy vehicle adjustment factor	Adjusted volume (pcph)	Capacity (vphpl)
12:00 AM	12:15 AM	2.6	48.7	0.0	39	0.66	236	867
12:15 AM	12:30 AM	0.0	41.3	0.0	46	0.71	260	928
12:30 AM	12:45 AM	1.8	47.3	3.6	55	0.65	336	859
12:45 AM	1:00 AM	3.6	39.3	0.0	28	0.70	160	918
1:00 AM	1:15 AM	0.0	48.7	0.0	39	0.67	232	882
1:15 AM	1:30 AM	0.0	45.8	2.1	48	0.68	284	887
1:30 AM	1:45 AM	0.0	50.0	0.0	30	0.67	180	874
1:45 AM	2:00 AM	0.0	58.3	2.8	36	0.62	232	814
2:00 AM	2:15 AM	10.0	50.0	0.0	30	0.63	192	820
2:15 AM	2:30 AM	12.8	50.0	0.0	43	0.61	280	806
2:30 AM	2:45 AM	3.6	50.0	0.0	28	0.65	172	854
2:45 AM	3:00 AM	2.9	38.2	2.9	34	0.69	196	910
3:00 AM	3:15 AM	2.8	50.0	2.8	36	0.64	224	843
3:15 AM	3:30 AM	25.0	50.0	5.0	30	0.56	216	729
3:30 AM	3:45 AM	17.9	50.0	7.1	28	0.57	196	749
3:45 AM	4:00 AM	16.7	50.0	0.0	30	0.60	200	787
4:00 AM	4:15 AM	4.7	46.5	2.3	43	0.65	264	854
4:15 AM	4:30 AM	0.0	38.3	1.7	60	0.71	336	937
4:30 AM	4:45 AM	0.0	50.9	0.0	55	0.66	332	869
4:45 AM	5:00 AM	0.0	30.3	5.3	76	0.74	412	968
5:00 AM	5:15 AM	1.4	33.8	1.4	74	0.73	404	961
5:15 AM	5:30 AM	1.4	33.8	1.4	74	0.73	404	961
5:30 AM	5:45 AM	1.0	19.2	1.9	104	0.82	508	1,074
5:45 AM	6:00 AM	0.7	19.9	0.7	141	0.82	684	1,081
6:00 AM	6:15 AM	0.6	13.4	1.2	172	0.87	792	1,225
6:15 AM	6:30 AM	1.0	11.0	1.4	209	0.88	948	1,243
6:30 AM	6:45 AM	0.4	16.7	1.3	227	0.84	1,076	1,190
6:45 AM	7:00 AM	2.4	14.9	2.4	255	0.84	1,220	1,179
7:00 AM	7:15 AM	0.4	14.0	3.3	242	0.85	1,140	1,197
7:15 AM	7:30 AM	0.4	14.3	0.7	279	0.87	1,288	1,222
7:30 AM	7:45 AM	0.3	13.1	0.0	306	0.88	1,388	1,243
7:45 AM	8:00 AM	0.8	13.3	1.4	362	0.87	1,672	1,221
8:00 AM	8:15 AM	0.0	14.9	0.9	343	0.86	1,588	1,218
8:15 AM	8:30 AM	1.5	16.1	0.4	261	0.85	1,232	1,195
8:30 AM	8:45 AM	1.3	14.7	1.0	306	0.85	1,432	1,205
8:45 AM	9:00 AM	1.0	14.6	0.7	288	0.86	1,340	1,212
9:00 AM	9:15 AM	0.9	16.8	2.1	333	0.83	1,596	1,177
9:15 AM	9:30 AM	0.3	16.9	3.7	326	0.83	1,576	1,167
9:30 AM	9:45 AM	0.4	18.4	3.2	283	0.82	1,380	1,157
9:45 AM	10:00 AM	0.0	25.0	0.9	232	0.79	1,168	1,120
10:00 AM	10:15 AM	1.1	17.3	2.8	283	0.83	1,372	1,163
10:15 AM	10:30 AM	0.4	23.1	3.1	260	0.79	1,316	1,114
10:30 AM	10:45 AM	1.6	19.9	4.0	251	0.80	1,260	1,124
10:45 AM	11:00 AM	1.1	25.4	2.2	276	0.78	1,420	1,096
11:00 AM	11:15 AM	1.4	21.4	1.7	295	0.80	1,468	1,133
11:15 AM	11:30 AM	1.9	21.2	3.0	264	0.79	1,332	1,118
11:30 AM	11:45 AM	1.6	21.5	2.0	251	0.80	1,256	1,127
11:45 AM	12:00 PM	0.9	22.2	2.6	230	0.80	1,156	1,122
12:00 PM	12:15 PM	0.7	21.0	4.4	272	0.79	1,372	1,118
12:15 PM	12:30 PM	0.4	23.8	4.8	252	0.78	1,300	1,093
12:30 PM	12:45 PM	1.1	19.1	4.0	277	0.81	1,376	1,135
12:45 PM	1:00 PM	0.8	20.0	2.5	240	0.81	1,184	1,143

Description (Continued…)

Traffic Demand:

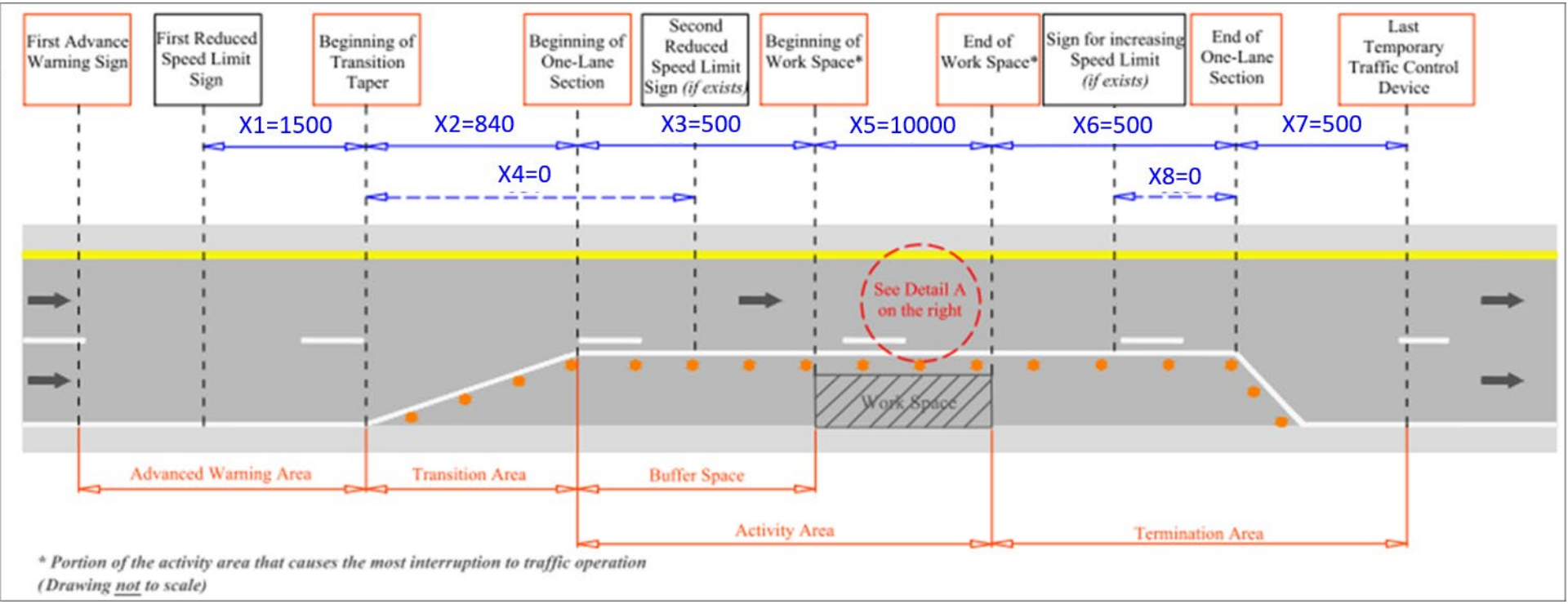
1:00 PM	1:15 PM	1.1	19.2	1.8	281	0.82	1,372	1,155
1:15 PM	1:30 PM	1.9	18.4	3.4	266	0.81	1,316	1,140
1:30 PM	1:45 PM	2.2	23.7	2.6	228	0.78	1,172	1,097
1:45 PM	2:00 PM	0.3	23.6	2.8	288	0.79	1,460	1,113
2:00 PM	2:15 PM	3.1	22.9	2.7	292	0.78	1,504	1,095
2:15 PM	2:30 PM	2.7	18.8	2.4	292	0.81	1,448	1,137
2:30 PM	2:45 PM	1.8	20.0	1.8	325	0.81	1,608	1,140
2:45 PM	3:00 PM	1.3	18.3	3.8	317	0.81	1,564	1,143
3:00 PM	3:15 PM	0.7	20.1	2.2	274	0.81	1,348	1,146
3:15 PM	3:30 PM	1.6	21.1	3.4	322	0.79	1,624	1,118
3:30 PM	3:45 PM	1.7	18.6	0.3	295	0.83	1,424	1,168
3:45 PM	4:00 PM	1.7	16.6	2.5	355	0.83	1,716	1,167
4:00 PM	4:15 PM	1.1	18.1	0.8	370	0.83	1,776	1,175
4:15 PM	4:30 PM	0.9	18.7	0.3	316	0.83	1,516	1,176
4:30 PM	4:45 PM	1.1	20.6	3.1	350	0.80	1,748	1,129
4:45 PM	5:00 PM	0.3	17.2	3.0	296	0.83	1,428	1,169
5:00 PM	5:15 PM	0.3	18.6	3.2	317	0.82	1,548	1,155
5:15 PM	5:30 PM	0.6	20.5	3.2	312	0.80	1,552	1,134
5:30 PM	5:45 PM	1.7	13.5	2.7	297	0.85	1,400	1,196
5:45 PM	6:00 PM	0.9	21.0	2.1	333	0.81	1,652	1,137
6:00 PM	6:15 PM	1.1	13.2	0.7	280	0.87	1,288	1,140
6:15 PM	6:30 PM	0.7	19.0	0.7	274	0.83	1,320	1,089
6:30 PM	6:45 PM	1.2	20.6	4.0	253	0.80	1,272	1,043
6:45 PM	7:00 PM	0.5	21.3	0.9	211	0.81	1,036	1,068
7:00 PM	7:15 PM	0.0	27.3	1.6	187	0.78	964	1,017
7:15 PM	7:30 PM	2.3	21.5	0.6	177	0.80	880	1,055
7:30 PM	7:45 PM	0.6	27.2	3.5	173	0.76	908	999
7:45 PM	8:00 PM	1.2	17.2	1.2	169	0.84	808	1,097
8:00 PM	8:15 PM	0.0	30.6	1.4	144	0.76	760	994
8:15 PM	8:30 PM	0.7	21.9	2.9	137	0.80	688	1,044
8:30 PM	8:45 PM	1.4	21.6	2.2	139	0.80	696	1,048
8:45 PM	9:00 PM	0.0	27.9	0.8	122	0.78	628	1,019
9:00 PM	9:15 PM	0.7	24.4	0.7	135	0.79	680	1,041
9:15 PM	9:30 PM	1.8	24.6	0.0	114	0.79	576	1,038
9:30 PM	9:45 PM	0.0	25.5	2.0	102	0.78	520	1,029
9:45 PM	10:00 PM	0.0	23.5	1.0	102	0.80	508	1,053
10:00 PM	10:15 PM	0.0	25.2	1.7	119	0.79	604	1,033
10:15 PM	10:30 PM	0.0	28.9	2.4	83	0.76	436	999
10:30 PM	10:45 PM	1.1	37.0	3.3	92	0.71	520	928
10:45 PM	11:00 PM	3.8	29.1	6.3	79	0.72	440	942
11:00 PM	11:15 PM	1.4	32.4	0.0	71	0.75	380	980
11:15 PM	11:30 PM	1.4	41.1	0.0	73	0.70	416	920
11:30 PM	11:45 PM	1.6	42.6	1.6	61	0.69	356	899
11:45 PM	12:00 AM	0.0	43.4	3.8	53	0.68	312	891

Description (Continued…)



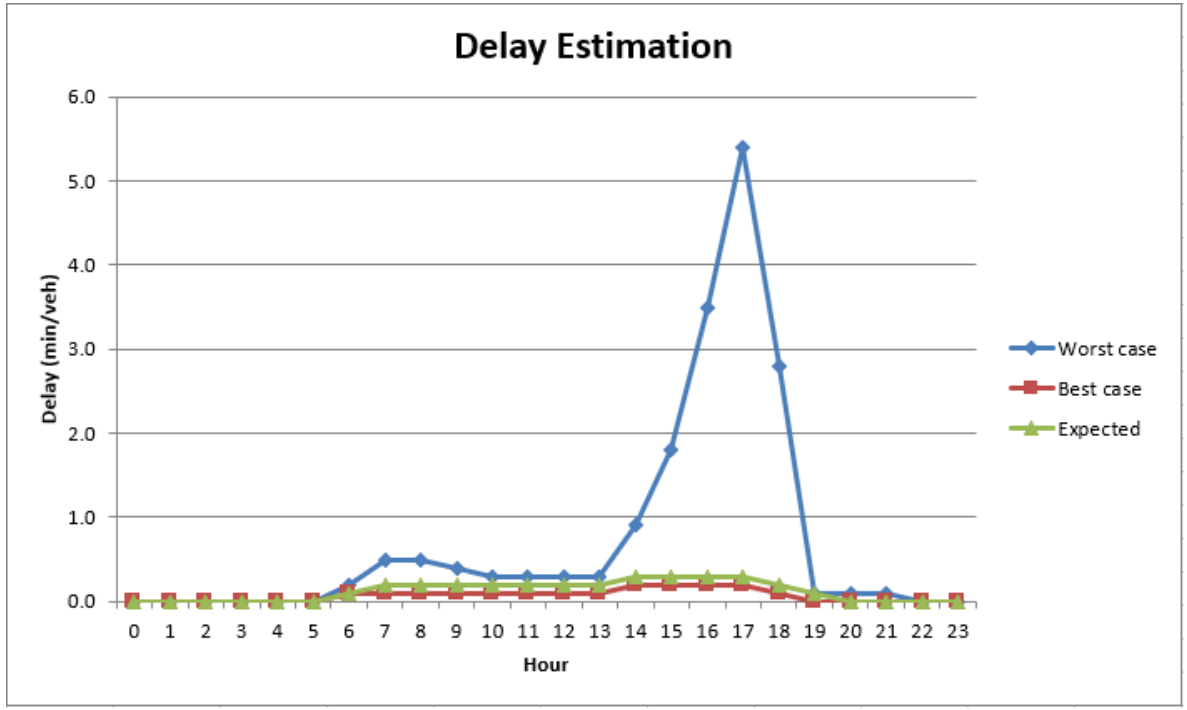
Geometric Data

Geometric data: Longitudinal distances in the sketch below



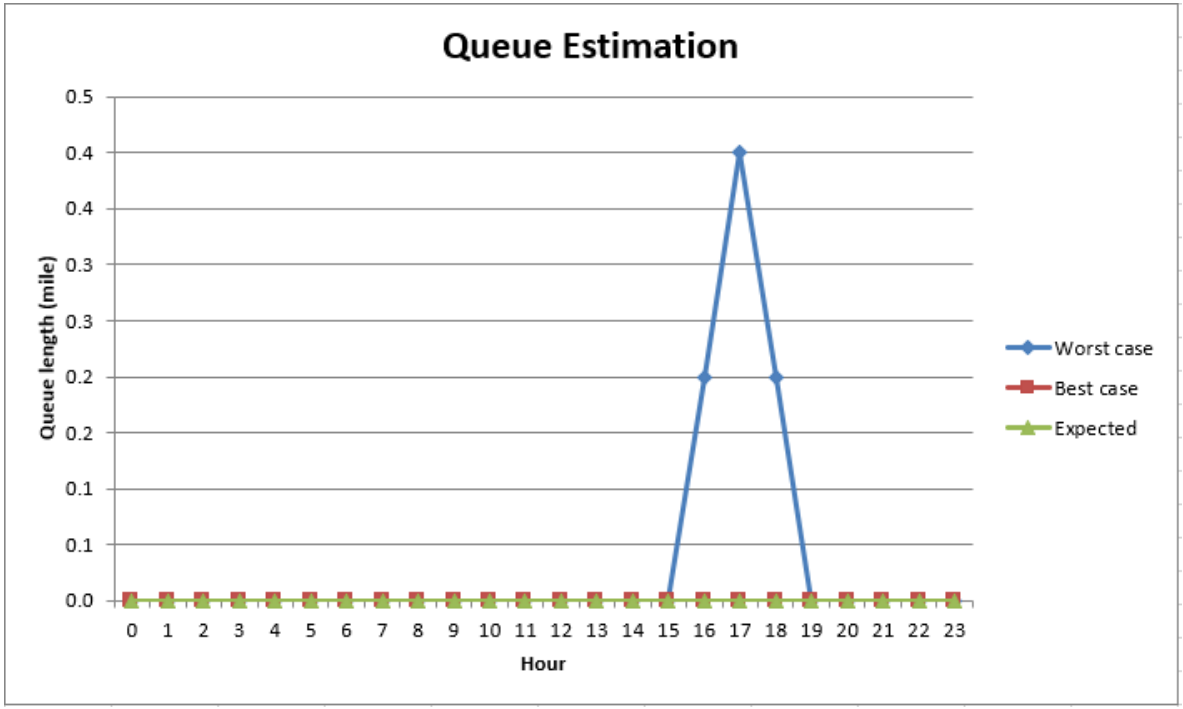
QDAT Delay Output

Expected: Estimated Delay(min/veh)		
start hour	0	0.0
	1	0.0
	2	0.0
	3	0.0
	4	0.0
	5	0.0
	6	0.1
	7	0.2
	8	0.2
	9	0.2
	10	0.2
	11	0.2
	12	0.2
	13	0.2
	14	0.3
	15	0.3
	16	0.3
	17	0.3
	18	0.2
	19	0.1
	20	0.0
	21	0.0
	22	0.0
end hour	23	0.0



QDAT Queue Output

Expected: Estimated Queue(mile)		
start hour	0	0.0
	1	0.0
	2	0.0
	3	0.0
	4	0.0
	5	0.0
	6	0.0
	7	0.0
	8	0.0
	9	0.0
	10	0.0
	11	0.0
	12	0.0
	13	0.0
	14	0.0
	15	0.0
	16	0.0
	17	0.0
	18	0.0
	19	0.0
	20	0.0
	21	0.0
	22	0.0
end hour	23	0.0



MoDOT Output

BASE CONDITIONS

Open Lane Capacity (veh/h/lane):	1900

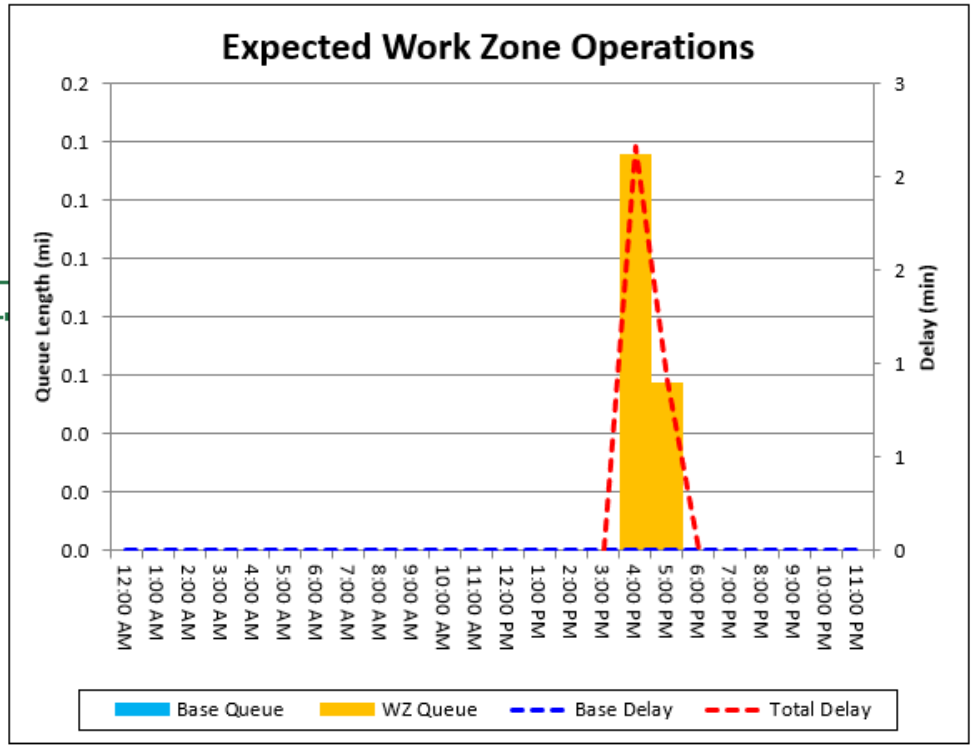
Base Conditions Capacity (Total for ALL Lanes): 3800 veh/h

WORKZONE DETAILS

Work Description:	(Example: Pothole Patching - Close One Lane OR Joint Repair - Two Lanes Closed)
Work Location:	Workers & equipment less than 4 feet from travel lane
Travel Lane Width (ft):	> 11.5
Number of Lanes Open:	1
ESTIMATED Work Zone Capacity (veh/h):	1286
USER DEFINED Work Zone Capacity (veh/h):	
Start Time:	12:00 AM
End Time:	12:00 AM
Duration of Closure (hrs):	24

RESULTS

Measure of Effectiveness	Base Conditions	Work Zone	Total
Max Queue Length (mi):	0.0	0.1	0.1
Max Delay (minutes):	0	2	2
Cost ($):	$0	$26	$26



WorkZoneQ-Pro Output

Start of Interval	End of Interval	No. of vehicles in queue*	Average spacing between vehicles in queue (ft)	Front-of-queue (ft)	Back-of-queue (ft)	Distance queue occupied (ft)	Average speed in queue (mph)	Summary of Users' Costs ($) All (SQ+MQ+SMV)	
								Based on WZ speed limit	Based on speed limit outside of the WZ
12:00 AM	12:15 AM	0	0	0	0	0	-	$11.05	$16.43
12:15 AM	12:30 AM	0	-	-	-	-	-	$12.92	$19.20
12:30 AM	12:45 AM	0	-	-	-	-	-	$15.88	$23.60
12:45 AM	1:00 AM	0	-	-	-	-	-	$7.83	$11.64
1:00 AM	1:15 AM	0	-	-	-	-	-	$11.06	$16.44
1:15 AM	1:30 AM	0	-	-	-	-	-	$13.72	$20.40
1:30 AM	1:45 AM	0	-	-	-	-	-	$8.52	$12.67
1:45 AM	2:00 AM	0	-	-	-	-	-	$10.50	$15.61
2:00 AM	2:15 AM	0	-	-	-	-	-	$8.49	$12.61
2:15 AM	2:30 AM	0	-	-	-	-	-	$12.15	$18.06
2:30 AM	2:45 AM	0	-	-	-	-	-	$7.94	$11.81
2:45 AM	3:00 AM	0	-	-	-	-	-	$9.66	$14.35
3:00 AM	3:15 AM	0	-	-	-	-	-	$10.38	$15.42
3:15 AM	3:30 AM	0	-	-	-	-	-	$8.67	$12.88
3:30 AM	3:45 AM	0	-	-	-	-	-	$8.21	$12.21
3:45 AM	4:00 AM	0	-	-	-	-	-	$8.46	$12.58
4:00 AM	4:15 AM	0	-	-	-	-	-	$12.30	$18.28
4:15 AM	4:30 AM	0	-	-	-	-	-	$16.94	$25.18
4:30 AM	4:45 AM	0	-	-	-	-	-	$15.65	$23.26
4:45 AM	5:00 AM	0	-	-	-	-	-	$21.66	$32.20
5:00 AM	5:15 AM	0	-	-	-	-	-	$20.72	$30.80
5:15 AM	5:30 AM	0	-	-	-	-	-	$20.72	$30.80
5:30 AM	5:45 AM	0	-	-	-	-	-	$28.65	$42.58
5:45 AM	6:00 AM	0	-	-	-	-	-	$47.34	$66.11
6:00 AM	6:15 AM	0	-	-	-	-	-	$46.45	$69.21
6:15 AM	6:30 AM	0	-	-	-	-	-	$70.72	$99.85
6:30 AM	6:45 AM	0	-	-	-	-	-	$87.80	$121.74
6:45 AM	7:00 AM	0	-	-	-	-	-	$111.16	$149.38
7:00 AM	7:15 AM	0	-	-	-	-	-	$99.91	$136.37
7:15 AM	7:30 AM	56	180	0	10,000	10,000	39.8	$125.73	$167.16
7:30 AM	7:45 AM	59	169	0	10,000	10,000	39.2	$144.48	$189.65
7:45 AM	8:00 AM	129	111	0	12,840	12,840	36.1	$320.90	$368.70
8:00 AM	8:15 AM	171	96	0	13,373	13,373	33.1	$634.45	$683.80
8:15 AM	8:30 AM	131	110	0	12,840	12,840	32.7	$647.42	$695.64
8:30 AM	8:45 AM	136	106	0	12,840	12,840	33.7	$545.85	$594.66
8:45 AM	9:00 AM	116	115	0	12,340	12,340	34.1	$503.43	$552.44

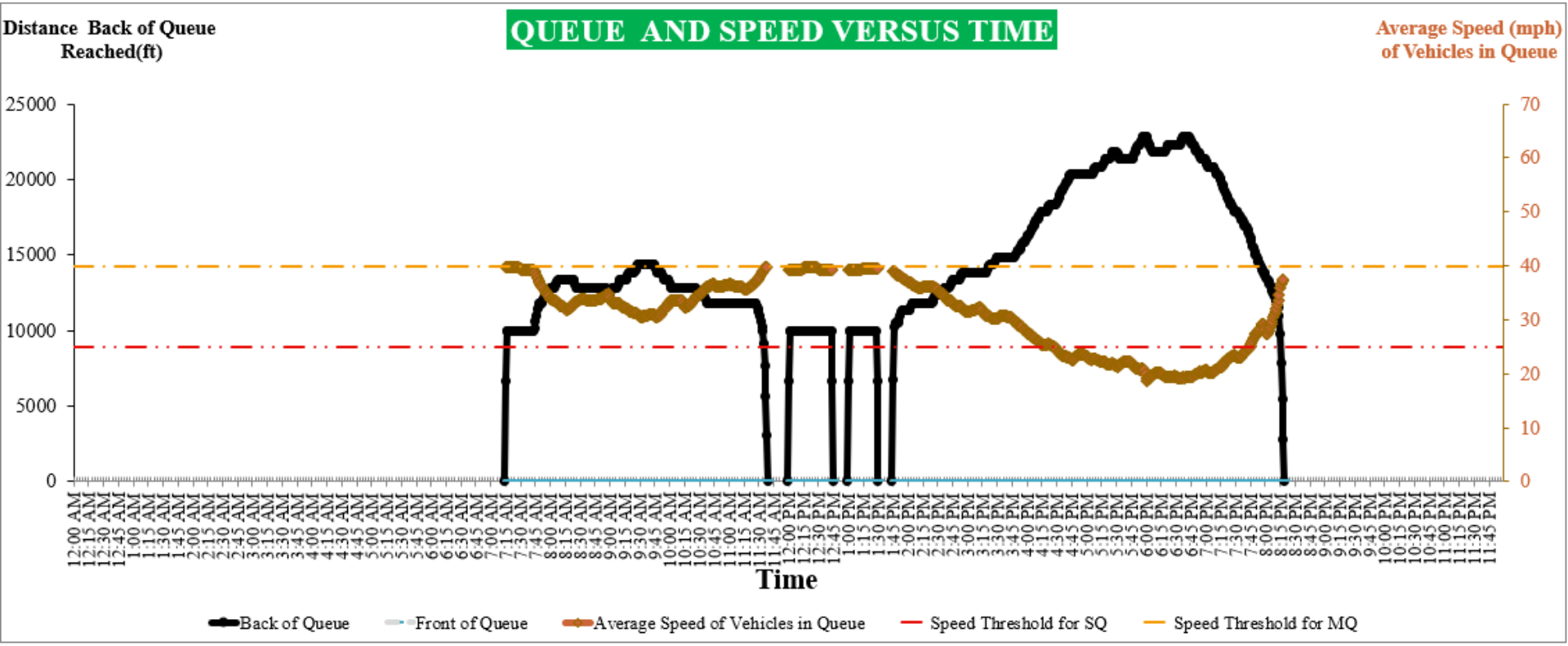
WorkZoneQ-Pro Output

9:00 AM	9:15 AM	157	98	0	13,340	13,340	32.9	$579.19	$627.15
9:15 AM	9:30 AM	194	89	0	14,340	14,340	31.6	$822.76	$870.87
9:30 AM	9:45 AM	188	92	0	14,340	14,340	30.8	$905.44	$953.11
9:45 AM	10:00 AM	138	111	0	13,340	13,340	31.5	$748.85	$794.71
10:00 AM	10:15 AM	130	110	0	12,840	12,840	33.6	$573.80	$621.52
10:15 AM	10:30 AM	107	125	0	12,340	12,340	33.2	$499.00	$545.01
10:30 AM	10:45 AM	76	162	0	11,840	11,840	35.8	$310.75	$355.48
10:45 AM	11:00 AM	78	158	0	11,840	11,840	36.2	$216.92	$259.73
11:00 AM	11:15 AM	89	139	0	11,840	11,840	36.2	$271.16	$315.30
11:15 AM	11:30 AM	68	167	0	11,340	11,340	36.3	$242.28	$285.86
11:30 AM	11:45 AM	0	167	0	0	0	38.8	$129.49	$169.15
11:45 AM	12:00 PM	0	-	-	-	-	-	$96.85	$131.75
12:00 PM	12:15 PM	56	180	0	10,000	10,000	39.3	$132.13	$173.76
12:15 PM	12:30 PM	56	180	0	10,000	10,000	39.7	$118.57	$157.37
12:30 PM	12:45 PM	56	180	0	10,000	10,000	39.3	$134.14	$176.31
12:45 PM	1:00 PM	0	180	0	0	0	-	$102.87	$139.16
1:00 PM	1:15 PM	56	180	0	10,000	10,000	39.3	$134.12	$176.38
1:15 PM	1:30 PM	56	180	0	10,000	10,000	39.6	$124.29	$164.61
1:30 PM	1:45 PM	0	180	0	0	0	-	$97.36	$132.01
1:45 PM	2:00 PM	68	168	0	11,340	11,340	38.1	$167.81	$210.38
2:00 PM	2:15 PM	86	144	0	11,840	11,840	36.3	$236.89	$279.74
2:15 PM	2:30 PM	97	137	0	12,340	12,340	36.0	$319.82	$364.83
2:30 PM	2:45 PM	141	109	0	13,340	13,340	34.3	$469.98	$516.37
2:45 PM	3:00 PM	174	94	0	13,840	13,840	32.3	$708.18	$755.47
3:00 PM	3:15 PM	161	101	0	13,840	13,840	31.9	$759.96	$807.08
3:15 PM	3:30 PM	207	89	0	14,840	14,840	30.6	$890.29	$936.51
3:30 PM	3:45 PM	212	87	0	14,840	14,840	30.6	$1,012.57	$1,059.86
3:45 PM	4:00 PM	281	76	0	16,040	16,040	29.0	$1,260.52	$1,308.33
4:00 PM	4:15 PM	363	67	0	17,840	17,840	26.6	$1,724.40	$1,772.16
4:15 PM	4:30 PM	387	66	0	18,340	18,340	25.3	$2,059.05	$2,106.76
4:30 PM	4:45 PM	461	64	0	20,340	20,340	23.4	$2,439.59	$2,486.08
4:45 PM	5:00 PM	467	63	0	20,340	20,340	23.3	$2,640.07	$2,688.11
5:00 PM	5:15 PM	496	61	0	20,840	20,840	22.7	$2,782.39	$2,829.99
5:15 PM	5:30 PM	528	61	0	21,840	21,840	21.9	$2,999.98	$3,046.79
5:30 PM	5:45 PM	527	59	0	21,340	21,340	21.9	$3,006.21	$3,054.92
5:45 PM	6:00 PM	580	59	0	22,840	22,840	21.0	$3,267.90	$3,314.40
6:00 PM	6:15 PM	576	56	0	21,840	21,840	19.6	$3,301.51	$3,347.39
6:15 PM	6:30 PM	579	58	0	22,340	22,340	19.6	$3,403.23	$3,447.30
6:30 PM	6:45 PM	573	60	0	22,840	22,840	19.3	$3,480.56	$3,523.65
6:45 PM	7:00 PM	515	61	0	21,340	21,340	20.0	$3,177.06	$3,220.71

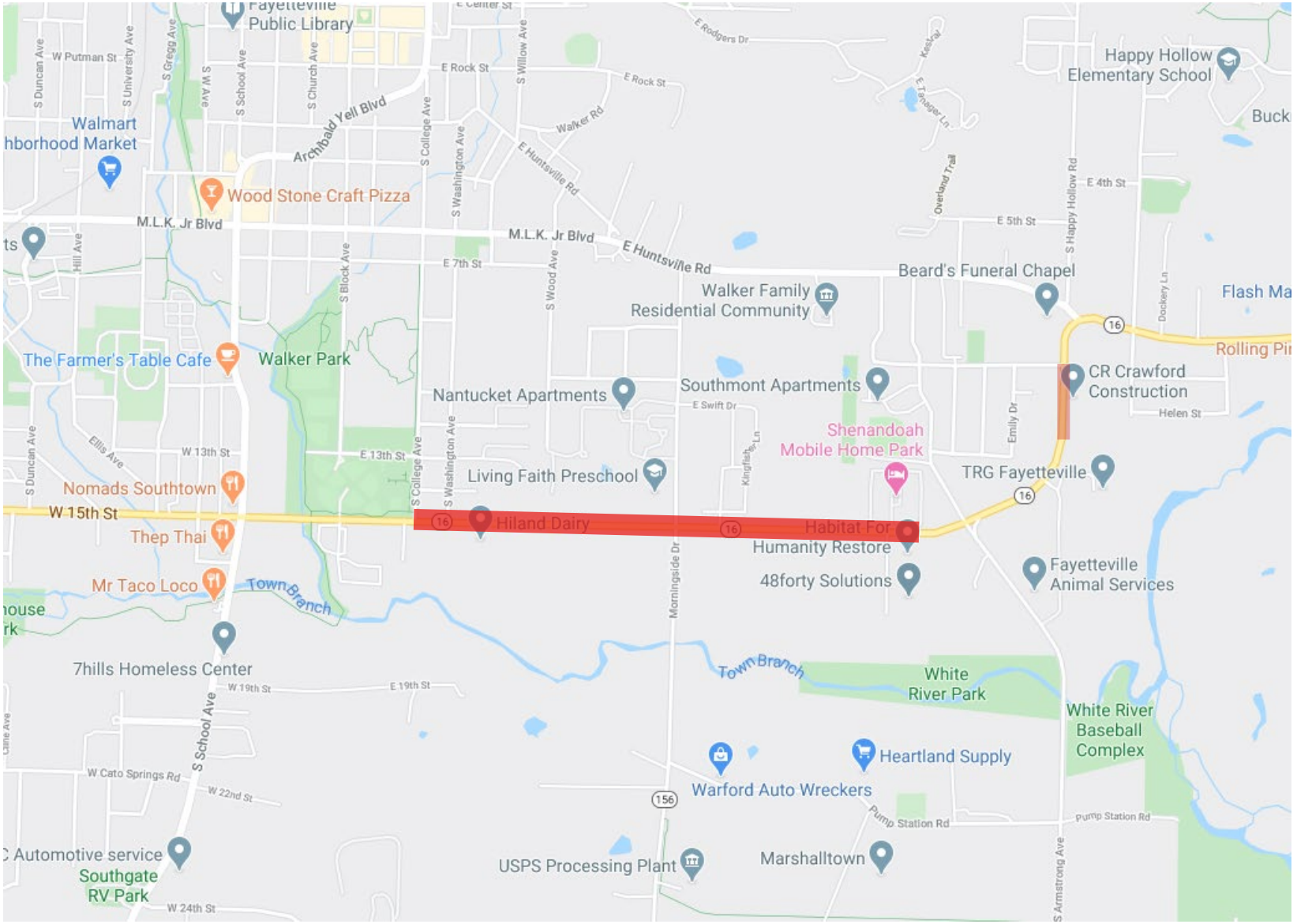
WorkZoneQ-Pro Output

7:00 PM	7:15 PM	438	65	0	20,207	20,207	20.5	$2,854.51	$2,896.37
7:15 PM	7:30 PM	355	68	0	17,840	17,840	22.5	$2,264.02	$2,306.98
7:30 PM	7:45 PM	276	77	0	16,340	16,340	23.7	$1,806.28	$1,847.80
7:45 PM	8:00 PM	171	96	0	13,840	13,840	27.6	$1,132.42	$1,176.84
8:00 PM	8:15 PM	58	180	0	11,228	11,228	30.0	$515.22	$555.01
8:15 PM	8:30 PM	0	180	0	0	0	36.8	$63.97	$85.39
8:30 PM	8:45 PM	0	-	-	-	-	-	$48.27	$66.97
8:45 PM	9:00 PM	0	-	-	-	-	-	$36.40	$52.84
9:00 PM	9:15 PM	0	-	-	-	-	-	$45.25	$63.35
9:15 PM	9:30 PM	0	-	-	-	-	-	$31.27	$46.48
9:30 PM	9:45 PM	0	-	-	-	-	-	$28.36	$42.15
9:45 PM	10:00 PM	0	-	-	-	-	-	$28.12	$41.80
10:00 PM	10:15 PM	0	-	-	-	-	-	$33.15	$49.21
10:15 PM	10:30 PM	0	-	-	-	-	-	$23.24	$34.54
10:30 PM	10:45 PM	0	-	-	-	-	-	$26.15	$38.87
10:45 PM	11:00 PM	0	-	-	-	-	-	$22.58	$33.56
11:00 PM	11:15 PM	0	-	-	-	-	-	$19.69	$29.27
11:15 PM	11:30 PM	0	-	-	-	-	-	$20.48	$30.45
11:30 PM	11:45 PM	0	-	-	-	-	-	$17.31	$25.73
11:45 PM	12:00 AM	0	-	-	-	-	-	$15.25	$22.66
					Maximum distance back-of-queue reached (ft)	Maximum distance queue occupied (ft)		SUM All	SUM All
*: At the end of the corresponding interval or when there is no more vehicle in queue					*22,840*	*22,840*		*$59,067.63*	*$61,916.04*

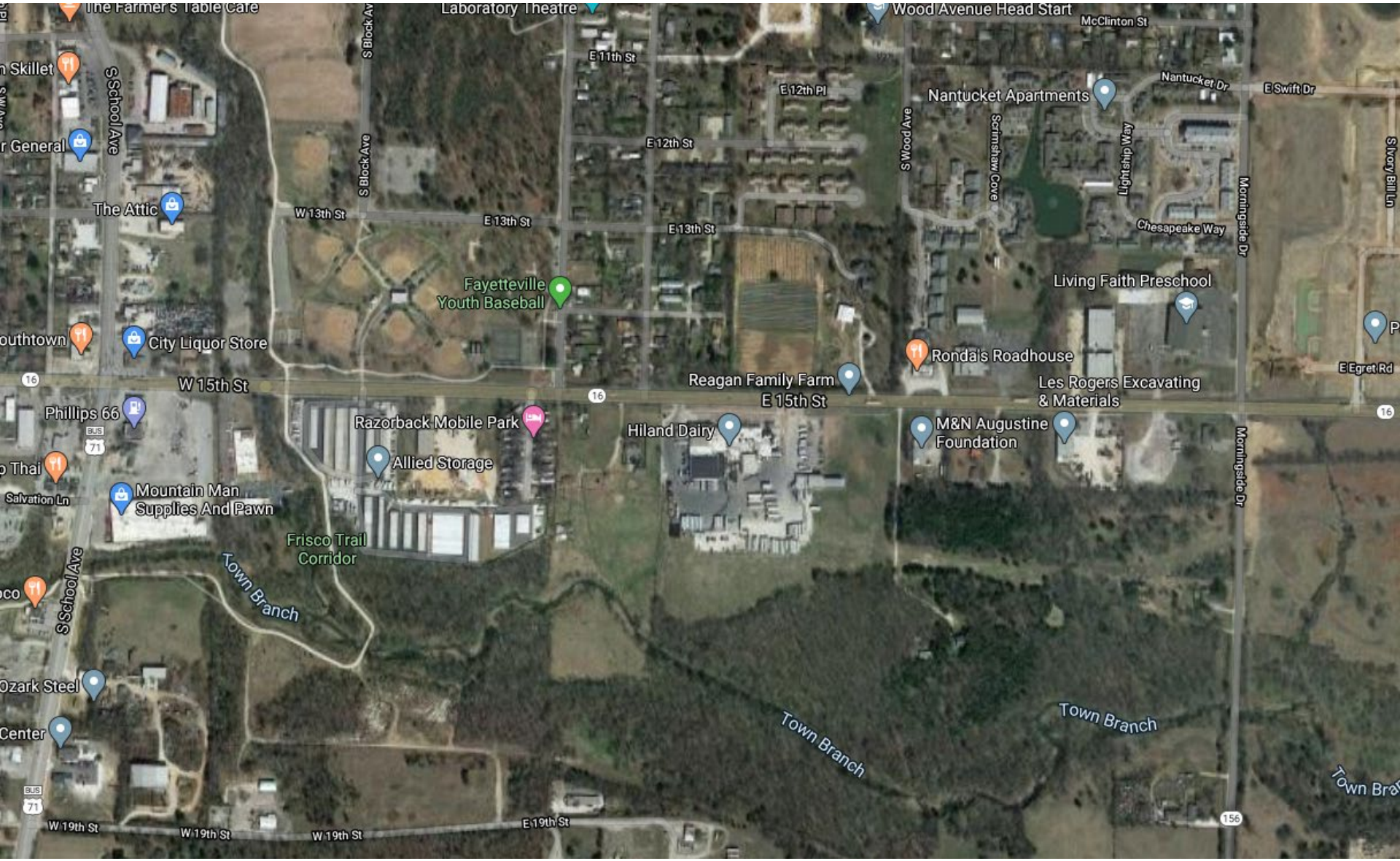
WorkZoneQ-Pro Output Cont.



Example 2: Route 16 at College Ave – Huntsville Road, Fayetteville, Arkansas



Description (Continued…)



Description (Continued…)

This project uses one lane closure on two lanes in urban arterial

Assumed description:

Lane width = 11 ft

Shoulder width = 2 ft (right: 2 ft and left: 0 ft)

Rural area and level terrain

Speed limit outside is 35 mph

Clear weather condition

Assumed night-time: 6 PM – 6 AM

WZ conditions:

WZ speed limit = 35 mph

Workers separated by drum barrier and moderate work intensity

Use default Passenger Car Equivalency (PCE) factors

Description (Continued…)

Traffic Demand:

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)	Heavy vehicle adjustment factor	Adjusted demand (pcph)	Capacity (vphpl)
12:00 AM	12:15 AM	0.0	6.3	0.0	16	0.94	68	737
12:15 AM	12:30 AM	0.0	0.0	0.0	11	1.00	44	783
12:30 AM	12:45 AM	0.0	0.0	0.0	5	1.00	20	783
12:45 AM	1:00 AM	0.0	16.7	0.0	12	0.86	56	671
1:00 AM	1:15 AM	0.0	15.4	0.0	13	0.87	60	678
1:15 AM	1:30 AM	0.0	0.0	16.7	6	0.86	28	671
1:30 AM	1:45 AM	0.0	0.0	25.0	4	0.80	20	626
1:45 AM	2:00 AM	0.0	25.0	25.0	4	0.67	24	522
2:00 AM	2:15 AM	0.0	0.0	0.0	8	1.00	32	783
2:15 AM	2:30 AM	0.0	0.0	0.0	15	1.00	60	783
2:30 AM	2:45 AM	0.0	14.3	14.3	7	0.78	36	609
2:45 AM	3:00 AM	0.0	0.0	0.0	15	1.00	60	783
3:00 AM	3:15 AM	0.0	10.5	5.3	19	0.86	88	676
3:15 AM	3:30 AM	0.0	0.0	33.3	3	0.75	16	587
3:30 AM	3:45 AM	0.0	16.7	0.0	12	0.86	56	671
3:45 AM	4:00 AM	0.0	20.0	0.0	5	0.83	24	652
4:00 AM	4:15 AM	0.0	0.0	18.8	16	0.84	76	659
4:15 AM	4:30 AM	0.0	26.7	6.7	15	0.75	80	587
4:30 AM	4:45 AM	0.0	0.0	0.0	14	1.00	56	783
4:45 AM	5:00 AM	0.0	0.0	0.0	17	1.00	68	783
5:00 AM	5:15 AM	0.0	5.6	5.6	18	0.90	80	704
5:15 AM	5:30 AM	0.0	5.0	0.0	20	0.95	84	745
5:30 AM	5:45 AM	0.0	6.7	6.7	30	0.88	136	691
5:45 AM	6:00 AM	0.0	4.6	6.2	65	0.90	288	707
6:00 AM	6:15 AM	0.0	2.5	6.3	79	0.92	344	773
6:15 AM	6:30 AM	0.0	4.1	10.2	49	0.88	224	736
6:30 AM	6:45 AM	0.0	2.3	17.2	87	0.84	416	704
6:45 AM	7:00 AM	0.0	3.4	5.1	117	0.92	508	775
7:00 AM	7:15 AM	0.0	3.2	4.0	126	0.93	540	786
7:15 AM	7:30 AM	0.0	4.0	4.0	125	0.93	540	779
7:30 AM	7:45 AM	0.0	2.1	4.2	95	0.94	404	792
7:45 AM	8:00 AM	0.0	4.7	3.1	127	0.93	548	780
8:00 AM	8:15 AM	0.0	3.6	3.6	167	0.93	716	785
8:15 AM	8:30 AM	0.0	4.2	4.2	118	0.92	512	776
8:30 AM	8:45 AM	0.0	4.3	5.2	115	0.91	504	768
8:45 AM	9:00 AM	0.0	4.2	7.4	95	0.90	424	754
9:00 AM	9:15 AM	0.0	4.3	6.0	116	0.91	512	763
9:15 AM	9:30 AM	0.0	9.6	12.3	73	0.82	356	690
9:30 AM	9:45 AM	0.0	6.5	9.8	92	0.86	428	724
9:45 AM	10:00 AM	0.0	2.2	8.7	92	0.90	408	759
10:00 AM	10:15 AM	0.0	4.9	7.3	82	0.89	368	750
10:15 AM	10:30 AM	0.0	4.4	10.0	90	0.87	412	735
10:30 AM	10:45 AM	0.0	6.8	8.0	88	0.87	404	733
10:45 AM	11:00 AM	0.0	6.4	11.5	78	0.85	368	714
11:00 AM	11:15 AM	0.0	9.7	2.8	72	0.89	324	748
11:15 AM	11:30 AM	0.0	9.4	5.2	96	0.87	440	735
11:30 AM	11:45 AM	0.0	5.2	2.1	97	0.93	416	785
11:45 AM	12:00 PM	0.0	11.2	6.7	89	0.85	420	713
12:00 PM	12:15 PM	0.0	7.8	6.9	116	0.87	532	734
12:15 PM	12:30 PM	0.0	2.5	14.2	120	0.86	560	721
12:30 PM	12:45 PM	0.0	5.7	4.1	123	0.91	540	767
12:45 PM	1:00 PM	0.0	5.2	2.6	116	0.93	500	781
1:00 PM	1:15 PM	0.0	7.3	4.1	123	0.90	548	756
1:15 PM	1:30 PM	0.0	7.3	9.8	123	0.85	576	719
1:30 PM	1:45 PM	0.0	6.1	9.6	115	0.86	532	728
1:45 PM	2:00 PM	0.0	3.8	3.8	106	0.93	456	783
2:00 PM	2:15 PM	0.0	4.1	5.1	98	0.92	428	771
2:15 PM	2:30 PM	0.0	3.0	8.2	134	0.90	596	757
2:30 PM	2:45 PM	0.0	3.0	4.5	134	0.93	576	783
2:45 PM	3:00 PM	0.0	1.5	0.7	136	0.98	556	824

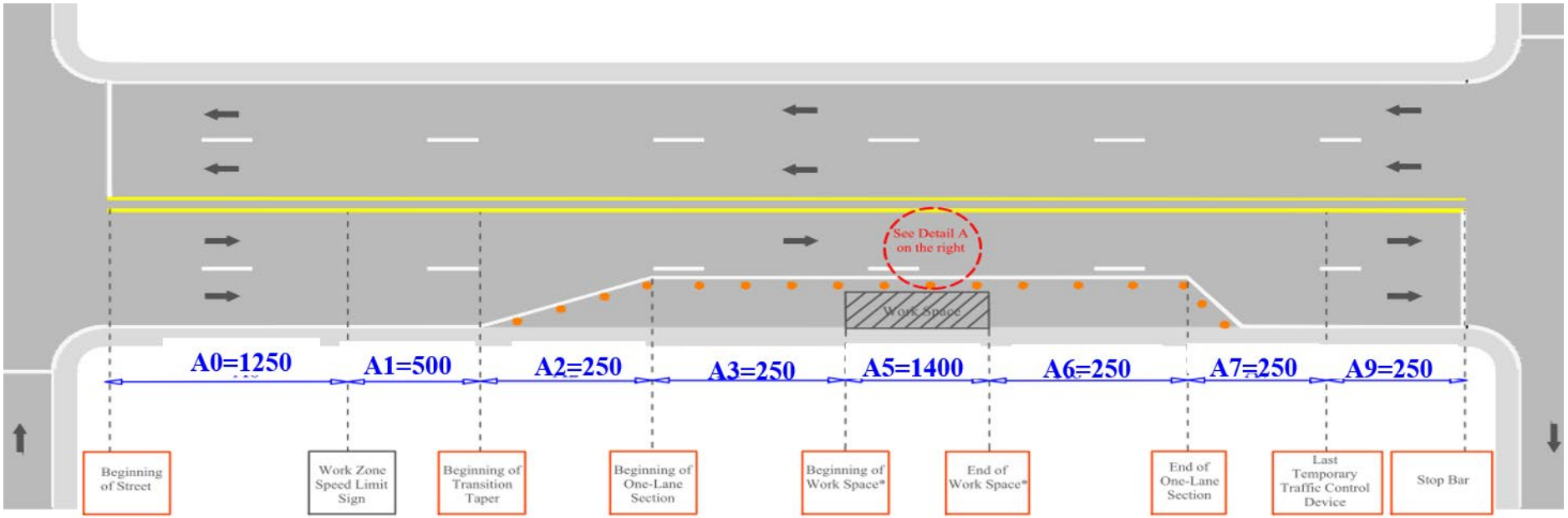
Description (Continued…)

Traffic Demand:

3:00 PM	3:15 PM	0.0	4.4	6.2	113	0.90	500	761
3:15 PM	3:30 PM	0.0	4.0	2.7	149	0.94	636	789
3:30 PM	3:45 PM	0.0	2.2	6.6	136	0.92	592	773
3:45 PM	4:00 PM	0.0	0.6	4.3	163	0.95	684	802
4:00 PM	4:15 PM	0.0	1.6	7.2	125	0.92	544	774
4:15 PM	4:30 PM	0.0	1.2	5.4	168	0.94	716	790
4:30 PM	4:45 PM	0.0	1.4	7.2	138	0.92	600	774
4:45 PM	5:00 PM	0.0	1.2	3.1	163	0.96	680	807
5:00 PM	5:15 PM	0.0	0.0	2.8	144	0.97	592	819
5:15 PM	5:30 PM	0.0	2.2	1.1	186	0.97	768	815
5:30 PM	5:45 PM	0.0	3.2	0.0	156	0.97	644	816
5:45 PM	6:00 PM	0.0	1.1	0.6	177	0.98	720	828
6:00 PM	6:15 PM	0.0	0.6	1.3	154	0.98	628	768
6:15 PM	6:30 PM	0.0	2.2	0.7	139	0.97	572	761
6:30 PM	6:45 PM	0.0	0.9	1.7	116	0.97	476	763
6:45 PM	7:00 PM	0.0	1.0	1.0	104	0.98	424	768
7:00 PM	7:15 PM	0.0	0.0	4.1	98	0.96	408	752
7:15 PM	7:30 PM	0.0	1.2	1.2	82	0.98	336	764
7:30 PM	7:45 PM	0.0	1.3	1.3	77	0.97	316	763
7:45 PM	8:00 PM	0.0	3.7	0.0	54	0.96	224	755
8:00 PM	8:15 PM	0.0	1.6	1.6	62	0.97	256	758
8:15 PM	8:30 PM	0.0	1.6	0.0	63	0.98	256	771
8:30 PM	8:45 PM	0.0	7.8	0.0	51	0.93	220	726
8:45 PM	9:00 PM	0.0	3.5	0.0	57	0.97	236	756
9:00 PM	9:15 PM	0.0	0.0	0.0	37	1.00	148	783
9:15 PM	9:30 PM	0.0	0.0	0.0	44	1.00	176	783
9:30 PM	9:45 PM	0.0	0.0	3.2	31	0.97	128	758
9:45 PM	10:00 PM	0.0	0.0	0.0	30	1.00	120	783
10:00 PM	10:15 PM	0.0	0.0	0.0	27	1.00	108	783
10:15 PM	10:30 PM	0.0	0.0	5.0	20	0.95	84	745
10:30 PM	10:45 PM	0.0	0.0	0.0	26	1.00	104	783
10:45 PM	11:00 PM	0.0	8.6	2.9	35	0.90	156	702
11:00 PM	11:15 PM	0.0	5.0	5.0	20	0.91	88	712
11:15 PM	11:30 PM	0.0	0.0	0.0	30	1.00	120	783
11:30 PM	11:45 PM	0.0	0.0	0.0	22	1.00	88	783
11:45 PM	12:00 AM	0.0	4.5	0.0	22	0.96	92	749

Geometric Data

Geometric data: Longitudinal distances for 2-to-1 in the sketch below



WorkZoneQ-Pro output

Start of Interval	End of Interval	No. of vehicles in queue in the link*	Average spacing between vehicles in queue (ft)	Front-of-Queue (ft)	Back-of-Queue (ft)	Distance queue occupied (ft)	Average speed in queue (mph)	Summary of Users' Costs ($) All (SQ+MQ+SMV)	
								Based on WZ speed limit	Based on speed limit outside of the WZ
12:00 AM	12:15 AM	1	180	0	1,400	1,400	23.0	$1.67	$1.67
12:15 AM	12:30 AM	1	180	0	1,400	1,400	23.0	$1.14	$1.14
12:30 AM	12:45 AM	0	180	0	1,400	1,400	23.0	$0.52	$0.52
12:45 AM	1:00 AM	1	180	0	1,400	1,400	23.0	$1.27	$1.27
1:00 AM	1:15 AM	1	180	0	1,400	1,400	23.0	$1.38	$1.38
1:15 AM	1:30 AM	0	180	0	1,400	1,400	23.0	$0.68	$0.68
1:30 AM	1:45 AM	0	180	0	1,400	1,400	23.0	$0.48	$0.48
1:45 AM	2:00 AM	0	180	0	1,400	1,400	23.0	$0.49	$0.49
2:00 AM	2:15 AM	0	180	0	1,400	1,400	23.0	$0.83	$0.83
2:15 AM	2:30 AM	1	180	0	1,400	1,400	23.0	$1.56	$1.56
2:30 AM	2:45 AM	0	180	0	1,400	1,400	23.0	$0.80	$0.80
2:45 AM	3:00 AM	1	180	0	1,400	1,400	23.0	$1.56	$1.56
3:00 AM	3:15 AM	1	180	0	1,400	1,400	23.0	$2.06	$2.06
3:15 AM	3:30 AM	0	180	0	1,400	1,400	23.0	$0.37	$0.37
3:30 AM	3:45 AM	1	180	0	1,400	1,400	23.0	$1.27	$1.27
3:45 AM	4:00 AM	0	180	0	1,400	1,400	23.0	$0.53	$0.53
4:00 AM	4:15 AM	1	180	0	1,400	1,400	23.0	$1.85	$1.85
4:15 AM	4:30 AM	1	180	0	1,400	1,400	23.0	$1.68	$1.68
4:30 AM	4:45 AM	1	180	0	1,400	1,400	23.0	$1.45	$1.45
4:45 AM	5:00 AM	1	180	0	1,400	1,400	23.0	$1.76	$1.76
5:00 AM	5:15 AM	1	180	0	1,400	1,400	23.0	$1.94	$1.94
5:15 AM	5:30 AM	1	180	0	1,400	1,400	23.0	$2.09	$2.09
5:30 AM	5:45 AM	1	180	0	1,400	1,400	23.0	$3.27	$3.27
5:45 AM	6:00 AM	3	180	0	1,400	1,400	23.0	$7.04	$7.04
6:00 AM	6:15 AM	3	180	0	1,400	1,400	24.9	$6.66	$6.66
6:15 AM	6:30 AM	0	416	0	0	0	-	$4.16	$4.16
6:30 AM	6:45 AM	4	180	0	1,400	1,400	24.3	$8.43	$8.43
6:45 AM	7:00 AM	5	180	0	1,400	1,400	23.8	$11.30	$11.30
7:00 AM	7:15 AM	6	180	0	1,400	1,400	23.7	$12.28	$12.28
7:15 AM	7:30 AM	6	180	0	1,400	1,400	23.7	$12.19	$12.19
7:30 AM	7:45 AM	4	180	0	1,400	1,400	24.4	$8.46	$8.46
7:45 AM	8:00 AM	6	180	0	1,400	1,400	23.7	$12.39	$12.39

WorkZoneQ-Pro output

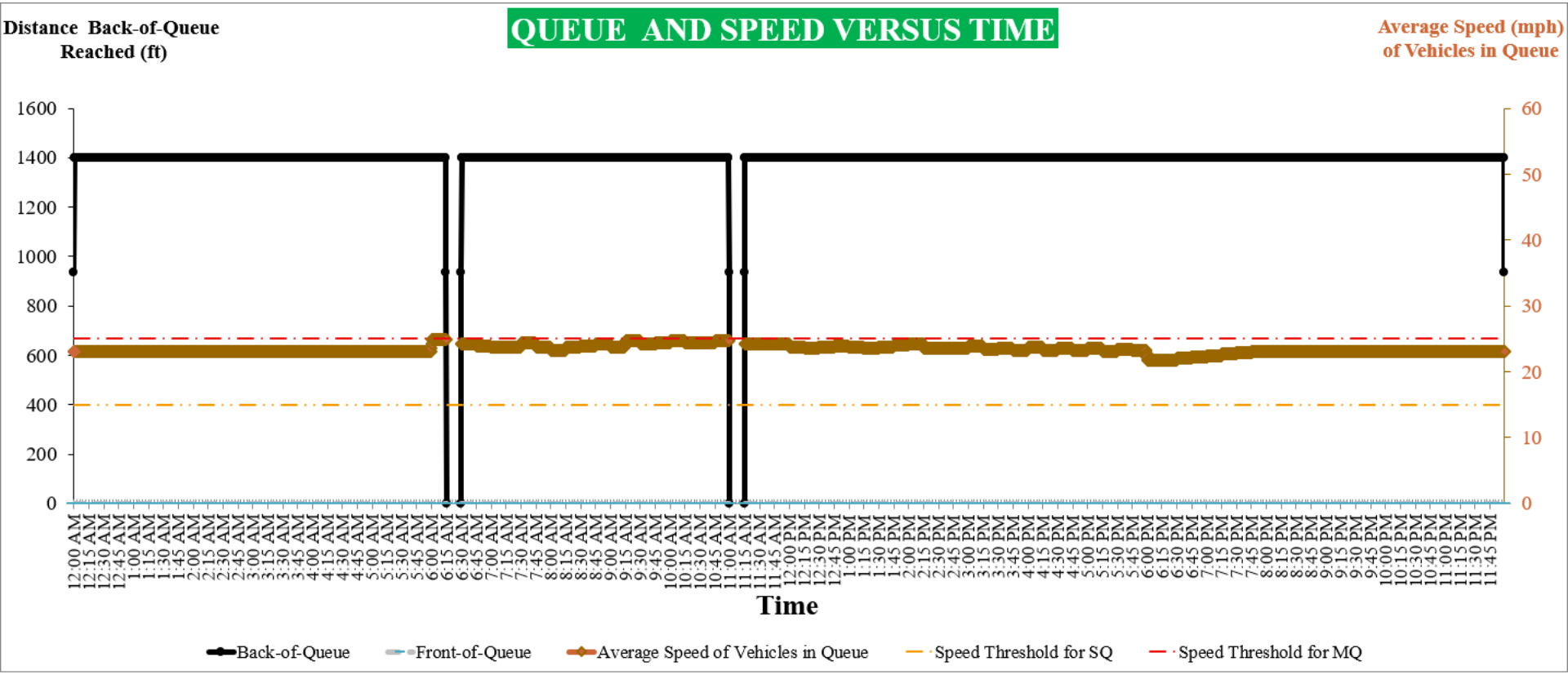
8:00 AM	8:15 AM	8	180	0	1,400	1,400	23.2	$17.26	$17.26
8:15 AM	8:30 AM	5	180	0	1,400	1,400	23.8	$11.37	$11.37
8:30 AM	8:45 AM	5	180	0	1,400	1,400	23.8	$11.10	$11.10
8:45 AM	9:00 AM	4	180	0	1,400	1,400	24.3	$8.79	$8.79
9:00 AM	9:15 AM	5	180	0	1,400	1,400	23.8	$11.30	$11.30
9:15 AM	9:30 AM	3	180	0	1,400	1,400	24.8	$6.53	$6.53
9:30 AM	9:45 AM	4	180	0	1,400	1,400	24.2	$8.69	$8.69
9:45 AM	10:00 AM	4	180	0	1,400	1,400	24.4	$8.44	$8.44
10:00 AM	10:15 AM	4	180	0	1,400	1,400	24.7	$7.19	$7.19
10:15 AM	10:30 AM	4	180	0	1,400	1,400	24.3	$8.37	$8.37
10:30 AM	10:45 AM	4	180	0	1,400	1,400	24.4	$8.06	$8.06
10:45 AM	11:00 AM	3	180	0	1,400	1,400	24.7	$7.02	$7.02
11:00 AM	11:15 AM	0	417	0	0	0	-	$5.90	$5.90
11:15 AM	11:30 AM	4	180	0	1,400	1,400	24.2	$8.95	$8.95
11:30 AM	11:45 AM	4	180	0	1,400	1,400	24.3	$8.66	$8.66
11:45 AM	12:00 PM	4	180	0	1,400	1,400	24.3	$8.26	$8.26
12:00 PM	12:15 PM	5	180	0	1,400	1,400	23.7	$11.52	$11.52
12:15 PM	12:30 PM	5	180	0	1,400	1,400	23.6	$12.49	$12.49
12:30 PM	12:45 PM	6	180	0	1,400	1,400	23.7	$12.03	$12.03
12:45 PM	1:00 PM	5	180	0	1,400	1,400	23.9	$11.01	$11.01
1:00 PM	1:15 PM	6	180	0	1,400	1,400	23.7	$12.10	$12.10
1:15 PM	1:30 PM	6	180	0	1,400	1,400	23.6	$12.66	$12.66
1:30 PM	1:45 PM	5	180	0	1,400	1,400	23.7	$11.57	$11.57
1:45 PM	2:00 PM	5	180	0	1,400	1,400	24.1	$9.84	$9.84
2:00 PM	2:15 PM	4	180	0	1,400	1,400	24.2	$8.98	$8.98
2:15 PM	2:30 PM	6	180	0	1,400	1,400	23.5	$13.70	$13.70
2:30 PM	2:45 PM	6	180	0	1,400	1,400	23.6	$13.30	$13.30
2:45 PM	3:00 PM	6	180	0	1,400	1,400	23.7	$13.06	$13.06
3:00 PM	3:15 PM	5	180	0	1,400	1,400	23.9	$10.94	$10.94
3:15 PM	3:30 PM	7	180	0	1,400	1,400	23.4	$14.98	$14.98
3:30 PM	3:45 PM	6	180	0	1,400	1,400	23.5	$13.74	$13.74
3:45 PM	4:00 PM	7	180	0	1,400	1,400	23.3	$16.71	$16.71
4:00 PM	4:15 PM	6	180	0	1,400	1,400	23.7	$12.40	$12.40
4:15 PM	4:30 PM	8	180	0	1,400	1,400	23.2	$17.49	$17.49
4:30 PM	4:45 PM	6	180	0	1,400	1,400	23.5	$14.02	$14.02
4:45 PM	5:00 PM	7	180	0	1,400	1,400	23.3	$16.58	$16.58

WorkZoneQ-Pro output

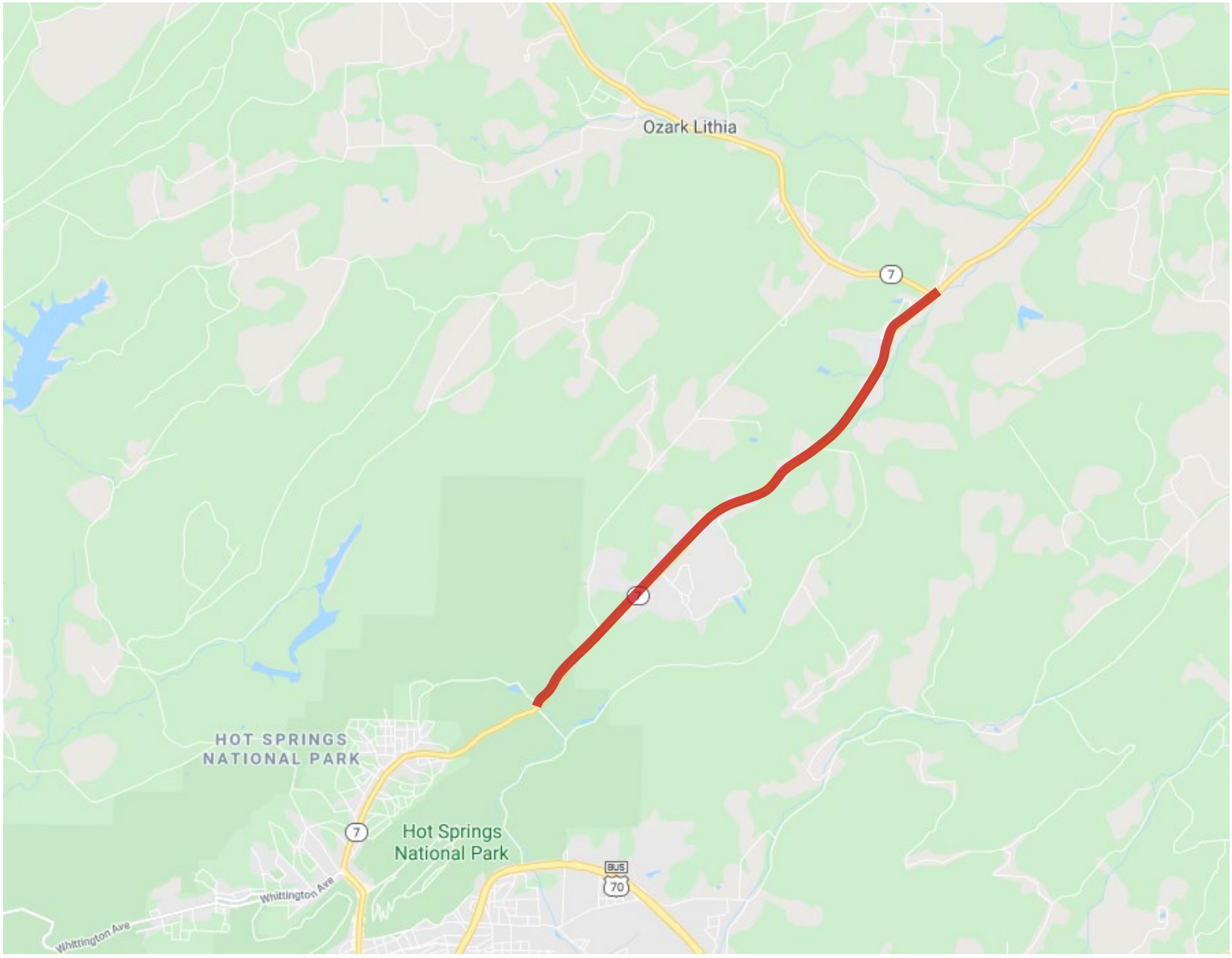
5:00 PM	5:15 PM	6	180	0	1,400	1,400	23.5	$14.18	$14.18
5:15 PM	5:30 PM	9	164	0	1,400	1,400	23.1	$19.46	$19.46
5:30 PM	5:45 PM	7	180	0	1,400	1,400	23.4	$15.46	$15.46
5:45 PM	6:00 PM	8	173	0	1,400	1,400	23.2	$17.93	$17.93
6:00 PM	6:15 PM	8	180	0	1,400	1,400	21.7	$20.52	$20.52
6:15 PM	6:30 PM	7	180	0	1,400	1,400	21.8	$17.87	$17.87
6:30 PM	6:45 PM	6	180	0	1,400	1,400	22.1	$13.79	$13.79
6:45 PM	7:00 PM	5	180	0	1,400	1,400	22.3	$11.91	$11.91
7:00 PM	7:15 PM	5	180	0	1,400	1,400	22.3	$11.32	$11.32
7:15 PM	7:30 PM	4	180	0	1,400	1,400	22.8	$8.86	$8.86
7:30 PM	7:45 PM	4	180	0	1,400	1,400	22.9	$8.16	$8.16
7:45 PM	8:00 PM	2	180	0	1,400	1,400	23.0	$5.63	$5.63
8:00 PM	8:15 PM	3	180	0	1,400	1,400	23.0	$6.51	$6.51
8:15 PM	8:30 PM	3	180	0	1,400	1,400	23.0	$6.55	$6.55
8:30 PM	8:45 PM	2	180	0	1,400	1,400	23.0	$5.35	$5.35
8:45 PM	9:00 PM	3	180	0	1,400	1,400	23.0	$5.94	$5.94
9:00 PM	9:15 PM	2	180	0	1,400	1,400	23.0	$3.84	$3.84
9:15 PM	9:30 PM	2	180	0	1,400	1,400	23.0	$4.57	$4.57
9:30 PM	9:45 PM	1	180	0	1,400	1,400	23.0	$3.28	$3.28
9:45 PM	10:00 PM	1	180	0	1,400	1,400	23.0	$3.11	$3.11
10:00 PM	10:15 PM	1	180	0	1,400	1,400	23.0	$2.80	$2.80
10:15 PM	10:30 PM	1	180	0	1,400	1,400	23.0	$2.14	$2.14
10:30 PM	10:45 PM	1	180	0	1,400	1,400	23.0	$2.70	$2.70
10:45 PM	11:00 PM	2	180	0	1,400	1,400	23.0	$3.74	$3.74
11:00 PM	11:15 PM	1	180	0	1,400	1,400	23.0	$2.15	$2.15
11:15 PM	11:30 PM	1	180	0	1,400	1,400	23.0	$3.11	$3.11
11:30 PM	11:45 PM	1	180	0	1,400	1,400	23.0	$2.28	$2.28
11:45 PM	12:00 AM	1	180	0	1,400	1,400	23.0	$2.30	$2.30
					Maximum distance back-of-queue reached (ft)	Maximum distance queue occupied (ft)		SUM All	SUM All
					1,400	*1,400*		*$744.04*	*$744.04*

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

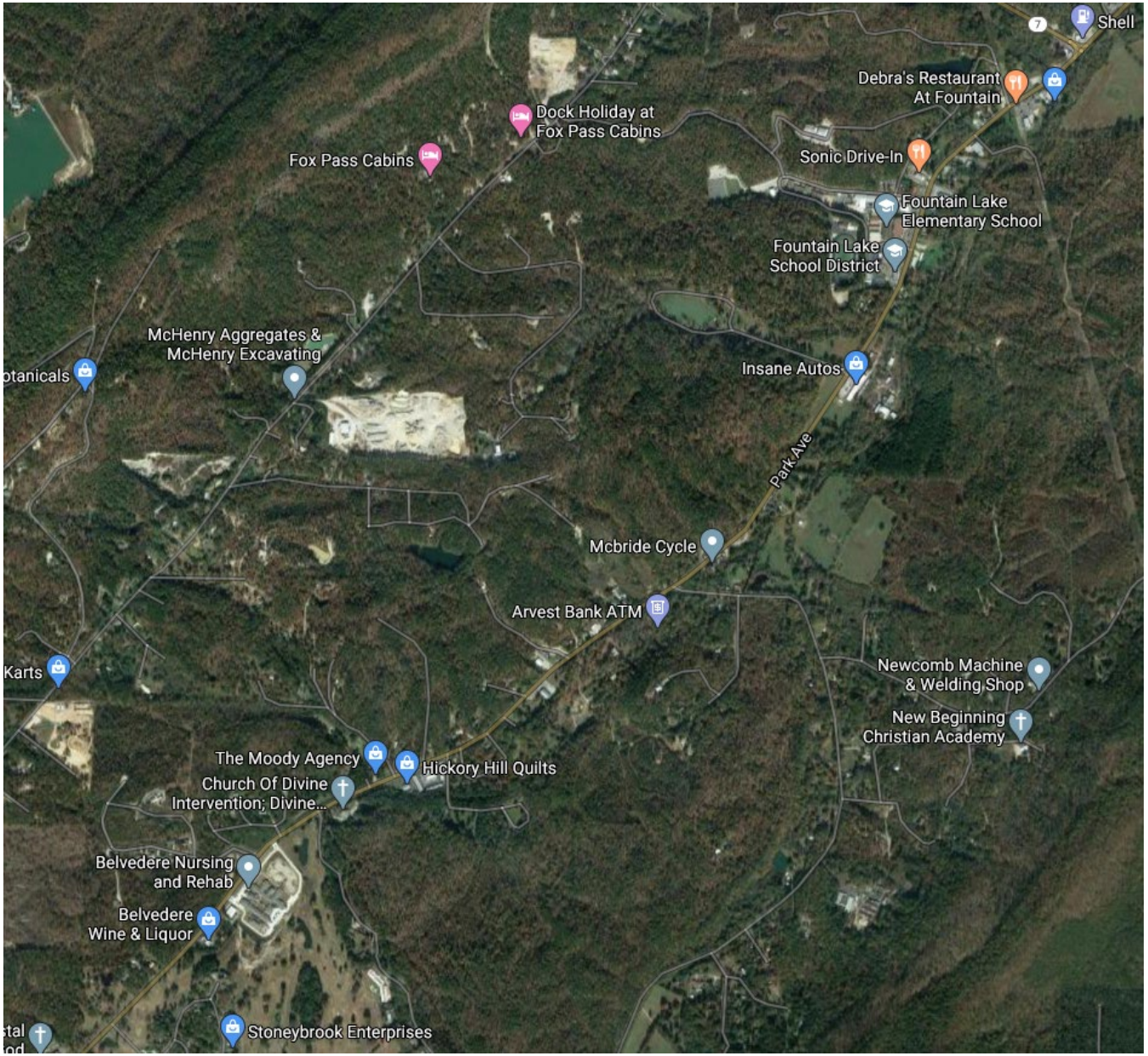
WorkZoneQ-Pro output Cont.



Example 3: One-Lane Operation on HWY. 7S – HWY. 5 (S), Garland County, Arkansas



Description (Continued…)



Description (Continued…)

This illustrated project is one-lane two-way operation

Description:

Lane width = 11 ft, and right shoulder width = 4 ft

Rural area and level terrain

Speed limit outside = 40 mph

Assumed WZ conditions:

Work space speed limit = 40 mph

Moderate work intensity, workers are separated with drums

Description (Continued…)

Volume conditions:

Start of Interval	End of Interval	Traffic Info for CLOSED direction						Traffic Info for OPEN direction					
		Percentage of trucks (%)	Percentage of recreational vehicles (%)	Expected traffic volume during the interval (veh)	Heavy vehicle adjustment factor	Adjusted volume (pcph)	Capacity (vphpl)	Percentage of trucks (%)	Percentage of recreational vehicles (%)	Expected traffic volume during the interval (veh)	Heavy vehicle adjustment factor	Adjusted volume (pcph)	Capacity (vphpl)
12:00 AM	12:15 AM	0.0	11.1	9	0.90	40	360	0.0	0.0	15	1.00	60	633
12:15 AM	12:30 AM	0.0	0.0	6	1.00	24	400	0.0	0.0	4	1.00	16	633
12:30 AM	12:45 AM	0.0	0.0	14	1.00	56	400	0.0	0.0	9	1.00	36	633
12:45 AM	1:00 AM	0.0	0.0	10	1.00	40	400	0.0	0.0	5	1.00	20	633
1:00 AM	1:15 AM	0.0	0.0	9	1.00	36	400	0.0	0.0	5	1.00	20	633
1:15 AM	1:30 AM	0.0	0.0	5	1.00	20	400	0.0	0.0	5	1.00	20	633
1:30 AM	1:45 AM	0.0	0.0	5	1.00	20	400	0.0	0.0	6	1.00	24	633
1:45 AM	2:00 AM	0.0	0.0	4	1.00	16	400	0.0	0.0	6	1.00	24	633
2:00 AM	2:15 AM	0.0	0.0	5	1.00	20	400	0.0	0.0	6	1.00	24	633
2:15 AM	2:30 AM	0.0	0.0	3	1.00	12	400	25.0	0.0	4	0.80	20	507
2:30 AM	2:45 AM	0.0	0.0	4	1.00	16	400	0.0	0.0	5	1.00	20	633
2:45 AM	3:00 AM	0.0	0.0	7	1.00	28	400	0.0	0.0	1	1.00	4	633
3:00 AM	3:15 AM	20.0	0.0	5	0.83	24	333	0.0	0.0	2	1.00	8	633
3:15 AM	3:30 AM	0.0	0.0	4	1.00	16	400	0.0	0.0	4	1.00	16	633
3:30 AM	3:45 AM	0.0	0.0	6	1.00	24	400	0.0	0.0	1	1.00	4	633
3:45 AM	4:00 AM	0.0	0.0	3	1.00	12	400	0.0	0.0	4	1.00	16	633
4:00 AM	4:15 AM	0.0	0.0	3	1.00	12	400	0.0	0.0	7	1.00	28	633
4:15 AM	4:30 AM	0.0	0.0	7	1.00	28	400	0.0	0.0	4	1.00	16	633
4:30 AM	4:45 AM	0.0	10.0	10	0.91	44	363	0.0	0.0	0	1.00	0	633
4:45 AM	5:00 AM	0.0	0.0	8	1.00	32	400	0.0	0.0	13	1.00	52	633
5:00 AM	5:15 AM	0.0	0.0	6	1.00	24	400	0.0	0.0	11	1.00	44	633
5:15 AM	5:30 AM	0.0	0.0	10	1.00	40	400	0.0	0.0	11	1.00	44	633
5:30 AM	5:45 AM	7.1	0.0	14	0.93	60	373	0.0	0.0	21	1.00	84	633
5:45 AM	6:00 AM	8.3	0.0	12	0.92	52	369	0.0	0.0	31	1.00	124	633
6:00 AM	6:15 AM	0.0	0.0	16	1.00	64	400	0.0	0.0	24	1.00	96	633
6:15 AM	6:30 AM	0.0	4.0	25	0.96	104	384	2.3	0.0	44	0.98	180	619
6:30 AM	6:45 AM	0.0	2.8	36	0.97	148	389	0.0	0.0	62	1.00	248	633
6:45 AM	7:00 AM	0.0	0.0	50	1.00	200	400	0.0	0.0	50	1.00	200	633
7:00 AM	7:15 AM	1.8	0.0	57	0.98	232	393	0.0	1.4	74	0.99	300	625
7:15 AM	7:30 AM	3.0	1.5	66	0.96	276	382	0.0	1.2	82	0.99	332	626

Description (Continued…)

Volume conditions:

7:30 AM	7:45 AM	0.0	0.0	96	1.00	384	400	0.0	0.8	123	0.99	496	628
7:45 AM	8:00 AM	2.1	0.0	95	0.98	388	391	2.0	0.7	152	0.97	624	617
8:00 AM	8:15 AM	0.0	3.6	55	0.96	228	385	1.7	0.6	180	0.98	736	620
8:15 AM	8:30 AM	1.4	1.4	74	0.97	304	389	1.5	0.8	132	0.98	540	619
8:30 AM	8:45 AM	3.1	0.0	64	0.97	264	387	1.1	1.1	89	0.98	364	619
8:45 AM	9:00 AM	2.1	4.2	48	0.94	204	376	0.0	0.0	83	1.00	332	633
9:00 AM	9:15 AM	0.0	0.0	50	1.00	200	400	1.1	0.0	94	0.99	380	627
9:15 AM	9:30 AM	1.6	0.0	61	0.98	248	393	0.0	2.6	76	0.97	312	617
9:30 AM	9:45 AM	4.8	3.2	62	0.93	268	370	1.1	1.1	89	0.98	364	619
9:45 AM	10:00 AM	1.7	0.0	60	0.98	244	393	1.0	1.0	105	0.98	428	621
10:00 AM	10:15 AM	6.8	1.7	59	0.92	256	368	4.4	2.2	91	0.94	388	594
10:15 AM	10:30 AM	0.0	0.0	46	1.00	184	400	6.7	1.1	89	0.93	384	587
10:30 AM	10:45 AM	1.6	0.0	63	0.98	256	393	5.3	0.0	57	0.95	240	602
10:45 AM	11:00 AM	4.1	0.0	74	0.96	308	384	0.0	1.3	76	0.99	308	625
11:00 AM	11:15 AM	6.1	1.2	82	0.93	352	372	2.9	0.0	69	0.97	284	615
11:15 AM	11:30 AM	2.4	1.2	84	0.97	348	386	7.5	1.5	67	0.92	292	581
11:30 AM	11:45 AM	1.6	1.6	62	0.97	256	387	1.3	0.0	76	0.99	308	625
11:45 AM	12:00 PM	4.3	1.4	70	0.95	296	378	3.8	5.1	79	0.92	344	582
12:00 PM	12:15 PM	1.6	1.6	62	0.97	256	387	3.1	0.0	64	0.97	264	614
12:15 PM	12:30 PM	1.5	3.1	65	0.96	272	382	1.4	1.4	72	0.97	296	616
12:30 PM	12:45 PM	0.0	0.0	63	1.00	252	400	1.2	1.2	82	0.98	336	618
12:45 PM	1:00 PM	4.7	1.6	64	0.94	272	376	2.5	0.0	81	0.98	332	618
1:00 PM	1:15 PM	3.6	1.8	56	0.95	236	379	3.5	0.0	86	0.97	356	612
1:15 PM	1:30 PM	2.9	0.0	68	0.97	280	388	2.3	1.1	87	0.97	360	612
1:30 PM	1:45 PM	2.6	0.0	78	0.98	320	390	4.3	1.4	69	0.95	292	599
1:45 PM	2:00 PM	4.2	2.1	95	0.94	404	376	3.6	1.2	83	0.95	348	604
2:00 PM	2:15 PM	1.5	0.0	65	0.98	264	393	5.2	2.6	77	0.93	332	588
2:15 PM	2:30 PM	3.6	0.0	83	0.97	344	386	1.8	0.0	57	0.98	232	622
2:30 PM	2:45 PM	3.9	2.6	77	0.94	328	375	2.6	2.6	78	0.95	328	602
2:45 PM	3:00 PM	2.4	0.0	85	0.98	348	390	3.9	0.0	77	0.96	320	610
3:00 PM	3:15 PM	3.4	1.1	87	0.96	364	382	2.7	1.3	75	0.96	312	609
3:15 PM	3:30 PM	3.1	1.0	96	0.96	400	384	4.5	1.1	89	0.95	376	600
3:30 PM	3:45 PM	0.9	1.9	106	0.97	436	389	2.0	0.0	101	0.98	412	621
3:45 PM	4:00 PM	2.7	0.0	75	0.97	308	389	0.0	0.0	96	1.00	384	633

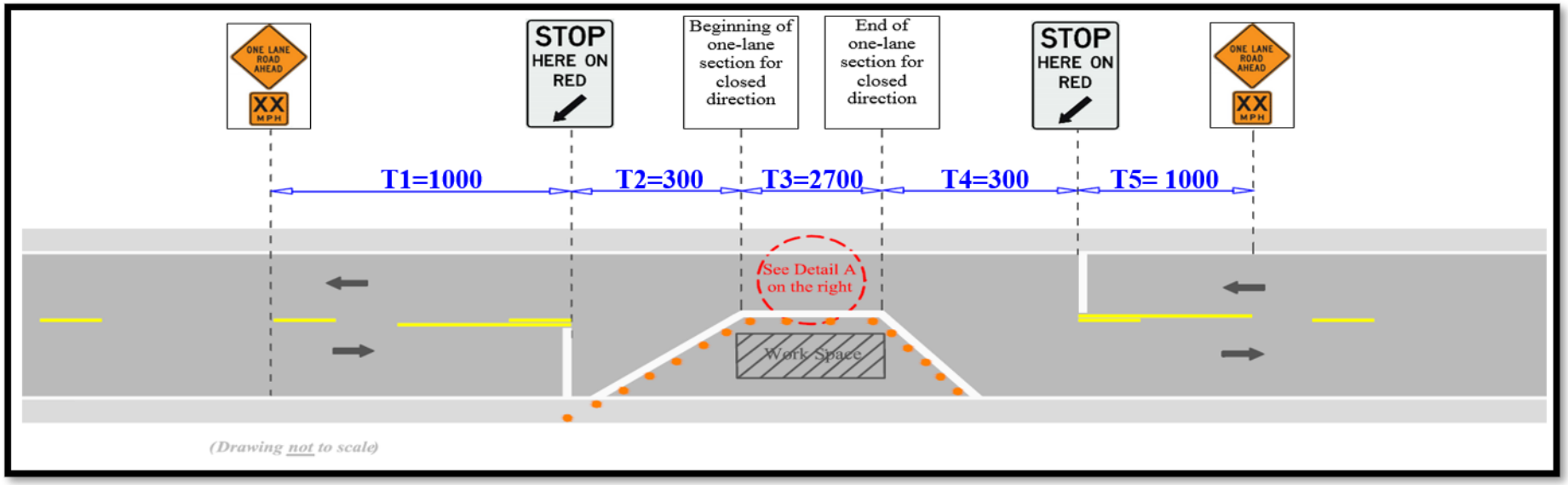
Description (Continued…)

Volume conditions:

4:00 PM	4:15 PM	0.9	2.8	106	0.96	440	385	0.9	0.9	115	0.98	468	623
4:15 PM	4:30 PM	2.1	1.0	96	0.97	396	387	0.0	1.1	90	0.99	364	626
4:30 PM	4:45 PM	1.1	0.0	92	0.99	372	395	1.2	0.0	86	0.99	348	626
4:45 PM	5:00 PM	0.9	0.0	107	0.99	432	396	0.0	1.3	75	0.99	304	625
5:00 PM	5:15 PM	1.1	1.1	94	0.98	384	391	3.4	2.3	88	0.95	372	599
5:15 PM	5:30 PM	0.0	0.0	115	1.00	460	400	0.0	1.1	87	0.99	352	626
5:30 PM	5:45 PM	1.6	0.0	129	0.98	524	393	1.3	1.3	80	0.98	328	618
5:45 PM	6:00 PM	0.0	1.2	82	0.99	332	395	1.3	0.0	78	0.99	316	625
6:00 PM	6:15 PM	1.2	0.0	82	0.99	332	395	0.0	0.0	94	1.00	376	633
6:15 PM	6:30 PM	0.0	0.0	68	1.00	272	400	0.0	1.2	81	0.99	328	626
6:30 PM	6:45 PM	0.0	0.0	68	1.00	272	400	0.0	0.0	59	1.00	236	633
6:45 PM	7:00 PM	0.0	2.0	51	0.98	208	392	0.0	0.0	45	1.00	180	633
7:00 PM	7:15 PM	0.0	1.5	68	0.99	276	394	0.0	2.4	42	0.98	172	619
7:15 PM	7:30 PM	0.0	0.0	51	1.00	204	400	0.0	4.3	47	0.96	196	607
7:30 PM	7:45 PM	0.0	0.0	66	1.00	264	400	0.0	0.0	49	1.00	196	633
7:45 PM	8:00 PM	0.0	2.0	51	0.98	208	392	0.0	0.0	53	1.00	212	633
8:00 PM	8:15 PM	0.0	0.0	59	1.00	236	400	0.0	0.0	42	1.00	168	633
8:15 PM	8:30 PM	0.0	0.0	53	1.00	212	400	0.0	2.2	45	0.98	184	620
8:30 PM	8:45 PM	0.0	0.0	39	1.00	156	400	0.0	0.0	16	1.00	64	633
8:45 PM	9:00 PM	0.0	0.0	54	1.00	216	400	3.7	0.0	27	0.96	112	611
9:00 PM	9:15 PM	0.0	0.0	31	1.00	124	400	0.0	0.0	16	1.00	64	633
9:15 PM	9:30 PM	0.0	0.0	40	1.00	160	400	0.0	0.0	25	1.00	100	633
9:30 PM	9:45 PM	0.0	0.0	35	1.00	140	400	0.0	0.0	21	1.00	84	633
9:45 PM	10:00 PM	0.0	0.0	32	1.00	128	400	0.0	0.0	22	1.00	88	633
10:00 PM	10:15 PM	0.0	0.0	18	1.00	72	400	0.0	0.0	9	1.00	36	633
10:15 PM	10:30 PM	3.8	0.0	26	0.96	108	385	0.0	0.0	16	1.00	64	633
10:30 PM	10:45 PM	0.0	0.0	24	1.00	96	400	0.0	0.0	19	1.00	76	633
10:45 PM	11:00 PM	0.0	0.0	15	1.00	60	400	0.0	0.0	10	1.00	40	633
11:00 PM	11:15 PM	0.0	4.2	24	0.96	100	384	0.0	0.0	8	1.00	32	633
11:15 PM	11:30 PM	0.0	0.0	13	1.00	52	400	0.0	0.0	22	1.00	88	633
11:30 PM	11:45 PM	0.0	0.0	10	1.00	40	400	0.0	0.0	19	1.00	76	633
11:45 PM	12:00 AM	0.0	7.7	13	0.93	56	371	0.0	0.0	15	1.00	60	633

Geometric Data

Geometric data: Longitudinal distances in the sketch below



WorkZoneQ-Pro Output

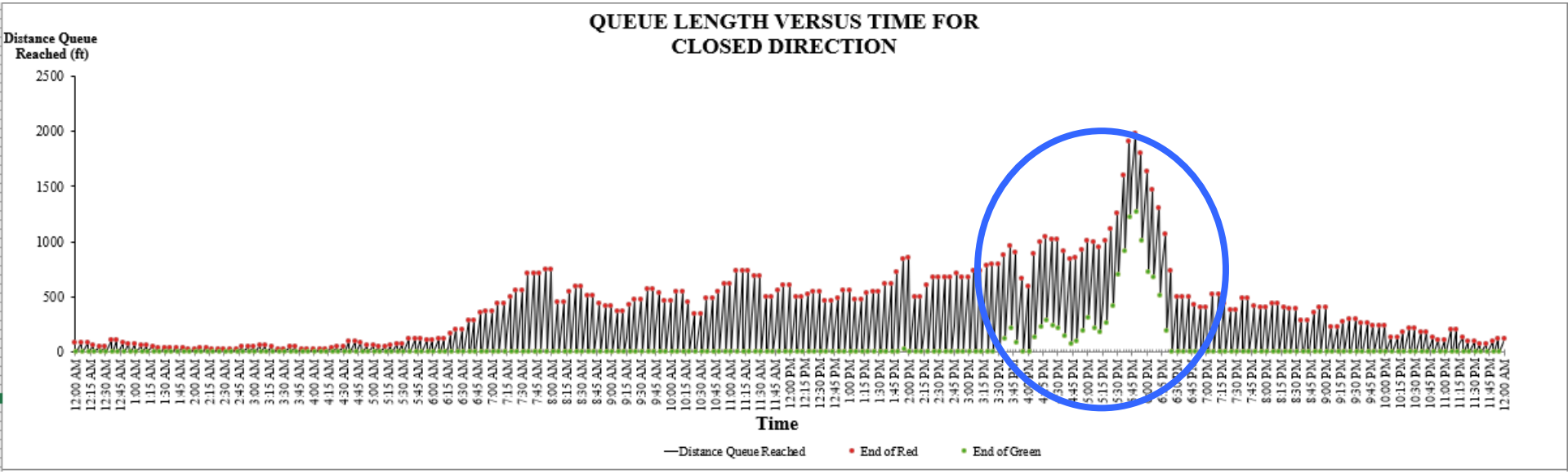
Start of Interval	End of Interval	Results for CLOSED direction						Results for OPEN direction						Users' costs ($) in BOTH directions
		No. of vehicles in queue in the beginning of green*	Average spacing between vehicles in queue (ft)	Distance queue reached (ft)	Average delay per vehicle (hr)	Delay experienced by all vehicles on CLOSED direction	Users' costs ($) in the CLOSED direction	No. of vehicles in queue in the beginning of green*	Average spacing between vehicles in queue (ft)	Distance queue reached (ft)	Average delay per vehicle (hr)	Delay experienced by all vehicles on OPEN direction	Users' costs ($) in the OPEN direction	
12:00 AM	12:15 AM	3	29	87	0.033	0.3	$8.28	4	24	96	0.025	0.4	$9.67	$17.95
12:15 AM	12:30 AM	2	24	48	0.033	0.2	$5.16	1	24	24	0.024	0.1	$2.56	$7.73
12:30 AM	12:45 AM	4	24	96	0.033	0.5	$12.11	2	24	48	0.024	0.2	$5.78	$17.89
12:45 AM	1:00 AM	3	24	72	0.033	0.3	$8.63	1	24	24	0.024	0.1	$3.21	$11.83
1:00 AM	1:15 AM	3	24	72	0.033	0.3	$7.76	1	24	24	0.024	0.1	$3.21	$10.96
1:15 AM	1:30 AM	2	24	48	0.033	0.2	$4.30	1	24	24	0.024	0.1	$3.21	$7.50
1:30 AM	1:45 AM	2	24	48	0.033	0.2	$4.30	2	24	48	0.024	0.1	$3.85	$8.15
1:45 AM	2:00 AM	1	24	24	0.033	0.1	$3.44	2	24	48	0.024	0.1	$3.85	$7.29
2:00 AM	2:15 AM	2	24	48	0.033	0.2	$4.30	2	24	48	0.024	0.1	$3.85	$8.15
2:15 AM	2:30 AM	1	24	24	0.033	0.1	$2.58	1	35	35	0.024	0.1	$2.66	$5.23
2:30 AM	2:45 AM	1	24	24	0.033	0.1	$3.44	1	24	24	0.024	0.1	$3.21	$6.64
2:45 AM	3:00 AM	2	24	48	0.033	0.2	$6.03	0	24	0	0.024	0.0	$0.64	$6.67
3:00 AM	3:15 AM	2	33	66	0.033	0.2	$4.42	1	24	24	0.024	0.0	$1.28	$5.71
3:15 AM	3:30 AM	1	24	24	0.033	0.1	$3.44	1	24	24	0.024	0.1	$2.56	$6.00
3:30 AM	3:45 AM	2	24	48	0.033	0.2	$5.16	0	24	0	0.024	0.0	$0.64	$5.80
3:45 AM	4:00 AM	1	24	24	0.033	0.1	$2.58	1	24	24	0.024	0.1	$2.56	$5.14
4:00 AM	4:15 AM	1	24	24	0.033	0.1	$2.58	2	24	48	0.024	0.2	$4.49	$7.07
4:15 AM	4:30 AM	2	24	48	0.033	0.2	$6.03	1	24	24	0.024	0.1	$2.56	$8.59
4:30 AM	4:45 AM	3	29	86	0.033	0.3	$9.15	0	24	0	0.024	0.0	$0.00	$9.15
4:45 AM	5:00 AM	2	24	48	0.033	0.3	$6.89	3	24	72	0.025	0.3	$8.37	$15.26
5:00 AM	5:15 AM	2	24	48	0.033	0.2	$5.16	3	24	72	0.025	0.3	$7.07	$12.24
5:15 AM	5:30 AM	3	24	72	0.033	0.3	$8.63	3	24	72	0.025	0.3	$7.07	$15.70
5:30 AM	5:45 AM	5	27	136	0.033	0.5	$12.24	5	24	120	0.025	0.5	$13.58	$25.82
5:45 AM	6:00 AM	4	28	111	0.033	0.4	$10.49	8	24	192	0.025	0.8	$20.15	$30.65
6:00 AM	6:15 AM	5	24	120	0.033	0.5	$13.85	6	24	144	0.025	0.6	$15.54	$29.40
6:15 AM	6:30 AM	8	26	206	0.033	0.8	$22.30	12	25	300	0.025	1.1	$28.92	$51.22
6:30 AM	6:45 AM	11	25	278	0.033	1.2	$32.11	16	24	384	0.025	1.6	$41.00	$73.11
6:45 AM	7:00 AM	15	24	360	0.034	1.7	$44.25	13	24	312	0.025	1.3	$32.85	$77.09
7:00 AM	7:15 AM	18	25	446	0.034	1.9	$50.83	20	25	492	0.025	1.9	$49.69	$100.52
7:15 AM	7:30 AM	21	26	547	0.034	2.3	$59.94	22	25	540	0.025	2.1	$55.27	$115.21
7:30 AM	7:45 AM	30	24	720	0.035	3.3	$87.66	32	24	780	0.026	3.2	$84.68	$172.34
7:45 AM	8:00 AM	30	25	748	0.035	3.3	$87.06	41	25	1,033	0.027	4.0	$106.85	$193.91
8:00 AM	8:15 AM	18	26	461	0.034	1.9	$49.96	72	25	1,800	0.027	4.9	$128.60	$178.56
8:15 AM	8:30 AM	23	25	580	0.034	2.5	$67.30	36	25	901	0.030	4.0	$105.26	$172.56
8:30 AM	8:45 AM	20	25	508	0.034	2.2	$57.49	24	25	600	0.026	2.3	$60.32	$117.81
8:45 AM	9:00 AM	16	27	429	0.034	1.6	$43.69	22	24	528	0.025	2.1	$55.54	$99.23
9:00 AM	9:15 AM	15	24	360	0.034	1.7	$44.25	25	24	612	0.026	2.4	$63.42	$107.67
9:15 AM	9:30 AM	19	25	470	0.034	2.1	$54.54	20	25	504	0.025	1.9	$51.51	$106.04
9:30 AM	9:45 AM	21	28	580	0.034	2.1	$56.94	24	25	600	0.026	2.3	$60.32	$117.26
9:45 AM	10:00 AM	19	25	470	0.034	2.0	$53.61	28	25	696	0.026	2.7	$71.73	$125.34
10:00 AM	10:15 AM	20	28	556	0.034	2.0	$53.74	25	27	674	0.026	2.3	$62.56	$116.30
10:15 AM	10:30 AM	14	24	336	0.034	1.5	$40.60	25	28	688	0.026	2.3	$60.96	$101.56
10:30 AM	10:45 AM	20	25	494	0.034	2.1	$56.40	16	26	422	0.025	1.4	$37.93	$94.33
10:45 AM	11:00 AM	24	26	620	0.034	2.5	$67.06	20	25	492	0.025	1.9	$51.08	$118.14
11:00 AM	11:15 AM	27	27	737	0.035	2.8	$75.64	19	25	481	0.025	1.7	$46.04	$121.68
11:15 AM	11:30 AM	27	26	691	0.035	2.9	$77.01	19	28	533	0.025	1.7	$45.44	$122.46
11:30 AM	11:45 AM	20	25	509	0.034	2.1	$56.04	20	25	492	0.025	1.9	$50.78	$106.81
11:45 AM	12:00 PM	23	27	611	0.034	2.4	$63.87	22	28	616	0.026	2.0	$54.83	$118.70

WorkZoneQ-Pro Output Cont.

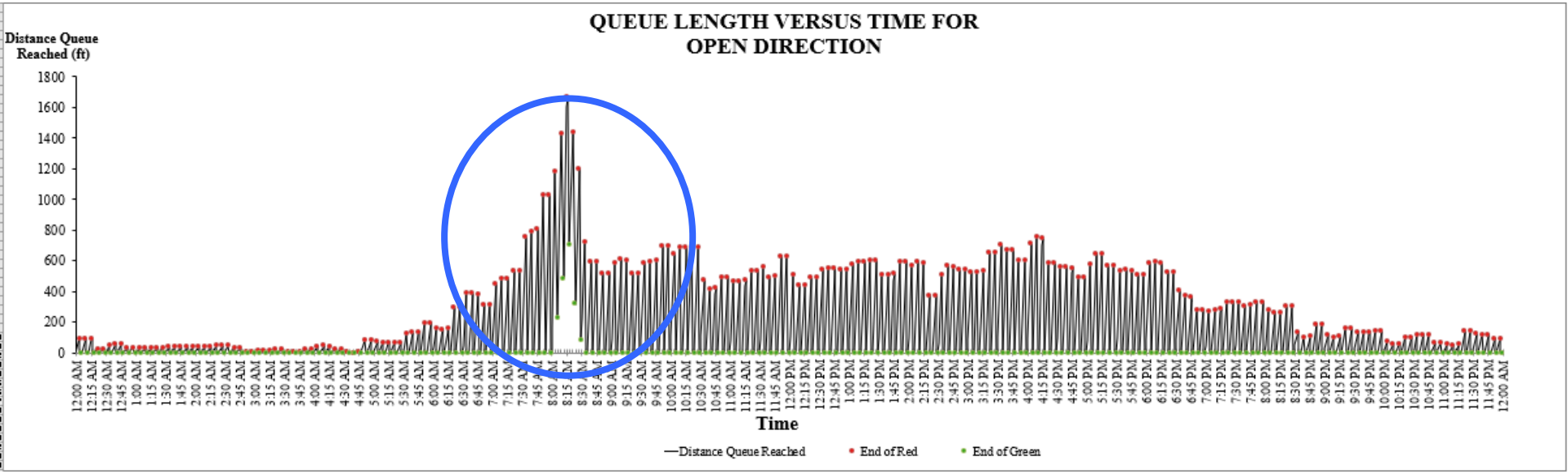
12:00 PM	12:15 PM	20	25	509	0.034	2.1	$56.04	17	25	432	0.025	1.6	$42.60	$98.64
12:15 PM	12:30 PM	21	26	548	0.034	2.2	$59.41	19	25	480	0.025	1.8	$48.42	$107.83
12:30 PM	12:45 PM	19	24	456	0.034	2.1	$56.23	22	25	552	0.026	2.1	$55.39	$111.63
12:45 PM	1:00 PM	21	27	563	0.034	2.2	$58.23	22	25	552	0.025	2.1	$54.39	$112.62
1:00 PM	1:15 PM	18	26	475	0.034	1.9	$50.64	23	26	588	0.026	2.2	$58.02	$108.66
1:15 PM	1:30 PM	22	25	557	0.034	2.3	$61.23	24	26	613	0.026	2.2	$59.03	$120.27
1:30 PM	1:45 PM	25	25	629	0.034	2.7	$70.68	19	27	506	0.025	1.7	$46.59	$117.27
1:45 PM	2:00 PM	31	27	832	0.035	3.3	$88.66	23	26	602	0.026	2.1	$56.34	$145.00
2:00 PM	2:15 PM	20	25	494	0.034	2.2	$58.24	22	28	605	0.025	2.0	$52.70	$110.93
2:15 PM	2:30 PM	26	26	666	0.035	2.9	$75.64	15	25	372	0.025	1.4	$37.70	$113.34
2:30 PM	2:45 PM	25	27	673	0.034	2.7	$71.09	21	26	552	0.025	2.0	$53.15	$124.23
2:45 PM	3:00 PM	27	25	677	0.035	2.9	$77.38	21	26	541	0.025	2.0	$51.71	$129.09
3:00 PM	3:15 PM	28	26	730	0.035	3.0	$80.08	20	26	516	0.025	1.9	$50.63	$130.71
3:15 PM	3:30 PM	31	26	802	0.035	3.3	$88.83	25	27	663	0.026	2.3	$60.70	$149.53
3:30 PM	3:45 PM	42	25	1,061	0.035	3.7	$98.91	27	25	672	0.026	2.6	$68.55	$167.46
3:45 PM	4:00 PM	24	25	605	0.035	2.7	$70.02	25	24	600	0.026	2.5	$64.72	$134.74
4:00 PM	4:15 PM	43	26	1,105	0.035	3.7	$99.53	31	25	768	0.026	3.0	$78.97	$178.50
4:15 PM	4:30 PM	38	25	965	0.036	3.5	$92.21	24	25	588	0.026	2.3	$60.90	$153.11
4:30 PM	4:45 PM	29	24	710	0.035	3.2	$83.95	23	25	564	0.026	2.2	$57.77	$141.72
4:45 PM	5:00 PM	41	24	1,001	0.035	3.8	$98.66	20	25	492	0.025	1.9	$50.38	$149.05
5:00 PM	5:15 PM	33	25	824	0.036	3.4	$89.07	24	27	637	0.026	2.3	$60.30	$149.37
5:15 PM	5:30 PM	51	24	1,224	0.035	4.1	$106.44	23	25	564	0.026	2.2	$58.78	$165.22
5:30 PM	5:45 PM	86	25	2,124	0.040	5.2	$135.86	21	25	528	0.025	2.0	$53.99	$189.85
5:45 PM	6:00 PM	43	25	1,056	0.053	4.4	$115.47	21	25	516	0.025	2.0	$52.17	$167.64
6:00 PM	6:15 PM	26	25	638	0.034	2.8	$74.32	25	24	600	0.026	2.4	$63.30	$137.62
6:15 PM	6:30 PM	21	24	504	0.034	2.3	$60.90	21	25	516	0.025	2.1	$54.57	$115.47
6:30 PM	6:45 PM	21	24	504	0.034	2.3	$60.90	15	24	360	0.025	1.5	$38.95	$99.85
6:45 PM	7:00 PM	16	25	398	0.034	1.7	$45.72	12	24	288	0.025	1.1	$29.48	$75.20
7:00 PM	7:15 PM	21	25	518	0.034	2.3	$61.48	11	25	276	0.025	1.0	$27.87	$89.35
7:15 PM	7:30 PM	16	24	384	0.034	1.7	$45.16	13	26	337	0.025	1.2	$31.64	$76.80
7:30 PM	7:45 PM	20	24	480	0.034	2.2	$59.03	13	24	312	0.025	1.2	$32.17	$91.20
7:45 PM	8:00 PM	16	25	398	0.034	1.7	$45.72	14	24	336	0.025	1.3	$34.87	$80.59
8:00 PM	8:15 PM	18	24	432	0.034	2.0	$52.52	11	24	264	0.025	1.0	$27.47	$79.99
8:15 PM	8:30 PM	16	24	384	0.034	1.8	$46.99	12	25	300	0.025	1.1	$29.89	$76.88
8:30 PM	8:45 PM	12	24	288	0.033	1.3	$34.27	4	24	96	0.025	0.4	$10.32	$44.58
8:45 PM	9:00 PM	17	24	408	0.034	1.8	$47.91	7	26	180	0.025	0.7	$17.62	$65.53
9:00 PM	9:15 PM	10	24	240	0.033	1.0	$27.10	4	24	96	0.025	0.4	$10.32	$37.41
9:15 PM	9:30 PM	12	24	288	0.033	1.3	$35.17	7	24	168	0.025	0.6	$16.20	$51.37
9:30 PM	9:45 PM	11	24	264	0.033	1.2	$30.67	5	24	120	0.025	0.5	$13.58	$44.25
9:45 PM	10:00 PM	10	24	240	0.033	1.1	$27.99	6	24	144	0.025	0.5	$14.23	$42.22
10:00 PM	10:15 PM	6	24	144	0.033	0.6	$15.60	2	24	48	0.024	0.2	$5.78	$21.39
10:15 PM	10:30 PM	8	26	206	0.033	0.9	$22.79	4	24	96	0.025	0.4	$10.32	$33.11
10:30 PM	10:45 PM	7	24	168	0.033	0.8	$20.88	5	24	120	0.025	0.5	$12.27	$33.16
10:45 PM	11:00 PM	5	24	120	0.033	0.5	$12.98	3	24	72	0.024	0.2	$6.43	$19.41
11:00 PM	11:15 PM	8	26	207	0.033	0.8	$21.42	2	24	48	0.024	0.2	$5.14	$26.56
11:15 PM	11:30 PM	4	24	96	0.033	0.4	$11.23	6	24	144	0.025	0.5	$14.23	$25.47
11:30 PM	11:45 PM	3	24	72	0.033	0.3	$8.63	5	24	120	0.025	0.5	$12.27	$20.90
11:45 PM	12:00 AM	4	27	110	0.033	0.4	$11.76	4	24	96	0.025	0.4	$9.67	$21.43
				Maximum distance queue reached (ft)		SUM delay	SUM users' costs			distance queue reached (ft)		SUM delay	SUM users' costs	SUM users' costs for BOTH directions
				2,124		162.1	$4,286.84			1,800		128.6	$3,399.64	$7,686.48

*: At the end of the corresponding interval or when there is no

WorkZoneQ-Pro Closed Direction Plot



WorkZoneQ-Pro Open Direction Plot



Run on Separate Hours

24 Hour Phase Plan [Cycle Length: 360 sec]:

Phase plan for CLOSED direction				Phase plan for OPEN direction			
Green time (sec)	Yellow time (sec)	Road clearance time (sec)	Stop time (sec)	Green time (sec)	Yellow time (sec)	Road clearance time (sec)	Stop time (sec)
Suggest Initial Values							
83	4	72		125	4	72	
83	4	72		125	4	72	

AM Phase Plan (6:30 AM – 8:30 AM) [Cycle Length: 360 sec]:

Phase plan for CLOSED direction				Phase plan for OPEN direction			
Green time (sec)	Yellow time (sec)	Road clearance time (sec)	Stop time (sec)	Green time (sec)	Yellow time (sec)	Road clearance time (sec)	Stop time (sec)
Suggest Initial Values							
83	4	72		125	4	72	
83	4	72		125	4	72	

Run on Separate Hours Cont.

Mid Day Phase Plan (8:30 AM – 3:00 PM) [Cycle Length: 270 sec]:

Phase plan for CLOSED direction				Phase plan for OPEN direction			
Green time (sec)	Yellow time (sec)	Road clearance time (sec)	Step time (sec)	Green time (sec)	Yellow time (sec)	Road clearance time (sec)	Step time (sec)
Suggest Initial Values							
65	4	72		53	4	72	
65	4	72		53	4	72	

PM Phase Plan (3:00 PM – 6:00 PM) [Cycle Length: 319 sec] :

Phase plan for CLOSED direction				Phase plan for OPEN direction			
Green time (sec)	Yellow time (sec)	Road clearance time (sec)	Step time (sec)	Green time (sec)	Yellow time (sec)	Road clearance time (sec)	Step time (sec)
Suggest Initial Values							
83	4	72		84	4	72	
83	4	72		84	4	72	

Night Time Phase Plan (6:00 PM – 6:30 AM) [Cycle Length: 257 sec] :

Phase plan for CLOSED direction				Phase plan for OPEN direction			
Green time (sec)	Yellow time (sec)	Road clearance time (sec)	Step time (sec)	Green time (sec)	Yellow time (sec)	Road clearance time (sec)	Step time (sec)
Suggest Initial Values							
51	4	72		54	4	72	
51	4	72		54	4	72	

WorkZoneQ-Pro Night Time Output

Start of Interval	End of Interval	No. of study period	Results for CLOSED direction						Results for OPEN direction						Users' costs($) in BOTH directions
			No. of vehicles in queue in the beginning of green*	Average spacing between vehicles in queue (ft)	Distance queue reached (ft)	Average delay per vehicle (hr)	Delay experienced by all vehicles on CLOSED direction (hr)	Users' costs ($) in the CLOSED direction	No. of vehicles in queue in the beginning of green*	Average spacing between vehicles in queue (ft)	Distance queue reached (ft)	Average delay per vehicle (hr)	Delay experienced by all vehicles on OPEN direction (hr)	Users' costs ($) in the OPEN direction	
6:00 PM	6:15 PM	1	19	25	466	0.028	2.3	$59.51	21	24	504	0.027	2.5	$66.51	$126.02
6:15 PM	6:30 PM	1	16	24	384	0.027	1.9	$48.69	18	25	442	0.027	2.2	$57.24	$105.93
6:30 PM	6:45 PM	1	16	24	384	0.027	1.9	$48.69	13	24	312	0.026	1.6	$40.74	$89.43
6:45 PM	7:00 PM	1	12	25	299	0.027	1.4	$36.51	10	24	240	0.026	1.2	$30.78	$67.29
7:00 PM	7:15 PM	1	16	25	395	0.027	1.9	$49.16	10	25	251	0.026	1.1	$29.10	$78.26
7:15 PM	7:30 PM	1	12	24	288	0.027	1.4	$36.06	11	26	285	0.026	1.2	$33.06	$69.11
7:30 PM	7:45 PM	1	15	24	360	0.027	1.8	$47.19	11	24	264	0.026	1.3	$33.61	$80.79
7:45 PM	8:00 PM	1	12	25	299	0.027	1.4	$36.51	12	24	288	0.026	1.4	$36.45	$72.95
8:00 PM	8:15 PM	1	14	24	336	0.027	1.6	$41.96	9	24	216	0.026	1.1	$28.67	$70.63
8:15 PM	8:30 PM	1	12	24	288	0.027	1.4	$37.53	10	25	250	0.026	1.2	$31.21	$68.74
8:30 PM	8:45 PM	1	9	24	216	0.027	1.0	$27.33	4	24	96	0.026	0.4	$10.74	$38.07
8:45 PM	9:00 PM	1	12	24	288	0.027	1.5	$38.26	6	26	154	0.026	0.7	$18.36	$56.62
9:00 PM	9:15 PM	1	7	24	168	0.027	0.8	$21.60	4	24	96	0.026	0.4	$10.74	$32.34
9:15 PM	9:30 PM	1	9	24	216	0.027	1.1	$28.05	6	24	144	0.026	0.6	$16.88	$44.93
9:30 PM	9:45 PM	1	8	24	192	0.027	0.9	$24.46	5	24	120	0.026	0.5	$14.14	$38.60
9:45 PM	10:00 PM	1	7	24	168	0.027	0.9	$22.31	5	24	120	0.026	0.6	$14.83	$37.14
10:00 PM	10:15 PM	1	4	24	96	0.026	0.5	$12.43	2	24	48	0.025	0.2	$6.02	$18.45
10:15 PM	10:30 PM	1	6	26	154	0.026	0.7	$18.17	4	24	96	0.026	0.4	$10.74	$28.91
10:30 PM	10:45 PM	1	5	24	120	0.026	0.6	$16.64	4	24	96	0.026	0.5	$12.78	$29.42
10:45 PM	11:00 PM	1	3	24	72	0.026	0.4	$10.34	2	24	48	0.025	0.3	$6.69	$17.02
11:00 PM	11:15 PM	1	6	26	155	0.026	0.6	$17.07	2	24	48	0.025	0.2	$5.34	$22.41
11:15 PM	11:30 PM	1	3	24	72	0.026	0.3	$8.95	5	24	120	0.026	0.6	$14.83	$23.77
11:30 PM	11:45 PM	1	2	24	48	0.026	0.3	$6.87	4	24	96	0.026	0.5	$12.78	$19.65
11:45 PM	12:00 AM	1	3	27	82	0.026	0.3	$9.37	3	24	72	0.026	0.4	$10.06	$19.43
12:00 AM	12:15 AM	1	2	29	58	0.026	0.2	$6.59	3	24	72	0.026	0.4	$10.06	$16.66
12:15 AM	12:30 AM	1	1	24	24	0.026	0.2	$4.11	1	24	24	0.025	0.1	$2.67	$6.77
12:30 AM	12:45 AM	1	3	24	72	0.026	0.4	$9.64	2	24	48	0.025	0.2	$6.02	$15.66
12:45 AM	1:00 AM	1	2	24	48	0.026	0.3	$6.87	1	24	24	0.025	0.1	$3.33	$10.20
1:00 AM	1:15 AM	1	2	24	48	0.026	0.2	$6.18	1	24	24	0.025	0.1	$3.33	$9.51
1:15 AM	1:30 AM	1	1	24	24	0.026	0.1	$3.42	1	24	24	0.025	0.1	$3.33	$6.76
1:30 AM	1:45 AM	1	1	24	24	0.026	0.1	$3.42	1	24	24	0.025	0.2	$4.00	$7.42
1:45 AM	2:00 AM	1	1	24	24	0.026	0.1	$2.74	1	24	24	0.025	0.2	$4.00	$6.74
2:00 AM	2:15 AM	1	1	24	24	0.026	0.1	$3.42	1	24	24	0.025	0.2	$4.00	$7.42
2:15 AM	2:30 AM	1	1	24	24	0.026	0.1	$2.05	1	35	35	0.025	0.1	$2.76	$4.81
2:30 AM	2:45 AM	1	1	24	24	0.026	0.1	$2.74	1	24	24	0.025	0.1	$3.33	$6.07
2:45 AM	3:00 AM	1	2	24	48	0.026	0.2	$4.80	0	24	0	0.025	0.0	$0.67	$5.46
3:00 AM	3:15 AM	1	1	33	33	0.026	0.1	$3.52	0	24	0	0.025	0.1	$1.33	$4.85
3:15 AM	3:30 AM	1	1	24	24	0.026	0.1	$2.74	1	24	24	0.025	0.1	$2.67	$5.40
3:30 AM	3:45 AM	1	1	24	24	0.026	0.2	$4.11	0	24	0	0.025	0.0	$0.67	$4.77
3:45 AM	4:00 AM	1	1	24	24	0.026	0.1	$2.05	1	24	24	0.025	0.1	$2.67	$4.72
4:00 AM	4:15 AM	1	1	24	24	0.026	0.1	$2.05	2	24	48	0.025	0.2	$4.67	$6.72
4:15 AM	4:30 AM	1	2	24	48	0.026	0.2	$4.80	1	24	24	0.025	0.1	$2.67	$7.46
4:30 AM	4:45 AM	1	3	29	86	0.026	0.3	$7.28	0	24	0	0.025	0.0	$0.00	$7.28
4:45 AM	5:00 AM	1	2	24	48	0.026	0.2	$5.49	3	24	72	0.026	0.3	$8.71	$14.20
5:00 AM	5:15 AM	1	1	24	24	0.026	0.2	$4.11	2	24	48	0.025	0.3	$7.36	$11.47
5:15 AM	5:30 AM	1	2	24	48	0.026	0.3	$6.87	2	24	48	0.025	0.3	$7.36	$14.23
5:30 AM	5:45 AM	1	3	27	82	0.026	0.4	$9.75	5	24	120	0.026	0.5	$14.14	$23.89
5:45 AM	6:00 AM	1	3	28	83	0.026	0.3	$8.36	7	24	168	0.026	0.8	$21.01	$29.37
6:00 AM	6:15 AM	1	4	24	96	0.026	0.4	$11.03	5	24	120	0.026	0.6	$16.19	$27.23
6:15 AM	6:30 AM	1	6	26	155	0.026	0.7	$17.78	10	25	250	0.026	1.1	$30.19	$47.97
					Maximum distance queue reached		SUM delay	SUM users' costs			Maximum distance queue reached		SUM delay	SUM users' costs	SUM users' costs for BOTH
					466		32.2	$849.54			504		27.3	$719.46	$1,569.00

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

WorkZoneQ-Pro AM and Mid Day Output

Start of Interval	End of Interval	Results for CLOSED direction						Results for OPEN direction						Users' costs($) in BOTH directions
		No. of vehicles in queue in the beginning of green*	Average spacing between vehicles in queue (ft)	Distance queue reached (ft)	Average delay per vehicle (hr)	Delay experienced by all vehicles on CLOSED direction (hr)	Users' costs ($) in the CLOSED direction	No. of vehicles in queue in the beginning of green*	Average spacing between vehicles in queue (ft)	Distance queue reached (ft)	Average delay per vehicle (hr)	Delay experienced by all vehicles on OPEN direction (hr)	Users' costs ($) in the OPEN direction	
6:30 AM	6:45 AM	11	25	278	0.033	1.2	$32.11	16	24	384	0.025	1.6	$41.00	$73.11
6:45 AM	7:00 AM	15	24	360	0.034	1.7	$44.25	13	24	312	0.025	1.3	$32.85	$77.09
7:00 AM	7:15 AM	18	25	446	0.034	1.9	$50.83	20	25	492	0.025	1.9	$49.69	$100.52
7:15 AM	7:30 AM	21	26	547	0.034	2.3	$59.94	22	25	540	0.025	2.1	$55.27	$115.21
7:30 AM	7:45 AM	30	24	720	0.035	3.3	$87.66	32	24	780	0.026	3.2	$84.68	$172.34
7:45 AM	8:00 AM	30	25	748	0.035	3.3	$87.06	41	25	1,033	0.027	4.0	$106.85	$193.91
8:00 AM	8:15 AM	18	26	461	0.034	1.9	$49.96	72	25	1,800	0.027	4.9	$128.60	$178.56
8:15 AM	8:30 AM	23	25	580	0.034	2.5	$67.30	36	25	901	0.030	4.0	$105.26	$172.56
				Maximum distance queue reached (ft)		SUM delay	SUM users' costs			Maximum distance queue reached (ft)		SUM delay	SUM users' costs	SUM users' costs for BOTH directions
*: At the end of the corresponding interval or when there is no more				748		18.1	$479.10			1,800		22.9	$604.20	$1,083.30

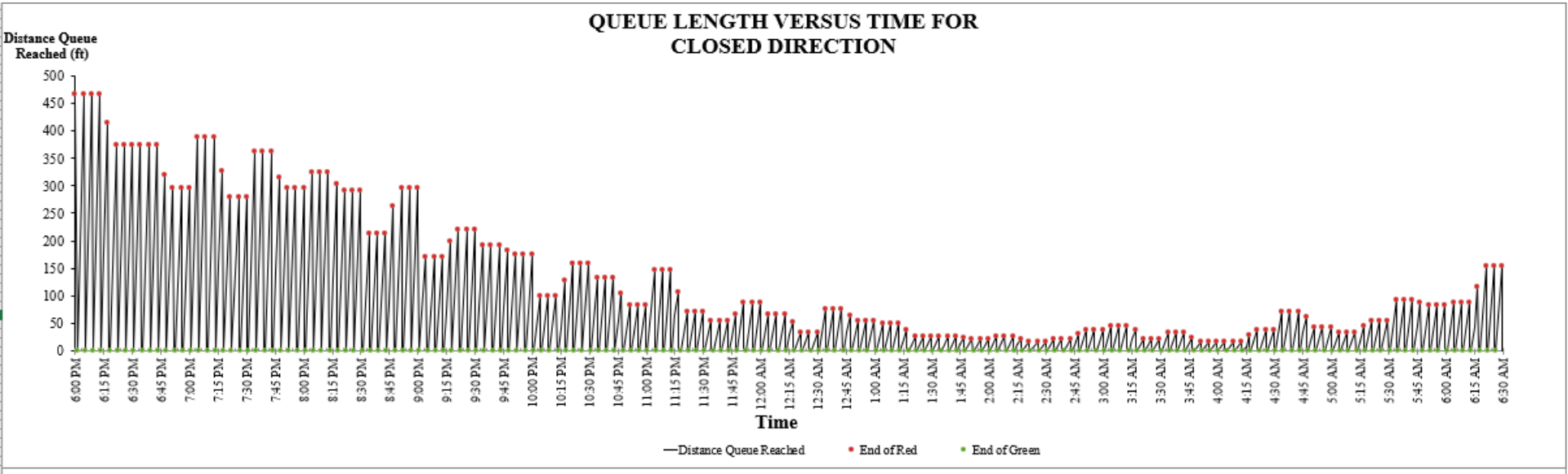
Start of Interval	End of Interval	Results for CLOSED direction						Results for OPEN direction						Users' costs($) in BOTH directions
		No. of vehicles in queue in the beginning of green*	Average spacing between vehicles in queue (ft)	Distance queue reached (ft)	Average delay per vehicle (hr)	Delay experienced by all vehicles on CLOSED direction (hr)	Users' costs ($) in the CLOSED direction	No. of vehicles in queue in the beginning of green*	Average spacing between vehicles in queue (ft)	Distance queue reached (ft)	Average delay per vehicle (hr)	Delay experienced by all vehicles on OPEN direction (hr)	Users' costs ($) in the OPEN direction	
8:30 AM	8:45 AM	15	25	381	0.026	1.6	$43.45	23	25	575	0.029	2.6	$68.36	$111.81
8:45 AM	9:00 AM	12	27	322	0.025	1.2	$33.02	20	24	480	0.029	2.4	$62.91	$95.92
9:00 AM	9:15 AM	11	24	264	0.025	1.3	$33.44	28	24	685	0.029	2.7	$71.93	$105.36
9:15 AM	9:30 AM	14	25	346	0.026	1.6	$41.21	19	25	479	0.029	2.2	$59.37	$100.58
9:30 AM	9:45 AM	15	28	414	0.026	1.6	$43.04	23	25	575	0.029	2.6	$68.36	$111.40
9:45 AM	10:00 AM	14	25	347	0.026	1.5	$40.51	44	25	1,094	0.029	3.1	$81.54	$122.06
10:00 AM	10:15 AM	15	28	417	0.026	1.5	$40.62	47	27	1,267	0.036	3.3	$87.71	$128.32
10:15 AM	10:30 AM	10	24	240	0.025	1.2	$30.68	38	28	1,046	0.032	2.8	$75.15	$105.83
10:30 AM	10:45 AM	15	25	371	0.026	1.6	$42.62	14	26	369	0.030	1.7	$44.50	$87.12
10:45 AM	11:00 AM	18	26	465	0.026	1.9	$50.69	19	25	467	0.029	2.2	$57.75	$108.44
11:00 AM	11:15 AM	20	27	546	0.026	2.1	$57.18	17	25	430	0.029	2.0	$52.01	$109.19
11:15 AM	11:30 AM	20	26	512	0.026	2.2	$58.21	18	28	505	0.029	1.9	$51.37	$109.58
11:30 AM	11:45 AM	15	25	382	0.026	1.6	$42.35	19	25	467	0.029	2.2	$57.41	$99.76
11:45 AM	12:00 PM	17	27	452	0.026	1.8	$48.27	21	28	588	0.029	2.3	$62.12	$110.39
12:00 PM	12:15 PM	15	25	382	0.026	1.6	$42.35	16	25	407	0.028	1.8	$48.09	$90.44
12:15 PM	12:30 PM	15	26	391	0.026	1.7	$44.90	18	25	455	0.029	2.1	$54.73	$99.63
12:30 PM	12:45 PM	14	24	336	0.026	1.6	$42.50	20	25	502	0.029	2.4	$62.70	$105.20
12:45 PM	1:00 PM	15	27	402	0.026	1.7	$44.01	20	25	502	0.029	2.3	$61.55	$105.57
1:00 PM	1:15 PM	13	26	343	0.026	1.4	$38.27	21	26	537	0.029	2.5	$65.74	$104.01
1:15 PM	1:30 PM	16	25	405	0.026	1.8	$46.28	22	26	562	0.029	2.5	$66.90	$113.18
1:30 PM	1:45 PM	18	25	453	0.026	2.0	$53.42	18	27	479	0.029	2.0	$52.65	$106.08
1:45 PM	2:00 PM	23	27	617	0.026	2.5	$67.03	21	26	550	0.029	2.4	$63.82	$130.85
2:00 PM	2:15 PM	15	25	370	0.026	1.7	$44.03	20	28	550	0.029	2.2	$59.66	$103.69
2:15 PM	2:30 PM	20	26	513	0.026	2.2	$57.17	14	25	347	0.028	1.6	$42.51	$99.68
2:30 PM	2:45 PM	19	27	512	0.026	2.0	$53.74	20	26	526	0.029	2.2	$60.15	$113.89
2:45 PM	3:00 PM	20	25	501	0.026	2.2	$58.49	19	26	489	0.029	2.2	$58.51	$116.99
				Maximum distance queue reached (ft)		SUM delay	SUM users' costs			Maximum distance queue reached (ft)		SUM delay	SUM users' costs	SUM users' costs for BOTH directions
*: At the end of the corresponding interval or when there is no more veh				617		45.1	$1,197.48			1,267		60.2	$1,597.50	$2,794.97

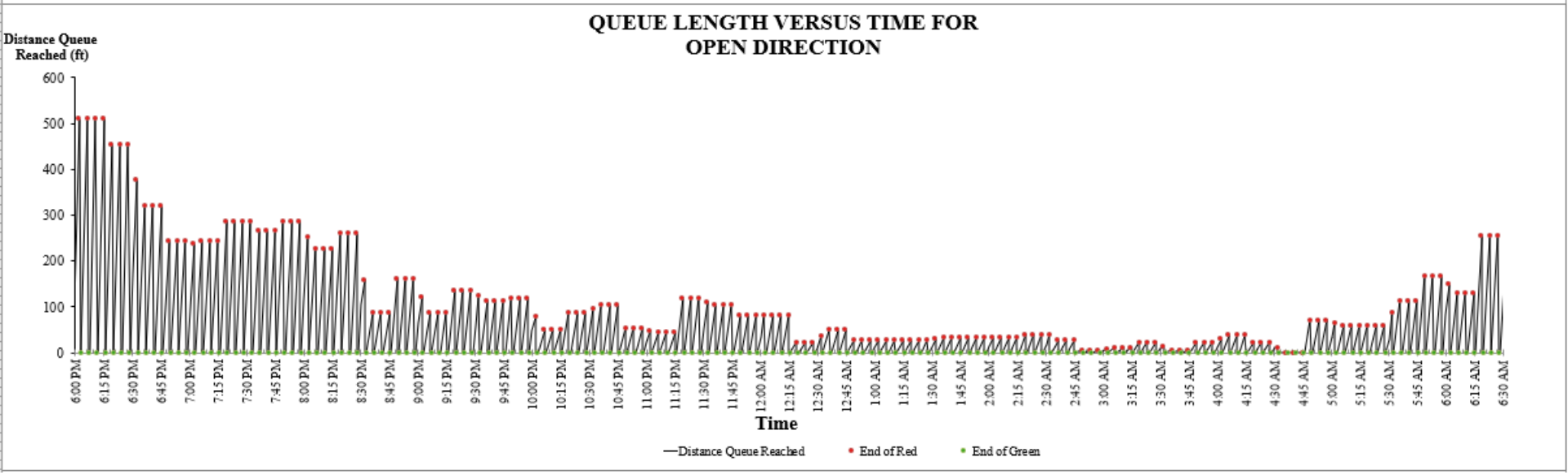
WorkZoneQ-Pro PM Output

Start of Interval	End of Interval	Results for CLOSED direction						Results for OPEN direction						Users' costs($) in BOTH directions
		No. of vehicles in queue in the beginning of green*	Average spacing between vehicles in queue (ft)	Distance queue reached (ft)	Average delay per vehicle (hr)	Delay experienced by all vehicles on CLOSED direction (hr)	Users' costs ($) in the CLOSED direction	No. of vehicles in queue in the beginning of green*	Average spacing between vehicles in queue (ft)	Distance queue reached (ft)	Average delay per vehicle (hr)	Delay experienced by all vehicles on OPEN direction (hr)	Users' costs ($) in the OPEN direction	
3:00 PM	3:15 PM	24	26	626	0.029	2.5	$66.83	20	26	516	0.028	2.1	$56.51	$123.33
3:15 PM	3:30 PM	26	26	673	0.029	2.8	$74.11	25	27	663	0.029	2.5	$67.81	$141.92
3:30 PM	3:45 PM	29	25	733	0.029	3.1	$82.49	27	25	672	0.029	2.9	$76.61	$159.10
3:45 PM	4:00 PM	20	25	504	0.029	2.1	$56.63	25	24	600	0.029	2.8	$72.30	$128.93
4:00 PM	4:15 PM	29	26	745	0.029	3.1	$83.01	31	25	768	0.029	3.3	$88.34	$171.34
4:15 PM	4:30 PM	26	25	661	0.029	2.8	$73.95	24	25	588	0.029	2.6	$68.02	$141.97
4:30 PM	4:45 PM	24	24	588	0.029	2.7	$70.05	23	25	564	0.029	2.5	$64.51	$134.56
4:45 PM	5:00 PM	28	24	684	0.029	3.1	$82.29	20	25	492	0.028	2.1	$56.23	$138.52
5:00 PM	5:15 PM	25	25	624	0.029	2.7	$72.17	24	27	637	0.029	2.5	$67.36	$139.53
5:15 PM	5:30 PM	32	24	768	0.029	3.4	$88.76	23	25	564	0.029	2.5	$65.64	$154.40
5:30 PM	5:45 PM	54	25	1,334	0.030	3.8	$101.08	21	25	528	0.028	2.3	$60.27	$161.35
5:45 PM	6:00 PM	22	25	540	0.033	2.7	$71.25	21	25	516	0.028	2.2	$58.23	$129.48
				Maximum distance queue reached (ft)		SUM delay	SUM users' costs			Maximum distance queue reached (ft)		SUM delay	SUM users' costs	SUM users' costs for BOTH directions
*: At the end of the corresponding interval or when there is no more vehicle in q				*1,334*		*34.9*	*$922.61*			*768*		*30.3*	*$801.83*	*$1,724.44*

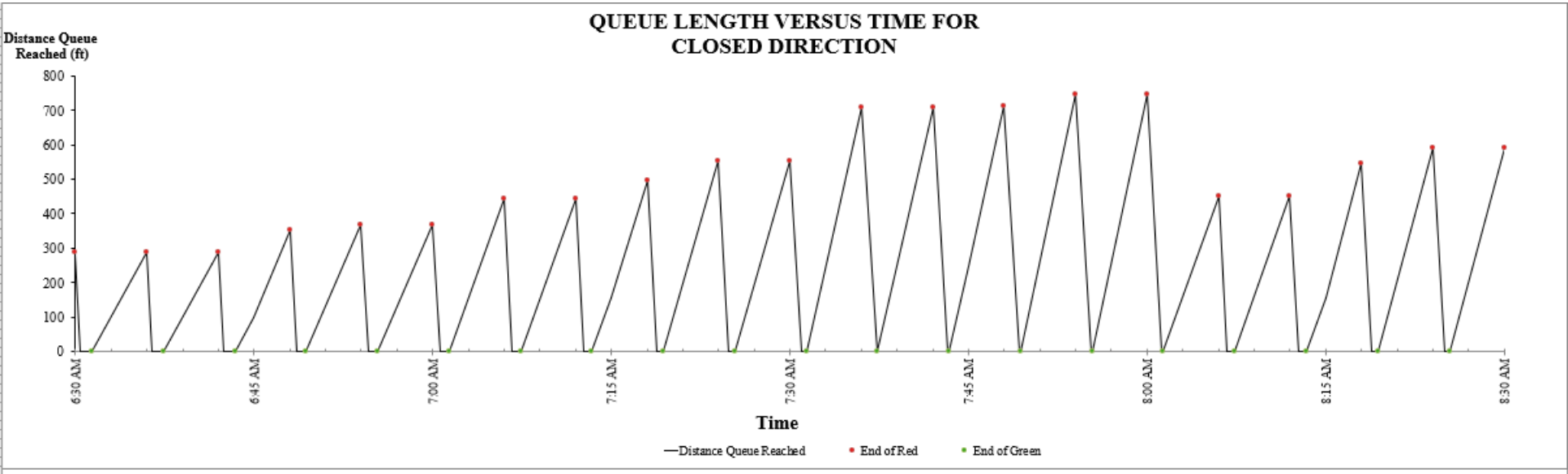
Total Users' cost: $1,569.00 (Night Time) + $1,083.30 (AM) + $2,794.97 (Mid Day) + $1,724.44 (PM) = $7,171.71 (One Phase Plan : $ 7,686.48)

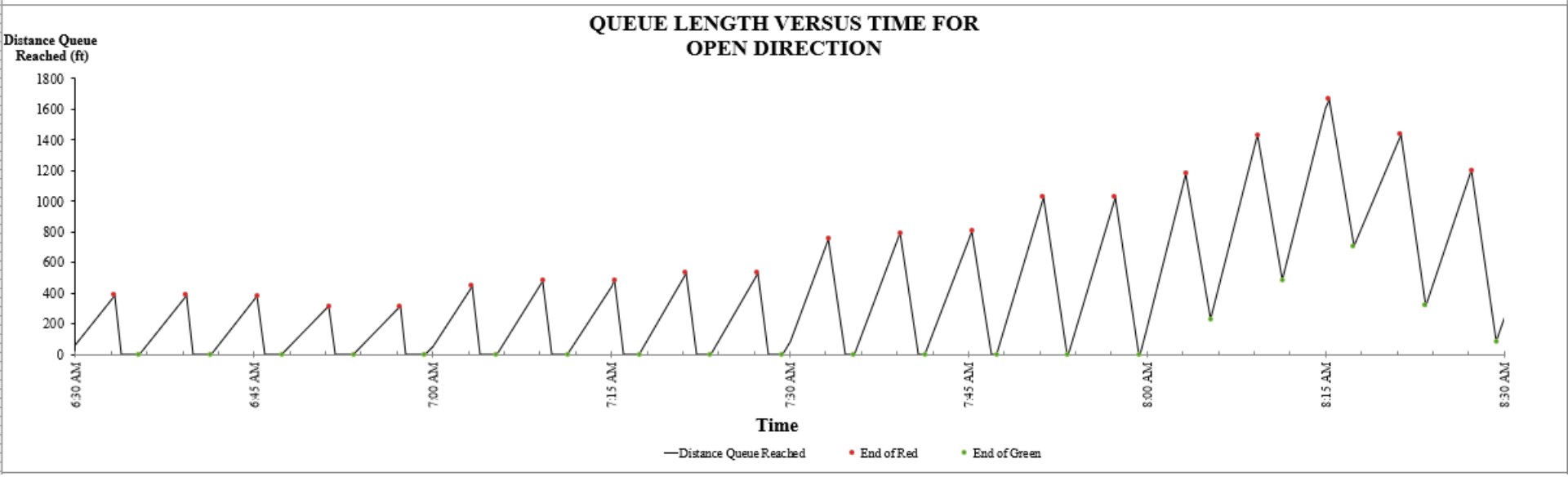
WorkZoneQ-Pro Night Time Plot



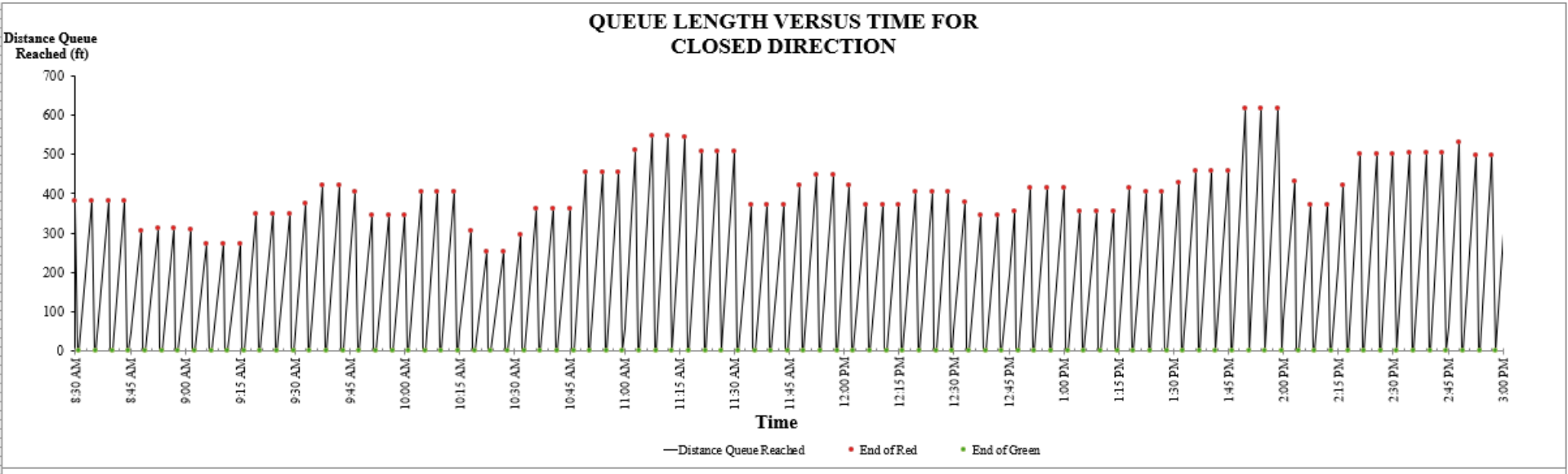


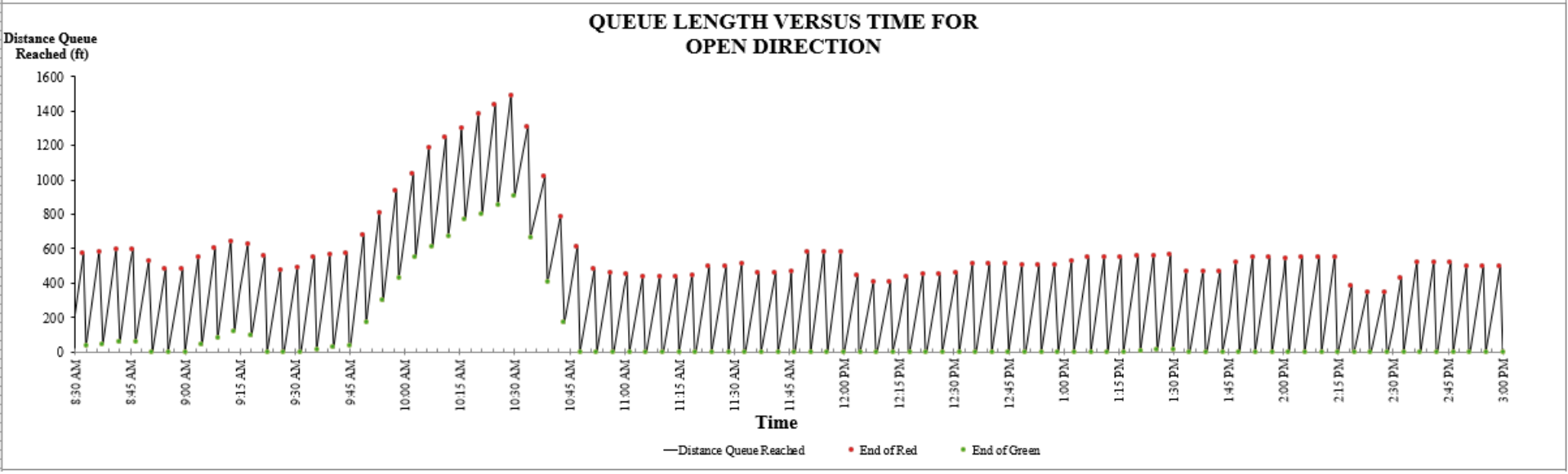
WorkZoneQ-Pro AM Plot



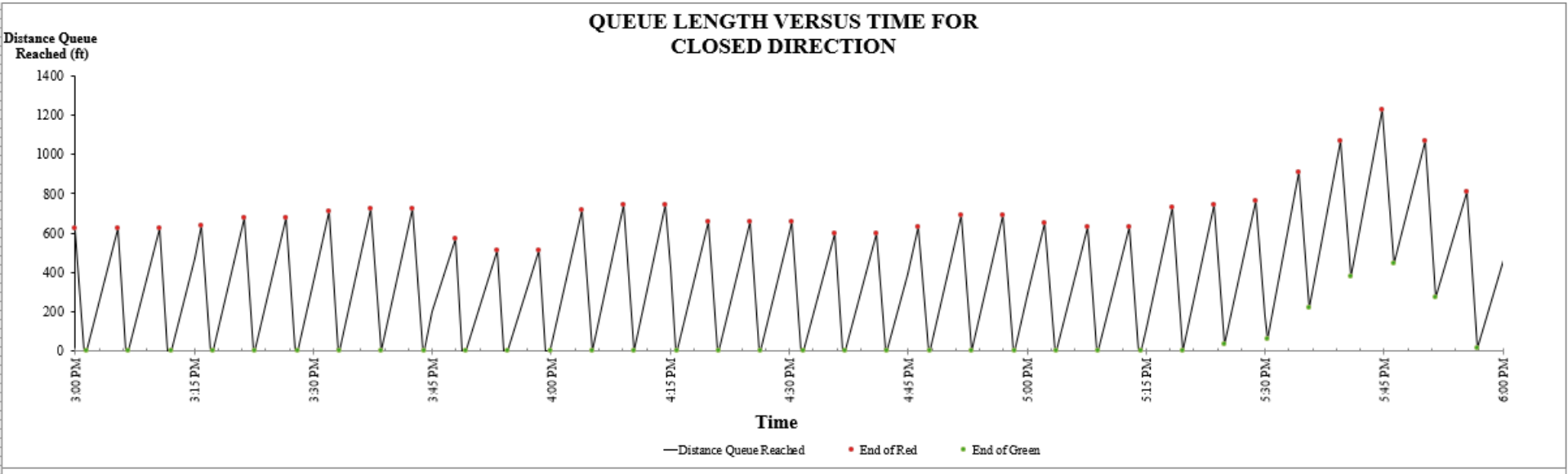


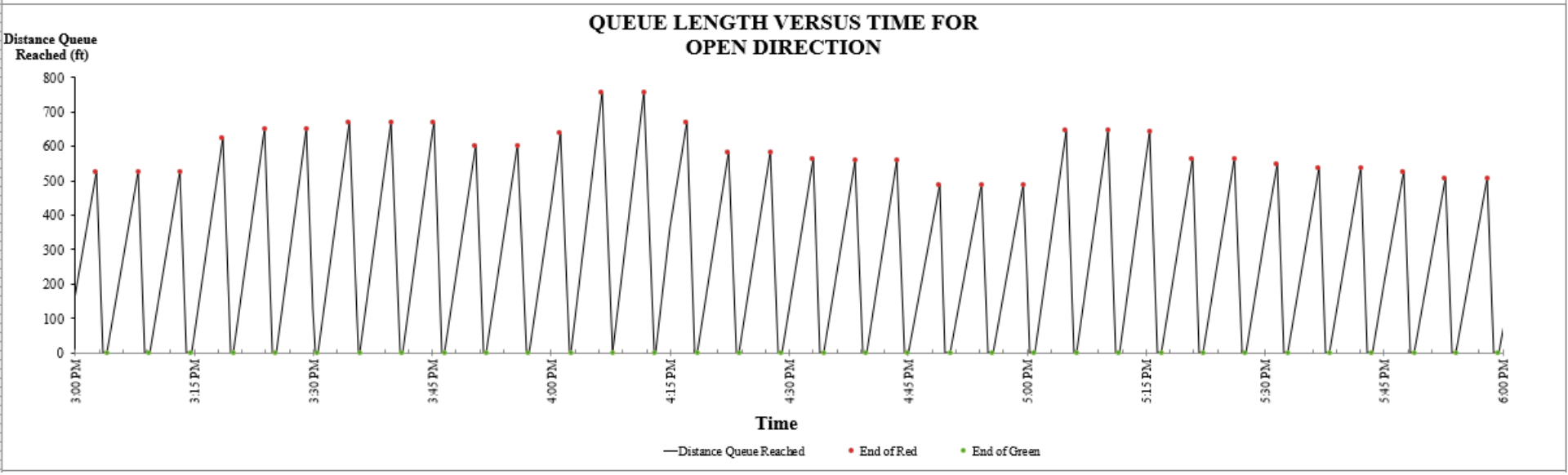
WorkZoneQ-Pro Mid Day Plot



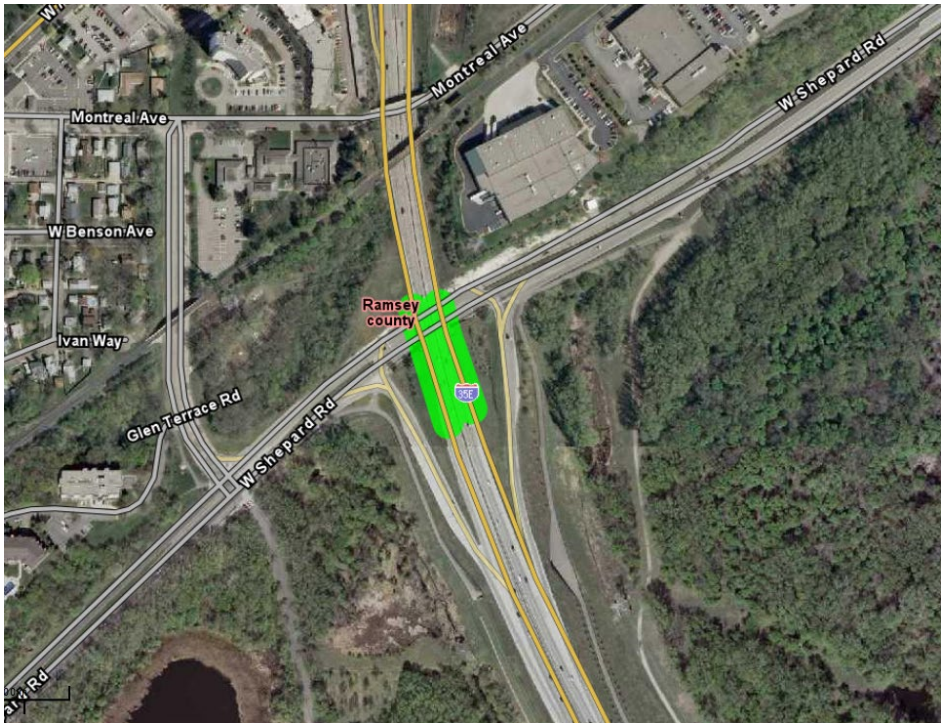


WorkZoneQ-Pro PM Plot





Example 4: I-35E at Shepard Road in St Paul, Minnesota



Problem:

Compare between 12 ft. lane with 2-to-1 freeway work zone and 11.5 ft. lane with 2-to-2 freeway work zone.

Assumed WZ Conditions:

Daytime, clear weather, Urban area and level terrain, Concrete barrier, low work intensity

Right shoulder 6 ft, Left shoulder 2 ft

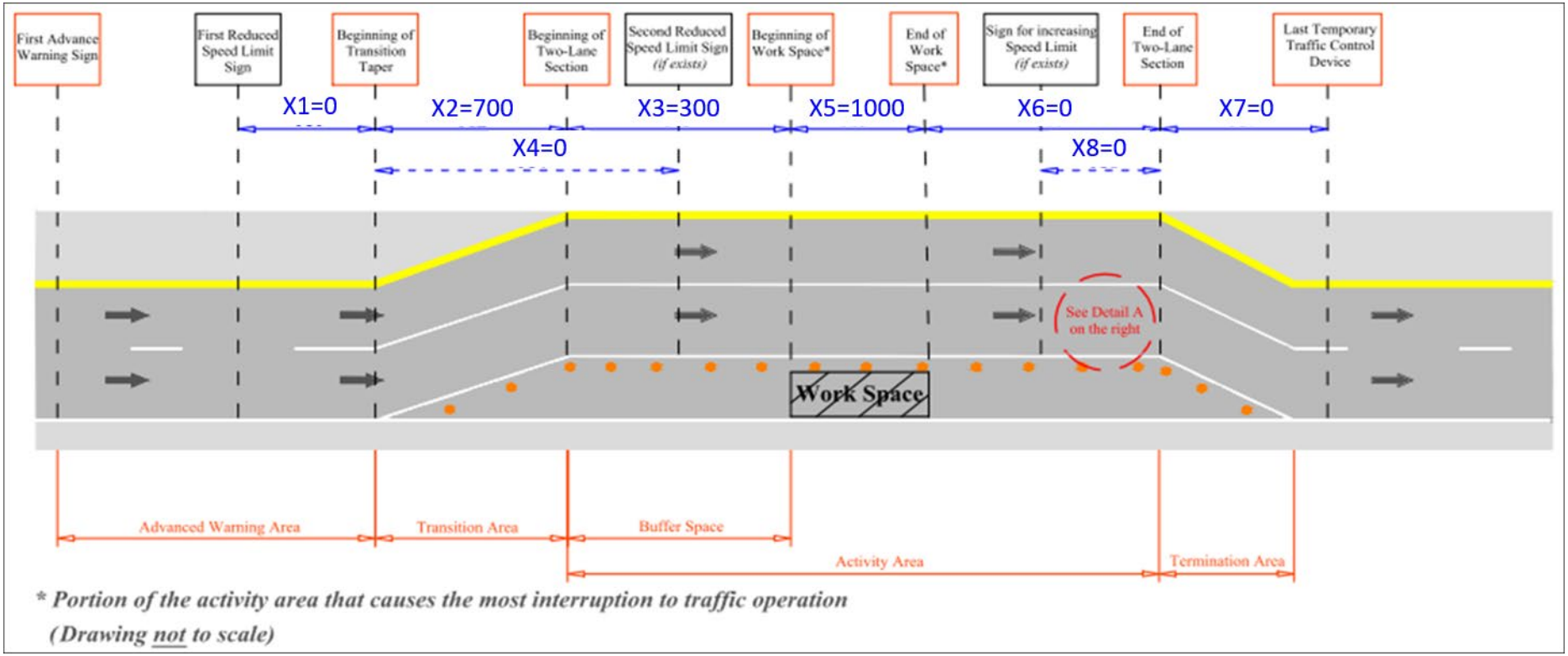
Speed limit: 55 outside & inside WZ

Single unit trucks is 1 %, combination trucks is 10 %, and no RV

For 2-to-1 WZ condition, queue exceeded 25 miles limit and WZQ-Pro stopped calculations.

Example 4: I-35E at Shepard Road in St Paul

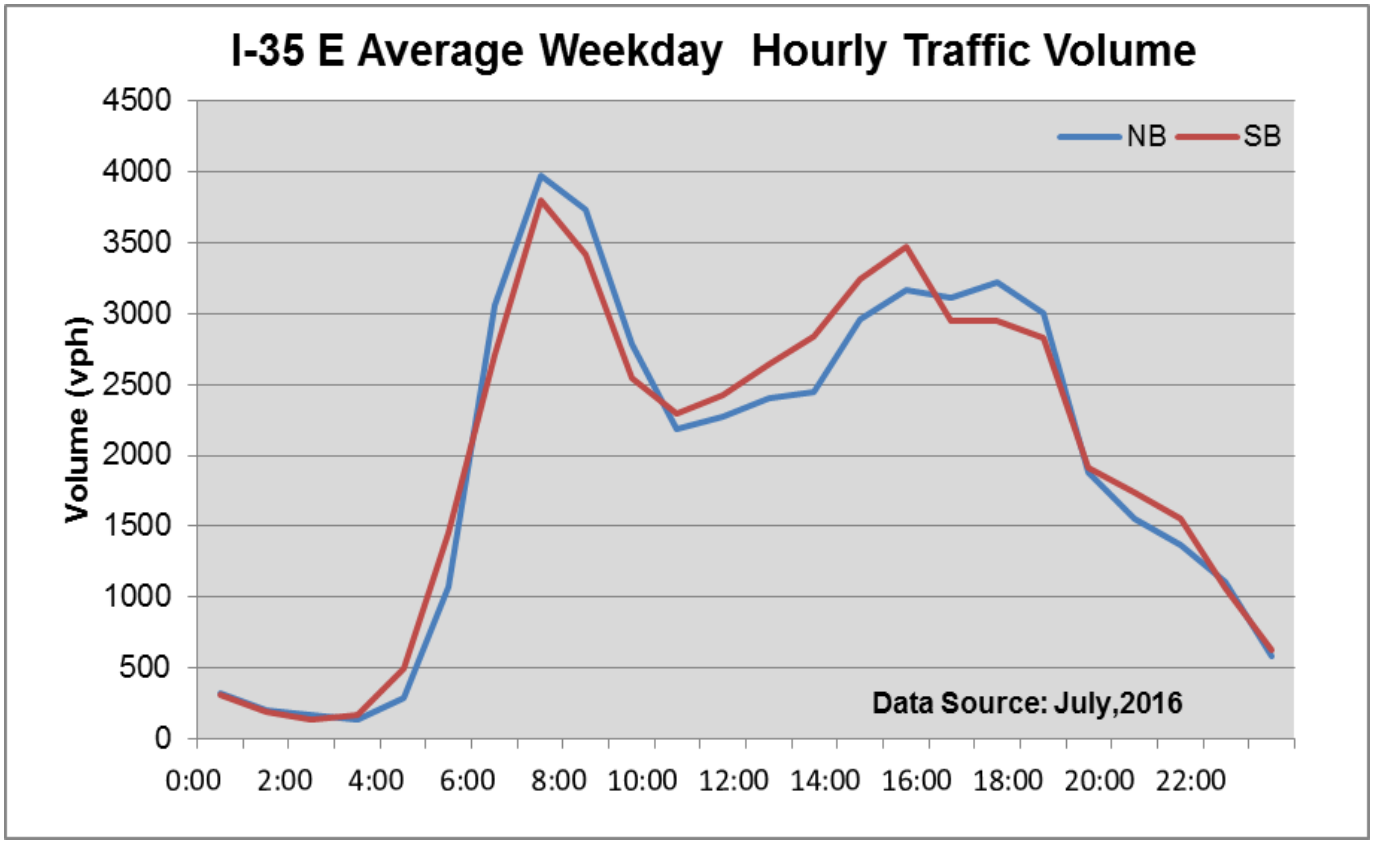
Assumed longitudinal distances



Description (Continued…)

WZ conditions:

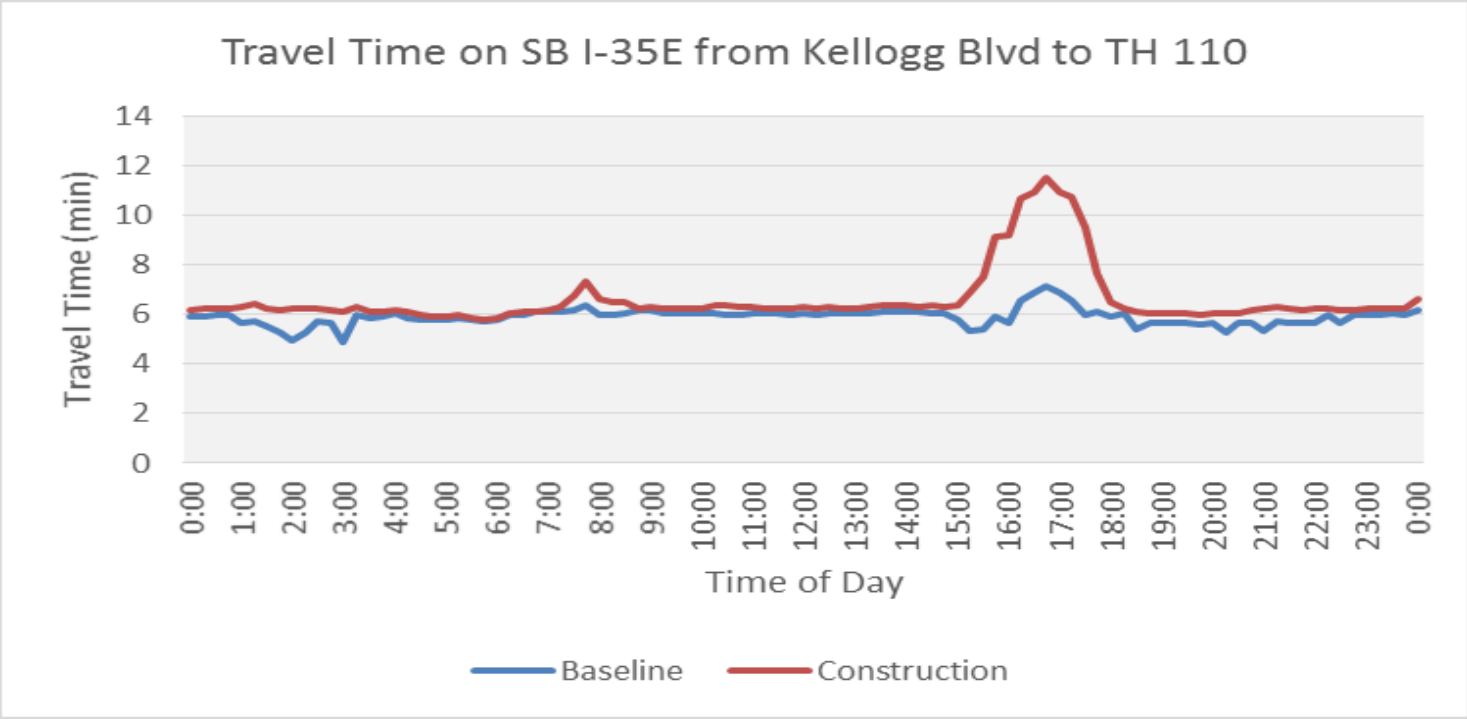
- Traffic volumes are taken from this graph:



Description (Continued…)

WZ field data:

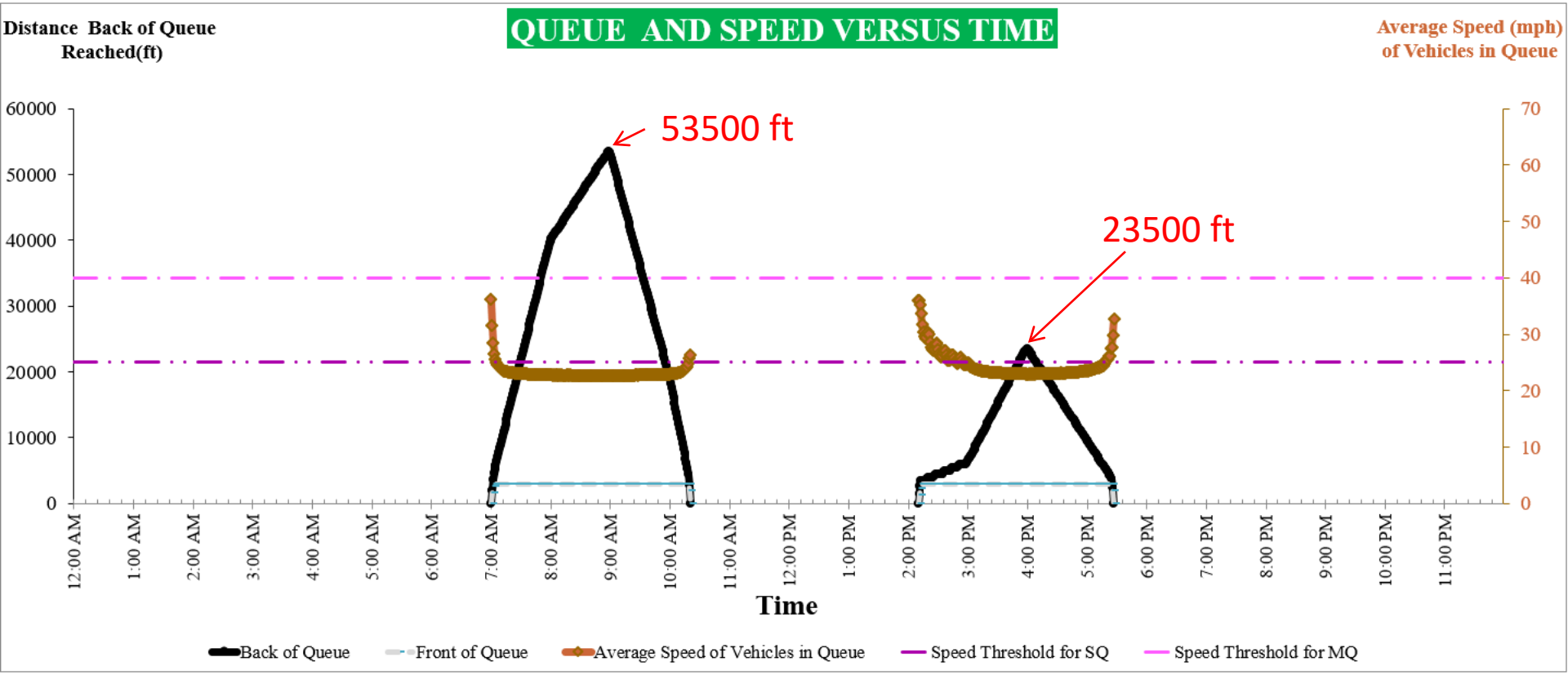
- Travel times on a 6 mile section of the road that included the work zone



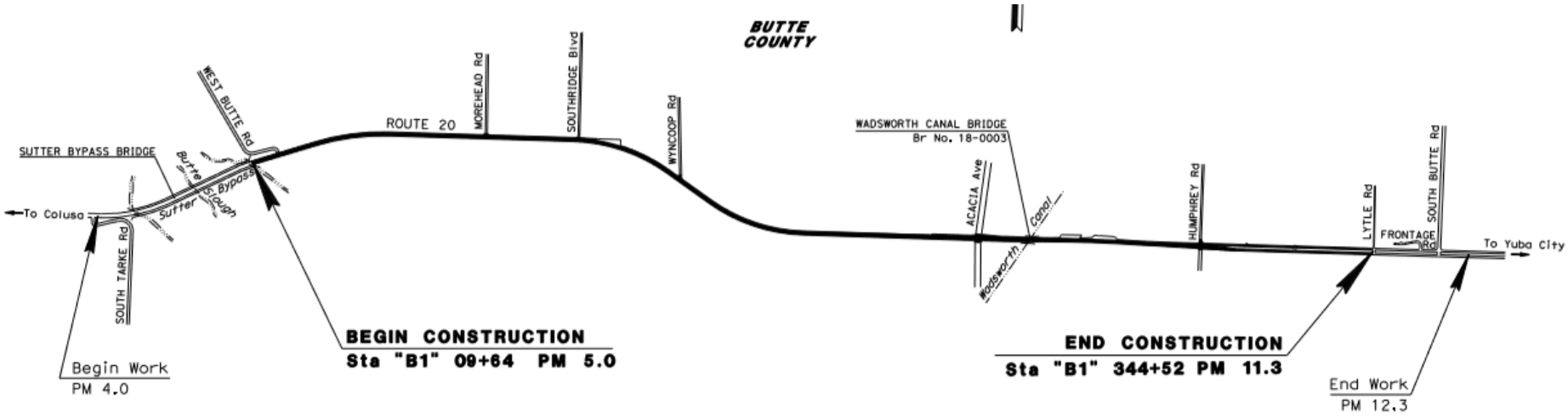
WorkZoneQ-Pro output

Start of Interval	End of Interval	No. of vehicles in queue*	Average spacing between vehicles in queue (ft)	Back-of-queue (ft)	Average speed in queue (mph)	Average delay per vehicle (hr)		Delay experienced by all vehicles (hr)		Summary of Users' Costs ($) All (SQ+MQ+SMV)	
						Based on WZ speed limit	Based on speed limit outside of the WZ	Based on WZ speed limit	Based on speed limit outside of the WZ	Based on WZ speed limit	Based on speed limit outside of the WZ
12:00 AM	1:00 AM	0	0	0	-	0.00	0.00	0.0	0.0	$0.77	$0.77
1:00 AM	2:00 AM	0	-	-	-	0.00	0.00	0.0	0.0	$0.44	$0.44
2:00 AM	3:00 AM	0	-	-	-	0.00	0.00	0.0	0.0	$0.33	$0.33
3:00 AM	4:00 AM	0	-	-	-	0.00	0.00	0.0	0.0	$0.40	$0.40
4:00 AM	5:00 AM	0	-	-	-	0.00	0.00	0.0	0.0	$1.10	$1.10
5:00 AM	6:00 AM	0	-	-	-	0.00	0.00	0.2	0.2	$5.35	$5.35
6:00 AM	7:00 AM	0	-	-	-	0.00	0.00	0.3	0.3	$8.51	$8.51
7:00 AM	8:00 AM	986	75	39,600	23.0	0.07	0.07	292.1	292.1	$7,773.37	$7,773.37
8:00 AM	9:00 AM	1,350	75	53,500	22.7	0.18	0.18	696.7	696.7	$18,539.77	$18,539.77
9:00 AM	10:00 AM	440	75	19,700	22.8	0.19	0.19	536.0	536.0	$14,263.87	$14,263.87
10:00 AM	11:00 AM	0	75	0	23.3	0.02	0.02	49.1	49.1	$1,307.37	$1,307.37
11:00 AM	12:00 PM	0	-	-	-	0.00	0.00	0.2	0.2	$5.14	$5.14
12:00 PM	1:00 PM	0	-	-	-	0.00	0.00	0.3	0.3	$8.51	$8.51
1:00 PM	2:00 PM	0	-	-	-	0.00	0.00	0.4	0.4	$11.20	$11.20
2:00 PM	3:00 PM	89	78	6,033	26.7	0.01	0.01	26.5	26.5	$705.82	$705.82
3:00 PM	4:00 PM	548	75	23,500	23.2	0.05	0.05	193.4	193.4	$5,147.81	$5,147.81
4:00 PM	5:00 PM	174	75	9,967	23.1	0.07	0.07	221.8	221.8	$5,903.41	$5,903.41
5:00 PM	6:00 PM	0	75	0	24.4	0.01	0.01	29.0	29.0	$772.03	$772.03
6:00 PM	7:00 PM	0	-	-	-	0.00	0.00	0.4	0.4	$11.20	$11.20
7:00 PM	8:00 PM	0	-	-	-	0.00	0.00	0.6	0.6	$16.73	$16.73
8:00 PM	9:00 PM	0	-	-	-	0.00	0.00	0.5	0.5	$13.31	$13.31
9:00 PM	10:00 PM	0	-	-	-	0.00	0.00	0.3	0.3	$8.76	$8.76
10:00 PM	11:00 PM	0	-	-	-	0.00	0.00	0.1	0.1	$2.32	$2.32
11:00 PM	12:00 AM	0	-	-	-	0.00	0.00	0.1	0.1	$1.43	$1.43
				Maximum distance back-of-queue reached (ft)				SUM Delay	SUM Delay	SUM All	SUM All
*: At the end of the corresponding interval or when there is				53,500				2,048.2	2,048.2	$54,508.95	$54,508.95

WorkZoneQ-Pro output



Example 5: Route 20 near Yuba City in Sutter County, California



Description:

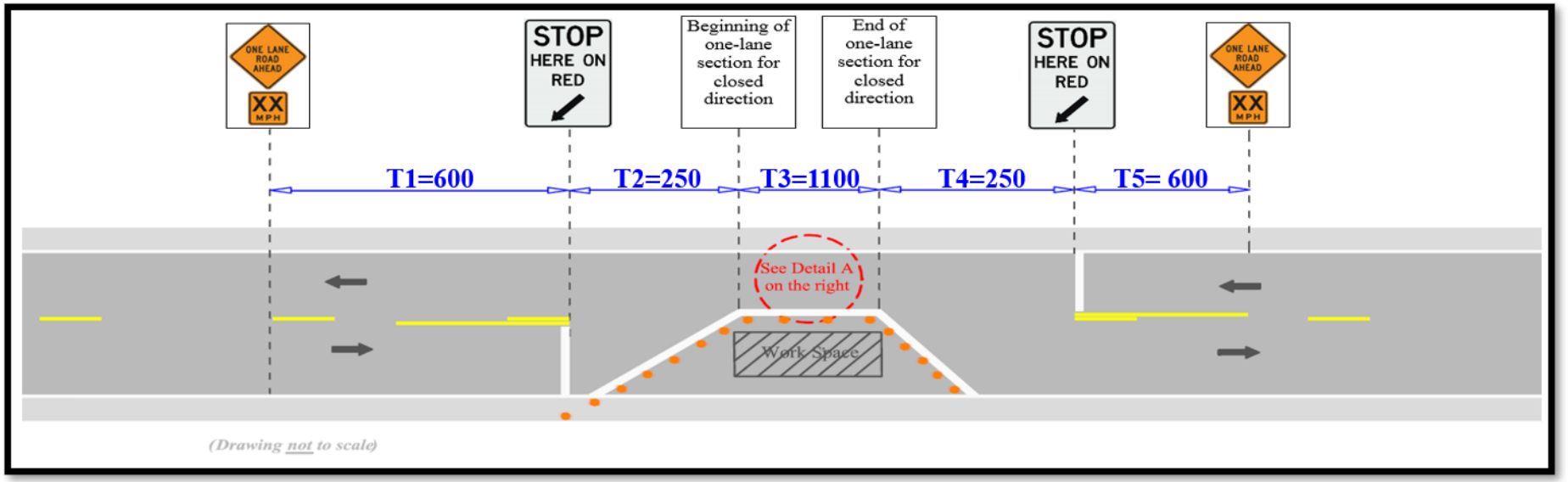
daytime, clear weather condition

Lane width = 11 ft, Shoulder width = 6 ft

Rural area and level terrain

Route 20 near Yuba City in Sutter County

Geometric data: Longitudinal distances in the sketch below



Description (Continued…)

WZ conditions:

- WZ speed limit is 35 mph, and speed limit outside of the WZ is 55 mph
- Workers separated by concrete barrier and low work intensity
- Use default Passenger Car Equivalency (PCE) factors
- Percentage of single unit trucks is 20 %, combination trucks and recreational vehicles is 0 %
- Work time plan:

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Mon–Thu	R	R	R	R	R																				
Fri																							R	R	R
Sat	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Sun	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R

Legend:

R	Provide at least 1 through traffic lane not less than 11 feet in width for use by both directions of travel. (Reversing Control)
	Work is allowed within the highway where a shoulder or lane closure is not required.

Description (Continued…)

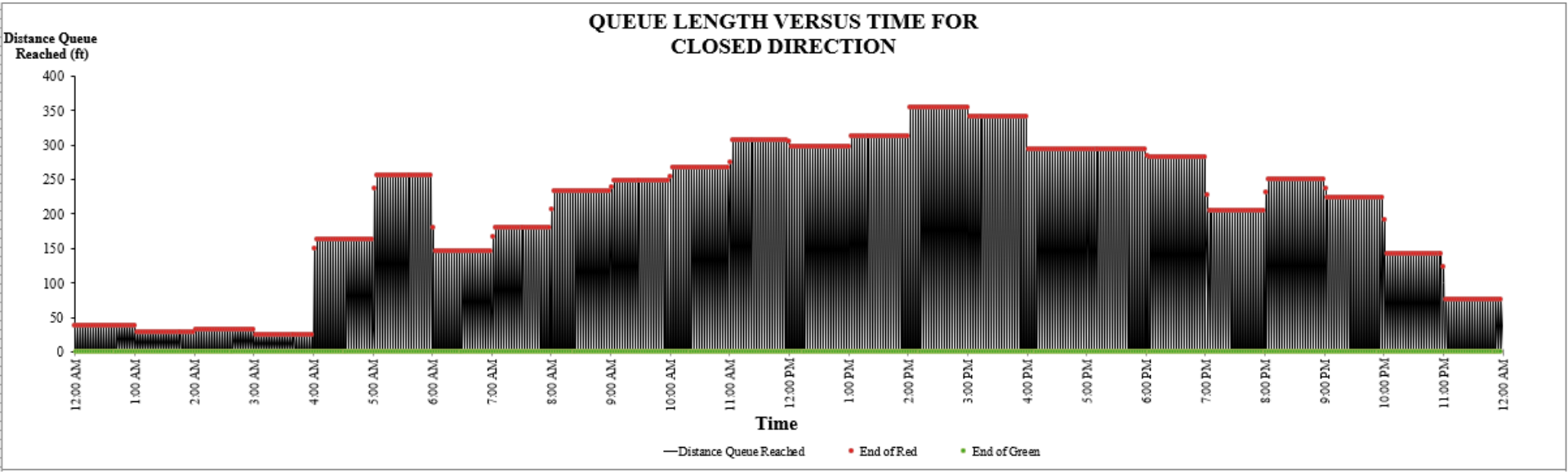
Traffic Volume Data:

	April 2018				April 2018				April 2018				April 2018			
	THURSDAY				FRIDAY				SATURDAY				SUNDAY			
ERIOD	DIRECTIO		TOTAL	TOTAL	ERIOD	DIRECTIO		TOTAL	TOTAL	ERIOD	DIRECTIO		TOTAL	TOTAL	ERIOD	DIRECTIO		TOTAL
ENDS	WB	EB	WB & EB	EAR 201	ENDS	WB	EB	WB & EB	EAR 201	ENDS	WB	EB	WB & EB	EAR 201	ENDS	WB	EB	WB & EB
1:00	11	40	53		1:00	32	45	80		1:00	29	75	108		1:00	29	75	108
2:00	17	27	46		2:00	17	23	42		2:00	22	35	59		2:00	19	35	56
3:00	6	26	33		3:00	11	21	33		3:00	25	36	63		3:00	27	36	66
4:00	26	36	64		4:00	15	28	45		4:00	19	38	59		4:00	10	38	50
5:00	75	43	123		5:00	83	34	122		5:00	124	21	151		5:00	28	21	51
6:00	263	73	349		6:00	181	75	266		6:00	194	43	246		6:00	93	43	141
7:00	428	210	664		7:00	370	163	554		7:00	111	91	210		7:00	63	91	160
8:00	405	379	815		8:00	385	319	732		8:00	136	135	282		8:00	106	135	251
9:00	310	286	620		9:00	312	316	653		9:00	176	183	373		9:00	102	183	296
10:00	223	210	450		10:00	227	301	549		10:00	188	230	435		10:00	134	230	379
11:00	235	296	552		11:00	297	299	620		11:00	202	252	472		11:00	190	252	460
12:00	276	344	645		12:00	280	322	626		12:00	232	274	526		12:00	205	274	498
13:00	287	336	648		13:00	296	343	665		13:00	226	282	528		13:00	255	282	558
14:00	318	313	656		14:00	324	362	713		14:00	237	242	498		14:00	305	242	569
15:00	314	371	712		15:00	370	351	750		15:00	268	335	627		15:00	326	335	687
16:00	338	522	894		16:00	383	526	945		16:00	259	319	601		16:00	297	319	641
17:00	362	509	906		17:00	375	494	904		17:00	223	292	536		17:00	243	292	556
18:00	407	551	996		18:00	395	504	935		18:00	223	224	465		18:00	271	224	515
19:00	239	313	574		19:00	326	393	748		19:00	214	204	435		19:00	217	204	438
20:00	177	207	399		20:00	264	268	553		20:00	155	138	305		20:00	150	138	300
21:00	129	132	271		21:00	245	167	428		21:00	189	121	322		21:00	155	121	287
22:00	119	92	219		22:00	186	109	307		22:00	169	106	286		22:00	137	106	253
23:00	84	78	168		23:00	107	100	215		23:00	108	112	229		23:00	85	112	205
24:00	38	54	96		24:00	55	86	147		24:00	57	118	186		24:00	29	118	156
	5087	5448	10535			5536	5649	11185			3786	3906	7692			3476	3906	7382

WorkZoneQ-Pro output (Saturday)

Results for CLOSED direction					
No. of vehicles in queue in the beginning of green*	Average spacing between vehicles in queue (ft)	Distance queue reached (ft)	Average delay per vehicle (hr)	Delay experienced by all vehicles on CLOSED direction (hr)	Users' costs ($) in the CLOSED direction
1	33	33	0.013	0.4	$10.36
1	33	33	0.013	0.3	$7.80
1	33	33	0.013	0.3	$8.89
1	33	33	0.013	0.2	$6.71
5	33	165	0.015	1.8	$49.92
8	33	264	0.017	3.3	$88.42
4	33	132	0.015	1.6	$43.86
5	33	165	0.015	2.1	$55.76
7	33	231	0.016	2.9	$77.30
8	33	264	0.017	3.1	$84.59
8	33	264	0.017	3.5	$93.75
9	33	297	0.019	4.3	$116.75
9	33	297	0.018	4.1	$111.68
9	33	297	0.019	4.5	$121.22
11	33	363	0.022	5.8	$156.01
10	33	330	0.021	5.3	$144.28
9	33	297	0.018	4.0	$109.24
9	33	297	0.018	4.0	$109.24
9	33	297	0.018	3.8	$102.30
6	33	198	0.016	2.4	$65.54
8	33	264	0.017	3.2	$85.22
7	33	231	0.016	2.7	$73.26
4	33	132	0.015	1.6	$42.50
2	33	66	0.014	0.8	$21.02
		Maximum distance queue reached (ft)		SUM delay	SUM users' costs
		363		*66.1*	*$1,785.63*

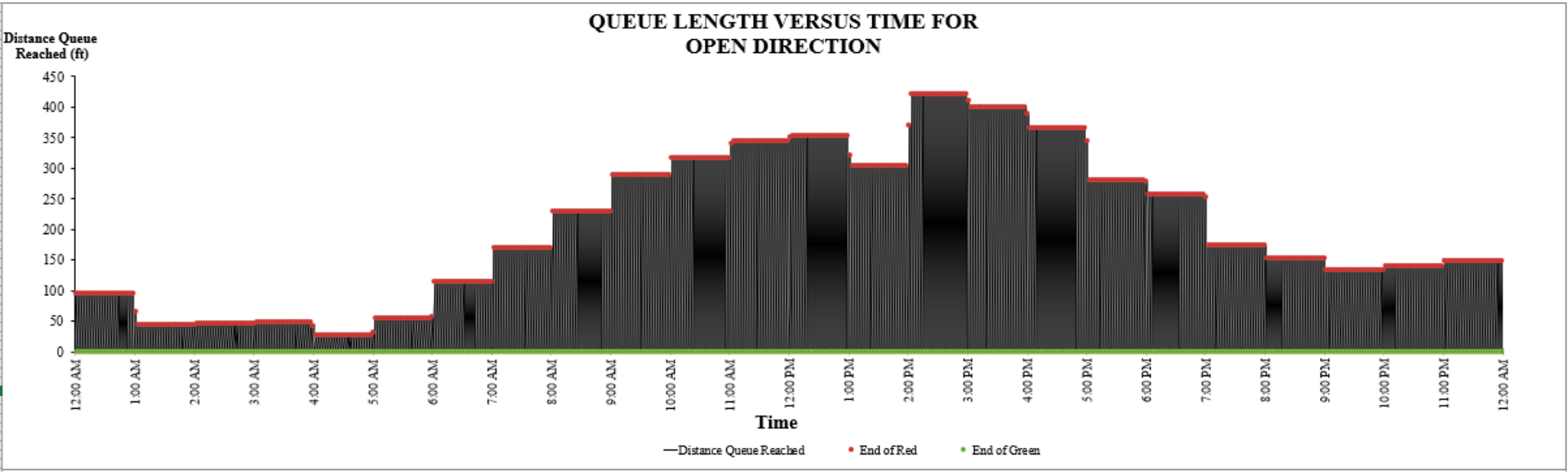
WorkZoneQ-Pro output Cont. (Saturday)



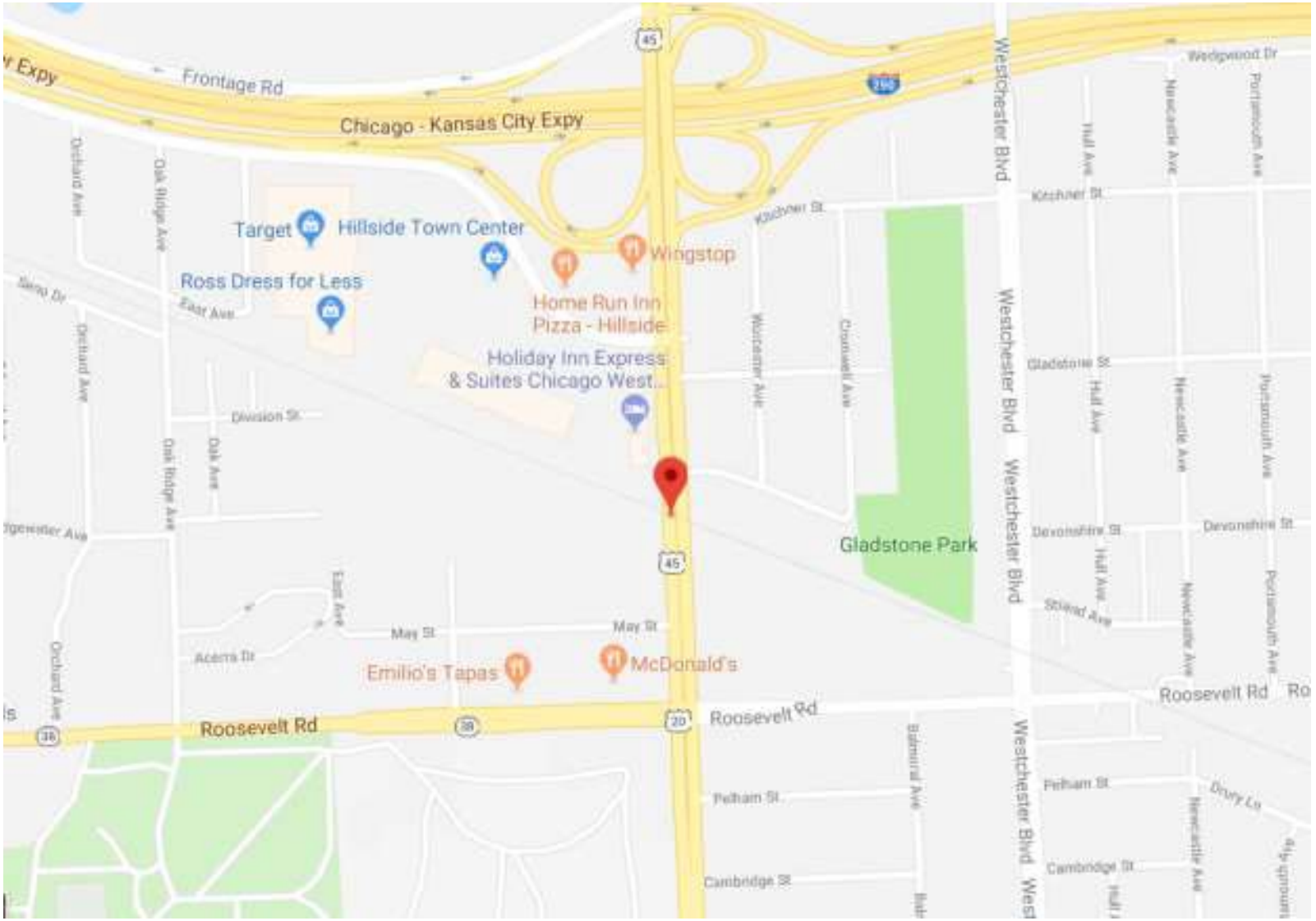
WorkZoneQ-Pro output Cont. (Saturday)

Results for OPEN direction					
No. of vehicles in queue in the beginning of green*	Average spacing between vehicles in queue (ft)	Distance queue reached (ft)	Average delay per vehicle (hr)	Delay experienced by all vehicles on OPEN direction (hr)	Users' costs ($) in the OPEN direction
3	33	99	0.012	0.9	$25.20
1	33	33	0.012	0.4	$11.30
1	33	33	0.012	0.4	$11.63
1	33	33	0.012	0.5	$12.30
1	33	33	0.012	0.2	$6.69
2	33	66	0.012	0.5	$13.99
3	33	99	0.013	1.2	$31.10
5	33	165	0.013	1.8	$48.47
7	33	231	0.014	2.6	$69.86
9	33	297	0.015	3.5	$94.33
10	33	330	0.016	4.0	$107.56
10	33	330	0.017	4.5	$122.47
11	33	363	0.017	4.8	$128.44
9	33	297	0.016	3.8	$101.37
13	33	429	0.020	6.7	$181.40
12	33	396	0.019	6.0	$161.98
11	33	363	0.017	5.1	$136.42
9	33	297	0.015	3.4	$90.95
8	33	264	0.015	3.0	$80.27
5	33	165	0.013	1.8	$49.73
5	33	165	0.013	1.6	$42.74
4	33	132	0.013	1.4	$36.82
4	33	132	0.013	1.5	$39.16
4	33	132	0.013	1.5	$41.54
		Maximum distance queue reached (ft)		SUM delay	SUM users' costs
		429		*61.0*	*$1,645.74*

WorkZoneQ-Pro output Cont. (Saturday)



Example 6: Painting of the railroad bridge over Mannheim Road in the Village of Hillside, Cook County, Illinois



Mannheim Road in the Village of Hillside, Cook County

This project uses 1 and 2 lane closures, so run 3-to-1

Description:

ADT for Western Avenue: 38,100 vehicles per day

Clear weather condition

Lane width = 12 ft

Shoulder width = 12 ft (right: 6 ft and left: 6 ft)

Urban area and level terrain

WZ conditions:

WZ speed limit and speed limit outside is 30 mph

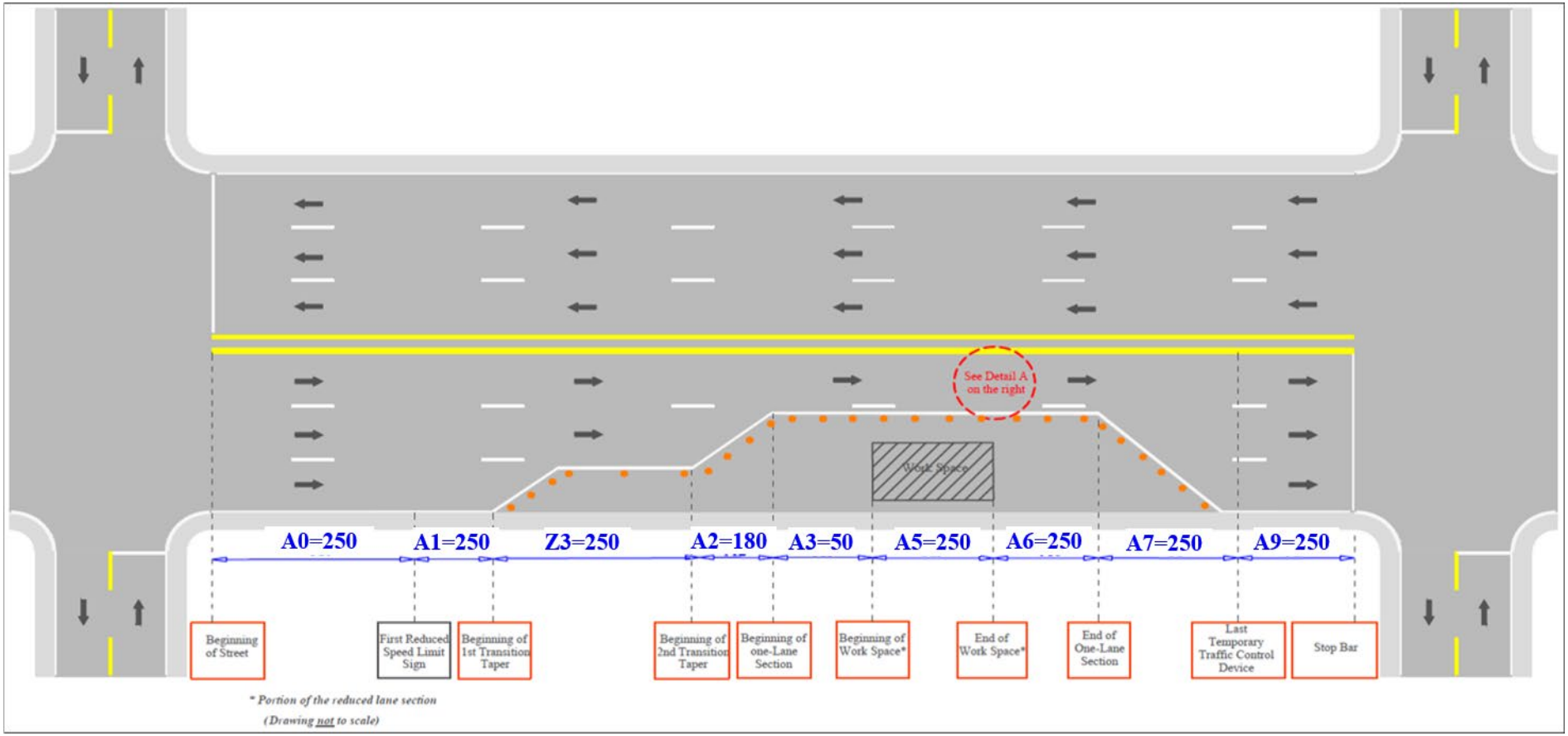
Workers separated by concrete barrier and low work intensity

Use default Passenger Car Equivalency (PCE) factors

Percentage of combination trucks is 6 %, single-unit trucks and recreational vehicles is 0 %

Mannheim Road in the Village of Hillside, Cook County

Geometric data: Longitudinal distances for 3-to-1 in the sketch below

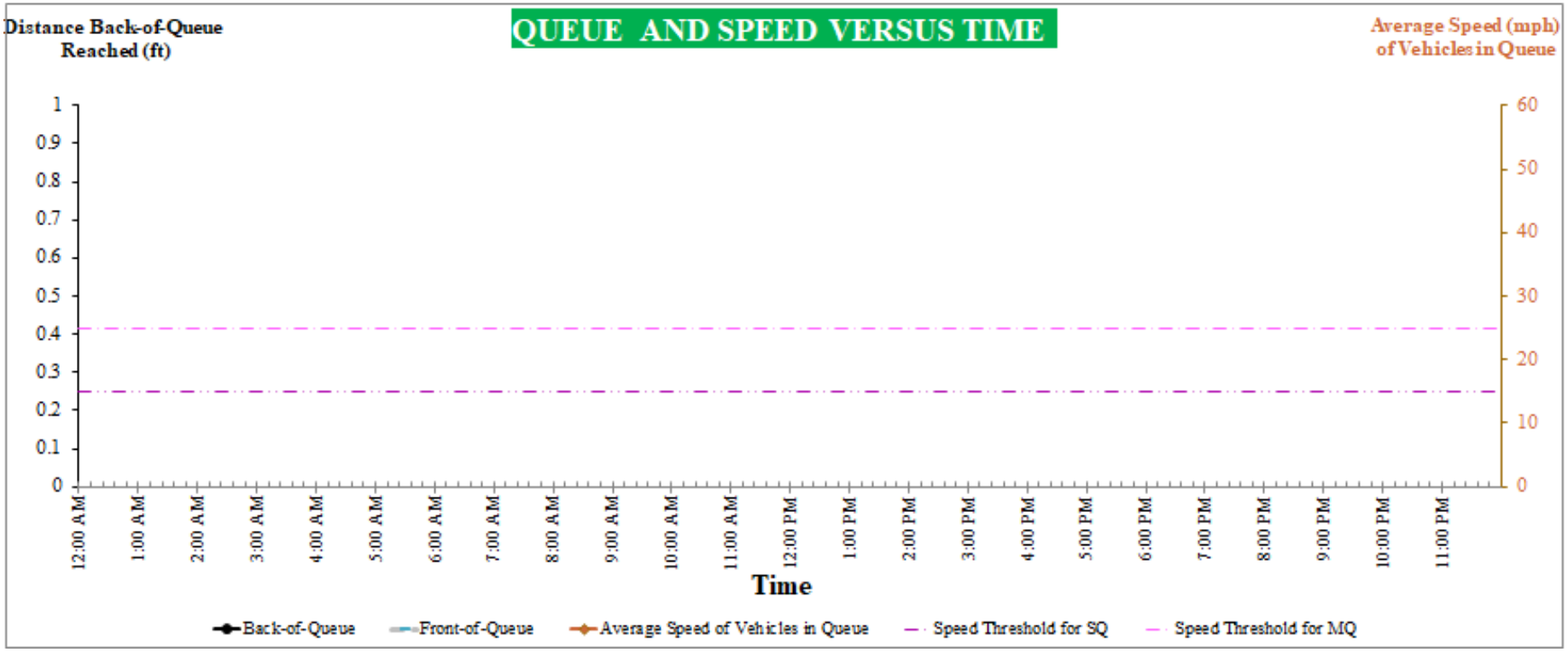


WorkZoneQ-Pro output

Start of Interval	End of Interval	No. of vehicles in queue in the link*	Average spacing between vehicles in queue (ft)	Front-of-Queue (ft)	Back-of-Queue (ft)	Distance queue occupied (ft)	Average speed in queue (mph)	Summary of Users' Costs ($) All (SQ+MQ+SMV)	
								Based on WZ speed limit	Based on speed limit outside of the WZ
12:00 AM	1:00 AM	0	0	0	0	0	-	$0.00	$0.00
1:00 AM	2:00 AM	0	-	-	-	-	-	$0.00	$0.00
2:00 AM	3:00 AM	0	-	-	-	-	-	$0.00	$0.00
3:00 AM	4:00 AM	0	-	-	-	-	-	$0.00	$0.00
4:00 AM	5:00 AM	0	-	-	-	-	-	$0.00	$0.00
5:00 AM	6:00 AM	0	-	-	-	-	-	$0.00	$0.00
6:00 AM	7:00 AM	0	-	-	-	-	-	$0.00	$0.00
7:00 AM	8:00 AM	0	-	-	-	-	-	$0.00	$0.00
8:00 AM	9:00 AM	0	-	-	-	-	-	$0.00	$0.00
9:00 AM	10:00 AM	0	-	-	-	-	-	$0.00	$0.00
10:00 AM	11:00 AM	0	-	-	-	-	-	$0.00	$0.00
11:00 AM	12:00 PM	0	-	-	-	-	-	$0.00	$0.00
12:00 PM	1:00 PM	0	-	-	-	-	-	$0.00	$0.00
1:00 PM	2:00 PM	0	-	-	-	-	-	$0.00	$0.00
2:00 PM	3:00 PM	0	-	-	-	-	-	$0.00	$0.00
3:00 PM	4:00 PM	the upstre	the upstred	the upstrea	d the upstrea	d the upstrea	he upstre	the upstrea	d the upstrean
4:00 PM	5:00 PM	the upstre	the upstred	the upstrea	d the upstrea	d the upstrea	he upstre	the upstrea	d the upstrean
5:00 PM	6:00 PM	the upstre	the upstred	the upstrea	d the upstrea	d the upstrea	he upstre	the upstrea	d the upstrean
6:00 PM	7:00 PM	0	-	-	-	-	-	$1.82	$1.82
7:00 PM	8:00 PM	0	-	-	-	-	-	$0.00	$0.00
8:00 PM	9:00 PM	0	-	-	-	-	-	$0.00	$0.00
9:00 PM	10:00 PM	0	-	-	-	-	-	$0.00	$0.00
10:00 PM	11:00 PM	0	-	-	-	-	-	$0.00	$0.00
11:00 PM	12:00 AM	0	-	-	-	-	-	$0.00	$0.00
					Maximum distance back-of-queue reached (ft)	Maximum distance queue occupied (ft)		SUM All	SUM All
*: At the end of the corresponding interval or when there is no more vehicle in que					*0*	*0*		*$1.82*	*$1.82*

WorkZoneQ-Pro output Cont.

Queue reached the upstream intersection. See UserComp



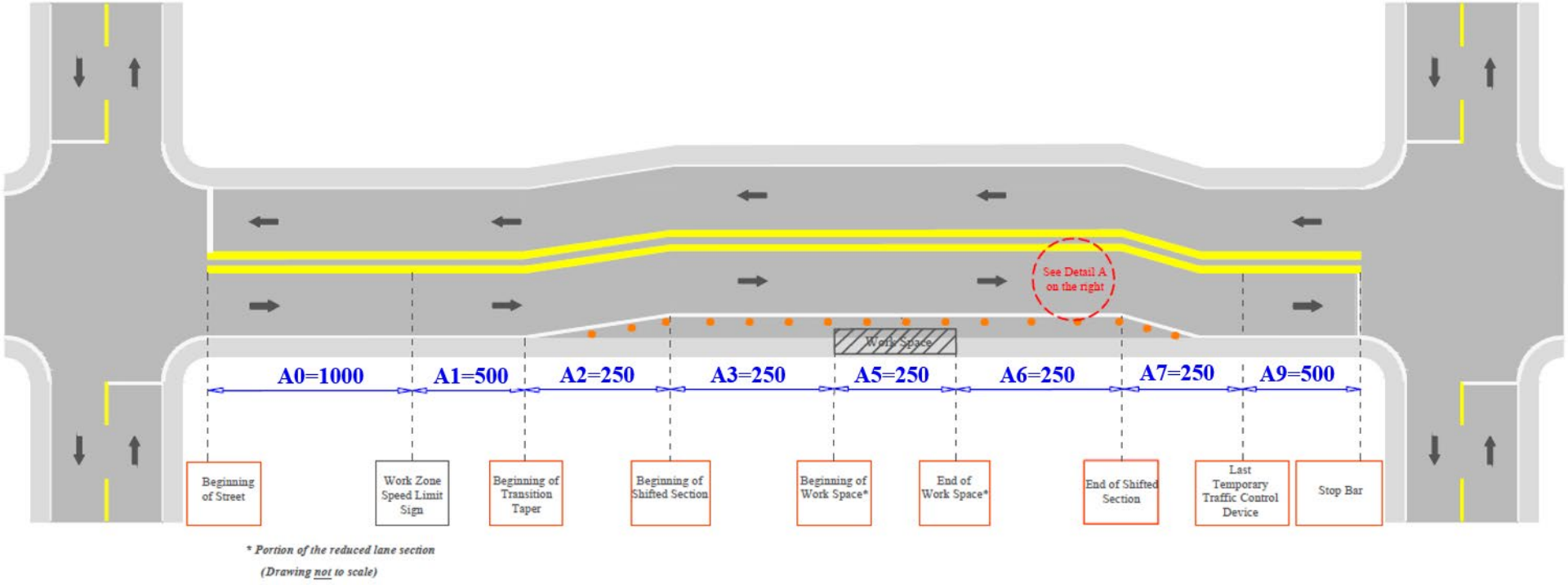
Example 7: US Route 2 and Vermont Route 14 in East Montpelier, Vermont

Problem:

Two lane highway Work zone is located on shoulder during day time for phase 1

US Route 2 and Vermont Route 14 in East Montpelier, Vermont

Geometric data: Longitudinal distances in the sketch below



US Route 2 and Vermont Route 14 in East Montpelier, Vermont

This project uses 1 lane and shoulder closure, so run 1-to-1 on Midblock Arterial WZ and One-lane Two-way WZ

Description:

ADT for US route 2: 13,200 vehicles per day, clear weather condition

Lane width = 11 ft

Shoulder width = 2 ft (right: 1 ft and left: 1 ft)

Rural area and level terrain

WZ conditions:

WZ speed limit is 25 mph and speed limit outside is 35 mph

Workers separated by concrete barrier, low work intensity during day time

Use default Passenger Car Equivalency (PCE) factors

Percentage of combination trucks is 4.9 %, single-unit trucks and recreational vehicles is 0 %

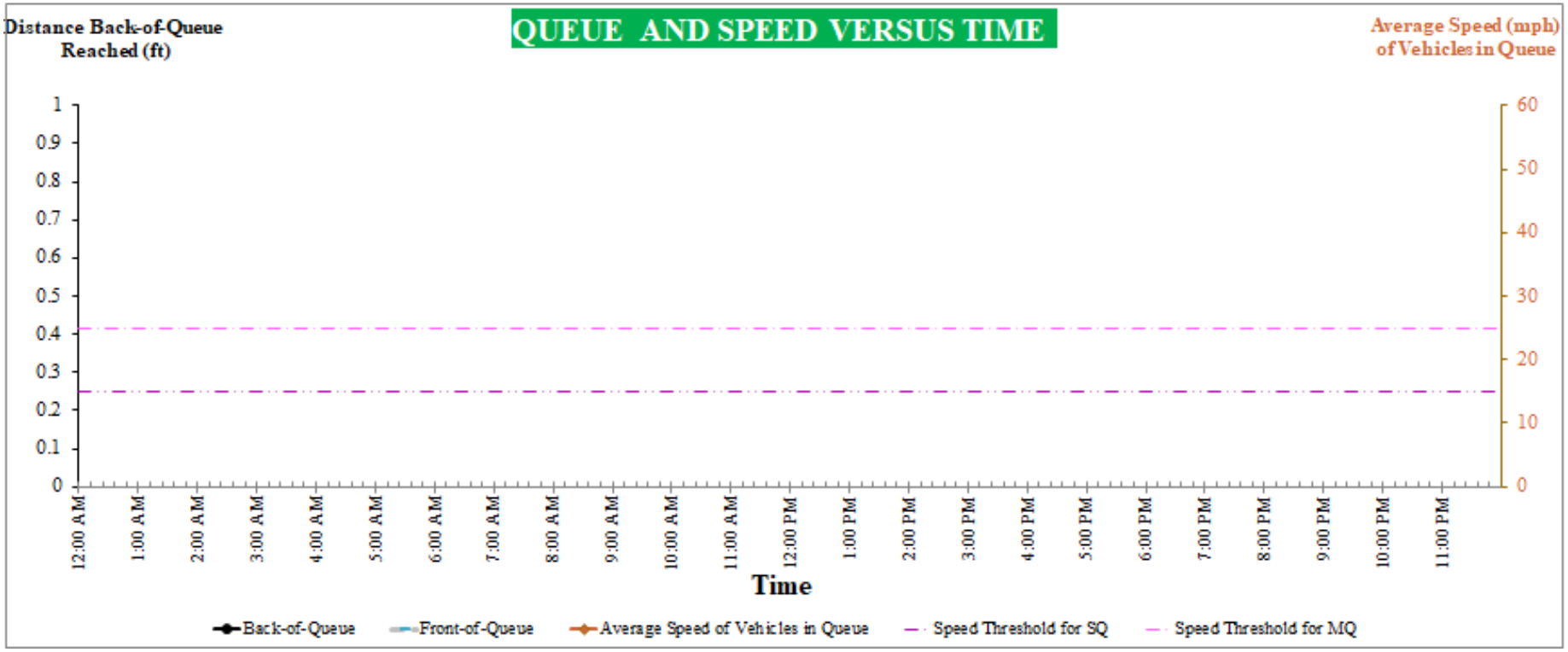
WorkZoneQ-Pro Output

Start of Interval	End of Interval	No. of vehicles in queue in the link*	Average spacing between vehicles in queue (ft)	Front-of-Queue (ft)	Back-of-Queue (ft)	Distance queue occupied (ft)	Average speed in queue (mph)	Summary of Users' Costs ($) All (SQ+MQ+SMV)	
								Based on WZ speed limit	Based on speed limit outside of the WZ
6:00 AM	7:00 AM	0	0	0	0	0	-	$3.97	$17.71
7:00 AM	8:00 AM	1	180	0	250	250	23.3	$14.61	$53.88
8:00 AM	9:00 AM	1	180	0	250	250	23.2	$15.67	$57.40
9:00 AM	10:00 AM	1	180	0	250	250	24.0	$8.14	$32.27
10:00 AM	11:00 AM	1	180	0	250	250	23.7	$10.54	$40.27
11:00 AM	12:00 PM	1	180	0	250	250	23.2	$15.24	$55.96
12:00 PM	1:00 PM	1	180	0	250	250	23.4	$13.37	$49.71
1:00 PM	2:00 PM	1	180	0	250	250	23.3	$14.09	$52.12
2:00 PM	3:00 PM	1	180	0	250	250	23.3	$14.47	$53.40
3:00 PM	4:00 PM	2	165	0	250	250	22.7	$23.57	$82.91
4:00 PM	5:00 PM	the upstre	the upstre	ed the upstream	ed the upstream	ed the upstream	the upstre	the upstre	d the upstrean
5:00 PM	6:00 PM	the upstre	the upstre	ed the upstream	ed the upstream	ed the upstream	the upstre	the upstre	d the upstrean
					Maximum distance back-of-queue reached (ft)	Maximum distance queue occupied (ft)		SUM All	SUM All
					ed the upstream	ed the upstream		the upstre	d the upstream

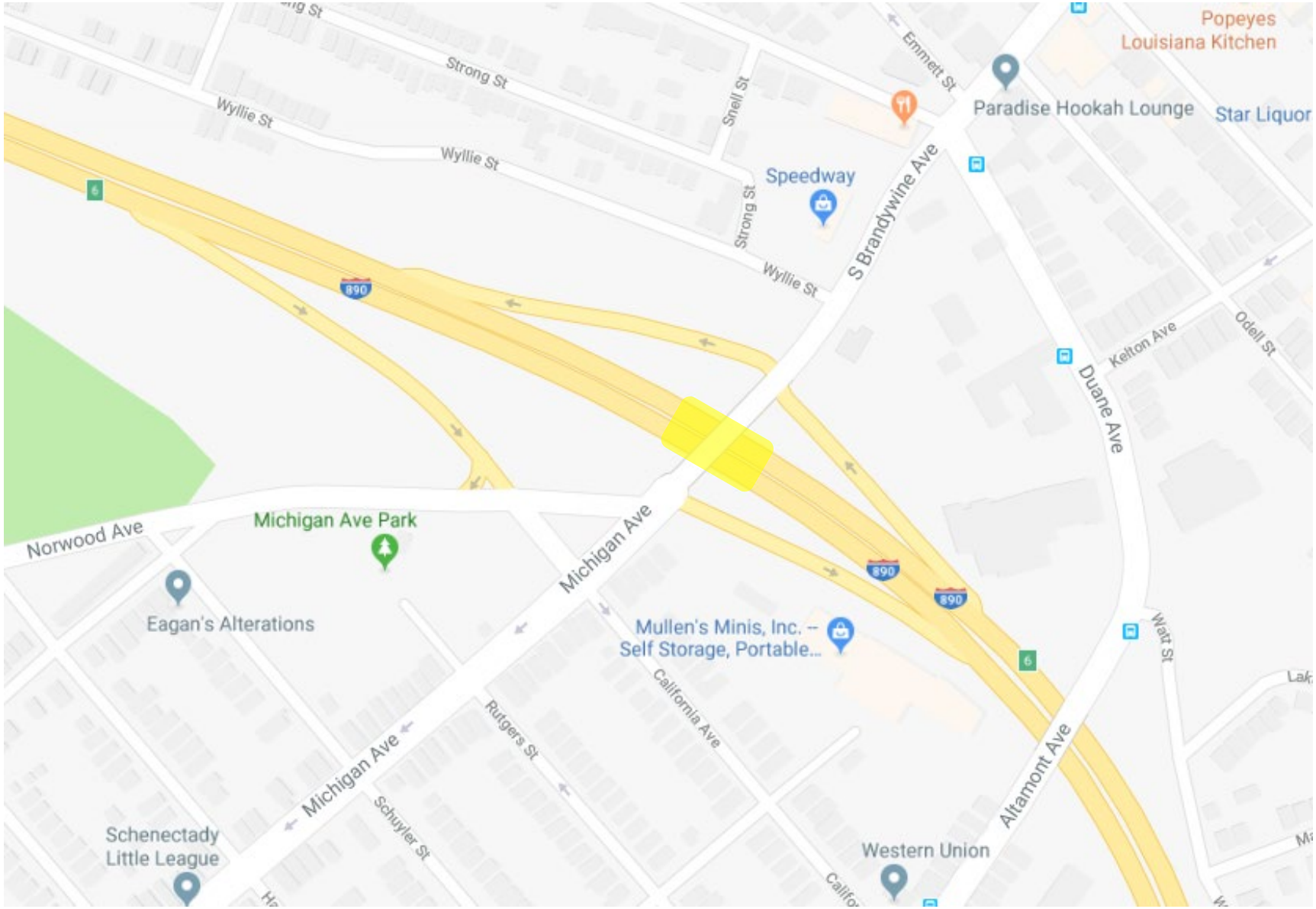
*: At the end of the corresponding interval or when there is no more vehicle in queue

WorkZoneQ-Pro Output Cont.

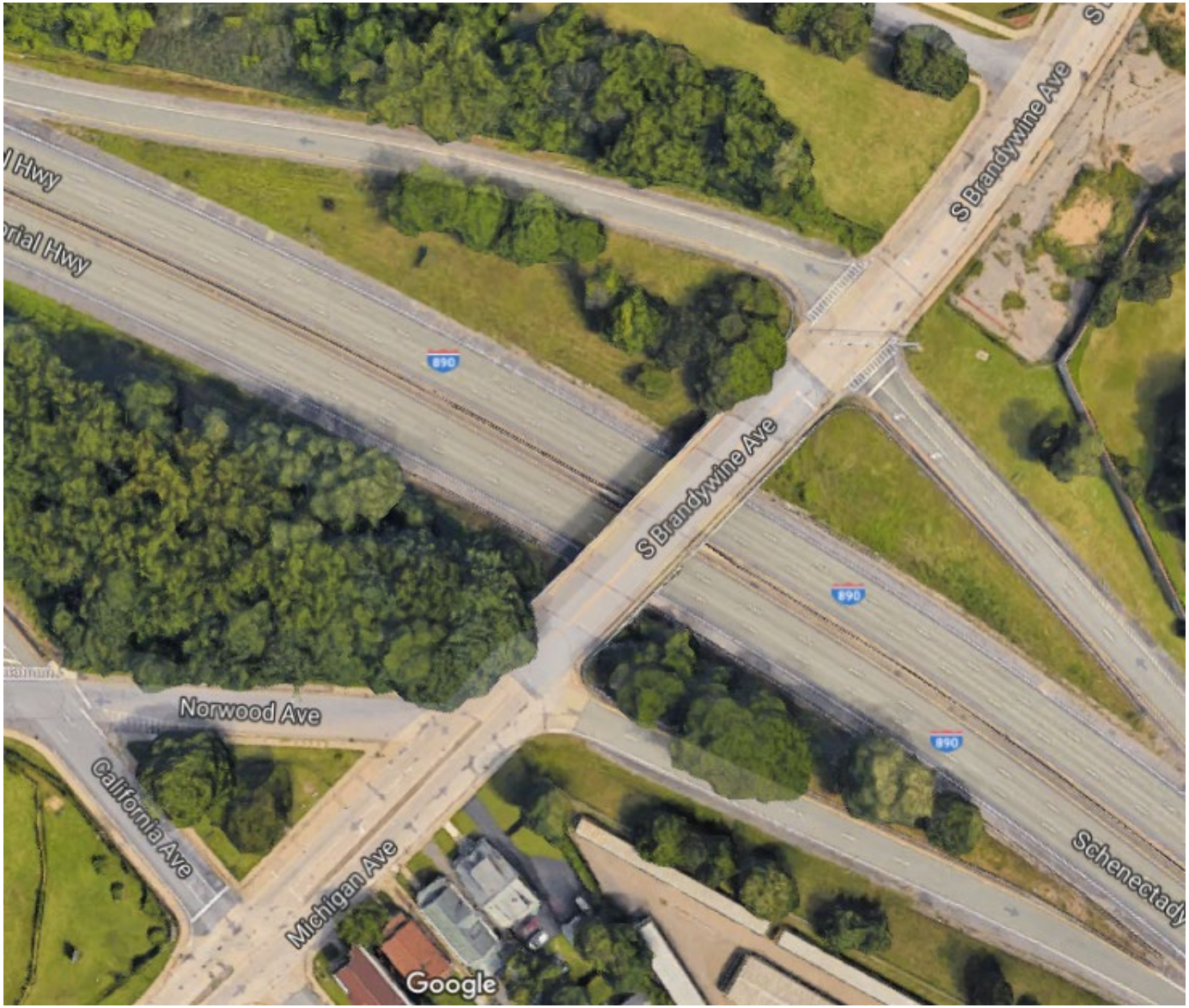
Queue reached the upstream intersection. See UserComp



Example 8: I-890 at Michigan Ave in Schenectady, NY



Description (Continued…)



Description (Continued…)

This project is 3-to-2 for night time operation

Description:

Lane width = 12 ft, left shoulder right = 1 ft, and left shoulder width = 1 ft

Urban area and level terrain

WZ conditions:

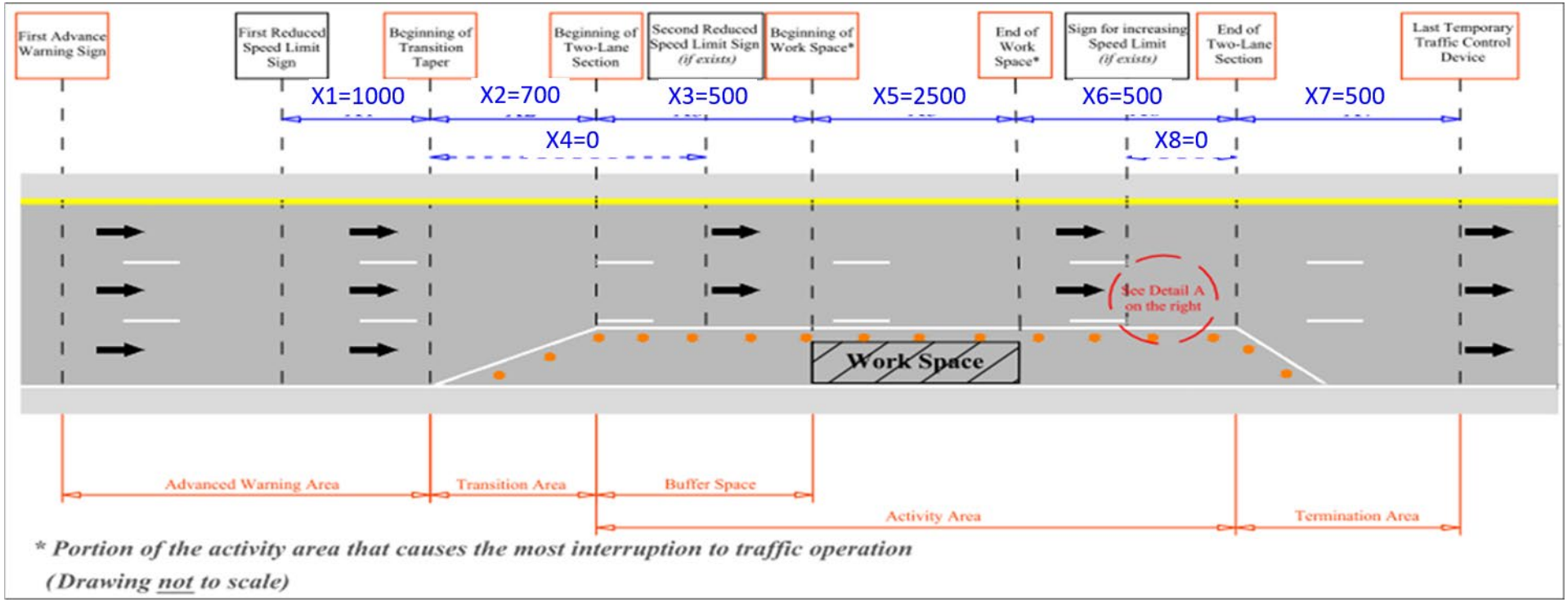
Speed limit inside work zone is 45 mph and outside is 55 mph

Concrete barrier, low work intensity

18 % trucks

Night Time Geometric Data

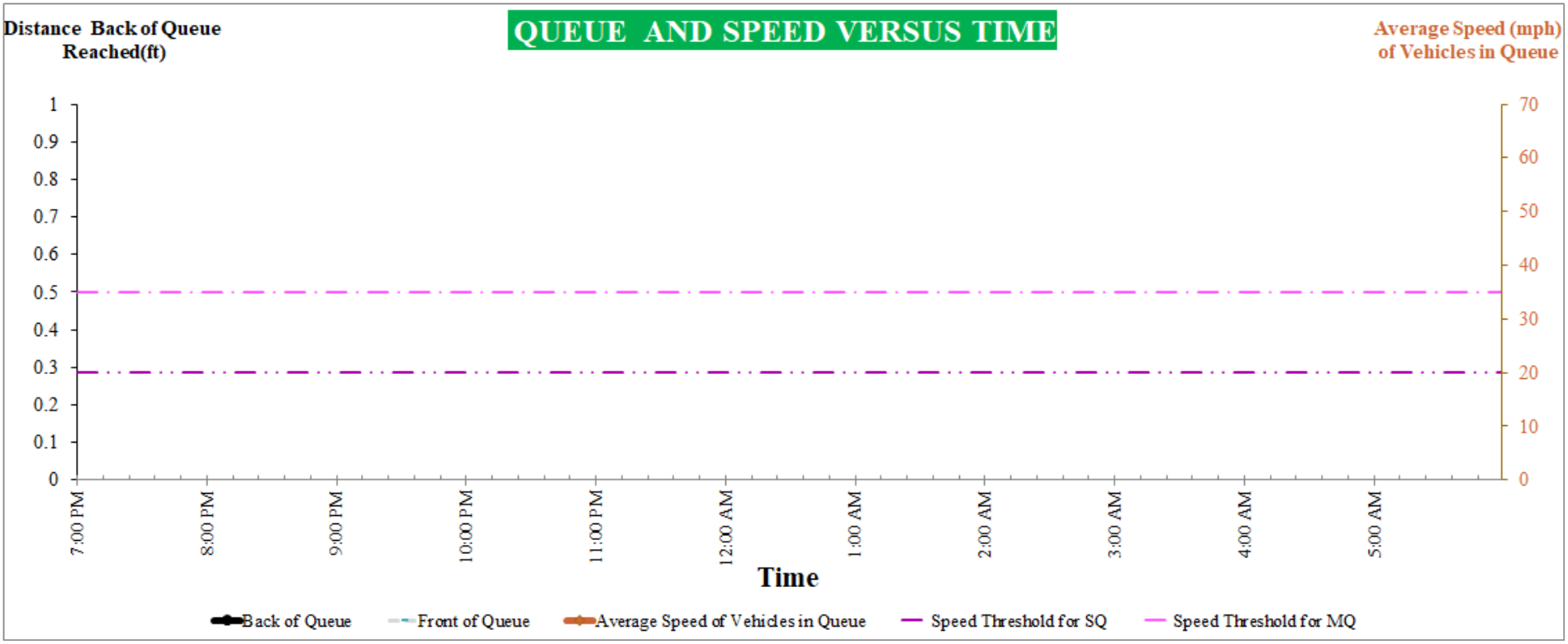
Geometric data: Longitudinal distances in the sketch below



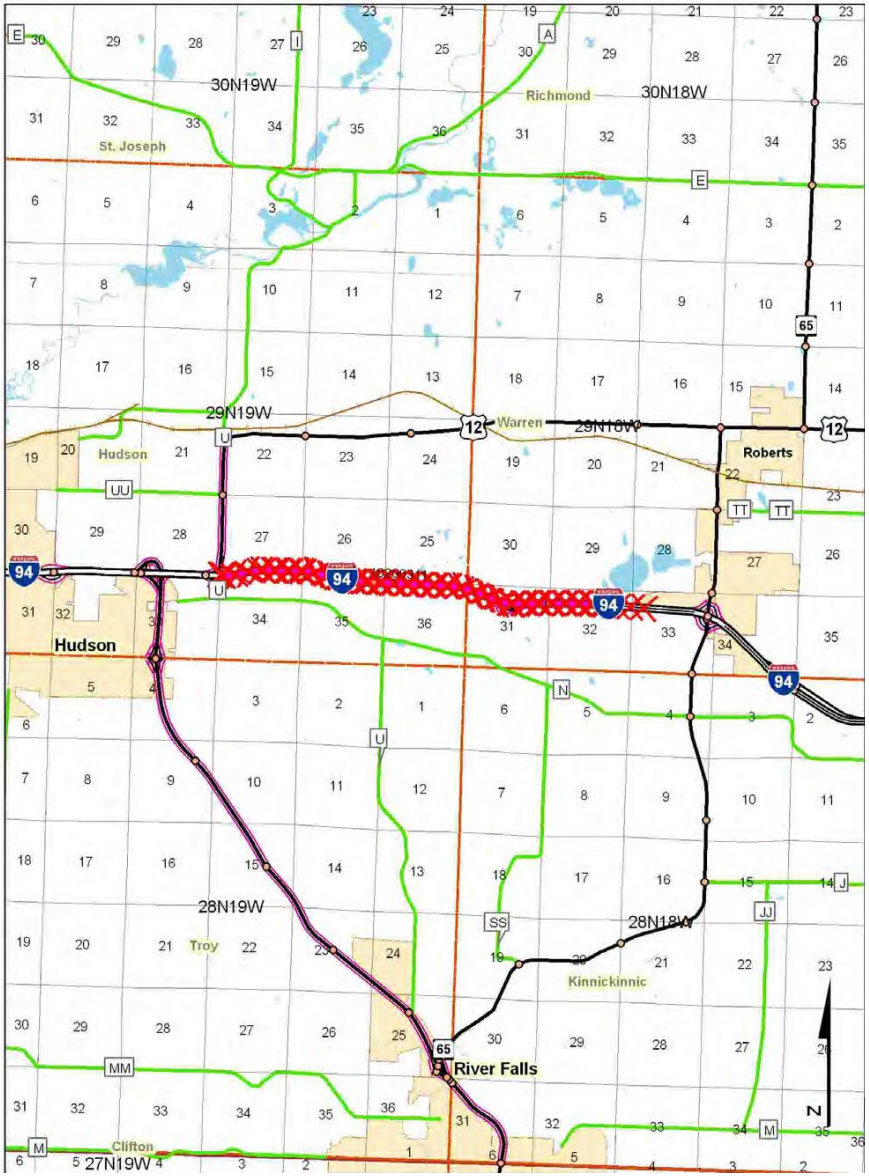
WorkZoneQ-Pro Output Cont.

Start of Interval	End of Interval	No. of vehicles in queue*	Average spacing between vehicles in queue (ft)	Front-of-queue (ft)	Back-of-queue (ft)	Distance queue occupied (ft)	Average speed in queue (mph)	Summary of Users' Costs ($) All (SQ+MQ+SMV)	
								Based on WZ speed limit	Based on speed limit outside of the WZ
7:00 PM	8:00 PM	0	0	0	0	0	-	$55.17	$138.34
8:00 PM	9:00 PM	0	-	-	-	-	-	$26.00	$82.45
9:00 PM	10:00 PM	0	-	-	-	-	-	$11.91	$58.48
10:00 PM	11:00 PM	0	-	-	-	-	-	$11.02	$54.08
11:00 PM	12:00 AM	0	-	-	-	-	-	$4.45	$21.86
12:00 AM	1:00 AM	0	-	-	-	-	-	$2.53	$12.42
1:00 AM	2:00 AM	0	-	-	-	-	-	$1.24	$6.08
2:00 AM	3:00 AM	0	-	-	-	-	-	$1.05	$5.17
3:00 AM	4:00 AM	0	-	-	-	-	-	$5.09	$24.97
4:00 AM	5:00 AM	0	-	-	-	-	-	$1.32	$6.47
5:00 AM	6:00 AM	0	-	-	-	-	-	$3.39	$16.62
					Maximum distance back-of-queue reached (ft)	Maximum distance queue occupied (ft)		SUM All	SUM All
*: At the end of the corresponding interval or when there is no more vehicle in queue					*0*	*0*		*$123.16*	*$426.95*

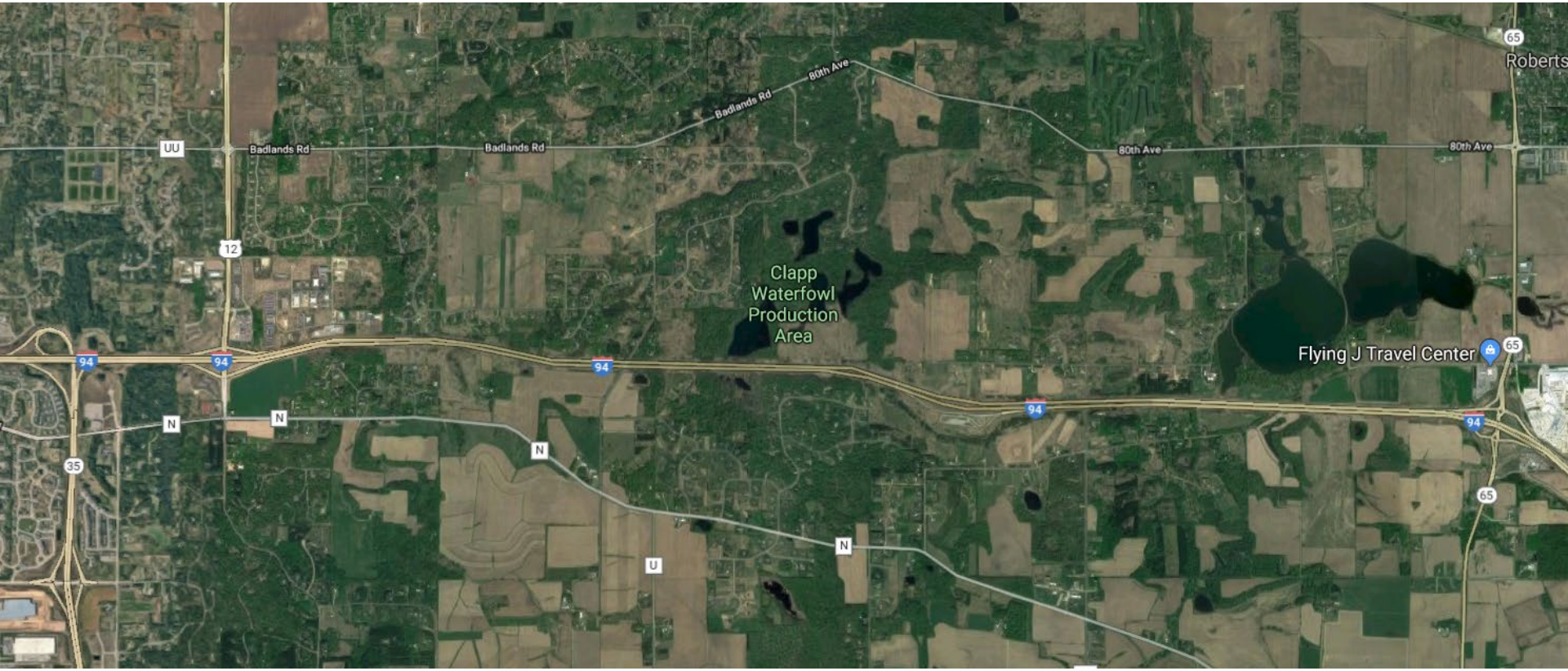
WorkZoneQ-Pro Output Cont.



Example 9: Resurfacing I-94 St. Croix County (Hudson – Baldwin), Wisconsin (USH 12 to STH 65)



Description (Continued…)



Description (Continued…)

This illustrated project is 2-to-1 for off peak hour operation (6 PM-5 AM)

Description:

Lane width = 12 ft, assumed right shoulder width = 2 ft, and left shoulder width = 2 ft

Rural area and level terrain

Assumed WZ conditions:

Speed limit inside work zone is 60 mph and outside is 70 mph

Concrete barrier, medium work intensity

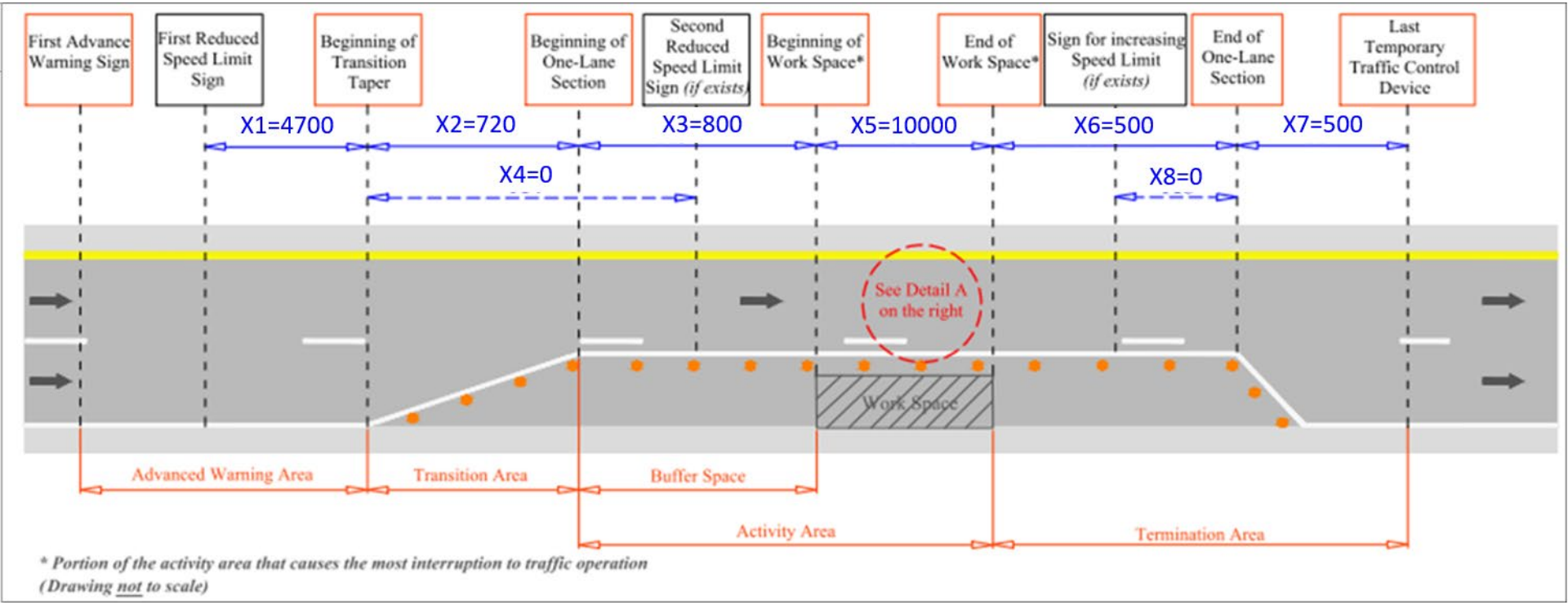
29 % trucks

Assumed Volume conditions:

Average of Tuesday, Wednesday, and Thursday traffic volume from Apr 2018 to pre-Memorial day (May 27, 2018) is used

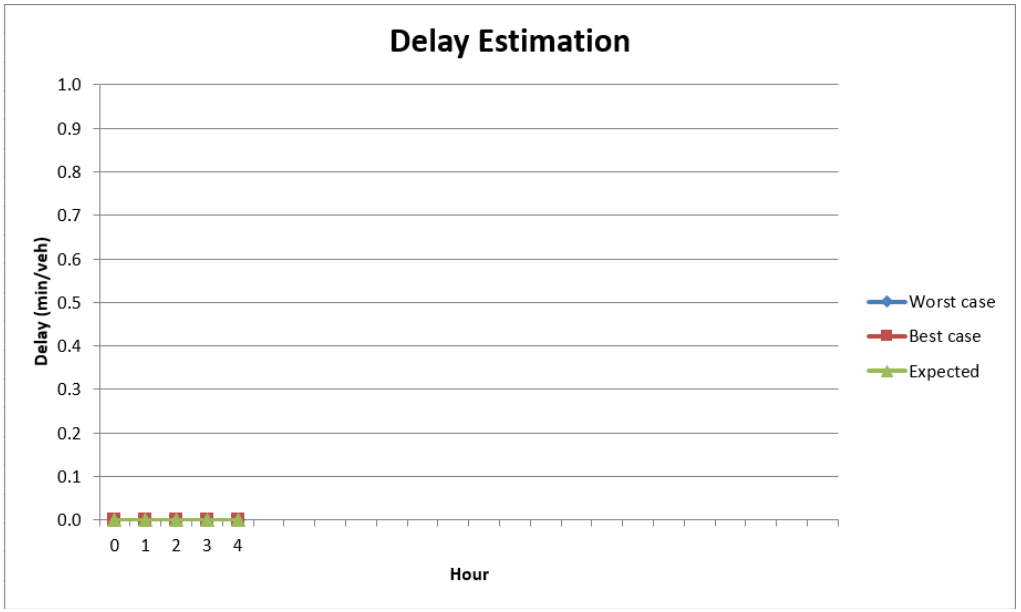
Geometric Data

Geometric data: Longitudinal distances in the sketch below

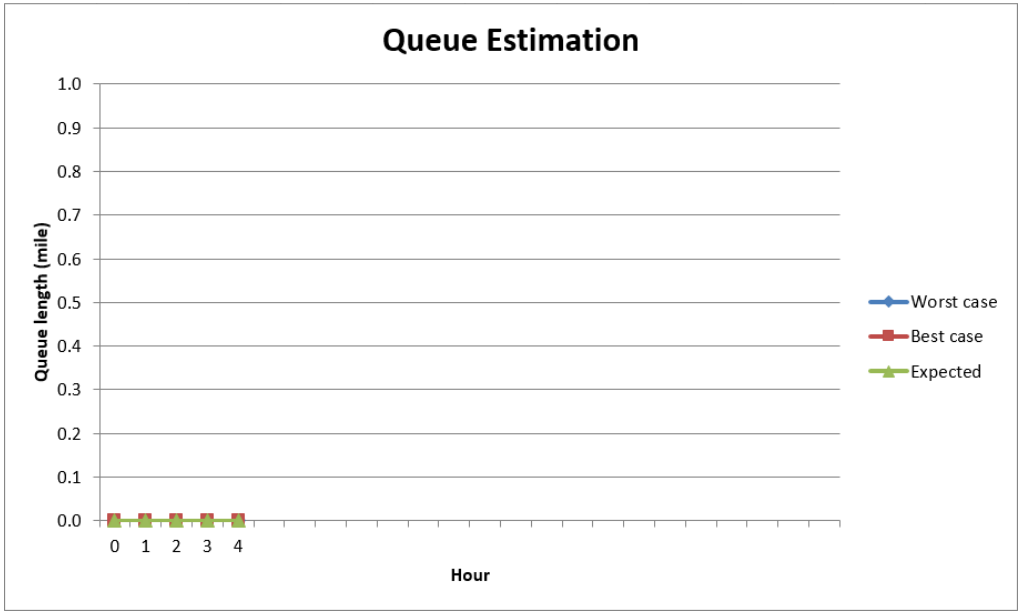


QDAT Morning output

Expected: Estimated Delay(min/veh)		
start hour	0	0.0
	1	0.0
	2	0.0
	3	0.0
end hour	4	0.0

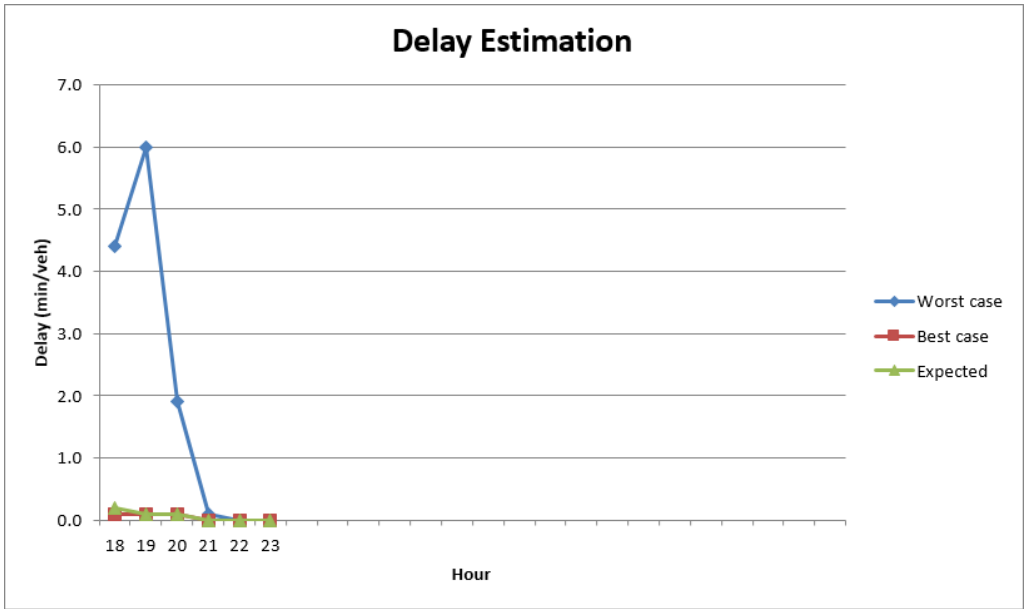


Expected: Estimated Queue(mile)		
start hour	0	0.0
	1	0.0
	2	0.0
	3	0.0
end hour	4	0.0

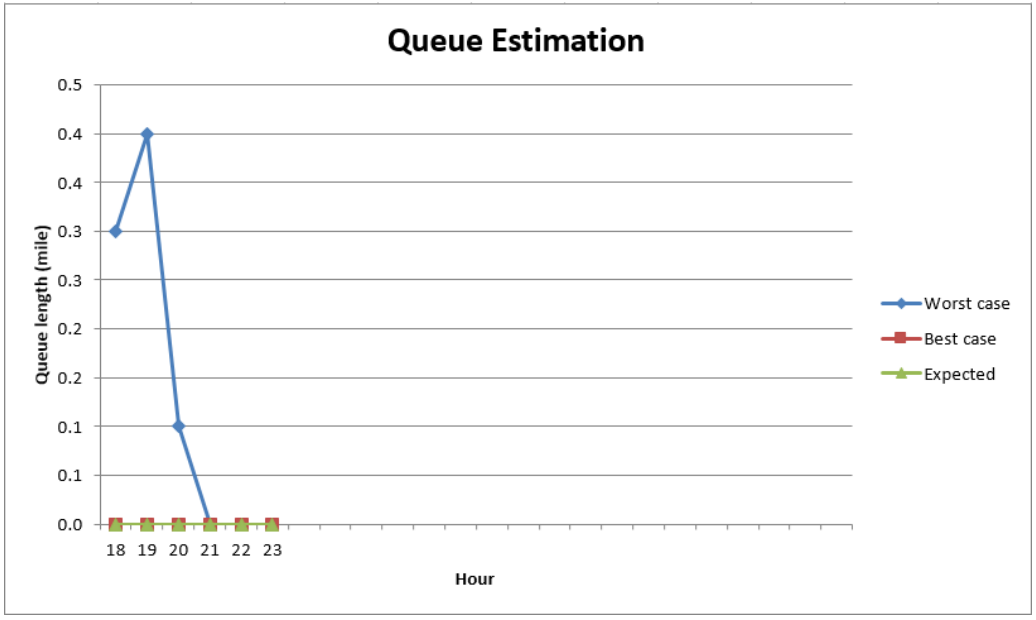


QDAT Night output

Expected: Estimated Delay(min/veh)		
start hour	18	0.2
	19	0.1
	20	0.1
	21	0.0
	22	0.0
end hour	23	0.0



Expected: Estimated Queue(mile)		
start hour	18	0.0
	19	0.0
	20	0.0
	21	0.0
	22	0.0
end hour	23	0.0



MoDOT Morning output

BASE CONDITIONS

Open Lane Capacity (veh/h/lane):	1900

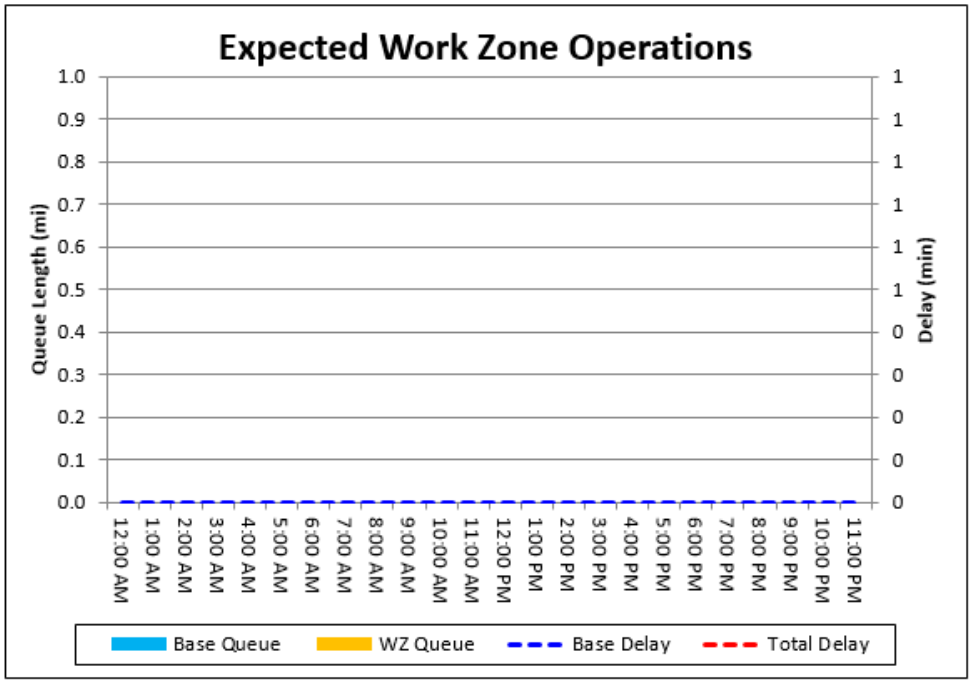
Base Conditions Capacity (Total for ALL Lanes): 3800 veh/h

WORKZONE DETAILS

Work Description:	(Example: Pothole Patching - Close One Lane OR Joint Repair - Two Lanes Closed)
Work Location:	Workers & equipment less than 4 feet from travel lane
Travel Lane Width (ft):	> 11.5
Number of Lanes Open:	1
ESTIMATED Work Zone Capacity (veh/h):	1258
USER DEFINED Work Zone Capacity (veh/h):	
Start Time:	12:00 AM
End Time:	5:00 AM
Duration of Closure (hrs):	5

RESULTS

Measure of Effectiveness	Base Conditions	Work Zone	Total
Max Queue Length (mi):	0.0	0.0	0.0
Max Delay (minutes):	0	0	0
Cost ($):	$0	$0	$0



MoDOT Night output

BASE CONDITIONS

Open Lane Capacity (veh/h/lane):	1900

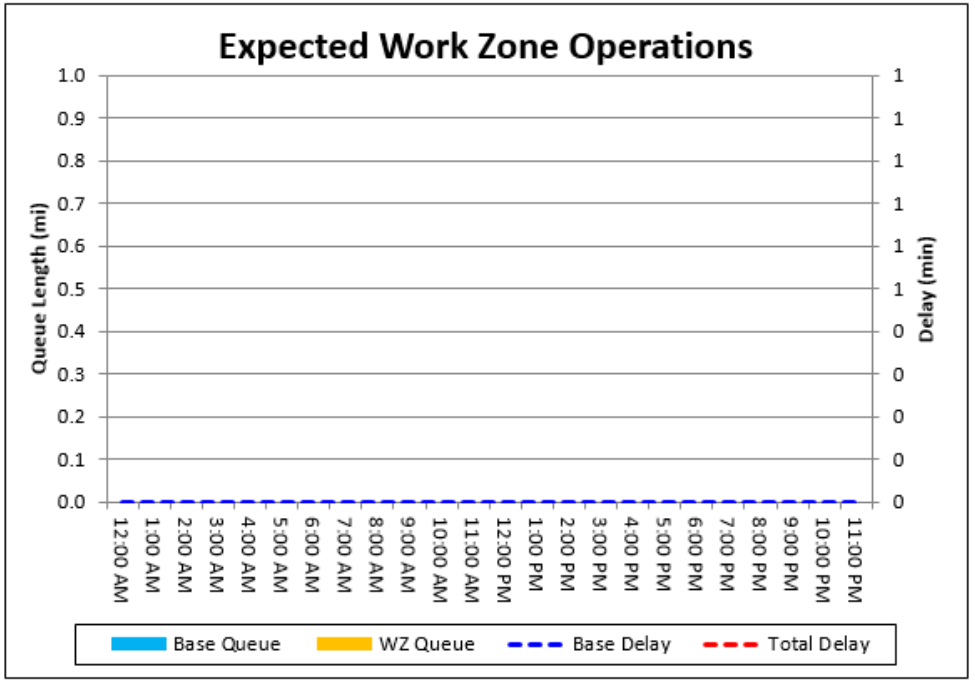
Base Conditions Capacity (Total for ALL Lanes): 3800 veh/h

WORKZONE DETAILS

Work Description:	(Example: Pothole Patching - Close One Lane OR Joint Repair - Two Lanes Closed)
Work Location:	Workers & equipment less than 4 feet from travel lane
Travel Lane Width (ft):	> 11.5
Number of Lanes Open:	1
ESTIMATED Work Zone Capacity (veh/h):	1258
USER DEFINED Work Zone Capacity (veh/h):	
Start Time:	6:00 PM
End Time:	12:00 AM
Duration of Closure (hrs):	6

RESULTS

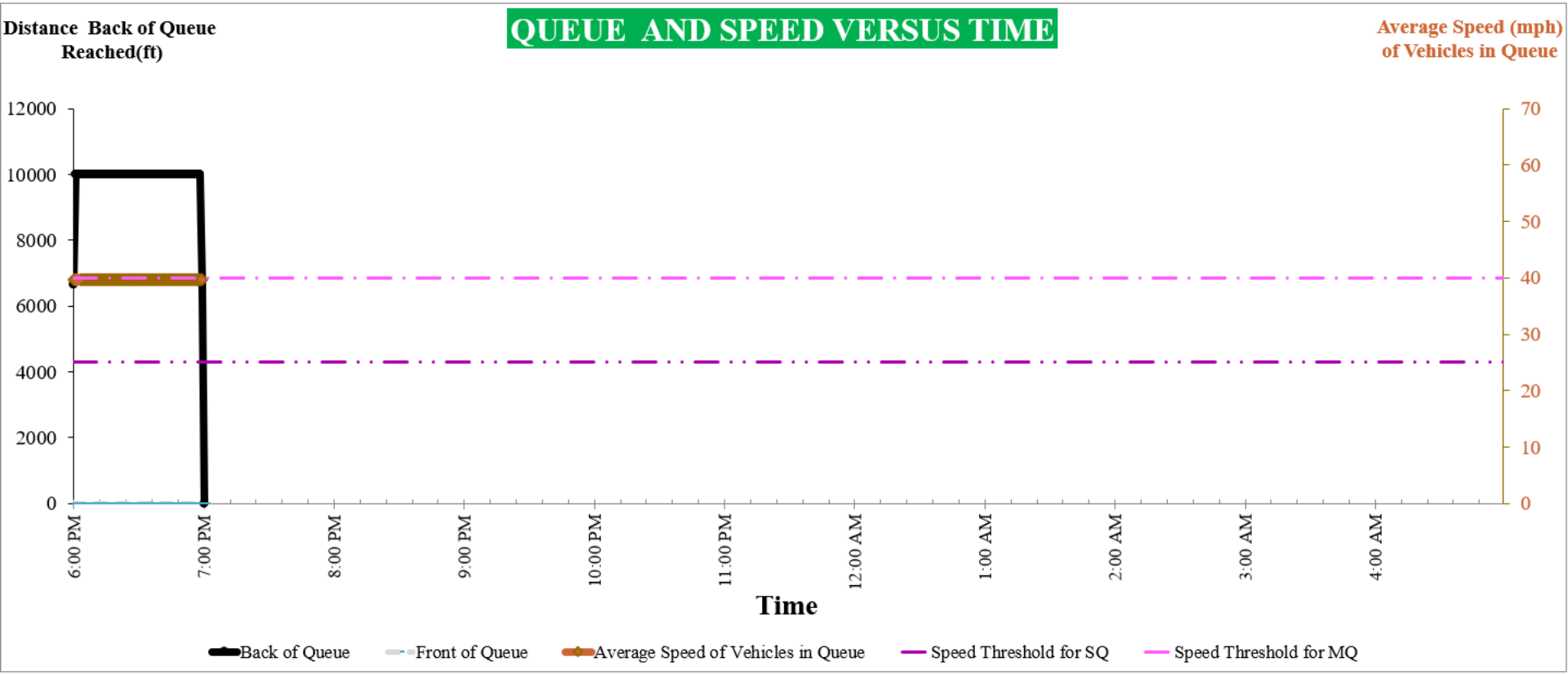
Measure of Effectiveness	Base Conditions	Work Zone	Total
Max Queue Length (mi):	0.0	0.0	0.0
Max Delay (minutes):	0	0	0
Cost ($):	$0	$0	$0



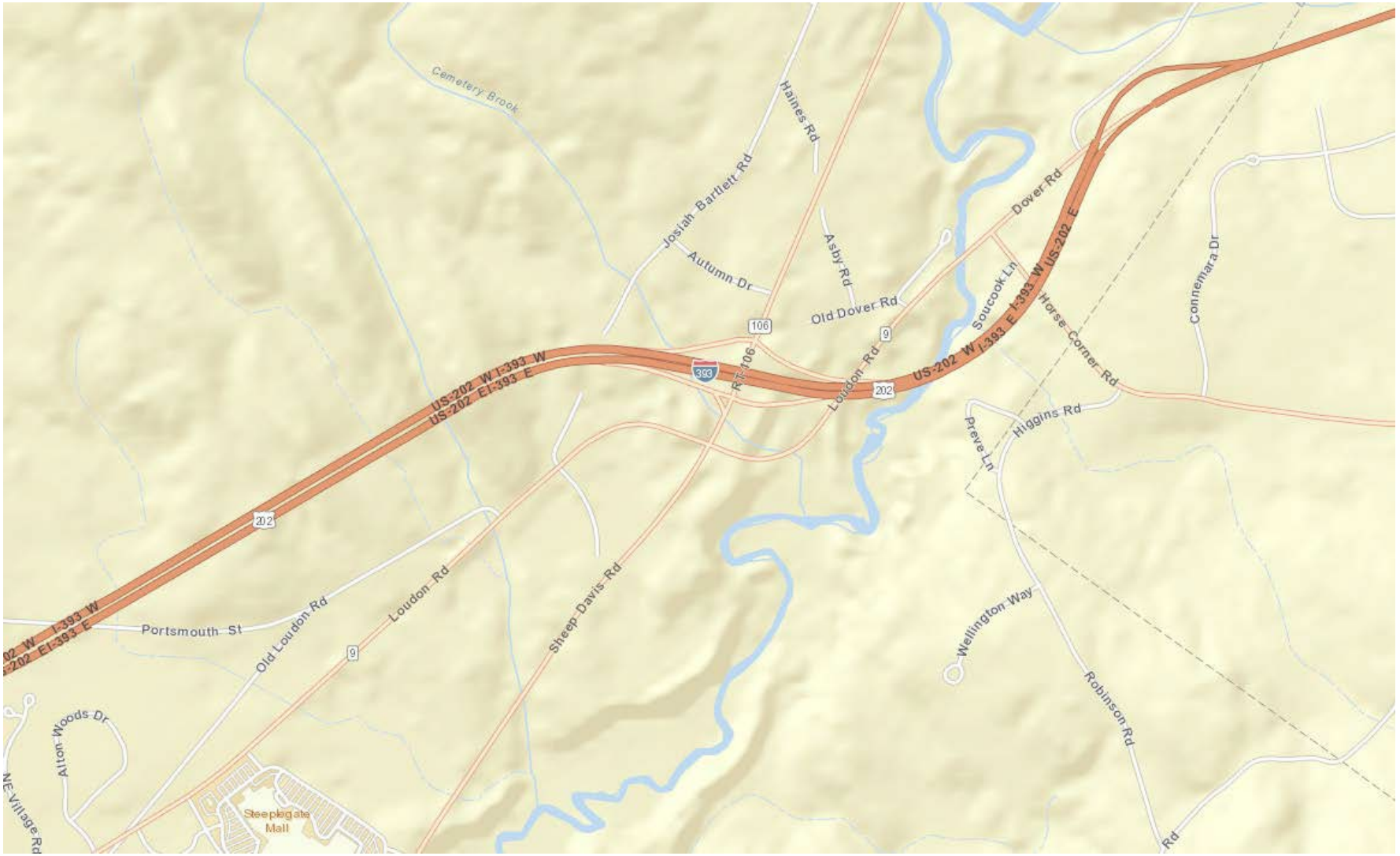
WorkZoneQ-Pro output

Start of Interval	End of Interval	No. of vehicles in queue*	Average spacing between vehicles in queue (ft)	Front-of-queue (ft)	Back-of-queue (ft)	Distance queue occupied (ft)	Average speed in queue (mph)	Summary of Users' Costs ($) All (SQ+MQ+SMV)	
								Based on WZ speed limit	Based on speed limit outside of the WZ
6:00 PM	7:00 PM	56	180	0	10,000	10,000	39.7	$493.49	$665.75
7:00 PM	8:00 PM	0	180	0	0	0	-	$327.61	$465.15
8:00 PM	9:00 PM	0	-	-	-	-	-	$213.91	$312.44
9:00 PM	10:00 PM	0	-	-	-	-	-	$96.86	$169.62
10:00 PM	11:00 PM	0	-	-	-	-	-	$69.74	$122.13
11:00 PM	12:00 AM	0	-	-	-	-	-	$39.52	$69.21
12:00 AM	1:00 AM	0	-	-	-	-	-	$26.73	$46.82
1:00 AM	2:00 AM	0	-	-	-	-	-	$23.05	$40.37
2:00 AM	3:00 AM	0	-	-	-	-	-	$25.76	$45.12
3:00 AM	4:00 AM	0	-	-	-	-	-	$47.27	$82.78
4:00 AM	5:00 AM	0	-	-	-	-	-	$70.51	$123.49
					Maximum distance back-of-queue reached (ft)	Maximum distance queue occupied (ft)		SUM All	SUM All
*: At the end of the corresponding interval or when there is no more vehicle in queue					*10,000*	*10,000*		*$1,434.46*	*$2,142.87*

WorkZoneQ-Pro output



Example 10: Concord-Pembroke US-202 I-393 Bridge repair in Concord, New Hampshire



Description (Continued…)

Description (Continued…)

This illustrated project is one lane closure on two lane freeway

Description:

Lane width = 12 ft, right shoulder width = 2 ft, and left shoulder width = 2 ft

Rural area and level terrain

WZ conditions:

Speed limit inside work zone is 45 mph and outside is 55 mph

Concrete barrier, medium work intensity

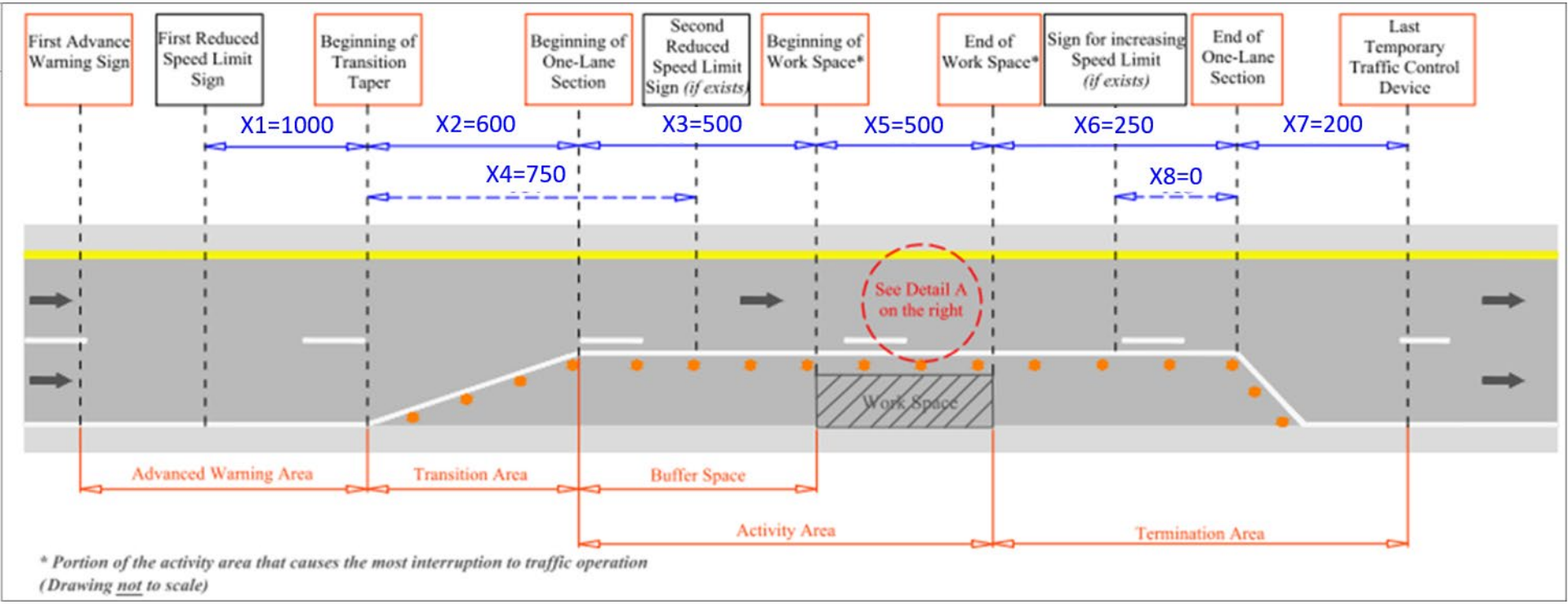
7.1 % trucks

Assumed Volume conditions:

Average of Tuesday, Wednesday, and Thursday traffic volume from July 2015 is used (eliminated volumes from July 19, 2015, because their volumes were zero in 4 - 7AM)

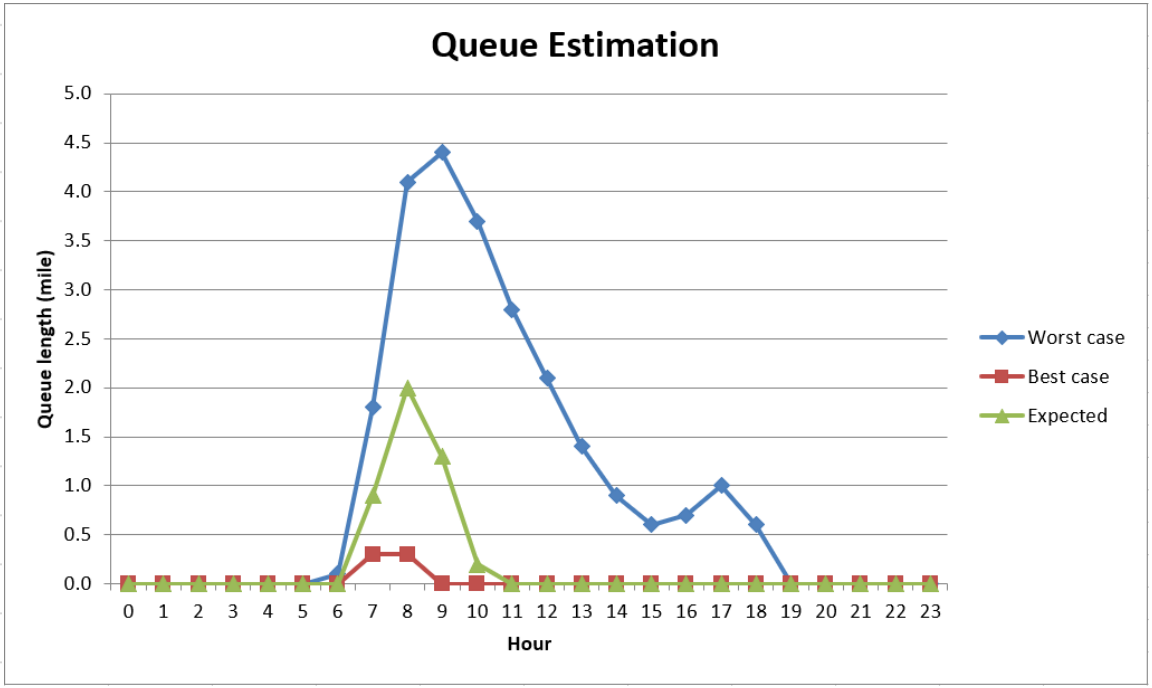
Geometric Data

Geometric data: Longitudinal distances in the sketch below



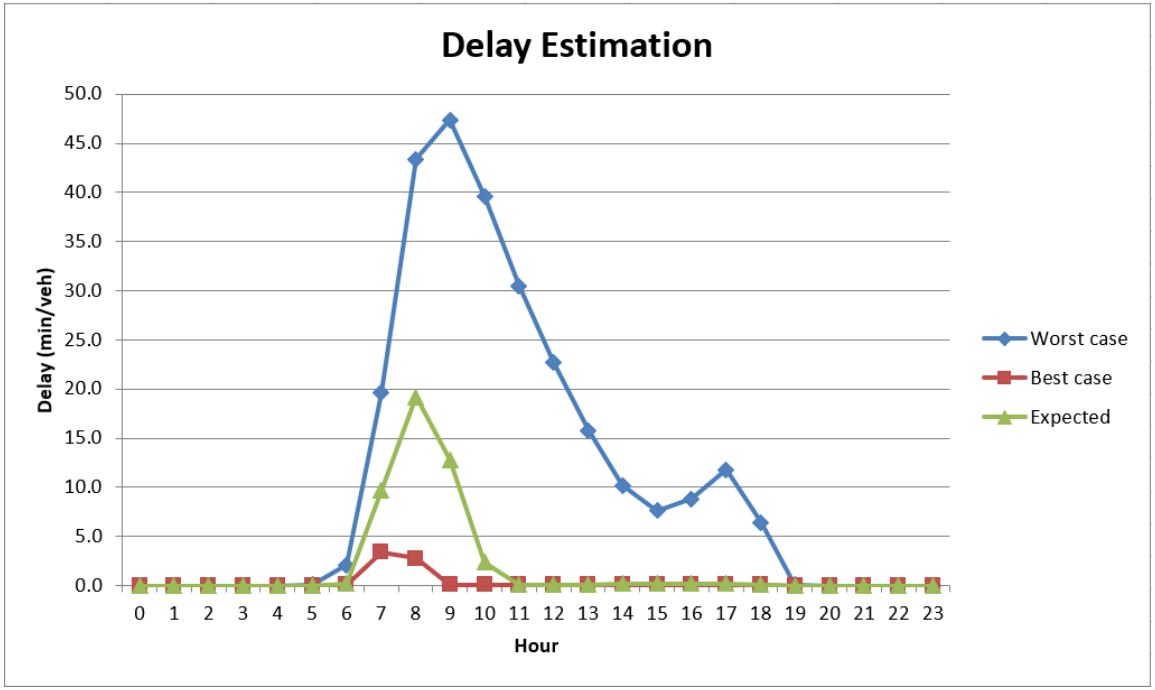
QDAT Queue output

Expected: Estimated Queue(mile)		
start hour	0	0.0
	1	0.0
	2	0.0
	3	0.0
	4	0.0
	5	0.0
	6	0.0
	7	0.9
	8	2.0
	9	1.3
	10	0.2
	11	0.0
	12	0.0
	13	0.0
	14	0.0
	15	0.0
	16	0.0
	17	0.0
	18	0.0
	19	0.0
	20	0.0
	21	0.0
	22	0.0
end hour	23	0.0



QDAT Queue output

Expected: Estimated Delay(min/veh)		
start hour	0	0.0
	1	0.0
	2	0.0
	3	0.0
	4	0.0
	5	0.0
	6	0.2
	7	9.7
	8	19.2
	9	12.8
	10	2.4
	11	0.1
	12	0.1
	13	0.1
	14	0.2
	15	0.2
	16	0.2
	17	0.2
	18	0.1
	19	0.0
	20	0.0
	21	0.0
	22	0.0
end hour	23	0.0



MoDOT output

BASE CONDITIONS

Open Lane Capacity (veh/h/lane):	1900

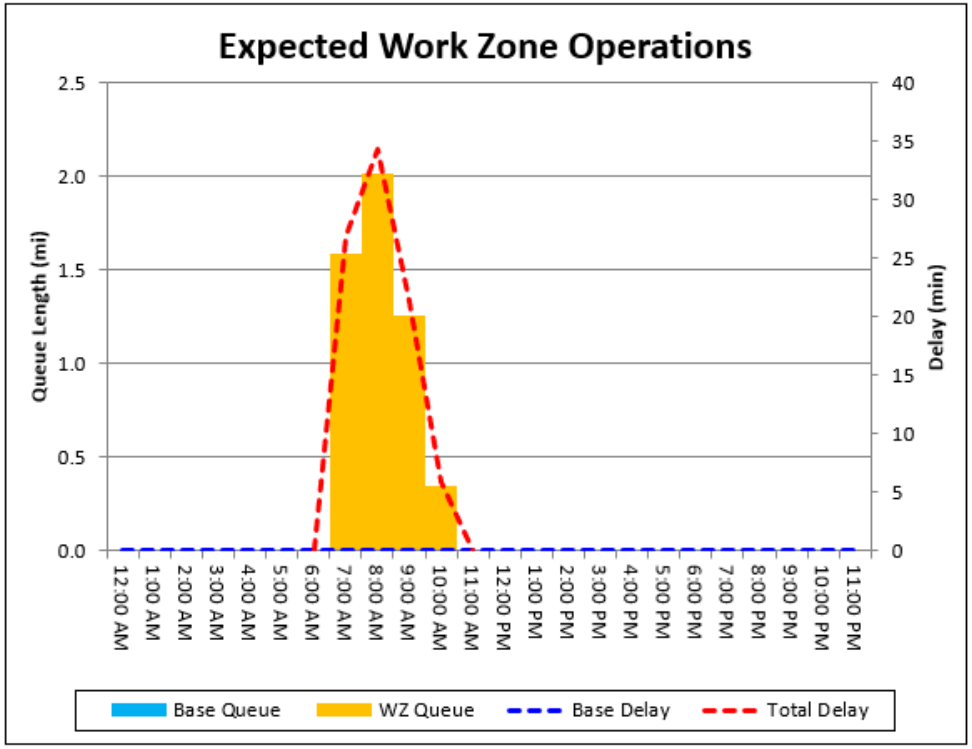
Base Conditions Capacity (Total for ALL Lanes): 3800 veh/h

WORKZONE DETAILS

Work Description:	(Example: Pothole Patching - Close One Lane OR Joint Repair - Two Lanes Closed)
Work Location:	Workers & equipment less than 4 feet from travel lane
Travel Lane Width (ft):	> 11.5
Number of Lanes Open:	1
ESTIMATED Work Zone Capacity (veh/h):	1391
USER DEFINED Work Zone Capacity (veh/h):	
Start Time:	12:00 AM
End Time:	12:00 AM
Duration of Closure (hrs):	24

RESULTS

Measure of Effectiveness	Base Conditions	Work Zone	Total
Max Queue Length (mi):	0.0	2.0	2.0
Max Delay (minutes):	0	34	34
Cost ($):	$0	$10,300	$10,300

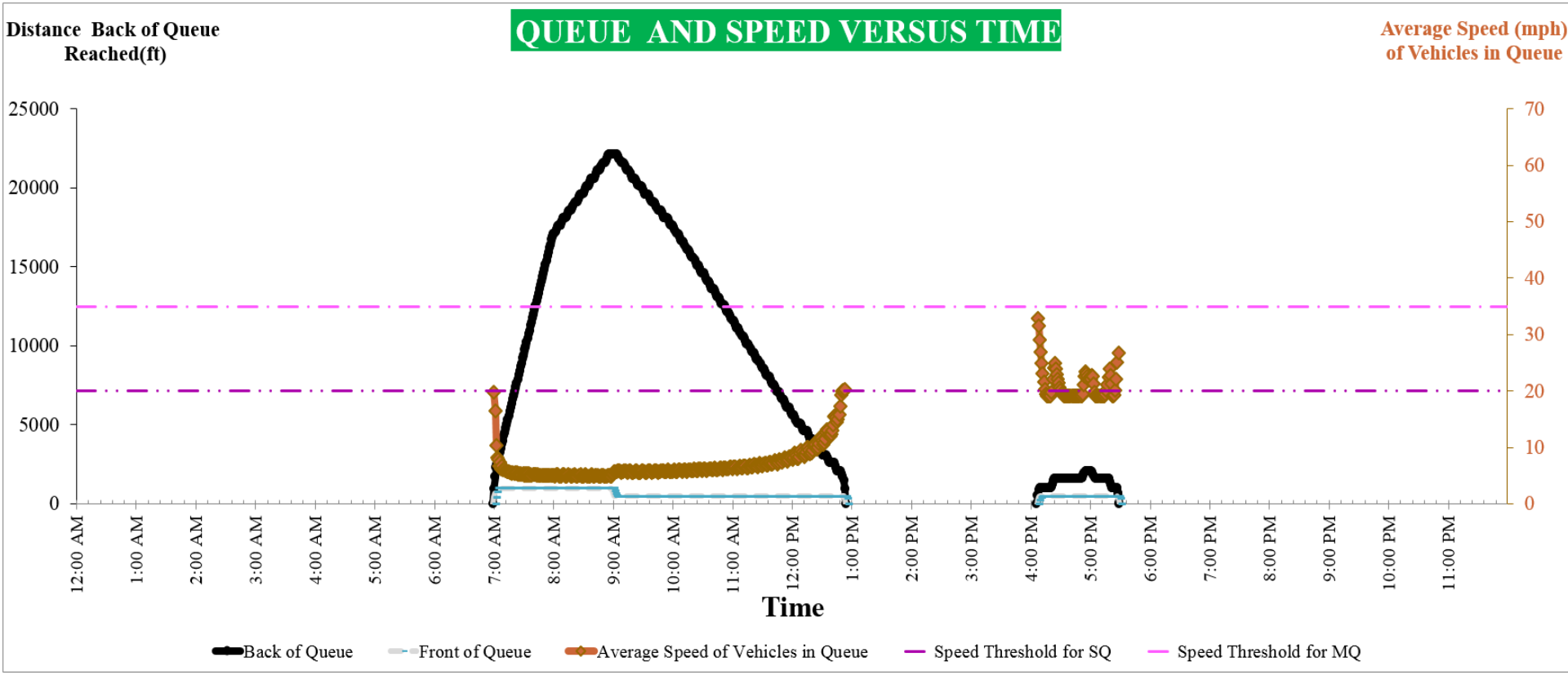


WorkZoneQ-Pro output

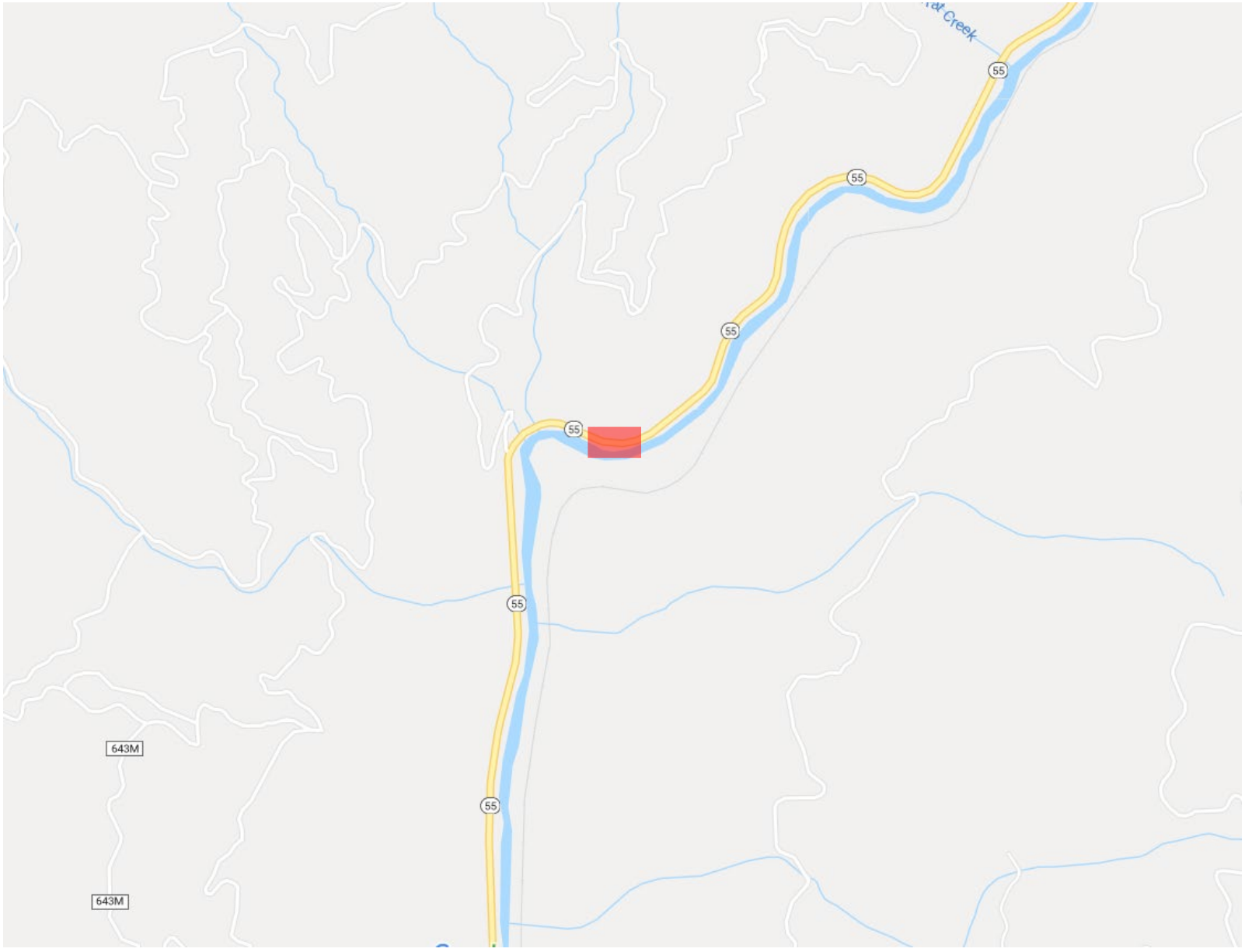
Start of Interval	End of Interval	Study period	No. of vehicles in queue*	Average spacing between vehicles in queue (ft)	Front-of-queue (ft)	Back-of-queue (ft)	Distance queue occupied (ft)	Average speed in queue (mph)	Summary of Users' Costs ($) All (SQ+MQ+SMV) Based on WZ speed limit	Summary of Users' Costs ($) All (SQ+MQ+SMV) Based on speed limit outside of the WZ
12:00 AM	1:00 AM	1	0	0	0	0	0	-	$0.53	$1.30
1:00 AM	2:00 AM	1	0	-	-	-	-	-	$0.23	$0.56
2:00 AM	3:00 AM	1	0	-	-	-	-	-	$0.24	$0.58
3:00 AM	4:00 AM	1	0	-	-	-	-	-	$0.37	$0.91
4:00 AM	5:00 AM	1	0	-	-	-	-	-	$1.25	$3.06
5:00 AM	6:00 AM	1	0	-	-	-	-	-	$0.00	$5.29
6:00 AM	7:00 AM	1	0	-	-	-	-	-	$11.83	$26.81
7:00 AM	8:00 AM	1	801	39	1,000	17,033	16,033	5.3	$9,482.40	$9,509.05
8:00 AM	9:00 AM	1	1,075	40	1,000	22,133	21,133	5.0	$22,464.99	$22,491.66
9:00 AM	10:00 AM	1	838	39	500	17,600	17,100	5.8	$22,904.61	$22,931.28
10:00 AM	11:00 AM	1	533	40	500	11,600	11,100	6.1	$16,355.48	$16,382.15
11:00 AM	12:00 PM	1	224	41	500	5,600	5,100	7.0	$8,939.32	$8,965.99
12:00 PM	1:00 PM	1	0	41	0	0	0	10.6	$2,314.59	$2,340.00
1:00 PM	2:00 PM	1	0	-	-	-	-	-	$5.32	$16.30
2:00 PM	3:00 PM	1	0	-	-	-	-	-	$7.73	$20.20
3:00 PM	4:00 PM	1	0	-	-	-	-	-	$9.47	$23.00
4:00 PM	5:00 PM	1	25	85	500	2,100	1,600	21.0	$187.73	$213.68
5:00 PM	6:00 PM	1	0	85	0	0	0	21.0	$111.08	$132.26
6:00 PM	7:00 PM	1	0	-	-	-	-	-	$2.88	$11.80
7:00 PM	8:00 PM	1	0	-	-	-	-	-	$0.00	$6.35
8:00 PM	9:00 PM	1	0	-	-	-	-	-	$3.40	$8.34
9:00 PM	10:00 PM	1	0	-	-	-	-	-	$2.60	$6.39
10:00 PM	11:00 PM	1	0	-	-	-	-	-	$1.53	$8.95
11:00 PM	12:00 AM	1	0	-	-	-	-	-	$0.89	$2.17
						Maximum distance back-of-queue reached (ft)	Maximum distance queue occupied (ft)		SUM All	SUM All
						22,133	*21,133*		*$82,808.44*	*$83,108.11*

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

WorkZoneQ-Pro output



Example 11: Pavement Rehab on SH-55 at Cascade, Idaho



Description (Continued…)

Description (Continued…)

This illustrated project is one-lane two-way operation

Description:

Lane width = 12 ft, right shoulder width = 1 ft, and left shoulder width = 1 ft

Rural area and level terrain

Assumed WZ conditions:

Speed limit outside and inside work zone is 55 mph

Medium work intensity, workers are separated with drums

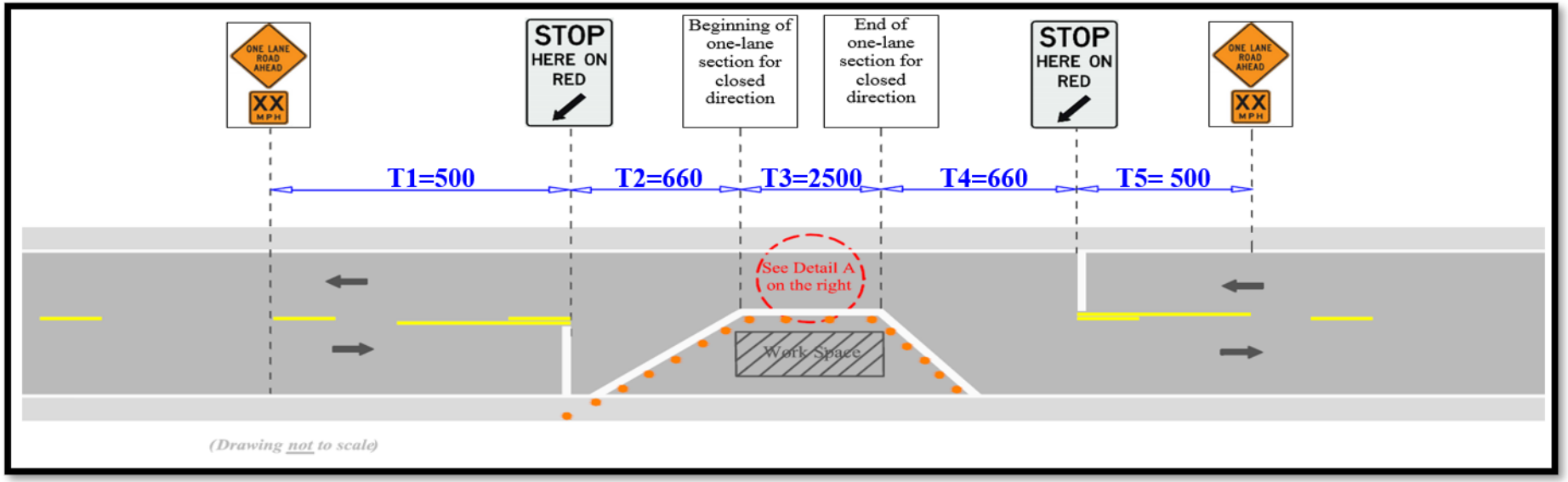
2 % trucks and 5 % recreational vehicles

Assumed Volume conditions:

Average of Monday, Tuesday, Wednesday, and Thursday traffic volume is used

Geometric Data

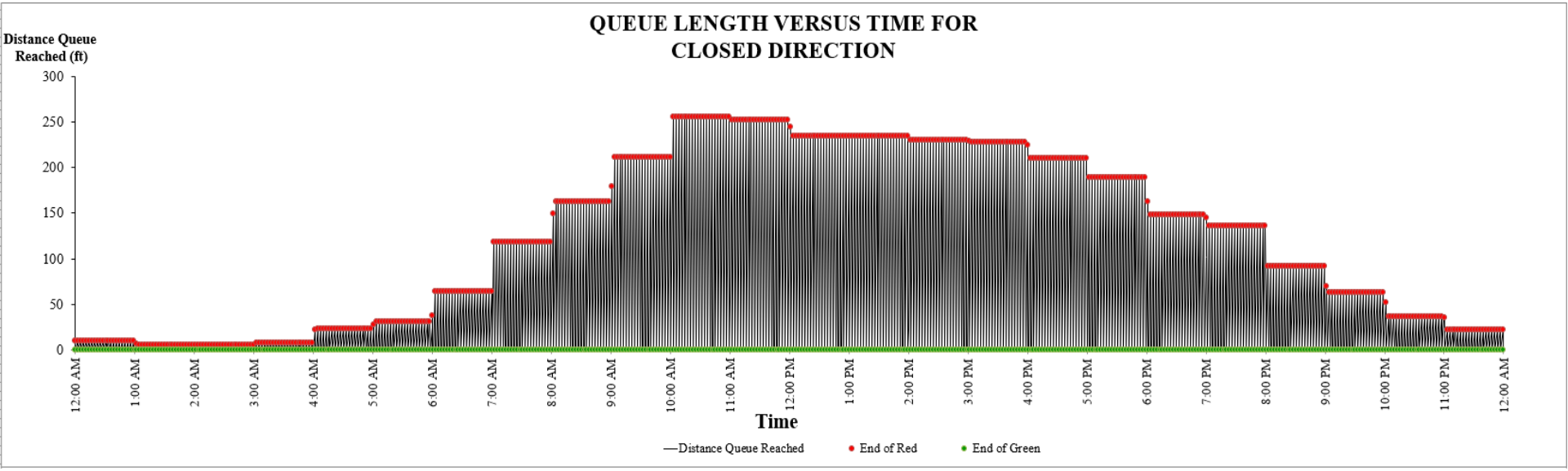
Geometric data: Longitudinal distances in the sketch below



WorkZoneQ-Pro Closed Direction Output

Results for CLOSED direction					
No. of vehicles in queue in the beginning of green*	Average spacing between vehicles in queue (ft)	Distance queue reached (ft)	Average delay per vehicle (hr)	Delay experienced by all vehicles on CLOSED direction	Users' costs ($) in the CLOSED direction
0	27	0	0.020	0.2	$4.93
0	27	0	0.020	0.1	$2.52
0	27	0	0.020	0.1	$2.65
0	27	0	0.020	0.1	$3.45
1	27	27	0.020	0.4	$10.91
1	27	27	0.020	0.5	$14.37
2	27	54	0.021	1.1	$30.82
4	27	109	0.022	2.2	$60.99
6	27	163	0.024	3.3	$90.15
8	27	217	0.028	5.0	$134.79
9	27	244	0.038	8.3	$224.75
9	27	244	0.036	7.8	$211.47
9	27	244	0.031	6.3	$171.16
9	27	244	0.031	6.3	$170.04
8	27	217	0.030	6.0	$162.11
8	27	217	0.030	5.9	$158.67
8	27	217	0.028	5.0	$134.43
7	27	190	0.026	4.1	$112.22
5	27	136	0.023	2.9	$79.90
5	27	136	0.023	2.6	$71.35
3	27	81	0.021	1.7	$45.38
2	27	54	0.021	1.1	$30.37
1	27	27	0.020	0.6	$17.18
1	27	27	0.020	0.4	$10.36
		Maximum distance queue reached (ft)		SUM delay	SUM users' costs
		244		*72.1*	*$1,954.97*

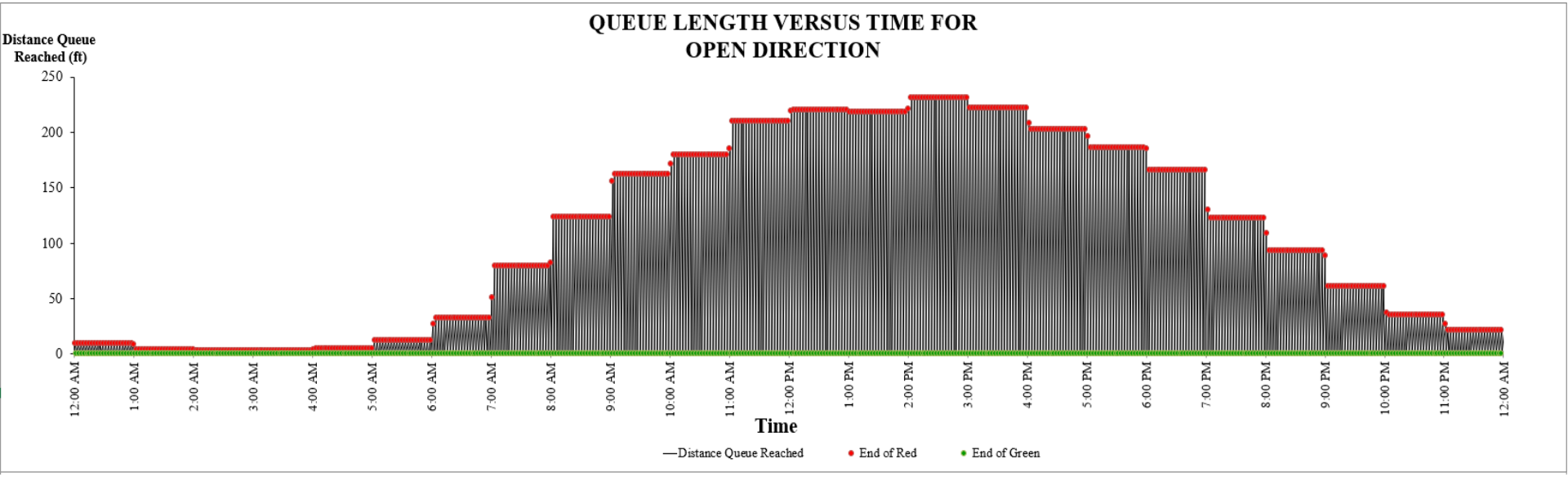
WorkZoneQ-Pro Closed Direction Output Cont.



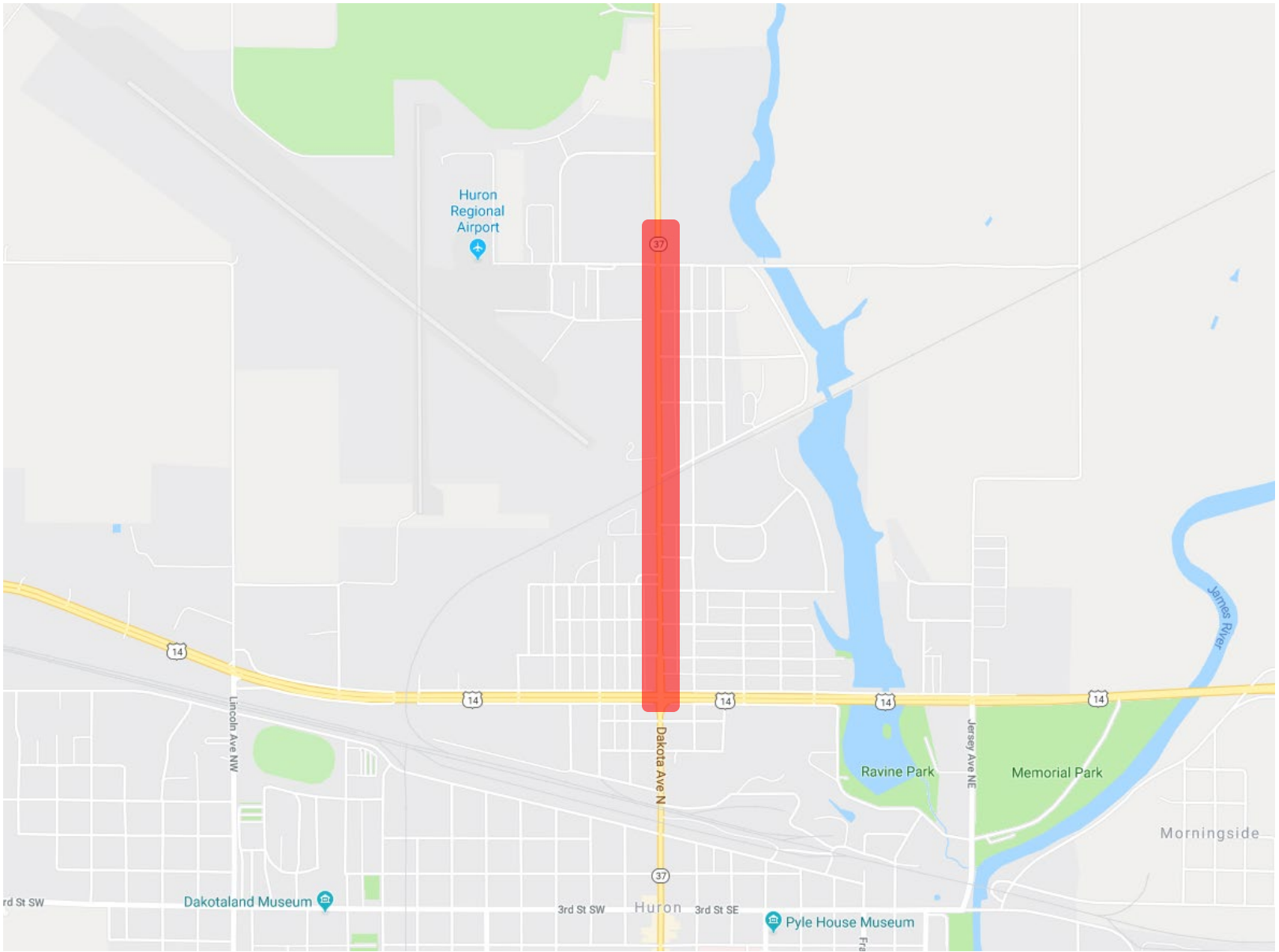
WorkZoneQ-Pro Open Direction Output

Results for OPEN direction					
No. of vehicles in queue in the beginning of green*	Average spacing between vehicles in queue (ft)	Distance queue reached (ft)	Average delay per vehicle (hr)	Delay experienced by all vehicles on OPEN direction (hr)	Users' costs ($) in the OPEN direction
0	27	0	0.021	0.2	$4.38
0	27	0	0.021	0.1	$1.69
0	27	0	0.021	0.1	$1.41
0	27	0	0.021	0.1	$1.55
0	27	0	0.021	0.1	$2.39
0	27	0	0.021	0.2	$5.53
1	27	27	0.021	0.6	$15.63
3	27	81	0.023	1.5	$40.31
5	27	136	0.024	2.5	$67.25
6	27	163	0.027	3.6	$98.35
7	27	190	0.029	4.4	$118.21
8	27	217	0.036	6.3	$171.33
8	27	217	0.041	7.4	$201.58
8	27	217	0.040	7.2	$194.30
9	27	244	0.048	9.2	$248.83
8	27	217	0.042	7.7	$209.41
7	27	190	0.034	5.7	$153.94
7	27	190	0.030	4.6	$125.83
6	27	163	0.028	3.8	$102.54
5	27	136	0.024	2.5	$66.84
3	27	81	0.023	1.8	$48.36
2	27	54	0.022	1.1	$30.05
1	27	27	0.021	0.6	$16.68
1	27	27	0.021	0.4	$10.30
		Maximum distance queue reached (ft)		SUM delay	SUM users' costs
		244		*71.4*	*$1,936.71*

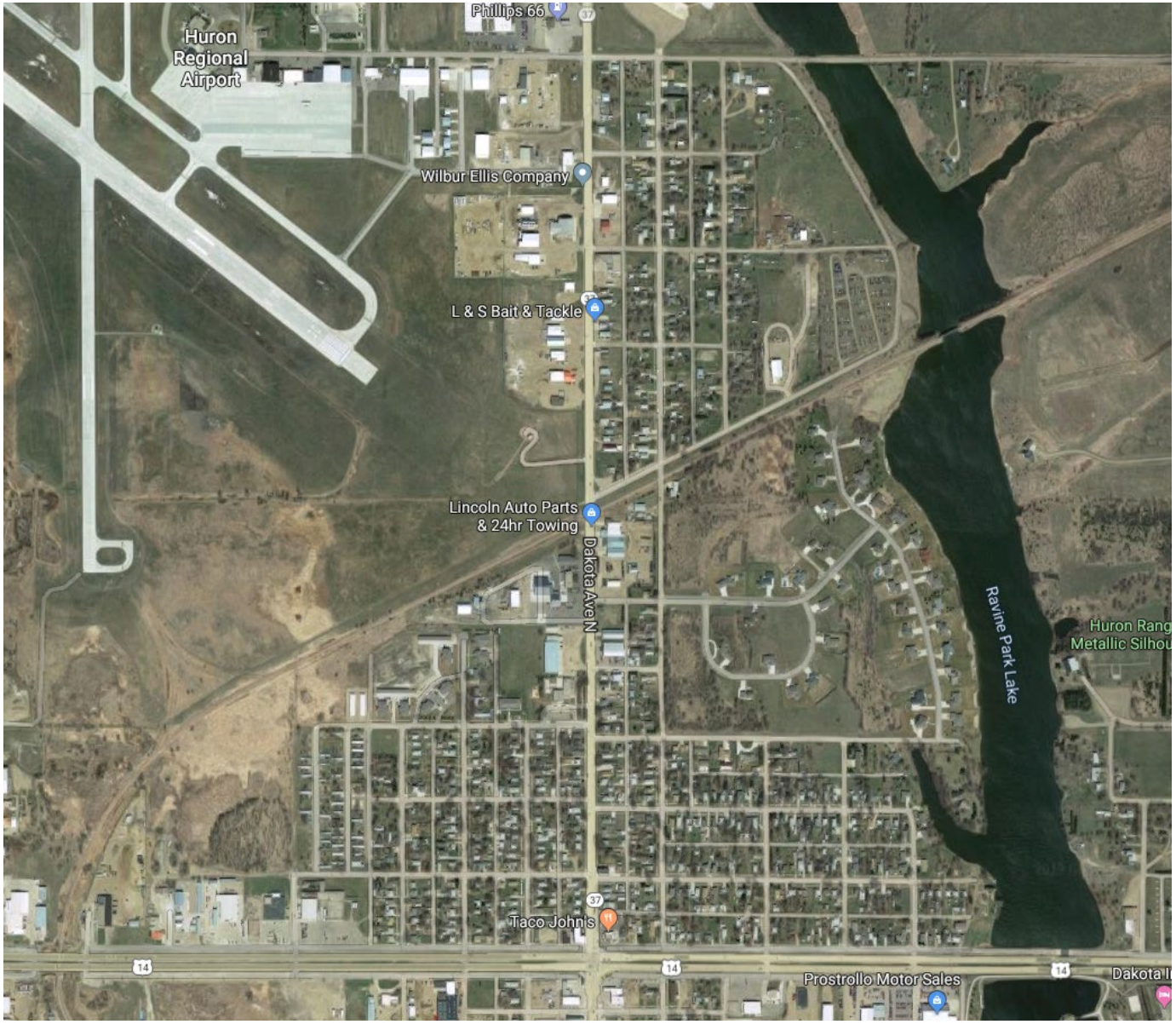
WorkZoneQ-Pro Open Direction Output Cont.



Example 12: SD Highway 37 and US Highway 14, Beadle County, South Dakota



Description (Continued…)



Description (Continued…)

This project uses 1 and 2 lane closures, so run 3-to-1

Description:

ADT for SD37 N of US14: 2,669 vehicles per day

Clear weather condition

Lane width = 10 ft, Shoulder width = 2 ft (right: 1 ft and left: 1 ft)

Rural area and level terrain

13 access points in 1.07 miles (10 access points / mile is used)

WZ conditions:

WZ speed limit is 25 mph and speed limit outside is 35 mph

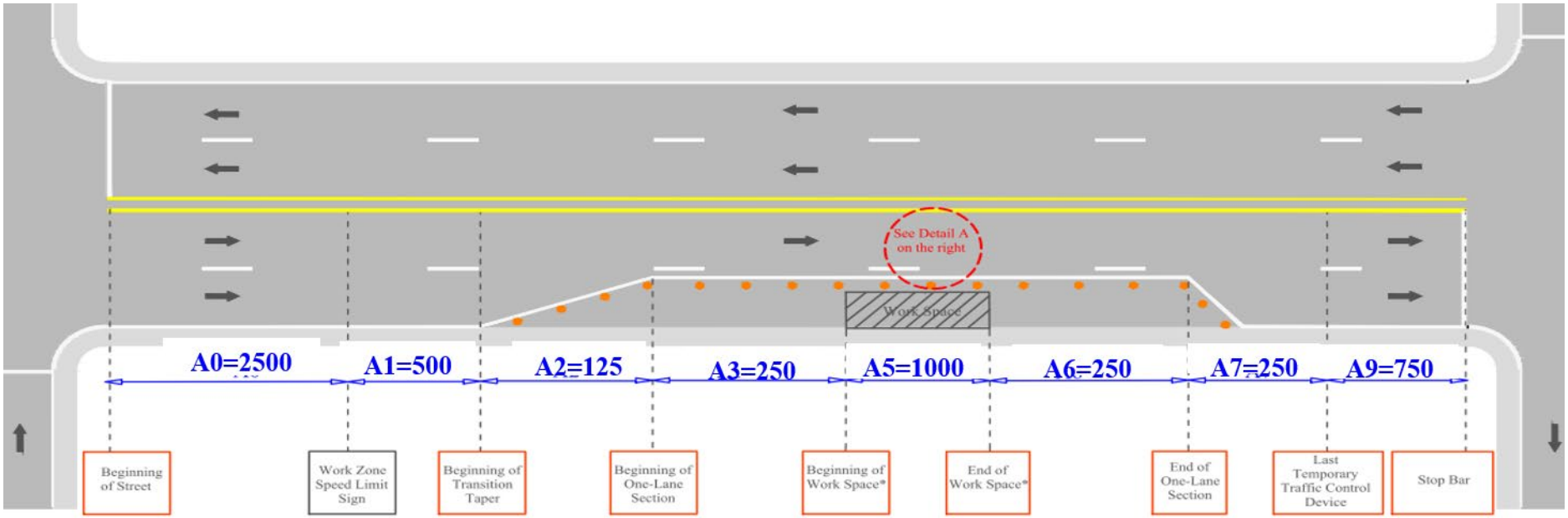
Workers separated by concrete barrier and medium work intensity

Use default Passenger Car Equivalency (PCE) factors

Percentage of combination trucks is 8.4 %, single-unit trucks and recreational vehicles is 0 %

Geometric Data

Geometric data: Longitudinal distances for 2-to-1 in the sketch below

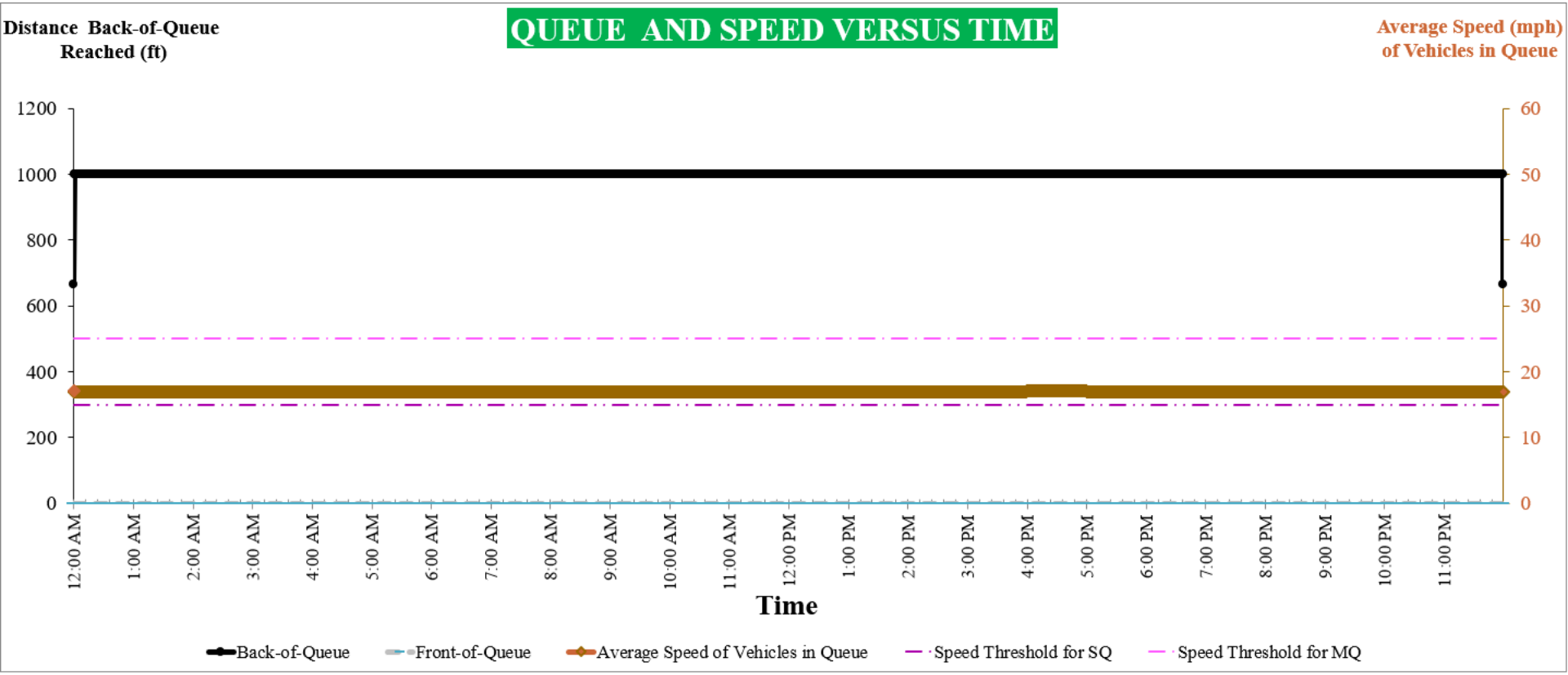


WorkZoneQ-Pro output

Start of Interval	End of Interval	Study period	No. of vehicles in queue in the link*	Average spacing between vehicles in queue (ft)	Front-of-Queue (ft)	Back-of-Queue (ft)	Distance queue occupied (ft)	Average speed in queue (mph)	Summary of Users' Costs ($) All (SQ+MQ+SMV)	
									Based on WZ speed limit	Based on speed limit outside of the WZ
12:00 AM	1:00 AM	1	0	180	0	1,000	1,000	17.0	$2.58	$4.58
1:00 AM	2:00 AM	1	0	180	0	1,000	1,000	17.0	$2.23	$3.96
2:00 AM	3:00 AM	1	0	180	0	1,000	1,000	17.0	$1.88	$3.34
3:00 AM	4:00 AM	1	0	180	0	1,000	1,000	17.0	$1.76	$3.13
4:00 AM	5:00 AM	1	0	180	0	1,000	1,000	17.0	$2.58	$4.58
5:00 AM	6:00 AM	1	0	180	0	1,000	1,000	17.0	$5.04	$8.95
6:00 AM	7:00 AM	1	1	180	0	1,000	1,000	17.0	$10.65	$18.93
7:00 AM	8:00 AM	1	2	180	0	1,000	1,000	17.0	$16.73	$29.74
8:00 AM	9:00 AM	1	1	180	0	1,000	1,000	17.0	$14.28	$25.38
9:00 AM	10:00 AM	1	1	180	0	1,000	1,000	17.0	$15.68	$27.87
10:00 AM	11:00 AM	1	2	180	0	1,000	1,000	17.0	$17.90	$31.82
11:00 AM	12:00 PM	1	2	180	0	1,000	1,000	17.0	$22.35	$39.72
12:00 PM	1:00 PM	1	2	180	0	1,000	1,000	17.0	$22.47	$39.93
1:00 PM	2:00 PM	1	2	180	0	1,000	1,000	17.0	$20.36	$36.19
2:00 PM	3:00 PM	1	2	180	0	1,000	1,000	17.0	$23.64	$42.01
3:00 PM	4:00 PM	1	2	180	0	1,000	1,000	17.0	$25.31	$45.04
4:00 PM	5:00 PM	1	3	180	0	1,000	1,000	17.0	$26.49	$47.23
5:00 PM	6:00 PM	1	2	180	0	1,000	1,000	17.0	$20.13	$35.77
6:00 PM	7:00 PM	1	2	180	0	1,000	1,000	17.0	$17.44	$30.99
7:00 PM	8:00 PM	1	1	180	0	1,000	1,000	17.0	$14.86	$26.42
8:00 PM	9:00 PM	1	1	180	0	1,000	1,000	17.0	$12.17	$21.63
9:00 PM	10:00 PM	1	1	180	0	1,000	1,000	17.0	$8.31	$14.77
10:00 PM	11:00 PM	1	1	180	0	1,000	1,000	17.0	$5.39	$9.57
11:00 PM	12:00 AM	1	0	180	0	1,000	1,000	17.0	$3.87	$6.87
						Maximum distance back-of-queue reached (ft)	Maximum distance queue occupied (ft)		SUM All	SUM All
						1,000	*1,000*		*$314.09*	*$558.44*

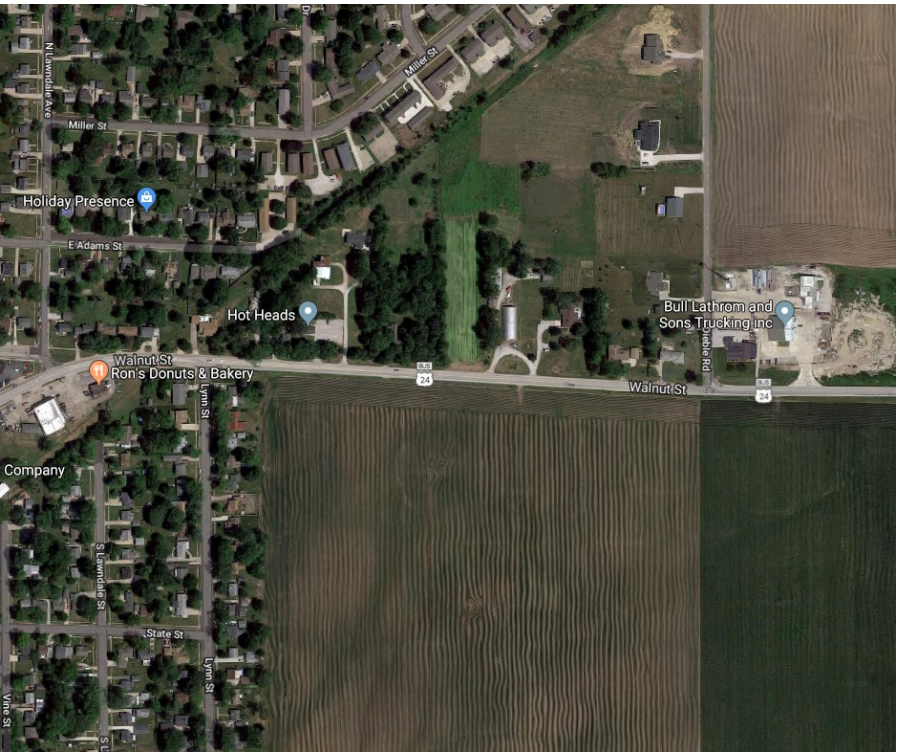
**: At the end of the corresponding interval or when there is no more vehicle in queue*

WorkZoneQ-Pro output Cont.



Example 13: One-Lane Operation on 2L2W US-24 passed Dieble Rd. going EB, Tazewell County

Description (Continued…)



Description (Continued…)

This illustrated project is one-lane two-way operation

Description:

Lane width = 11 ft, and left shoulder width = 4 ft

Rural area and level terrain

Speed limit outside = 55 mph

Assumed WZ conditions:

Work space speed limit = 35 mph

Moderate work intensity, workers are separated with drums

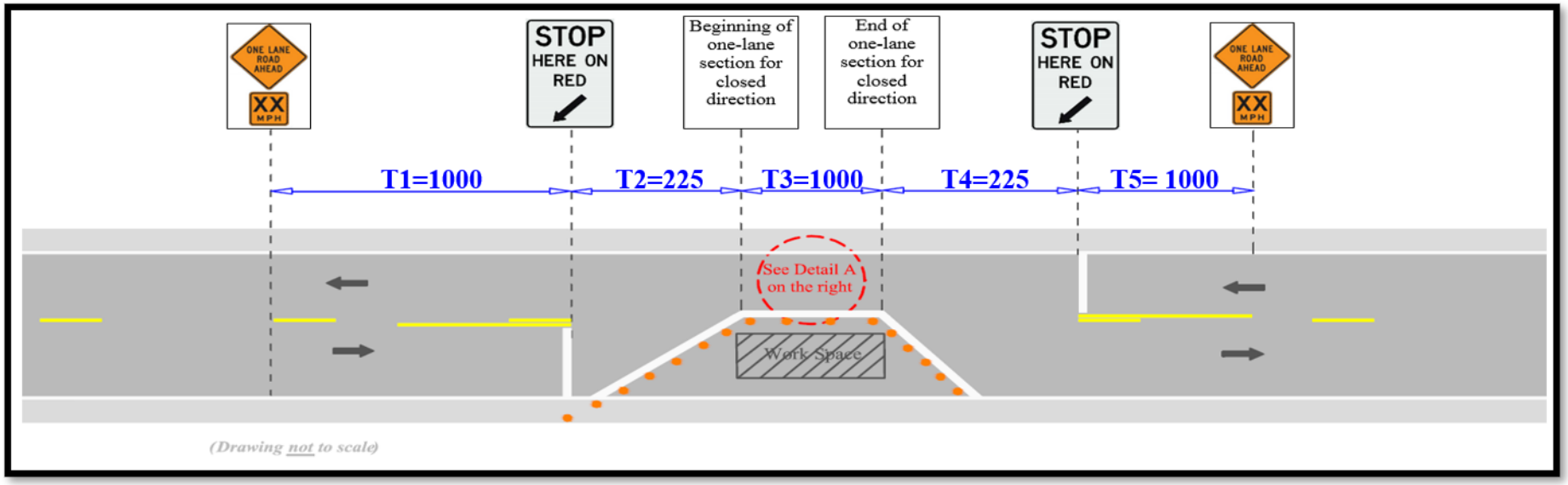
Description (Continued…)

Assumed Volume conditions:

Traffic Info for Closed EB Direction				Traffic Info for Open WB Direction	
Start of Interval	End of Interval	Percent of trucks (%)	Expected traffic volume during the interval	Percent of trucks (%)	Expected traffic volume during the interval
12:00 AM	1:00 AM	0	2	25.0	4
1:00 AM	2:00 AM	0	3	0.0	4
2:00 AM	3:00 AM	0	0	0.0	0
3:00 AM	4:00 AM	33.3	3	0.0	3
4:00 AM	5:00 AM	7.7	13	12.5	8
5:00 AM	6:00 AM	2.1	47	7.7	26
6:00 AM	7:00 AM	2	102	12.6	64
7:00 AM	8:00 AM	7.2	139	6.8	118
8:00 AM	9:00 AM	8.9	101	13.4	97
9:00 AM	10:00 AM	7	101	8.4	83
10:00 AM	11:00 AM	10	90	12.1	108
11:00 AM	12:00 PM	9.3	86	8.7	103
12:00 PM	1:00 PM	5.1	98	5.5	90
1:00 PM	2:00 PM	5.1	116	8.8	68
2:00 PM	3:00 PM	3.4	115	4.2	94
3:00 PM	4:00 PM	8.3	133	7.4	147
4:00 PM	5:00 PM	2.7	149	3.0	201
5:00 PM	6:00 PM	2.1	141	2.7	182
6:00 PM	7:00 PM	5	99	4.3	94
7:00 PM	8:00 PM	0	83	8.3	84
8:00 PM	9:00 PM	2.7	73	6.4	47
9:00 PM	10:00 PM	0	37	3.4	29
10:00 PM	11:00 PM	0	25	0.0	17
11:00 PM	12:00 AM	0	10	0.0	4

Geometric Data

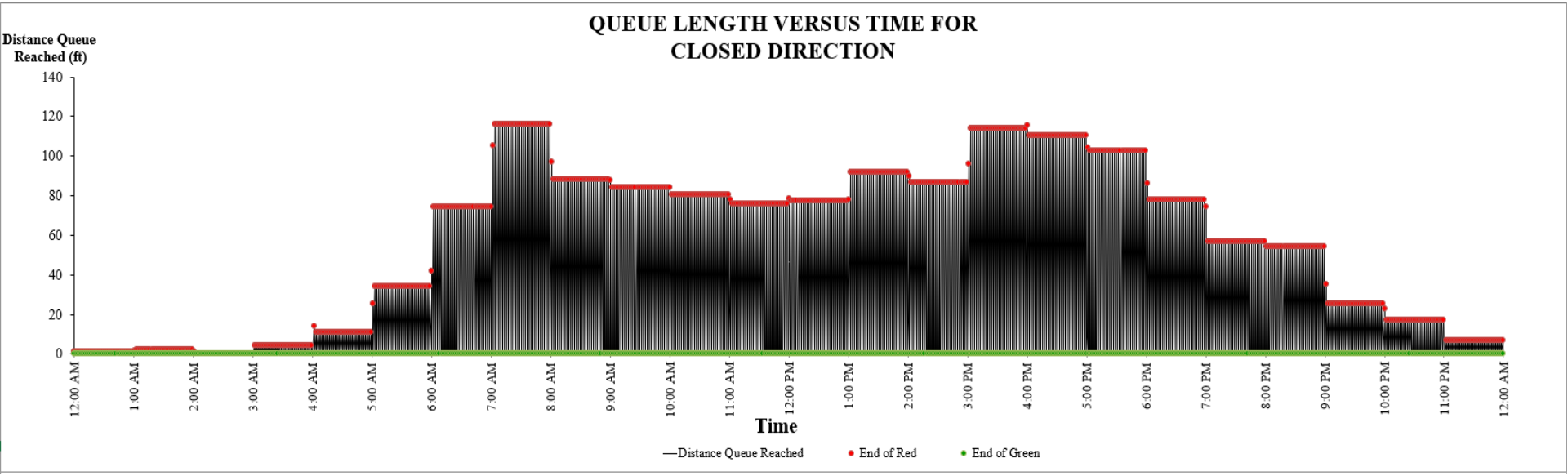
Geometric data: Longitudinal distances in the sketch below



WorkZoneQ-Pro Closed Direction Output

Results for CLOSED direction					
No. of vehicles in queue in the beginning of green*	Average spacing between vehicles in queue (ft)	Distance queue reached (ft)	Average delay per vehicle (hr)	Delay experienced by all vehicles on CLOSED direction (hr)	Users' costs ($) in the CLOSED direction
0	24	0	0.015	0.0	$0.77
0	24	0	0.015	0.0	$1.16
0	24	0	0.015	0.0	$0.00
0	39	0	0.015	0.0	$1.21
0	27	0	0.015	0.2	$5.16
1	25	25	0.016	0.8	$19.76
3	25	75	0.019	2.0	$51.34
4	27	109	0.027	3.8	$100.41
3	28	84	0.020	2.0	$53.22
3	27	81	0.020	2.0	$52.43
3	29	86	0.019	1.7	$45.12
3	28	85	0.018	1.6	$42.14
3	26	79	0.019	1.9	$49.41
3	26	79	0.021	2.5	$64.92
3	26	77	0.021	2.4	$62.89
4	28	111	0.026	3.4	$90.81
4	25	101	0.029	4.3	$112.88
4	25	100	0.026	3.6	$94.96
3	26	79	0.019	1.9	$50.13
2	24	48	0.018	1.5	$38.28
2	25	50	0.017	1.3	$32.98
1	24	24	0.016	0.6	$15.14
1	24	24	0.015	0.4	$9.99
0	24	0	0.015	0.1	$3.89
		Maximum distance queue reached (ft)		SUM delay	SUM users' costs
		111		*37.8*	*$998.99*

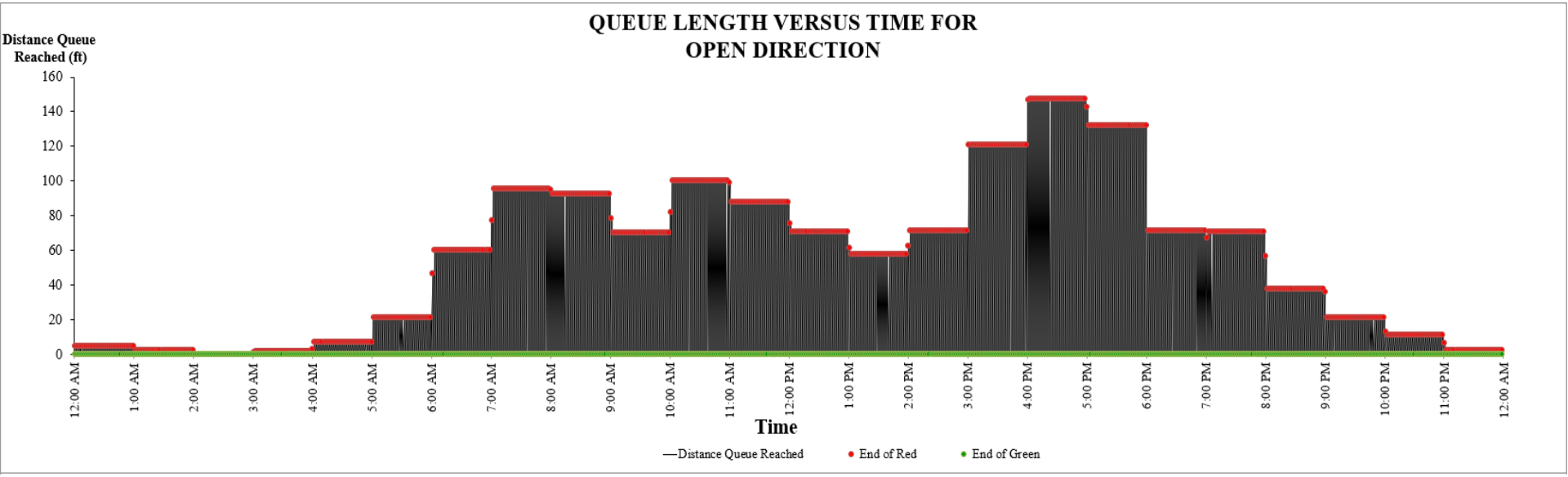
WorkZoneQ-Pro Closed Direction Output Cont.



WorkZoneQ-Pro Open Direction Output

Results for OPEN direction					
No. of vehicles in queue in the beginning of green*	Average spacing between vehicles in queue (ft)	Distance queue reached (ft)	Average delay per vehicle (hr)	Delay experienced by all vehicles on OPEN direction (hr)	Users' costs ($) in the OPEN direction
0	35	0	0.014	0.1	$1.54
0	24	0	0.014	0.1	$1.49
0	24	0	0.014	0.0	$0.00
0	24	0	0.014	0.0	$1.11
0	30	0	0.014	0.1	$3.05
1	27	27	0.015	0.4	$10.10
2	30	59	0.016	1.0	$26.98
4	27	108	0.018	2.1	$56.32
3	30	90	0.017	1.7	$44.78
3	28	83	0.016	1.4	$36.01
3	29	88	0.018	1.9	$51.38
3	28	84	0.017	1.8	$47.27
3	26	79	0.016	1.5	$39.27
2	28	56	0.016	1.1	$28.56
3	26	78	0.017	1.6	$41.20
4	27	109	0.021	3.0	$80.73
6	25	152	0.035	7.0	$184.64
5	25	126	0.026	4.7	$124.63
3	26	78	0.017	1.6	$41.22
3	28	83	0.016	1.4	$36.52
1	27	27	0.015	0.7	$18.83
1	26	26	0.015	0.4	$11.22
0	24	0	0.014	0.2	$6.43
0	24	0	0.014	0.1	$1.49
		Maximum distance queue reached (ft)		SUM delay	SUM users' costs
		152		*33.8*	*$894.79*

WorkZoneQ-Pro Open Direction Output Cont.

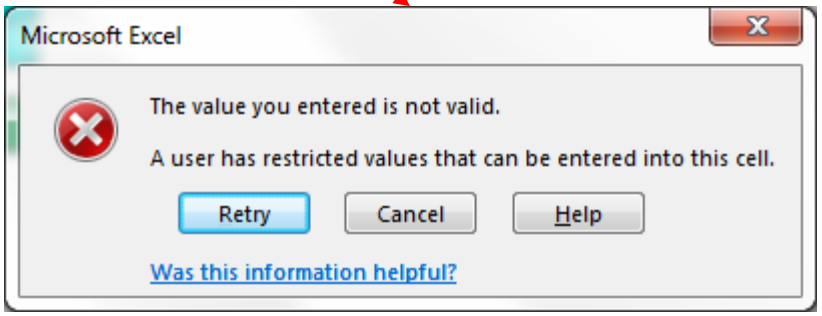


Appendix V

Troubleshooting and FAQs
For
WorkZoneQ-Pro

- Lane Configuration Issue
  If no of lanes inside has a value of 1, you can't directly enter 5 or 6 for outside lanes. Follow this sequence

Number of open lanes outside the work zone	Number of open lanes in the work zone
6	1



Solution

Number of open lanes outside the work zone	Number of open lanes in the work zone
2	1
2	2
6	2

Q. How can diversion effects on queue be implemented?

See Appendix O

Q. How can speed reduction effects of access point, street parking, median type (cross section) be implemented on Arterial Midblock?

See midblock arterial example in Module 4 (the total speed reduction effects are entered in Column M of GeoCond).

Q. How can flagger operation in one-lane two-way WZ be coded?

For each direction do the following:

a) input green time given by flagger in Green time cell,
b) enter 3 seconds in Yellow time cell
c) enter the time both flaggers are not allowing any vehicle to enter one-lane section in Road clearance time cell.

Solutions to Questions in Module 1

- **Q.1.1.** K decreases as AADT increase

- **Q.1.2.** DDHV=AADT*D*K
  DDHV=25000*0.6*0.1=1500

- **Q.1.3.** a) Free flow speed = 55 mph
  b) Capacity = 1550 pcphpl
  (Corresponding headway = 3600/1550 = 2.32 sec)
  c) Speed at capacity = 43 mph
  d) Density at capacity = 1550/43 = 36 pc/mi/ln
  (Corresponding spacing = 5280/36 = 146 ft)

Solutions to Questions in Module 1

- **Q. 2.1.** TMP components are:
  - I. Temporary Traffic Control (TTC) plan
  - II. Public Information (PI) component
  - III. Transportation Operations (TO) component

- **Q. 2.2.** "Section 630.1010 of the Rule defines a significant project as one that, alone or in combination with other concurrent projects nearby, is anticipated to cause sustained work zone impacts that are greater than what is considered tolerable based on State policy and/or engineering judgment.

  A significant project requires PI and TO components

Solutions to Questions in Module 1

Q.3.1. Work Space, Traffic Space, and Buffer Space

Q.3.2. The longitudinal buffer space is the distance from the end of the transition area to the beginning of the work space. It is equal to Stopping Sight Distance (SSD) shown in Table 6C-2 of MUTCD 2009

Q.3.3. MUTCD categorizes WZs based on work duration. The categories are:

A. Long-term stationary
B. Intermediate-term stationary
C. Short-term stationary
D. Short duration
E. Mobile

Solutions to Questions in Module 1

Q.3.4. Formulas for taper length are

Table 6C-4. Formulas for Determining Taper Length

Speed (S)	Taper Length (L) in feet
40 mph or less	$L = WS^2 / 60$
45 mph or more	$L = WS$

For speed of 40 mph or less, it is nonlinear.

Solutions to Questions in Module 1

Q.4.1. Queue length will be underestimated

Q.4.2. Example of geometry factors:

1) Number of lanes
2) Lane width
3) Lateral clearance

Example of traffic-related factors:

1) Percentage of trucks
2) Work zone speed limit
3) Driver composition

Solutions to Questions in Module 1

Q.4.3. HCM estimate capacity as follows:

For SHORT term WZs:

$$C_a = \{(1600+I) * f_{HV} * N\} - R$$

C_a: Adjusted capacity (vph)
I : Work intensity adjustment (pcphpl),
(Ranges between ±160 pcphpl)
f_{HV}: Heavy vehicle adjustment factor
N : Number of open lanes through the WZ
R : Adjustment for presence of on-ramp in WZ (vph)

For LONG term WZs:

Look-up table is provided

Solutions to Questions in Module 1

- **Q 5.1.**

  Advantages: It is simple and gives rough estimate of queue

  Disadvantages: Usually underestimates queue length and the magnitude of underestimation would be more significant for long queues. It may not consider speed and corresponding spacing between vehicles in the queue for delay and queue calculations.

- **Q 5.2.** Spacing in moving queue is larger

- **Q 5.3.** In general both methods are appropriate, but for long queues cell transmission might be more appropriate

- **Q 5.4.** Cell transmission

Capability of Spreadsheets

To consider the effects of	Spreadsheets			
	QDAT spreadsheet	MoDOT spreadsheet	HCM 2016 WZ capacity method	WZQ-Pro
1) Lane width	N	Y	N	Y
2) Shoulder width	N	N	Y	Y
3) Work intensity	Y	Y	N	Y
4) Speed limit inside WZ on capacity	N	N	N	Y
5) Speed control techniques in WZ	N	N	N	Y
6) Barrier type (concrete vs others)	N	N	Y	Y
7) WZ capacity changes during analysis period.	N	N	N	Y
8) % of trucks changes during analysis period.	N	N	N	Y
9) Adverse weather conditions	N	N	N	Y
10) Night time operation	N	N	Y	Y
11) Urban vs rural	N	N	Y	Y
12) Flagger operation	N	N	N	Y

Solutions to Questions related to Module 2 - 5

Performance Measure	Tools				
	QDAT spreadsheet	MoDOT spreadsheet	HCM 2016 WZ capacity method	WZQ-Pro	None
1) Computing delay in stopped queue.	Y	Y	N	Y	
2) Computing delay in moving queue.	N	N	N	Y	
3) Determining the times queue begins and ends.	Y	Y	N	Y	
4) Determining location of front and back of queue.	Y#	Y#	N	Y	
5) Determining effect of work space location on queue length.	N	N	N	Y	
6) Determining volume of diversion.					Y
7) Determining queue length when volume of diversion is known.	Y#	Y#	N	Y	
8) Determining queue length when WZ capacity varies during the construction hours.	N	N	N	Y	
9) It can be used for freeways	Y	Y	Y	Y	
10) It can be used for arterials	N	N	N	Y	