Sketch Methods for Estimating Incident-Related Impacts

final
report

prepared for

Federal Highway Administration

prepared by

Cambridge Systematics, Inc.

with

Harry Cohen
and
Science Applications International Corporation

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Sketch Methods for Estimating Incident-Related Impacts

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- Hua Tan, Capital Region Council of Governments, Hartford, Connecticut.

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1.0 Introduction

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This report summarizes the results of Task Order 21, Contract DTFH-61-95-C-00060, entitled *Sketch Methods for Estimating Incident-Related Impacts*. The research for this Task Order was undertaken to develop and validate a sketch planning method for estimating the impacts of non-recurring congestion (incidents) and the effects of strategies to mitigate that congestion.

1.1 Project Purpose

For the most part, transportation planners have not incorporated incident-related information into the planning process. The primary reason for this is that existing methods for determining the impacts of incidents are geared to traffic operations. Typical procedures include queuing-based methods as well as macroscopic and microscopic traffic simulation models. These procedures focus on the effects of *individual* incidents with a specific set of characteristics (e.g., duration, extent, time of day, and background volume) rather than the *cumulative* effect of incidents with varying characteristics. The interaction of recurring delay with incidents has also not been addressed. As a result, little guidance is available for planners who must assess the overall impacts of incidents on system performance. Further, documentation of the benefits of incident management programs is limited and tends to be site-specific. Application of site-specific results to new cases (e.g., City A experienced a 35 percent drop in delay due to instituting an incident management program) can lead to erroneous conclusions if base conditions are different.

This study addresses these issues by providing transportation planners with an easily applied methodology for studying incident impacts and the effects of incident management strategies. It does so by directly modeling the conditions that exist in a corridor rather than relying on delay-reduction factors, and considers the effects of both recurring and nonrecurring sources of congestion.

1.2 Background

1.2.1 Overview of Current Incident Methodologies

A variety of methods are available for analysts who wish to study the impact of individual incidents on traffic flow. For example, *queuing theory*-based approaches, such as those in the *Highway Capacity Manual,* use the concept of capacity to determine the onset of queuing and how long the queue lasts. *Macroscopic* simulation models also use capacity as an input. For both of these methods, however, incidents' effects on capacity must be determined independently of the model. In contrast, *microscopic* simulation models consider the effect of incidents directly and handle capacity changes as "emergent" from the model rather than using them as inputs. Microscopic simulation models offer the most comprehensive approach to modeling incidents, but their data requirements, run times, and unwieldy output make them impractical for studying a large number of cases and extended corridors.

This study identified two earlier attempts to study the cumulative effect of incidents. The first was Lindley's groundbreaking work with the FREWAY model (Reference 9). While Lindley's model relied on borrowed data and simplified traffic flow relationships, Sullivan, Taff, and Daly collected a comprehensive set of distributions for incident characteristics and employed a queuing-based methodology in developing their IMPACT model (Reference 8). Their data were applied directly to the model developed for *this* study. Although the underlying data are the same, it is worth noting several ways in which the approach used here differs from Sullivan *et al*:

- *The current approach is stochastic in nature, a feature that has several advantages.* First, it provides for a more realistic assignment of incident characteristics and captures those rare events that have a large effect (e.g., total freeway closures for long periods of time). Second, the effect of traffic variability can be modeled rather than relying on a static approach. Third, variability in delay estimates (i.e., reliability of travel time) can be directly assessed.

- *The interaction between recurring and non-recurring congestion is addressed.* In addition to estimating the effect of incidents solely, the current approach imposes recurring delay on the process as well. This allows direct estimation of the proportion of delay due to each component, a problematic issue in the past.

- *Delay equations are produced by the current approach.* In addition to providing a stochastic model, the results have been summarized in equations that are more appropriate for sketch planning application and can be incorporated into other analytic procedures easily. The equations require only data items that are readily available to planners.

- *Traffic characteristics of queues can be incorporated.* Although not used directly for this study, queue-related traffic parameters (headways, speeds, and capacities) derived from microscopic simulation experiments can be used to track queue dynamics. This feature could prove to be important for future applications where queue lengths (in miles rather than vehicles) and link speeds must be calculated.

1.2.2 Summary of Approach Taken

The study relied on adapting the QSIM model, previously developed by the project team, for studying incident effects (References 1 and 3). QSIM is a stochastic macroscopic simulation model that has been used previously to study recurring congestion. It has been adapted here to include the effects of incidents, including changes in incident duration, incident frequency, and incident location. Data for these and other incident characteristics were based on field data for freeways from selected urban areas (Reference 7).

The basic strategy is to run QSIM for a variety of incident scenarios and then fit equations to the model outputs for ease of application. The structure of the equations is simple enough to fit well within sketch planning applications. The emphasis of this study is freeways, although a preliminary effort aimed at signalized arterials was also undertaken. Due to the lack of available data for arterial incidents, the freeway data were modified by the project team to represent arterials. However, these results should be viewed with caution.

This report is organized into six additional sections. Section 2.0 discusses the methodology used to develop the incident impact estimation procedure, including model development and the input data that were used. Section 3.0 presents the results of the modeling procedure, including the final equations for predicting vehicle-hours of travel. Section 4.0 discusses how the final procedure was validated using Intelligent Transportation Systems (ITS) surveillance data. Section 5.0 documents the application of the procedure at two Metropolitan Planning Organizations (MPOs): Hartford, CT, and Knoxville, TN. Section 6.0 presents a study plan for how to approach the problem of estimating incident impacts on signalized arterials. Section 7.0 summarizes the project and offers several recommendations for extending the work.

Five Appendices are also included. Appendix A is the Application Guidelines and discusses how the procedure should be applied, including the development of input data. Appendices B and C present the results of the FRESIM and NETSIM simulation model experiments which were used to develop traffic parameters for incident conditions. Appendix D is example output from the modeling process used to develop the final procedure. Appendix E is the methodology used to develop the procedure.

2.0 Modeling Results

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2.1 Modeling Scenarios

The QSIM model can be applied to any specific set of circumstances that include temporal traffic variability and incident characteristics. However, the goal of this study is to produce a method that can be easily applied in at the sketch planning level of analysis. Therefore, the basic approach taken for the study was to develop a set of scenarios based on default values for the input distributions, run QSIM for each scenario, obtain summary statistics as QSIM output, and develop equations based on the output.

2.1.1 Incident-Related Factors Considered

One of the requirements for the sketch planning methodology is to analyze the impact of incident management programs and highway safety improvements. Therefore, the following factors were developed and applied.

1. **Duration Factor**. The primary influence of incident management programs is the reduction of incident duration due to improved practices for incident detection, verification, response, or clearance. The duration factor was applied to increase or decrease the average duration of incidents modeled. The levels studied were 0.7, 0.8, 0.9, 1.0, 1.1, and 1.2. Because duration is selected from a log-normal distribution, 60,000 replicates were used to ensure stability.

2. **Shoulder Factor**. The presence or absence of usable shoulders can have a dramatic impact on incident delay. (A "usable" shoulder is wide enough to store a vehicle without it encroaching on the adjacent traffic lane.) The default distributions developed in Reference 7 were for locations where shoulders existed. If shoulders do not exist, shoulder incidents become lane-blockage incidents. Three levels were studied: 1) usable shoulders on both sides; 2) usable shoulder on one side only; 3) no usable shoulders. The default distributions for lateral location are used directly for Level 1. For Level 2, half of the incidents determined to be on the shoulder are changed to lane blockages and for Level 3 all shoulder incidents become lane blockages.

3. **Incident Rate Factor**. Local conditions may lead to an overall incident rate that is different from the default. The incident rate factor was applied to increase or decrease the default total incident rate. The levels studied were 0.7, 0.8, 0.9, 1.0, 1.1, and 1.25.

4. **Accident Rate Factor**. To study the effect of changing the accident rate from the default relationship, a special run was made where accidents were the only type of incident present. These results were used to include a factor for changing the accident rate in the final equations (see below).

5. **Number of Lanes**. Two-, three-, and four-lane freeways (one direction) were studied. Two-lane arterials (one direction) were also studied.

6. **AADT/C Ratio**. AADT/C ratios from one to 18 were analyzed.

A full experimental design was not implemented. Rather, when either the duration, shoulder, or incident rate factors were varied, the others were set to 1.0. This precludes studying interaction of the factors, but the Research Team does not expect that any significant interactions exist.

2.2 Output Statistics

VHT and VMT are the key outputs used in this study. VHT for a given run is composed of unqueued VHT (VHT_u) and queued VHT. When the model is run for the incident scenarios mentioned above, queued VHT includes the combined effect of incidents and recurring congestion. To separate out the congestion due solely to incidents, a base case with no incidents was run. By subtraction, incident-queued VHT (VHT_i) can be obtained. The recurring-queued VHT (VHT_r) is obtained directly from the no-incident run. An example of the output appears in Appendix D. (Although output is produced for individual hours, the results in Appendix D have been summarized to the daily level for compactness.)

The analyst is cautioned that VHTi and VHTr are measures of systemwide delay due to queuing while VHTu is the total vehicle-hours of travel for vehicles traversing the segment, and, therefore, is not true delay. The delay incurred by vehicles for unqueued can be found by computing VHT under ideal or "desired" speeds for the segment (e.g., VHT at the free flow speed) and subtracting it from VHTu. Nearly all of the delay imbedded in VHTu is volume-related: the updated BPR curve predicts noticeable delay when V/C ratios exceed 0.75. Only a small amount of the delay is due to the capacity-reducing effect of incidents. The reason for incident's small influence on unqueued delay is that high volumes occur every day and incidents happen infrequently.

For curve fitting and application purposes, the outputs need to be normalized. The units selected were:

- $H_u = VHT_u/VMT$, (hours per vehicle-mile);
- $H_i = VHT_i/VMT$, (hours per vehicle-mile); and
- $H_r = (VHT_r/VMT)/$Length of segment, (hours per vehicle for a recurring bottleneck).

Note that H_r does not depend on the length of the section because section length does not influence the total length of a queue for a recurring bottleneck. For incidents, the length of the queue definitely depends on section length since the probability of an incident occurring depends on VMT (traffic volume * section length). This concept is based on the potential application of the procedure to an extended length of highway. For example, take a freeway section 10 miles long with interchanges every mile. This results in 10 individual "links," each with its own characteristics (particularly traffic volume). Every link has the potential for incidents, but only a small number (sometimes none) are recurring bottlenecks. Thus, vehicles traveling the full 10 miles would be exposed to perhaps one or two recurring bottlenecks.

The concept of recurring bottlenecks per mile is an important consideration in determining the relative share of congestion due to recurring and non-recurring sources. If the section of interest is short, then the proportion of congestion due to the recurring bottleneck is high. That is, the number of recurring bottlenecks per mile is high, leading to high estimates. The situation is shown in Table 2.1. Two bottlenecks per mile levels are shown: 0.67 (corresponding to one recurring bottleneck every 1.5 miles) and 0.1 (corresponding to one bottleneck every 10 miles). At low-AADT/C levels, all queuing delay is due to incidents. As AADT/C increases past six, incidents' share is reduced, although the reduction depends greatly on the number of recurring bottlenecks per mile and shoulder presence. Consider an AADT/C ratio of 12, which is a relatively congested freeway because it includes a recurring bottleneck. The share of queued delay attributable to incidents varies from 19 to 87 percent, depending on the length of the corridor being studied and the presence of usable shoulders.

Table 2.1 Influence of Recurring Bottlenecks per Mile on Recurring versus Non-Recurring Congestion (Daily)

	Percent of Daily Queued Delay Due to Incidents			
	Usable Shoulders Both Sides		No Usable Shoulders	
AADT/C	Bottlenecks per mi. = 0.67	Bottlenecks per mi. = 0.10	Bottlenecks per mi. = 0.67	Bottlenecks per mi. = 0.10
1	100.0	100.0	100.0	100.0
2	100.0	100.0	100.0	100.0
3	100.0	100.0	100.0	100.0
4	100.0	100.0	100.0	100.0
5	100.0	100.0	100.0	100.0
6	100.0	100.0	100.0	100.0
7	97.4	99.6	99.5	99.9
8	70.9	94.2	93.1	98.9
9	40.0	81.5	77.6	95.9
10	22.5	65.9	63.3	92.0
11	19.0	61.0	54.6	88.9
12	16.1	56.1	49.0	86.5
13	14.5	53.1	45.1	84.6
14	11.9	47.4	39.6	81.4
15	9.2	40.2	33.2	76.8
16	7.5	35.2	28.4	72.6
17	6.1	30.2	24.4	68.3
18	5.8	29.0	21.9	65.1

Note: Default factors for incident rate and duration were used.

■ 2.3 Prediction Equations for Freeways and Signalized Arterials

The QSIM output was used to fit a series of equations for both daily and peak-period values for H_u, H_i, and H_r. *The analyst is referred to Appendix A for a complete discussion of how to develop the independent variables and how to apply the procedure.* The analyst should be particularly aware of the different definitions used for queuing (H_r and H_i) and non-queuing (H_u) factors. The queuing factors account for actual delay due to queues. The non-queuing factor is basically the inverse of speed for the segment and therefore is not pure delay; delay can be obtained by comparing the computed speed to free flow or "desired" speed. (See discussion in Appendix A). The peak period is defined as weekdays from 6:00 a.m. to 10:00 a.m. and 3:00 p.m. to 7:00 p.m. for both directions of travel. The daily equations include both weekdays and weekends.

A preliminary attempt at developing incident relationships for signalized arterials was also undertaken, but as discussed in Appendix E, the basic incident distributions were borrowed from freeways (with the exception of the accident rate portion). Little is currently known about the characteristics of incidents on signalized arterials and the viability of using the freeway distributions is unknown. Therefore, the arterial equations should be applied judiciously. If anything, the equations probably overestimate delay because, in reality, diversion around arterial incidents is much more possible than on freeways. Limiting traffic flow impacts to just lane blockages helps to reduce the impact, but this was a purely judgmental decision on the part of the Research Team. The equations are as follows.

Table 2.2 Results for Freeways and Signalized Arterials
A.M. Peak Direction, Daily Traffic

Freeways

Travel Time without Queuing (hours per vehicle mile)

$$H_u = 1 / \text{Speed} = (1 / Sf) (1 + 5.44E\text{-}12 * X^{10})$$

for X <= 8

$$H_u = 1 / \text{Speed} = (1 / Sf) (1.23E{+}00 \quad 7.12E\text{-}02 * X + 6.78E\text{-}03 * X^2 + \quad 1.83E\text{-}04 * X^3)$$

for X > 8

Delay Due to Recurring Queues (hours per bottleneck)

$$H_r = \text{RECURRING DELAY} = 0$$

for X <=8

$$H_r = \text{RECURRING DELAY} = 6.77E\text{-}03 * (X \;\; 8) \quad 4.13E\text{-}03 * (X \;\; 8)^2 + 1.29E\text{-}03 * (X \;\; 8)^3$$

Delay Due to Incidents for Two Lane Facilities (hours per vehicle mile)

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 4.22 * (1\text{-}SF)^{1.05}) * 5.26E\text{-}08 * X^{6.26E+00} * e^{-4.53E-01 * X}$$

for X <= 8

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 4.22 * (1\text{-SF})^{1.05}) * 8.11E\text{-}10 * X^{7.23E+00} * e^{-1.83E-01 * X}$$

for X > 8

<u>Delay Due to Incidents for Three Lane Facilities (hours per vehicle mile)</u>

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.77 * (1\text{-SF})^{1.04}) * 1.64E\text{-}06 * X^{-4.34E-01} * e^{8.10E-01 * X}$$

for X <= 8

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.77 * (1\text{-SF})^{1.04}) * 3.39E\text{-}11 * X^{9.04E+00} * e^{-3.04E-01 * X}$$

for X > 8

<u>Delay Due to Incidents for Four Lane Facilities (hours per vehicle mile)</u>

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SF})^{1.04}) * 6.90E\text{-}08 * X^{1.27E+00} * e^{7.49E-01 * X}$$

for X <= 8

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SF})^{1.04}) * 1.09E\text{-}11 * X^{9.68E+00} * e^{-3.42E-01 * X}$$

for X > 8

<u>Delay Due to Accidents for Two Lane Facilities (hours per vehicle mile)</u>

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 4.22 * (1\text{-SF})^{1.05}) * 1.15E\text{-}06 * X^{2.63E+00} * e^{5.75E-02 * X}$$

for X <= 8

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 4.22 * (1\text{-SF})^{1.05}) * 1.50E\text{-}09 * X^{6.52E+00} * e^{-1.22E-01 * X}$$

for X > 8

<u>Delay Due to Accidents for Three Lane Facilities (hours per vehicle mile)</u>

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.77 * (1\text{-SF})^{1.04}) * 1.36E\text{-}07 * X^{3.09E+00} * e^{1.60E-01 * X}$$

for X <= 8

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.77 * (1\text{-SF})^{1.04}) * 6.09E\text{-}10 * X^{6.53E+00} * e^{-5.75E-02 * X}$$

for X > 8

<u>Delay Due to Accidents for Four Lane Facilities (hours per vehicle mile)</u>

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SF})^{1.04}) * 4.31E\text{-}08 * X^{2.82E+00} * e^{3.57E-01 * X}$$

for X <= 8

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SF})^{1.04}) * 1.47E\text{-}10 * X^{7.23E+00} * e^{-7.77E-02 * X}$$

for X > 8

Signalized Arterials

<u>Travel Time without Queuing (hours per vehicle mile)</u>

$$H_u = 1 / \text{Speed} = (1 / \text{Sf})(1 + 3.67E\text{-}02 * X^{8.58E-01})$$

<u>Daily Delay Due to Recurring Queues (hours per bottleneck)</u>

$$H_r = \text{RECURRING DELAY} = 0$$

for X <= 8

$$H_r = \text{RECURRING DELAY} = 0.00E{+}00 * (X\ \ 8)^2 + 6.89E{-}05 * (X\ \ 8)^3$$

for X > 8

<u>Delay Due to Incidents for Arterials (hour per vehicle mile)</u>

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * 1.17E{-}05 * X^{8.72E-01} * e^{1.75E-01 * X}$$

for X <= 8

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * 1.26E{-}05 * X^{8.12E-01} * e^{1.81E-01 * X}$$

for X > 8

Table 2.3 Key for Curve Fitting Results for Freeways and Signalized Arterials
A.M. Peak Direction, Peak Period Traffic

Freeways

<u>Travel Time without Queuing (hours per vehicle mile)</u>

$$H_u = 1 / \text{Speed} = (1 / Sf) (1 + 9.26E{-}12 * X^{10})$$

for X <= 8

$$H_u = 1 / \text{Speed} = (1 / Sf) (1.33E{+}00\ \ \ 1.05E{-}01 * X + 1.03E{-}02 * X^2\ \ \ 2.84E{-}04 * X^3)$$

for X > 8

<u>Delay Due to Recurring Queues (hours per bottleneck)</u>

$$H_r = \text{RECURRING DELAY} = 0$$

for X <=8

$$H_r = \text{RECURRING DELAY} = 7.52E{-}03 * (X\ \ 8)\ \ \ 2.12E{-}03 * (X\ \ 8)^2 + 1.07E{-}03 * (X\ \ 8)^3$$

for X > 8

<u>Delay Due to Incidents for Two Lane Facilities (hours per vehicle mile)</u>

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 4.22 * (1\text{-}SF)^{1.05}) * 1.21E{-}07 * X^{5.07E+00} * e^{-1.96E-01 * X}$$

for X <= 8

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 4.22 * (1\text{-}SF)^{1.05}) * 3.04E{-}09 * X^{6.94E+00} * e^{-2.21E-01 * X}$$

for X > 8

<u>Delay Due to Incidents for Three Lane Facilities (hours per vehicle mile)</u>

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.77 * (1\text{-}SF)^{1.04}) * 1.04E{-}05 * X^{-2.38E+00} * e^{1.14E+00 * X}$$

for X <= 8

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.77 * (1\text{-}SF)^{1.04}) * 7.39E{-}11 * X^{9.17E+00} * e^{-3.85E-01 * X}$$

for X > 8

<u>Delay Due to Incidents for Four Lane Facilities (hours per vehicle mile)</u>

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.45 * (1\text{-}SF)^{1.04})$$

$$* \ 2.87E\text{-}07 * X^{1.59E\text{-}01} * e^{9.15E\text{-}01 * X}$$

for X <= 8

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (\ 1 + 3.45 * (1\text{-}SF)^{1.04})$$
$$* \ 1.19E\text{-}11 * X^{1.04E+01} * e^{-4.73E\text{-}01 * X}$$

for X > 8

<u>Delay Due to Accidents for Two Lane Facilities (hours per vehicle mile)</u>

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (\ 1 + 4.22 * (1\text{-}SF)^{1.05})$$
$$* \ 4.12E\text{-}06 * X^{1.77E+00} * E^{1.71E\text{-}01 * X}$$

for X <= 8

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (\ 1 + 4.22 * (1\text{-}SF)^{1.05})$$
$$* \ 8.24E\text{-}09 * X^{6.07E+00} * e^{-1.70E\text{-}01 * X}$$

for X > 8

<u>Delay Due to Accidents for Three Lane Facilities (hours per vehicle mile)</u>

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (\ 1 + 3.77 * (1\text{-}SF)^{1.04})$$
$$* \ 2.05E\text{-}08 * X^{5.94E+00} * e^{-3.09E\text{-}01 * X}$$

for X <= 8

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (\ 1 + 3.77 * (1\text{-}SF)^{1.04})$$
$$* \ 9.73E\text{-}10 * X^{6.74E+00} * e^{-1.35E\text{-}01 * X}$$

for X > 8

<u>Delay Due to Accidents for Four Lane Facilities (hours per vehicle mile)</u>

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (\ 1 + 3.45 * (1\text{-}SF)^{1.04})$$
$$* \ 6.06E\text{-}11 * X^{1.13E+01} * e^{-9.78E\text{-}01 * X}$$

for X <= 8

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (\ 1 + 3.45 * (1\text{-}SF)^{1.04})$$
$$* \ 2.08E\text{-}10 * X^{7.58E+00} * e^{-1.77E\text{-}01 * X}$$

for X > 8

Signalized Arterials

<u>Travel Time without Queuing (hours per vehicle mile)</u>

$$H_u = 1 \ / \ \text{Speed} = (\ 1 \ / \ Sf\ )\ (\ 1 + 3.25E\text{-}02 * X^{9.53E\text{-}01})$$

<u>Daily Delay Due to Recurring Queues (hours per bottleneck)</u>

$$H_r = \text{RECURRING DELAY} = 0$$

for X <=8

$$H_r = \text{RECURRING DELAY} = 2.87E\text{-}04 * (X \quad 8)^{2} + 7.81E\text{-}05 * (X \quad 8)^{3}$$

for X > 8

<u>Delay Due to Incidents for Arterials (hours per vehicle mile)</u>

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * 7.67E\text{-}06 * X^{1.30E+00} * e^{1.23E\text{-}01 * X}$$

for X <= 8

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * 3.64E\text{-}06 * X^{1.72E+00} * e^{1.06E\text{-}01 * X}$$

for X > 8

Table 2.4 Key for Curve Fitting Results for Freeways and Signalized Arterials
P.M. Peak Direction, Daily Traffic

Freeways

Travel Time without Queuing (hours per vehicle mile)

$$H_u = 1 / \text{Speed} = (1 / Sf) (1 + 7.37E\text{-}12 * X^{10})$$

for $X <= 8$

$$H_u = 1 / \text{Speed} = (1 / Sf) (1.13E{+}00 \quad 4.39E\text{-}02 * X + 4.68E\text{-}03 * X^2 \quad 1.32E\text{-}04 * X^3)$$

for $X > 8$

Delay Due to Recurring Queues (hours per bottleneck)

$$H_r = \text{RECURRING DELAY} = 0$$

for X <=8

$$H_r = \text{RECURRING DELAY} = 4.11E\text{-}03 * (X \;\; 8) + 1.26E\text{-}03 * (X \;\; 8)^2 + 4.03E\text{-}04 * (X \;\; 8)^3$$

Delay Due to Incidents for Two Lane Facilities (hours per vehicle mile)

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 4.22 * (1\text{-}SF)^{1.05}) * 2.45E\text{-}08 * X^{6.90E+00} * e^{-4.80E-01 * X}$$

for $X <= 8$

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 4.22 * (1\text{-}SF)^{1.05}) * 4.38E\text{-}09 * X^{6.68E+00} * e^{-2.06E-01 * X}$$

for $X > 8$

Delay Due to Incidents for Three Lane Facilities (hours per vehicle mile)

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.77 * (1\text{-}SF)^{1.04}) * 1.15E\text{-}07 * X^{2.44E+00} * e^{4.45E-01 * X}$$

for $X <= 8$

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.77 * (1\text{-}SF)^{1.04}) * 1.33E\text{-}09 * X^{7.21E+00} * e^{-2.34E-01 * X}$$

for $X > 8$

Delay Due to Incidents for Four Lane Facilities (hours per vehicle mile)

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.45 * (1\text{-}SF)^{1.04}) * 6.03E\text{-}09 * X^{4.30E+00} * e^{3.19E-01 * X}$$

for $X <= 8$

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.45 * (1\text{-}SF)^{1.04}) * 3.86E\text{-}10 * X^{7.92E+00} * e^{-2.78E-01 * X}$$

for $X > 8$

Delay Due to Accidents for Two Lane Facilities (hours per vehicle mile)

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 4.22 * (1\text{-}SF)^{1.05}) * 4.12E\text{-}06 * X^{1.77E+00} * E^{1.71E-01 * X}$$

for $X <= 8$

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 4.22 * (1\text{-}SF)^{1.05}) * 8.24E\text{-}09 * X^{6.07E+00} * e^{-1.70E-01 * X}$$

for X > 8

Delay Due to Accidents for Three Lane Facilities (hours per vehicle mile)

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.77 * (1\text{-SF})^{1.04}) * 3.18\text{E-}07 * X^{1.84\text{E+}00} * e^{4.33\text{E-}01 * X}$$

for X <= 8

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.77 * (1\text{-SF})^{1.04}) * 3.85\text{E-}09 * X^{6.16\text{E+}00} * e^{-1.38\text{E-}01 * X}$$

for X > 8

Delay Due to Accidents for Four Lane Facilities (hours per vehicle mile)

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SF})^{1.04}) * 5.28\text{E-}08 * X^{2.09\text{E+}00} * e^{5.84\text{E-}01 * X}$$

for X <= 8

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SF})^{1.04}) * 8.65\text{E-}10 * X^{7.10\text{E+}00} * e^{-2.03\text{E-}01 * X}$$

for X > 8

Signalized Arterials

Travel Time without Queuing (hours per vehicle mile)

$$H_u = 1 / \text{Speed} = (1 / \text{Sf}) (1 + 3.67\text{E-}02 * X^{8.58\text{E-}01})$$

Daily Delay Due to Recurring Queues (hours per bottleneck)

$$H_r = \text{RECURRING DELAY} = 0$$

for X <=8

$$H_r = \text{RECURRING DELAY} = 1.31\text{E-}03 * (X \;\; 8)^2 + 1.31\text{E-}03 * (X \;\; 8)^3$$

for X > 8

Delay Due to Incidents for Arterials (hours per vehicle mile)

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * 4.19\text{E-}07 * X^{5.06\text{E+}00} * e^{-4.75\text{E-}01 * X}$$

for X <= 8

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * 4.98\text{E-}07 * X^{3.27\text{E+}00} * e^{-3.06\text{E-}02 * X}$$

for X > 8

Table 2.5 Key for Curve Fitting Results for Freeways and Signalized Arterials

P.M. Peak Direction, Peak Period Traffic

Freeways

Travel Time without Queuing (hours per vehicle mile)

$$H_u = 1 / \text{Speed} = (1 / \text{Sf}) (1 + 1.42\text{E-}11 * X^{10})$$

for X <= 8

$$H_u = 1 / \text{Speed} = (1 / \text{Sf}) (1.13\text{E+}00 \;\; 5.19\text{E-}02 * X + 6.21\text{E-}03 * X^2 + \;\; 1.85\text{E-}04 * X^3)$$

for X > 8

Delay Due to Recurring Queues (hours per bottleneck)

$$H_r = \text{RECURRING DELAY} = 0$$

for X <=8

$$H_r = \text{RECURRING DELAY} = 3.63E\text{-}03 * (X\ \ 8) + 5.03E\text{-}03 * (X\ \ 8)^{2} +\ \ 3.99E\text{-}05 * (X\ \ 8)^{3}$$

Delay Due to Incidents for Two Lane Facilities (hours per vehicle mile)

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 4.22 * (1\text{-SF})^{1.05}) * 1.42E\text{-}11 * X^{7.42E+00} * e^{-5.31E-01 * X}$$

for X <= 8

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 4.22 * (1\text{-SF})^{1.05}) * 1.52E\text{-}08 * X^{6.59E+00} * e^{-2.86E-01 * X}$$

for X > 8

Delay Due to Incidents for Three Lane Facilities (hours per vehicle mile)

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.77 * (1\text{-SF})^{1.04}) * 1.80E\text{-}08 * X^{4.96E+00} * e^{8.67E-02 * X}$$

for X <= 8

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.77 * (1\text{-SF})^{1.04}) * 2.97E\text{-}09 * X^{7.53E+00} * e^{-3.55E-01 * X}$$

for X > 8

Delay Due to Incidents for Four Lane Facilities (hours per vehicle mile)

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SF})^{1.04}) * 1.61E\text{-}09 * X^{6.48E+00} * e^{-1.48E-02 * X}$$

for X <= 8

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SF})^{1.04}) * 6.77E\text{-}10 * X^{8.46E+00} * e^{-4.22E-01 * X}$$

for X > 8

Delay Due to Accidents for Two Lane Facilities (hours per vehicle mile)

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 4.22 * (1\text{-SF})^{1.05}) * 3.51E\text{-}06 * X^{1.51E+00} * E^{2.13E-01 * X}$$

for X <= 8

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 4.22 * (1\text{-SF})^{1.05}) * 3.55E\text{-}08 * X^{5.10E+00} * e^{-1.46E-01 * X}$$

for X > 8

Delay Due to Accidents for Three Lane Facilities (hours per vehicle mile)

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.77 * (1\text{-SF})^{1.04}) * 1.64E\text{-}07 * X^{2.44E+00} * e^{3.80E-01 * X}$$

for X <= 8

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.77 * (1\text{-SF})^{1.04}) * 1.30E\text{-}08 * X^{5.77E+00} * e^{-1.70E-01 * X}$$

for X > 8

Delay Due to Accidents for Four Lane Facilities (hours per vehicle mile)

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SF})^{1.04}) * 1.77E\text{-}09 * X^{6.19E+00} * e^{-3.70E-02 * X}$$

for X <= 8

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.45 * (1-\text{SF})^{1.04}) * 2.43\text{E-}09 * X^{6.85\text{E+}00} * e^{-2.50\text{E-}01 * X}$$

for X > 8

Signalized Arterials

<u>Travel Time without Queuing (hours per vehicle mile)</u>

$$H_u = 1 / \text{Speed} = (1 / \text{Sf})\,(1 + 4.58\text{E-}02 * X^{8.23\text{E-}01})$$

<u>Daily Delay Due to Recurring Queues (hours per bottleneck)</u>

$$H_r = \text{RECURRING DELAY} = 0$$

for X <=8

$$H_r = \text{RECURRING DELAY} = 2.69\text{E-}03 * (X \;\; 8)^2 \;\; 1.23\text{E-}04 * (X \;\; 8)^3$$

for X > 8

<u>Delay Due to Incidents for Arterials (hours per vehicle mile)</u>

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * 8.79\text{E-}07 * X^{4.18\text{E+}00} * e^{-3.18\text{E-}01 * X}$$

for X <= 8

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * 5.05\text{E-}07 * X^{3.56\text{E+}00} * e^{-8.69\text{E-}02 * X}$$

for X > 8

Table 2.6 Key for Curve Fitting Results for Freeways and Signalized Arterials
Both Directions, Daily Traffic, Accident Delay Equations Only

Freeways

<u>Travel Time factor without Queuing, Hu (hour per vehicle mile)</u>

$$H_u = 1 / \text{Speed} = (1 / S_{ff})\,(1 + 4.87\text{E-}12 * X^{10})$$

for X <= 8

$$H_u = 1 / \text{Speed} = (1 / S_{ff})\,(1.16 \quad 5.04\text{E-}02 * X + 4.88\text{E-}03\,X^2 \quad 1.30\text{E-}04\,X^{3)}$$

for X > 8

<u>Delay Due to Recurring Queues, H_r (hours per vehicle per bottleneck)</u>

$$H_r = \text{RECURRING DELAY} = 0$$

for X<= 8

$$H_r = \text{RECURRING DELAY} = 4.69\text{E-}03 * (X \;\; 8) \quad 1.50\text{E-}03 * (X \;\; 8)^2 + 6.99\text{E-}04 * (X \;\; 8)^3$$

for X > 8

<u>Delay Due to Incidents for Two Lane Freeways (hours per vehicle mile)</u>

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 4.22 * (1-\text{SFac})^{1.05}) * 3.98\text{E-}06 * X^{4.39\text{E-}01} * e^{5.32\text{E-}01 * X}$$

for X <= 8

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 4.22 * (1-\text{SFac})^{1.05}) * 1.89\text{E-}09 * X^{6.89} * e^{-1.89\text{E-}01 * X}$$

for X > 8

Delay Due to Incidents for Three Lane Freeways (hours per vehicle mile)

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.77 * (1\text{-SFac})^{1.04}) * 1.21E\text{-}07 * X^{2.66} * e^{-3.27E-01 * X}$$

for X <= 8

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.77 * (1\text{-SFac})^{1.04}) * 2.46E\text{-}10 * X^{7.84} * e^{-2.44E-01 * X}$$

Delay Due to Incidents for Four Lane Freeways (hours per vehicle mile)

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SFac})^{1.04}) * 2.51E\text{-}08 * X^{2.43} * e^{5.73E-01 * X}$$

for X <= 8

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SFac})^{1.04}) * 6.43E\text{-}11 * X^{8.63} * e^{-2.94E-01 * X}$$

for X > 8

Delay Due to Accidents for Two Lane Facilities (hours per vehicle mile)

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 4.22 * (1\text{-SF})^{1.05}) * 3.51E\text{-}06 * X^{1.51E+00} * e^{2.13E-01 * X}$$

for X <= 8

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 4.22 * (1\text{-SF})^{1.05}) * 3.68E\text{-}09 * X^{6.16E+00} * e^{-1.38E-01 * X}$$

for X > 8

Delay Due to Accidents for Three Lane Facilities (hours per vehicle mile)

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.77 * (1\text{-SF})^{1.04}) * 1.13E\text{-}07 * X^{3.11E+00} * e^{1.81E-01 * X}$$

for X <= 8

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.77 * (1\text{-SF})^{1.04}) * 1.42E\text{-}09 * X^{6.27E+00} * e^{-9.20E-02 * X}$$

for X > 8

for X > 8

Delay Due to Accidents for Four Lane Facilities (hours per vehicle mile)

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SF})^{1.04}) * 1.23E\text{-}06 * X^{-1.49E+00} * e^{1.07E+00 * X}$$

for X <= 8

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SF})^{1.04}) * 3.36E\text{-}10 * X^{7.09E+00} * e^{-1.36E-01 * X}$$

for X > 8

Signalized Arterials

Travel Time without Queuing (hours per vehicle mile)

$$H_u = 1 / \text{Speed} = (1 / S_{ff})\ 1 + 0.0337 * X^{0.856})$$

Delay Due to Recurring Queues (hours per vehicle per bottleneck)

$$H_r = \text{RECURRING DELAY} = 0 \quad \text{for } X <= 8$$

$$H_r = \text{RECURRING DELAY} = 3.08E\text{-}04 * (X\ \ 8)^2 + 2.26E\text{-}05 * (X\ \ 8)^3 \quad \text{for } X > 8$$

Delay Due to Incidents for Arterials (hours per vehicle mile)

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2\ 1.69E\text{-}05 * X^{1.17E\text{-}01} * e^{3.33E\text{-}01 * X} \quad \text{for } X <= 8$$

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2\ 2.98E\text{-}06 * X^{1.94} * e^{7.63E\text{-}02 * X} \quad \text{for } X > 8$$

Delay Due to Accidents for Four Lane Facilities (hours per vehicle mile)

$$\text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.45 * (1\text{-}SF)^{1.04}) * 1.23E\text{-}06 * X^{-1.49E+00} * e^{1.07E+00 * X} \quad \text{for } X <= 8$$

$$\text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.45 * (1\text{-}SF)^{1.04}) * 3.36E\text{-}10 * X^{7.09E+00} * e^{-1.36E\text{-}01 * X} \quad \text{for } X > 8$$

Table 2.7 Key for Curve Fitting Results for Freeways and Signalized Arterials
Both Directions, Peak Period Traffic

Freeways

Period Delay Due to Recurring Queues (hours per vehicle per bottleneck)

$$H_r\ \text{RECURRING DELAY} = 0 \quad \text{for } X <= 8$$

$$H_r = \text{RECURRING DELAY} = 5.56E\text{-}03 * (X\ \ 8) + 1.44E\text{-}03 * (X\ \ 8)^2 + 5.17E\text{-}04 * (X\ \ 8)^3 \quad \text{for } X > 8$$

Period Delay Due to Incidents for Two Lane Freeways (hours per vehicle mile)

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 4.22 * (1\text{-}SFac)^{1.05}) * 4.94E\text{-}06 * X^{3.16E\text{-}01} * e^{6.16E\text{-}01 * X} \quad \text{for } X <= 8$$

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 4.22 * (1\text{-}SFac)^{1.05}) * 8.79E\text{-}09 * X^{6.68} * e^{-2.46E\text{-}01 * X} \quad \text{for } X > 8$$

Period Delay Due to Incidents for Three Lane Freeways (hours per vehicle mile)

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.77 * (1\text{-}SFac)^{1.04}) * 5.23E\text{-}07 * X^{1.06} * e^{6.53E\text{-}01 * X} \quad \text{for } X <= 8$$

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.77 * (1\text{-}SFac)^{1.04}) * 6.87E\text{-}10 * X^{8.13} * e^{-3.56E\text{-}01 * X}$$

for X > 8

Period Delay Due to Incidents for Four Lane Freeways (hours per vehicle mile)

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SFac})^{1.04}) * 1.99\text{E-}08 * X^{3.45} * e^{4.31\text{E-}01 * X}$$

for X <= 8

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SFac})^{1.04}) * 1.41\text{E-}10 * X^{9.14} * e^{-4.31\text{E-}01 * X}$$

for X > 8

Delay Due to Accidents for Two Lane Facilities (hours per vehicle mile)

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 4.22 * (1\text{-SF})^{1.05}) * 3.51\text{E-}06 * X^{1.51\text{E+}00} * E^{2.13\text{E-}01 * X}$$

for X <= 8

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 4.22 * (1\text{-SF})^{1.05}) * 3.68\text{E-}09 * X^{6.16\text{E+}00} * e^{-1.38\text{E-}01 * X}$$

for X > 8

Delay Due to Accidents for Three Lane Facilities (hours per vehicle mile)

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.77 * (1\text{-SF})^{1.04}) * 1.13\text{E-}07 * X^{3.11\text{E+}00} * e^{1.81\text{E-}01 * X}$$

for X <= 8

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.77 * (1\text{-SF})^{1.04}) * 1.42\text{E-}09 * X^{6.27\text{E+}00} * e^{-9.20\text{E-}02 * X}$$

for X > 8

Delay Due to Accidents for Four Lane Facilities (hours per vehicle mile)

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SF})^{1.04}) * 1.23\text{E-}06 * X^{-1.49\text{E+}00} * e^{1.07\text{E+}00 * X}$$

for X <= 8

$$H_a = \text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SF})^{1.04}) * 3.36\text{E-}10 * X^{7.09\text{E+}00} * e^{-1.36\text{E-}01 * X}$$

for X > 8

Signalized Arterials

Period Time without Queuing (hours per vehicle mile)

$$H_u = 1 / \text{Speed} = (1 / S_{ff})(1 + 0.0392 * X^{0.869})$$

Period Delay Due to Recurring Queues (hours per vehicle per bottleneck)

$$H_r = \text{RECURRING DELAY} = 0$$

for X <= 8

$$H_r = \text{RECURRING DELAY} = 9.87\text{E-}04 * (X \;\; 8)^2 \quad 1.42\text{E-}05 * (X \;\; 8)^3$$

for X > 8

Period Delay Due to Incidents for Arterials (hours per vehicle mile)

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * 1.16\text{E-}05 * X^{8.08\text{E-}01} * e^{2.23\text{E-}01 * X}$$

for X <= 8

$$H_i = \text{INCIDENT DELAY} = \text{IncRate} * \text{DurFac}^2 * 1.35\text{E-}06 * X^{2.69} * e^{3.69\text{E-}03 * X}$$

for X > 8

<u>Delay Due to Accidents for Four Lane Facilities (hours per vehicle mile)</u>

$$\text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SF})^{1.04}) * 1.23\text{E-}06 * X^{-1.49\text{E+}00} * e^{1.07\text{E+}00 * X}$$

for X <= 8

$$\text{ACCIDENT DELAY} = (\text{AccRate} - 1) * \text{DurFac}^2 * (1 + 3.45 * (1\text{-SF})^{1.04}) * 3.36\text{E-}10 * X^{7.09\text{E+}00} * e^{-1.36\text{E-}01 * X}$$

for X > 8

Where:

X	=	AADT/C ratio (0 to 18);
S_{ff}	=	free flow speed;
IncRate	=	incident rate factor;
	=	(target incident rate)/(default incident rate);
DurFac	=	duration factor;
	=	(target mean incident duration)/38.0;
SFac	=	shoulder factor;
	=	1.0 for usable shoulders both sides;
	=	0.5 for usable shoulders one side only;
	=	0 for no usable shoulders;
AccRate	=	accident rate factor; and
	=	(target accident rate)/(default accident rate).

Note that the selection of the incident rate, accident rate, and duration factors are based on comparison to the default values. For incident duration, the overall weighted average duration of all incidents for the default case is 38.0 minutes. Because both accident rate varies with traffic volume, Table 2.8 was prepared as a guide for setting the defaults. Selected plots of these equations appear in Figures 2.1 to 2.6.

Figure 2.1 Incident Delay: Two-Lane Freeway
Incident Rate Factor

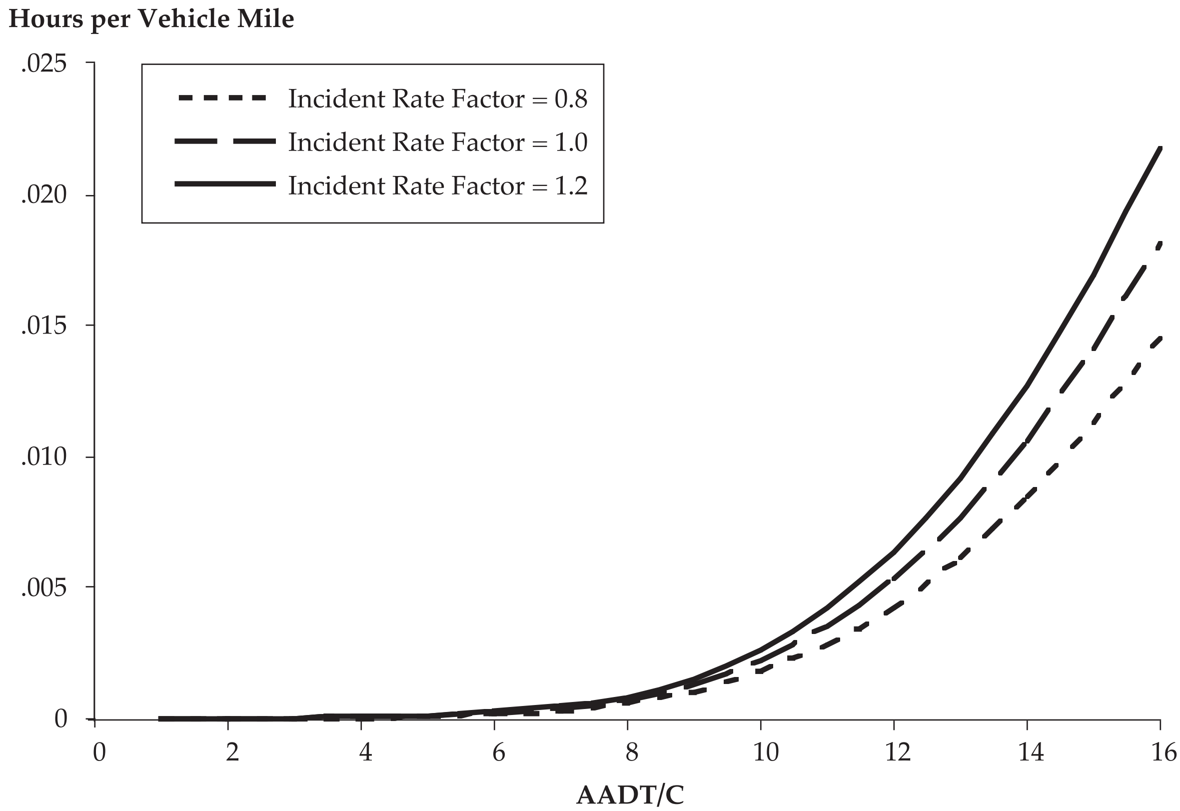


Figure 2.2 Incident Delay: Two-Lane Freeway
Duration Factor

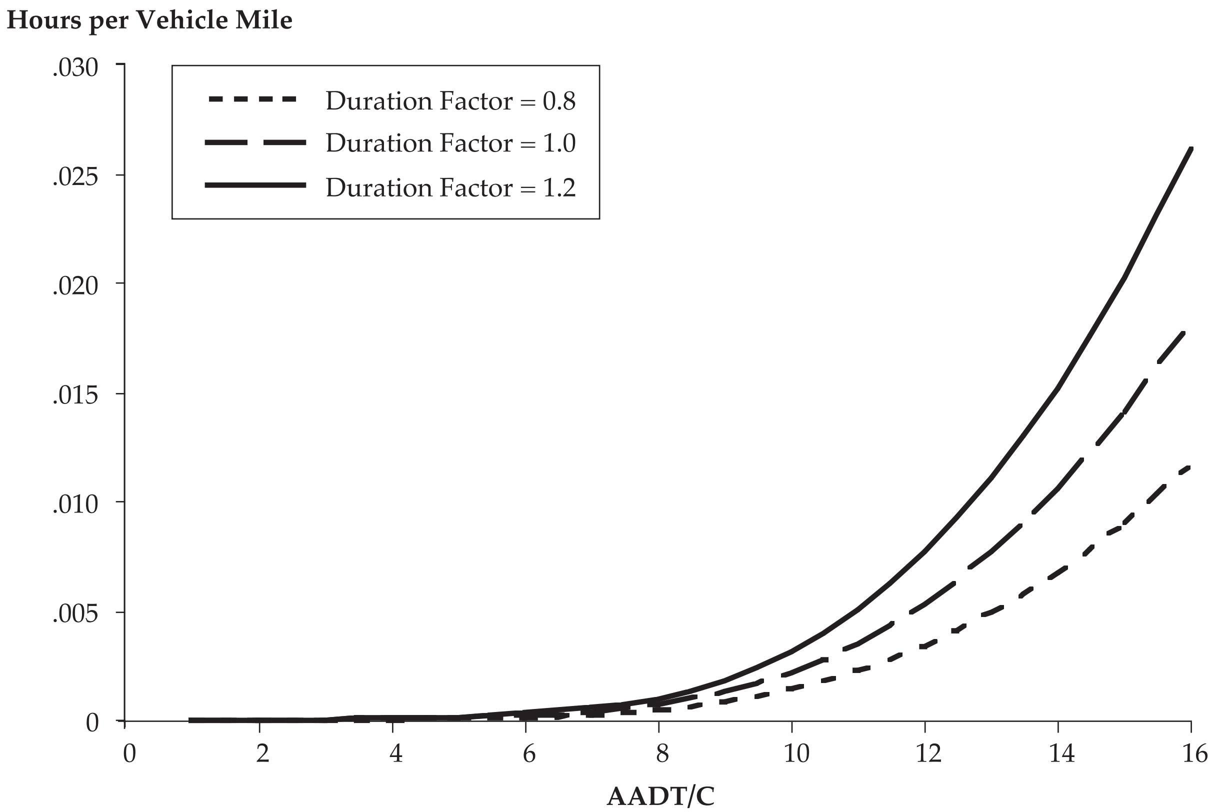


Figure 2.3 Incident Delay: Two-Lane Freeway
Shoulder Factor

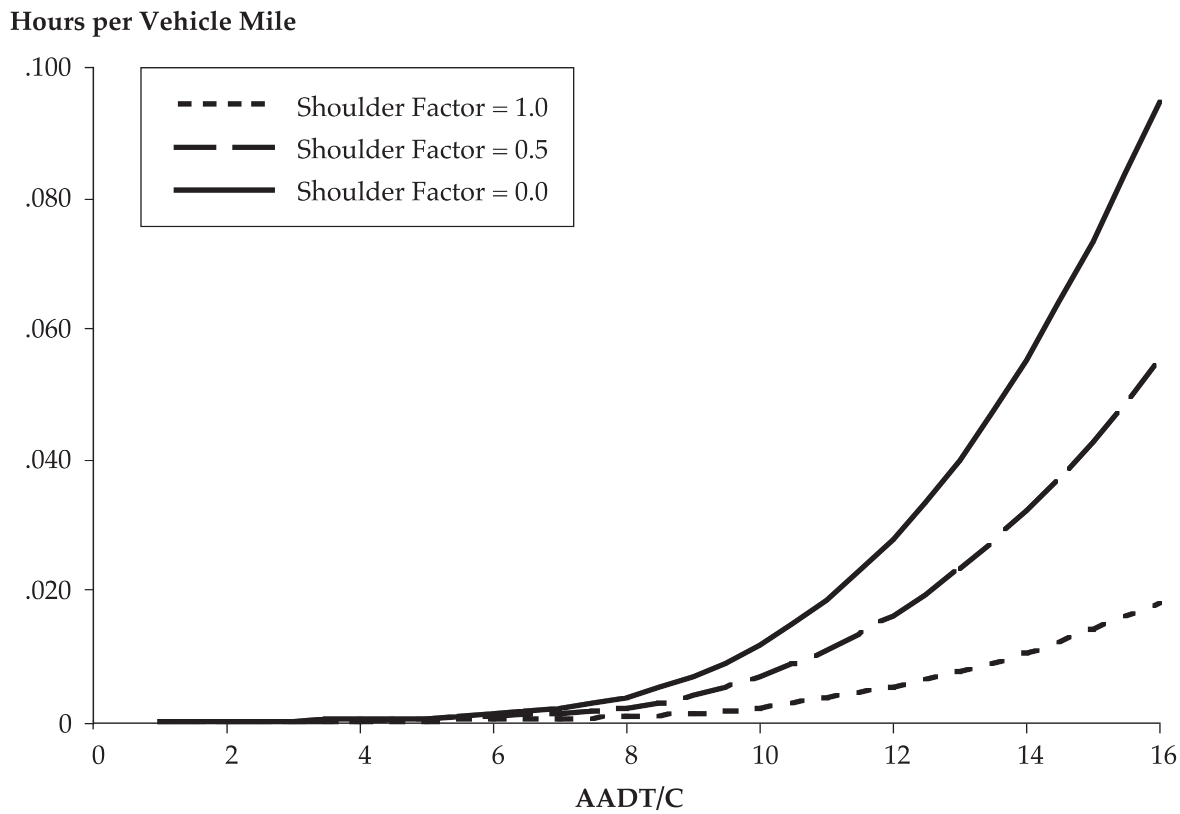


Figure 2.4 Freeway Incident Delay

Shoulder Factor = 0

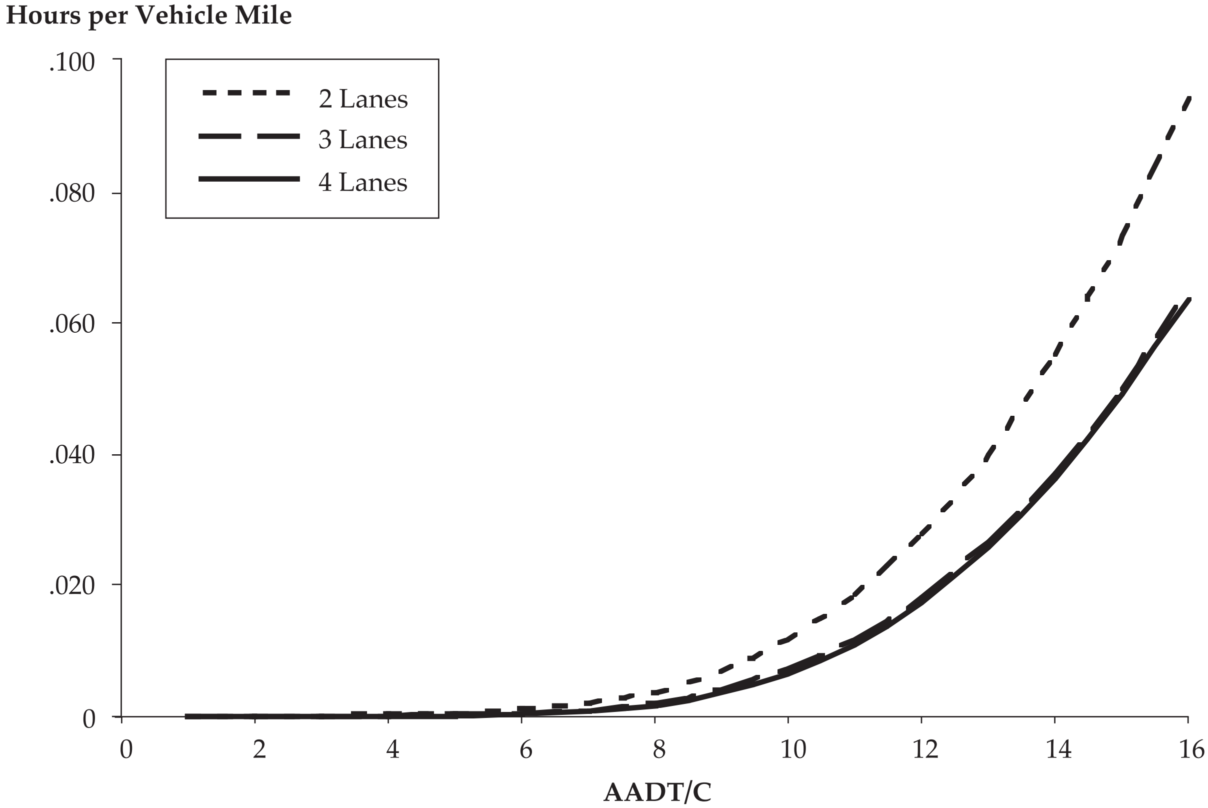


Figure 2.5 Freeway Incident Delay

Shoulder Factor = 0.5

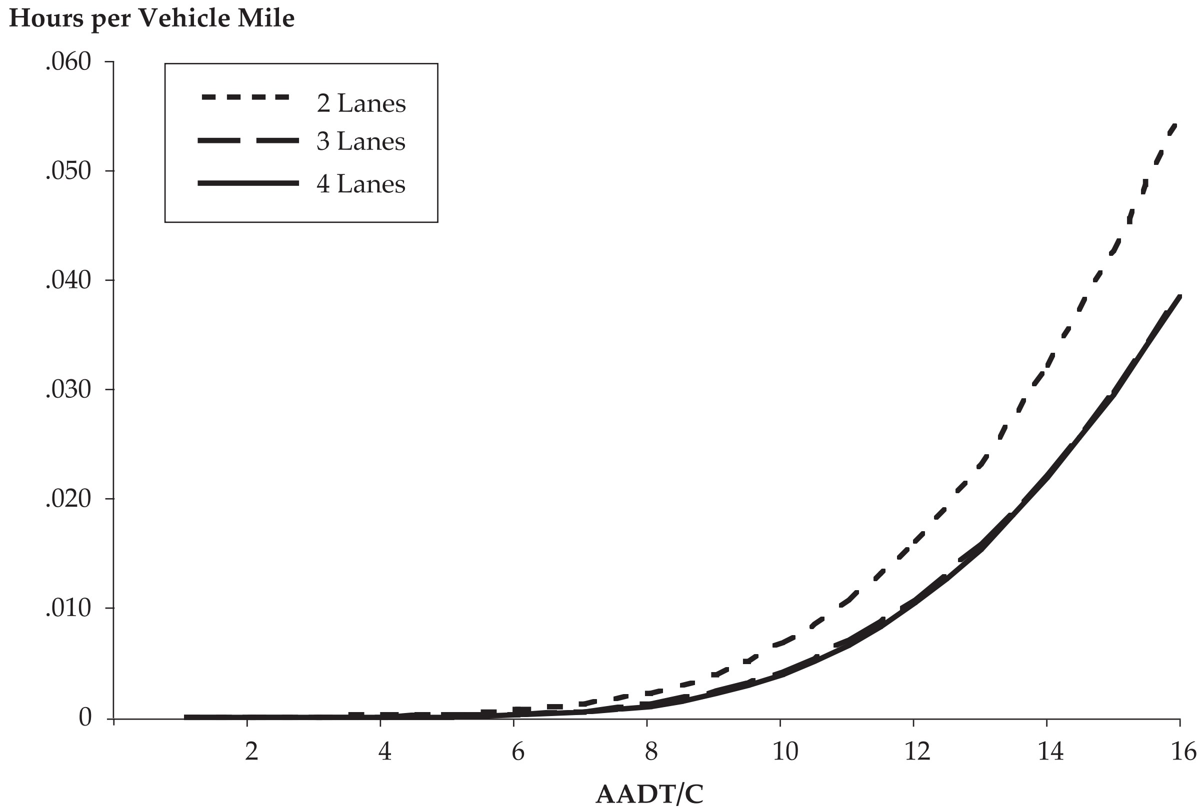


Figure 2.6 Freeway Incident Delay
Shoulder Factor = 1.0

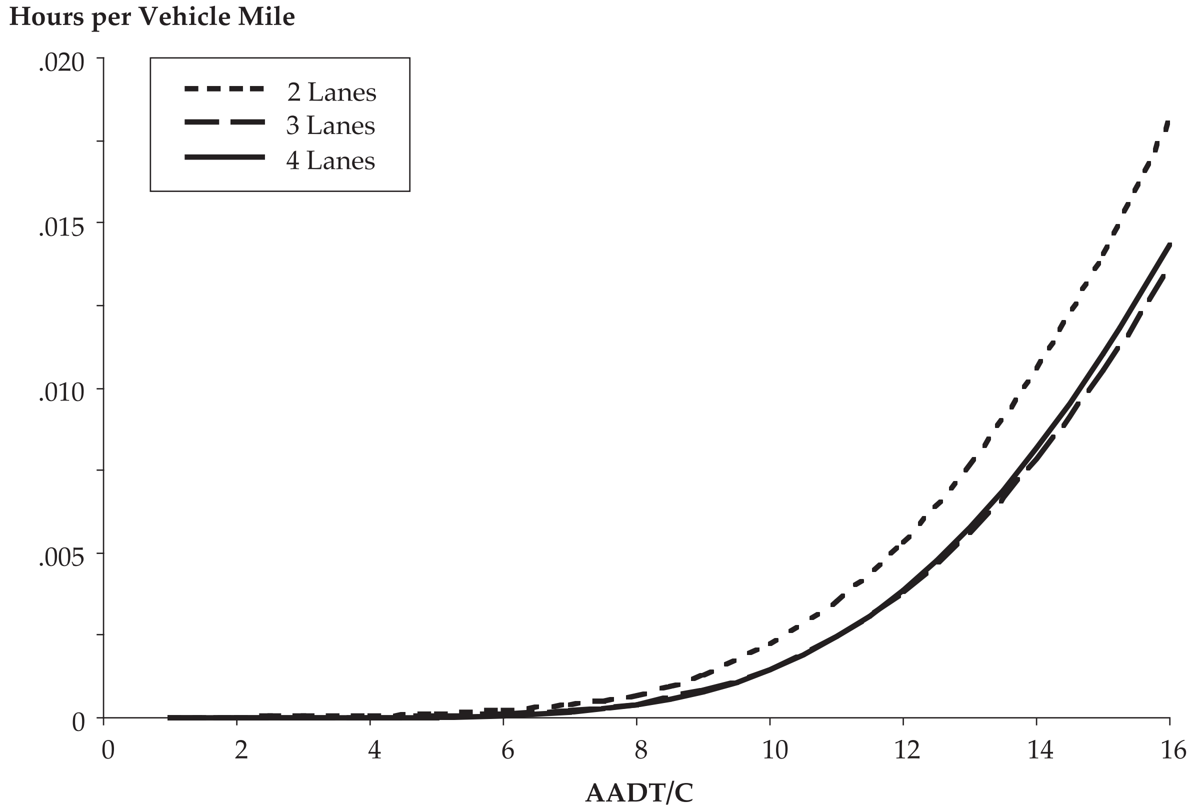


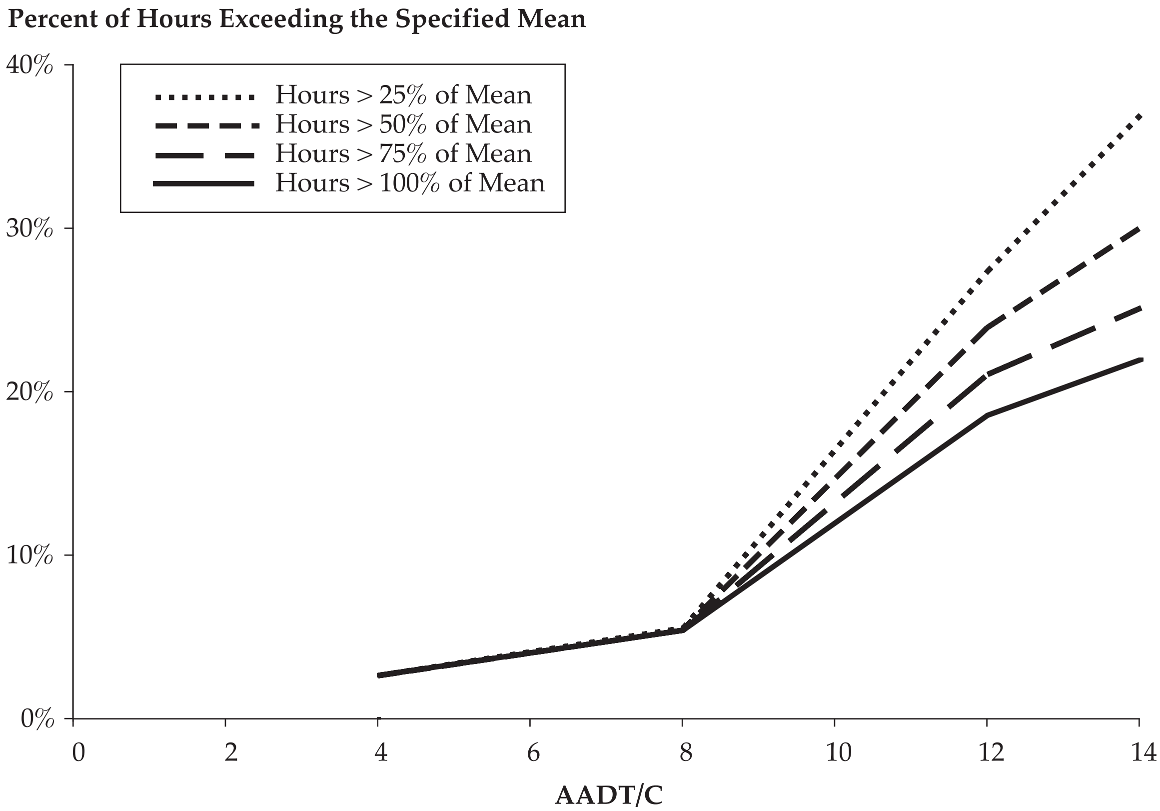
Table 2.8 Default Accident and Incident Rates by AADT/C

AADT/C	Accident Rate(per MVMT)	Total Incident Rate (per MVMT)
1	1.066	9.611
2	1.069	9.614
3	1.075	9.620
4	1.086	9.631
5	1.105	9.650
6	1.132	9.677
7	1.172	9.717
8	1.220	9.765
9	1.275	9.820
10	1.345	9.890
11	1.414	9.959
12	1.518	10.063
13	1.583	10.128
14	1.657	10.202
15	1.709	10.254
16	1.760	10.305
17	1.810	10.355
18	1.853	10.398

2.4 Variability in Delay Estimates

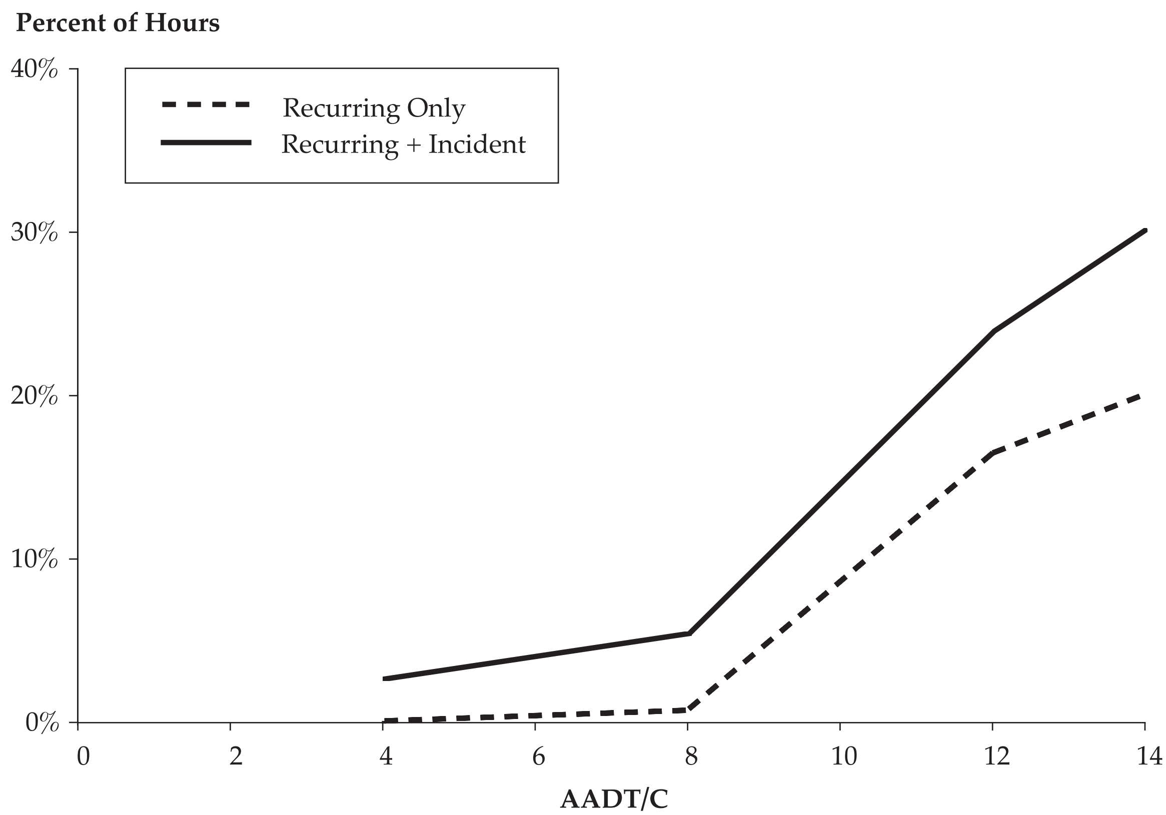
The stochastic nature of QSIM allows for computing the variability in delay estimates. Delay (travel time) variability is due to fluctuations in demand volume from day-to-day as well as to incident occurrence. Figures 2.7 and 2.8 display some aspects of delay variability for the base case scenario (all factors set to the default values). In these, the average delay *due to recurring congestion only* was first computed as a baseline. Then, an analysis of the percentage of hours in the peak period that exceed this average delay by 25, 50, 75 and 100 percent was performed. At AADT/C levels below 8.0, there is very little variability in recurring delay because volumes never get high enough for a queue to form (even allowing them to vary stochastically). What delay exists is theoretically due almost solely to incidents, and the variability is low less than five percent of hours in the peak period exceed the average by any amount. Since the lines are coincident at AADT/C values of 8.0 or less, it is clear that a small number of extreme incidents are causing the variability. Above an AADT/C of 8.0, variability increases dramatically due to the combined effect of incidents and recurring queues (which are caused by variations in volume). Figure 2.8 separates out the effects of incidents and recurring queues; the effect of incidents only can be found by subtracting values indicated by the two lines.

Figure 2.7 Peak Period Delay Variability
Combined Effect of Recurring Congestion and Incidents



Example: At AADT/C=12, 18% of hours in the peak period have delays that exceed the average delay by 100 or more percent.

Figure 2.8 Percent of Hours with Delay Greater than 50% of the Average
Peak Period



Thus, at an AADT/C of 8.0, it can be verified that almost all of the variability is attributable to incidents. At an AADT/C of 12.0, about 70 percent of peak-period variability is due to recurring congestion, an indication that while incidents of substantial impact do not happen every day while recurring congestion is more or less predictably high.

A few final notes on variability are in order. First, as can be seen in Figure 2.8, recurring congestion is subject to a good deal of variability within the model. This is because traffic volumes are allowed to fluctuate from day-to-day. Many other studies do not consider volume variations to be an aspect of recurring congestion, the assumption being that "recurring" congestion occurs in basically the same manner every day. This is probably not realistic since when volumes are near or above capacity, small changes affect delay in a nonlinear fashion. We have chosen to assign volume variability to recurring delay to distinguish it from incident-related delay.

Second, the model assumes that hourly traffic varies in accordance with data developed in Reference 3. That is, hourly coefficients of variation (CVs) are used to set the test volume for a given pass in the stochastic process. These data are composites developed from national data (more than 700 locations). CVs are important in determining not only variability but the average amount of delay because of the nonlinear nature of the volume/delay relationship. (High CVs will cause more occasions when volumes exceed capacity.) Individual facilities may exhibit less variability in their hourly volumes, particularly those that are heavily used by commuters. To test the viability of the default coefficients of variation, ITS surveillance data from Orlando (I-4), Seattle (I-5), and Denver (I-25) were examined. (More detail on these datasets are presented in the next Chapter). The Seattle data indicated slightly higher hourly CVs, the Denver CVs were roughly the same as the defaults, and the Orlando CVs were substantially lower than the defaults (almost half as large). All of these data represented only two-three months of data, so the actual annual CVs are likely to be larger. Therefore, as a national model the procedure used is reasonable. However, if conditions on a specific facility vary substantially from the defaults, absolute values for delay can be inaccurate. However, since the main purpose of the methodology is to gauge *relative* changes in delay due to implementing improvement strategies, it can still yield valuable information to planners.

Third, another way to consider variability is to look at the final corridor-wide estimates of recurring and incident delay predicted by the equations. These are based on average delay values. The predicted (average) incident delay can be thought of as additional delay over and above what can be expected from recurring bottlenecks. For example, consider a corridor that has been analyzed in accordance with the Application Guidelines and recurring delay is found to be 1,000 VHT and incident delay is found to be 500 VHT; these are the vehicle-hours of delay that can be expected on an "average" day. Therefore, on an average day, delay is increased by an additional 50 percent due to incidents. This increase could be thought of as variability in the base (recurring) delay estimates.

2.5 Estimation of Queue Lengths

Although the primary outputs from the modeling procedure are estimates of VHT and VMT, it is also possible to track queue lengths hour-by-hour. Currently, the model keeps tracks of queues in terms of number of vehicles. Queue lengths in terms of distance are a complex function of vehicle spacing (headway) in queues which are in turn a function of bottleneck severity (as shown by the FRESIM experiments conducted for this study.) Future versions of the model can use these queue traffic parameters but for simplicity the current study focused strictly on number of vehicles in queues. Also, it is possible to fit equations to estimate queue lengths in the same manner as for delay, but this was not performed here. Rather, a cursory analysis of queues was performed. Figure 2.9 displays the longest *average* hourly queue for the peak period. Note that there is very little difference in the recurring- and incident-caused queues on average; this is because incidents occur only rarely and while recurring congestion happens regularly. In terms of the single longest queue experienced, Figure 2.10 shows the effect of very rare but extremely severe incidents; these cause single occurrences of delay that are several orders of magnitude higher than the longest delay caused by recurring conditions. The fact that the lines in Figure 2.10 are not entirely smooth are a reflection of the stochastic process even with 15,000 replicates at each AADT/C level some minor perturbations exist. For application, users will want to smooth these curves by hand to ensure consistent results.

Figure 2.9 Average Hourly Queue Length, Peak Period

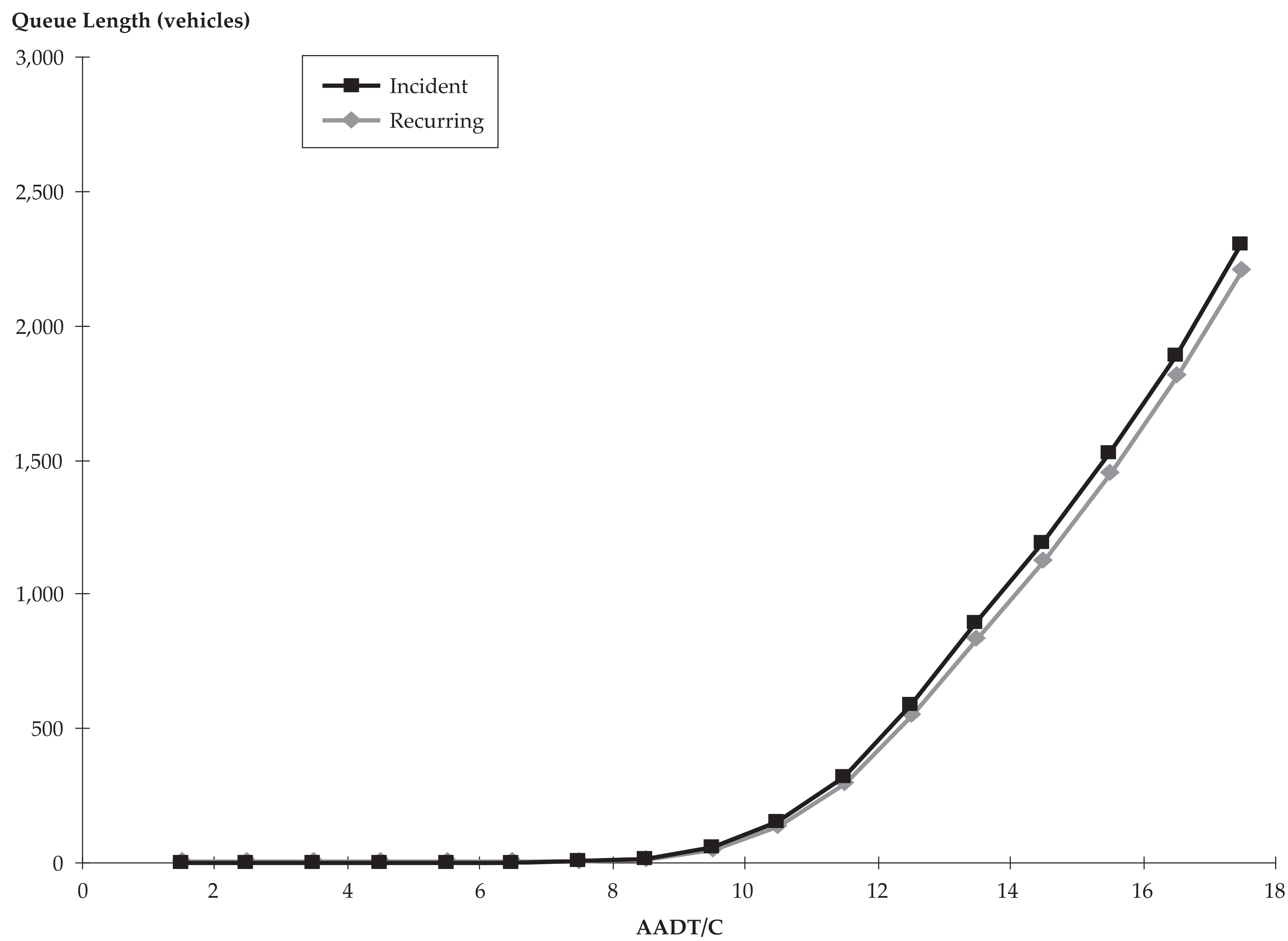
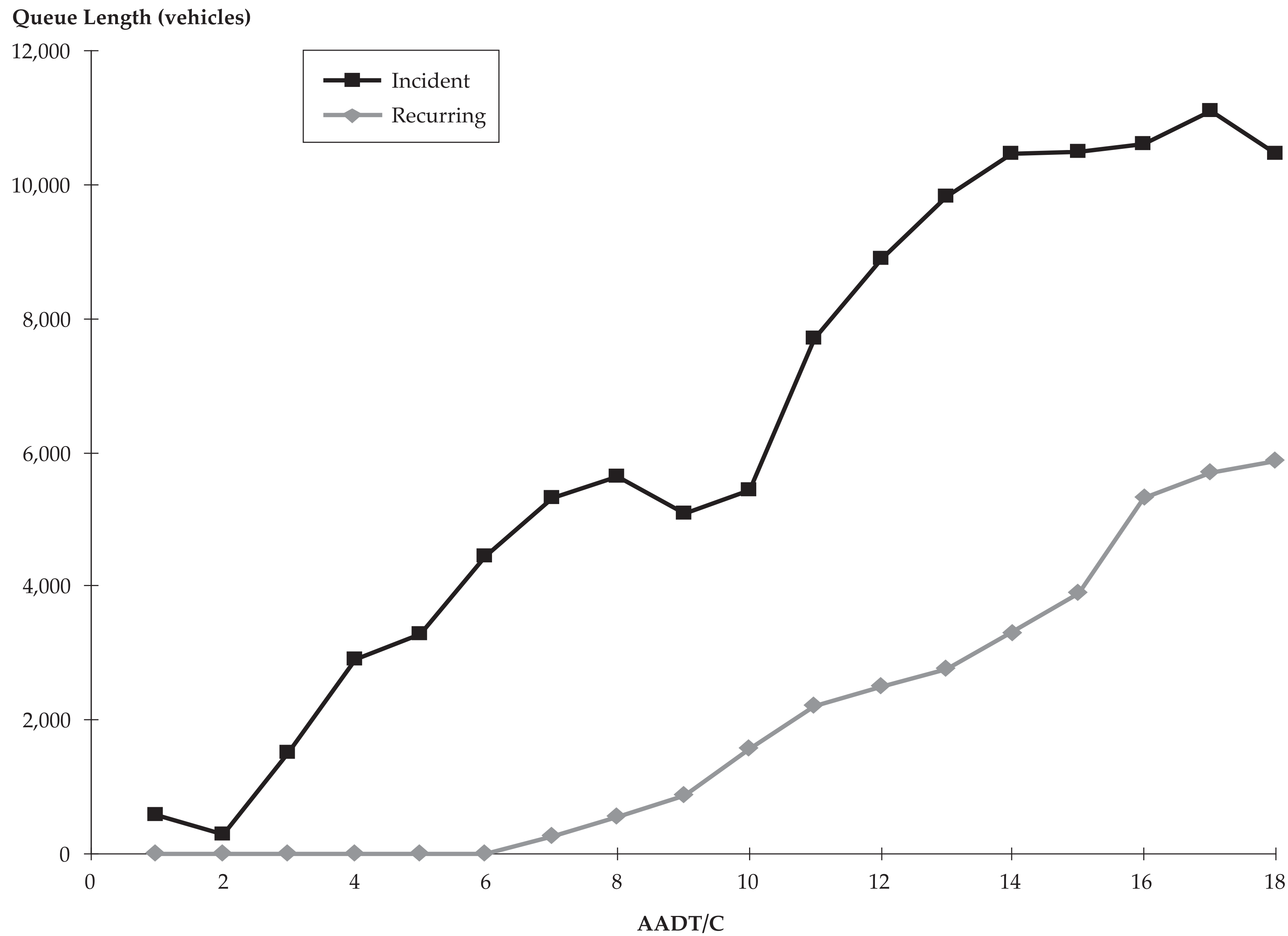


Figure 2.10 Longest Hourly Queue Lengths, Peak Period



3.0 Validation

3.0 Validation

3.1 Validation Approach

To validate the models, freeway surveillance data from Intelligent Transportation Systems (ITS) sources were used. These data are collected from loop detectors that are spaced at intervals along a freeway corridor. The data are used to monitor the performance of the freeway, re-set ramp meter timings, and for detecting incidents. The data are usually reported from the field equipment at 20- or 30-second intervals but are routinely stored by ITS operators at higher levels of aggregation, typically five-minute time periods. The data include volume counts, spot speeds, and loop occupancies (the percent of time the loops are "occupied" with a vehicle). Density can be estimated from occupancy by factoring in the loop length and assuming an average vehicle length.

ITS surveillance data were obtained from four urban areas: Seattle, WA; San Antonio, TX; Denver, CO; and Orlando, FL. Table 3.1 shows the basic characteristics of the freeway corridors from these areas. For Denver, only weekdays were present for the hours between 5:00 a.m. to 10:00 a.m. (northbound only) and 2:00 p.m. to 7:00 p.m. (southbound only). All other locations had 24 hours of data for both directions and included both weekdays and weekends.

Table 3.1 Basic Characteristics of Freeway Corridors Used in the Validation

Urban Area	Route	Corridor Length (mi.)	Corridor Location	Number of Lanes (both dir.)	Time Period	Year of Data	Number of Days with Complete data[1]
Seattle	I-5	15.40	One mile north of I-90 to Mountlake Terrace	6	5 min	1996	120
San Antonio	I-10	4.79	I-35 junction east for 4.79 miles	6 to 8	15 min	1997	79
Denver	I-25	9.70	County Line Road north to Colorado Blvd. (south of CBD)	6	5 min	1992	62
Orlando	I-4	10.99	McCleod Road north to Orange/Seminole county line	6	5 min	1992-1993	66

[1] Only days with no missing data were used in the analysis.

Figure 3.1 shows how the data were used to compute corridor VHT. The method is based on the assumption that the spot speed from the loop detector is applicable to a distance upstream and downstream of the detector; this distance is computed as half the distance to the detector's upstream and downstream "neighbors." VHT is computed for each time period, summed for an entire day, then averaged across days. The calculated VHT is then compared to the results of applying the incident impact procedure. (The equations for both directions combined were used in the comparisons.) The key inputs to the procedure were developed as follows:

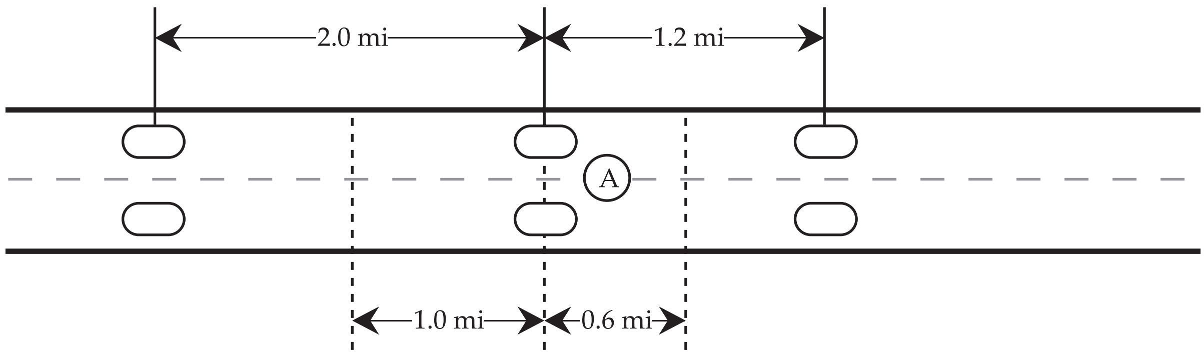
- AADT computed from surveillance data as the simple average of all days present. For Denver, AADT was factored up from the hourly counts assuming that 30 percent of daily travel occurred in the hours and direction present and that weekday daily traffic is 7.57 percent higher than AADT; both of these factors came from Reference 2.
- Speed limit, capacity, and shoulder width 1995 HPMS data were used to identify these values for the specific facilities. (Fortunately, mileposts were present in the HPMS data.)
- Recurring bottlenecks for Seattle and San Antonio, state DOT personnel identified which locations were recurring bottlenecks. For Denver and Orlando, the recurring bottlenecks were identified using speed contour plots developed from the data.
- Incident characteristics default values were used.

3.2 Validation Results

The results of the validation appear in Table 3.2. On a daily basis, the modeling procedure tends to overestimate delay: the predicted delay was six to 17 percent higher than the measured values. There is more variability in the peak-period estimates: in Orlando the predicted day was five percent lower than the measured but was nine and 19 percent higher in Seattle and Denver, respectively.

Overall, these results are encouraging. The project team anticipated that the procedure would overestimate delay for two reasons. First, with only several hundred days present in the field data, it is unlikely that highly severe incidents are present, whereas the procedure includes such incidents. Second, the equations predict the total *systemwide* impact of incidents; in the modeling procedure queues were allowed to extend beyond the length of the test segment. In contrast, the field data can only represent conditions on the actual segment, thus the total delay for severe congestion is missed. In spite of these factors, there was one case where the procedure produced lower delay estimates: the peak period in Orlando. One possible explanation for this difference is that the peak period in Orlando experienced more travel than indicated by the default temporal distributions. Figures 3.2 and 3.3 compare the average temporal distributions from Orlando (the average of all locations) and the default distributions. Especially in the PM peak direction, the Orlando afternoon peak is larger (more traffic) than predicted by the default distributions. Deviations of the temporal distributions for specific facilities from the default distributions (which are national averages) are to be expected and indicate one possible area for future improvement to the procedure.

Figure 3.1 Computing VHT from ITS Loop Detector Data



$$VHT_t = \frac{V_t * L}{S_t}$$

Where:
- t = time period t (usually 5 minutes)
- VHT_t = vehicle-hours of travel in time period t
- V_t = volume in time period t
- S_t = spot speed in time period t
- L = length of the "zone of influence" associated with the detector, computed as half the distance to the detectors upstream *and* downstream of the target detector (1.6 miles in above example)

Table 3.2 Comparison of Measured vs. Predicted VHT, Selected Freeway Corridors

Corridor	Composite AADT/C	Number of Recurring Bottlenecks	Average Daily VHT Measured	Average Daily VHT Predicted	Average Daily VHT % Diff.	Average Peak-Period VHT Measured	Average Peak-Period VHT Predicted	Average Peak-Period VHT % Diff.	Incident % of delay[2]
Seattle/I-5	10.4	1	35,468	41,556	+17.2	20,181	18,470	+9.3	59
San Antonio/I-10	4.7	0	4,460	4,747	+6.4	-	-	-	100
Denver/I-25	9.1	2	-[3]	-[3]	-[3]	6,986	8,290	+18.7	29
Orlando/I-4	10.0	2	29,466	34,329	+16.5	17,709	16,791	-5.2	32

Notes:

1 Sum of AADT for all locations divided by sum of capacity for all locations.

2 Incident VHT divided by the sum of incident and recurring VHT.

3 Hours available for Denver were 5:00 a.m. to 10:00 a.m. and 2:00 p.m to 7:00 p.m.

The validation indicated two factors to which the procedure is highly sensitive: the identification of recurring bottlenecks (for recurring congestion) and the presence of usable shoulders (for non-recurring congestion). As shown in Section 3.0, recurring bottlenecks also influence the proportion of queued delay that is attributable to incidents. In Table 3.2, note that on the section of I-10 in San Antonio, where no recurring bottlenecks exist, 100 percent of queued delay is due to incidents. That number decreases sharply to 29 percent in Denver where there are two recurring bottlenecks in the corridor studied (0.2 recurring bottlenecks per mile).

Figure 3.2 Comparison of Temporal Distributions, P.M. Peak Direction

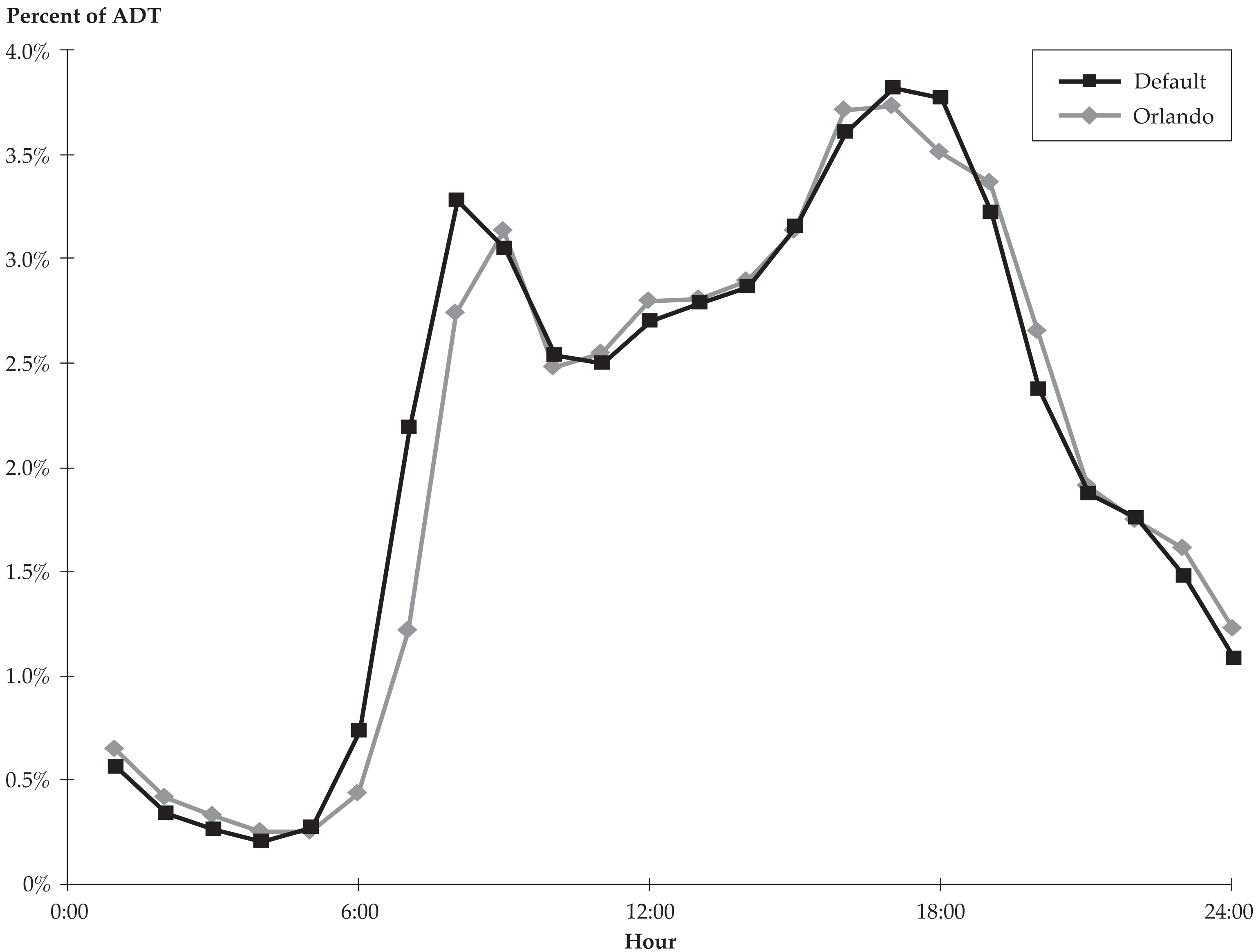
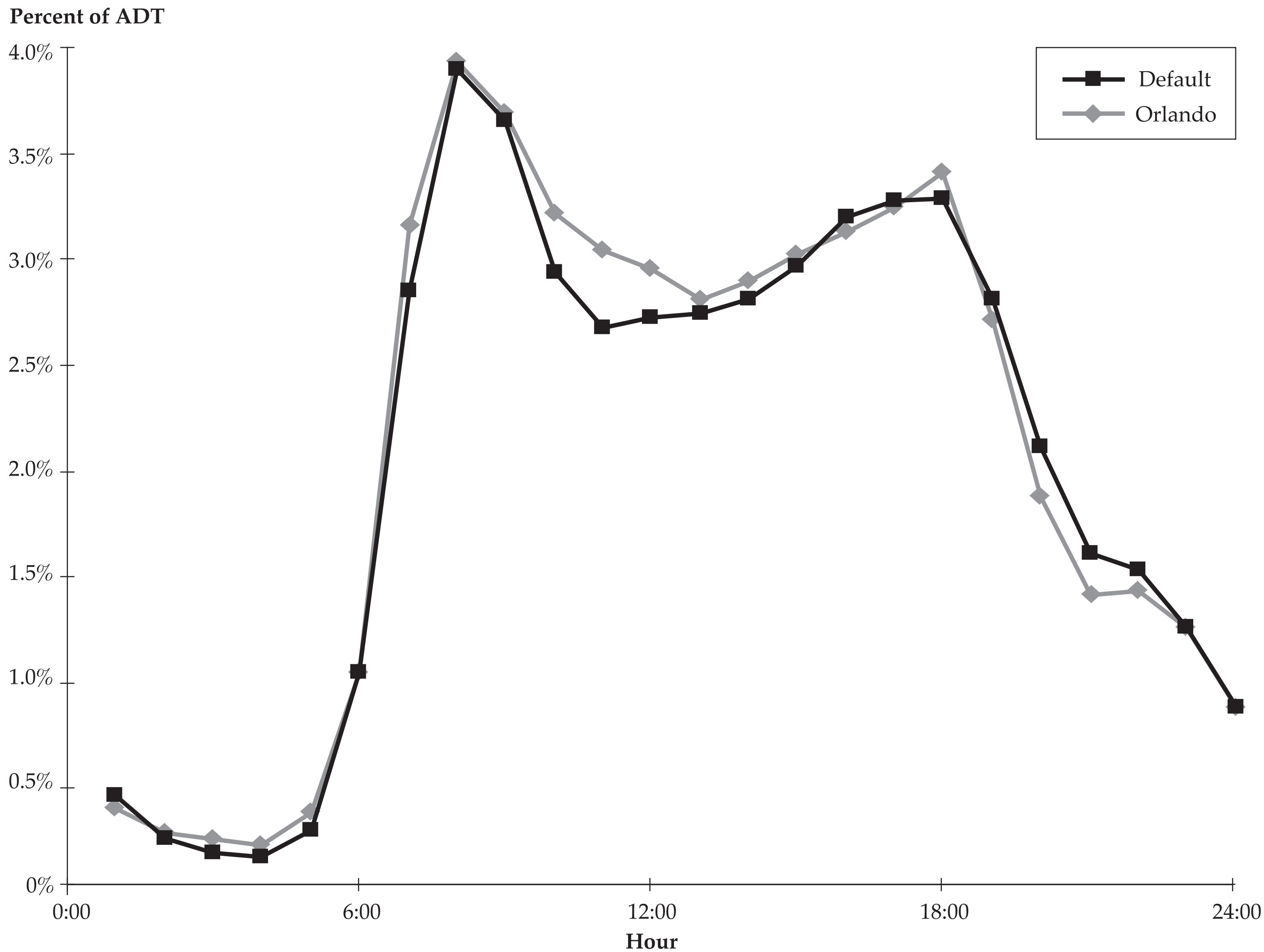


Figure 3.3 Comparison of Temporal Distributions, A.M. Peak Direction



4.0 Case Study Applications Freeways

4.0 Case Study Applications Freeways

4.1 Introduction

To gain an understanding of how local planners would use the incident impact estimation procedure and to revise the Application Guidelines accordingly, two Metropolitan Planning Organizations were selected for case studies: Hartford, CT and Knoxville, TN. Hartford was selected because it has an established incident management program. Knoxville currently has no incident management program but has recently completed its Early Deployment Plan (EDP) which focuses strongly on instituting one. As an aid in applying the equations in a consistent manner, an Excel spreadsheet was developed in accordance with the guidelines in Appendix A. The spreadsheet proved to be very useful in applying the equations and performing sensitivity analysis, thereby reducing the burden on the planners.

4.2 Case Study Findings: Knoxville, TN

4.2.1 Description of Corridor

The corridor selected by the Knoxville MPO for the case study is the most heavily traveled corridor in the region. (The MPO expressed interest in applying the procedure to several more freeway corridors at some time in the future.) The corridor begins at a point three miles west of the CBD at the I-40 and I-75 junction; the two Interstates then run coincidentally throughout the corridor. The corridor ends at the western junction of I-40 and I-75, a total length of 16.80 miles. The study corridor runs through the most rapidly growing area of the Knoxville area. Traffic steadily builds as one progresses from west to east. Through truck traffic is extremely high: over 25,000 trucks per day have been counted at the weigh station that is located near the western terminus of the corridor. The freeway consists of three basic through lanes in each direction. The corridor is currently undergoing a major reconstruction that consists of adding a through lane in each direction and reconstructing eight of the 10 interchanges. (The I-40/75 junctions at either end of the corridor are not undergoing reconstruction.) A parallel arterial exists in the corridor, State Route 11/70, and has a five-lane cross-section (center two-way left turn lane). One recurring bottleneck was identified in the corridor at the east end. The basic input data for the procedure appears in Table 4.1.

Table 4.1 Basic Data for Knoxville Study Corridor (I-40/75)

Name	AADT	Percent Peak Period	Speed Limit	Number Lanes (one-way)	One-Way Capacity (vph)	Link Length (miles)	Shoulders	Recurring Bottleneck?
I-640 Papermill Drive	145,230	38.14	55	3	6,552	1.90	Both	Y
Papermill Drive West Hills	133,230	38.14	55	3	6,552	2.80	Both	N
West Hills Gallaher View	131,510	38.14	55	3	6,552	1.60	Both	N
Gallaher View Cedar Bluff	127,910	38.14	55	3	6,552	1.20	Both	N
Cedar Bluff Pellissippi Parkway	110,820	38.14	55	3	6,552	2.20	Both	N
Pellissippi Parkway Lovell Road	94,170	38.14	55	3	6,552	1.70	Both	N
Lovell Road Campbell Station Road	87,250	38.14	55	3	6,552	1.80	Both	N
Campbell Station Road Watt Road	76,270	38.14	70	3	6,552	3.60	Both	N
Total						**16.80**		

4.2.2 Scenarios Analyzed

The base case for study was chosen using the six basic through lane configuration and ignored the effect of work zones that are currently in place. The analysis scenarios included:

- Traditional incident management strategies (service patrols coupled with freeway monitoring and incident response protocols); these reduced the default incident duration by 10, 25 and 50 percent;
- Traveler information; AADTs for the segments were reduced by one and 10 percent;
- Several strategies based on guidance developed in the EDP. These were:
    1. Implementing a basic ITS Infrastructure (incident duration reduced by 41 percent and accident rate reduced by 42 percent {due to elimination of secondary accidents});
    2. A complete incident management system (accident rate reduced by 15 percent, incident duration decreased by 30 minutes, increase AADT by 10 percent to account for induced travel, and increase capacity by 15 percent);
    3. Transit improvements (reduce incident duration by 15 percent, reduce accident rate by 10 percent, and decrease AADT by 30); and

- Several scenarios to study the effect of workzones on current operations were also run. These alternated single links as the workzones, which replicates the staging of the reconstruction. When a link became a workzone, the capacity was reduced by 10 percent, shoulders were eliminated, and the link was designated as a recurring bottleneck. (The decision to identify links as recurring bottlenecks was based on observations of what is occurring in the corridor now.)

Several of the assumed impacts from the EDP-based strategies appear to be inconsistent or unrealistic. For example, the 30-minute incident duration reduction compared to the default of 38 minutes is a 77 percent decrease! Also, the 15 percent increase in capacity seems like a double counting of benefits given that incident duration has already been reduced. However, the goal was not to measure the exact benefits but rather to test the procedure under a variety of conditions. Therefore, the assumptions do not need to be questioned here.

4.2.3 Model Results

The base case resulted in the following statistics for the corridor, as shown in Table 4.2:

Table 4.2 Base Case Results for Knoxville, I-40/75

	Hours	Percent
Daily		
Delay due to Incidents	2,495.98	7.20%
Delay due to Recurring Bottlenecks	3,003.82	8.67%
Uncongested Vehicle Hours of Travel	29,152.84	84.13%
Total	**34,652.64**	**100.00%**
Peak Period		
Delay due to Incidents	1,654.88	10.69%
Delay due to Recurring Bottlenecks	2,546.58	16.44%
Uncongested Vehicle Hours of Travel	11,285.25	72.87%
Total	**15,486.71**	**100.00%**

Approximately 45 percent of the daily delay in the corridor is due to incidents. All of the incident management scenarios reduced the incident-related delay:

- Basic ITS Infrastructure: 65 percent reduction in incident delay;

- Ten, 25, and 50 percent reduction in incident duration: 19, 44, and 75 percent reduction in incident delay;

- Complete Incident Management System: 96 percent reduction in incident delay (due to large assumed decrease in duration);
- Transit Improvements: 28 percent reduction in incident delay; and
- Traveler Information (decreases in AADT of one and 10 percent): six and 49 percent reduction in incident delay.

More dramatic results (higher delays) were obtained by assigning individual links as workzones one-by-one. The reason for large increases in delay is that the two most sensitive factors of the model were changed: identification of recurring bottlenecks and the shoulder factor. For example, assigning the third link in Table 4.1 as a workzone more than doubled the incident delay *in the entire corridor* and almost doubled recurring delay. Given the base data on lateral location which indicate that around 90 percent of total incidents occur on shoulders these results are not unreasonable. Also, it must be remembered that the entire length of the link was coded as a workzone for simplicity; in reality, the actual workzone will be confined to the interchange area.

4.2.4 MPO Staff Reactions

Ease of Use

The Knoxville MPO staff was impressed with the ease of applying the spreadsheet. However, if the spreadsheet had not already operationalized the equations and the Application Guidelines, they would have felt uncomfortable developing their own spreadsheet or applying the procedure manually. (The number and complexity of the equations increased the chance of improper coding.) Based on the first session with the procedure, a number of productive comments were generated: these comments led to changes in the spreadsheet and the Application Guidelines:

- The capacity calculations should be for through lanes only (sometimes called general purpose lanes) and should ignore extended acceleration lanes or auxiliary lanes to handle interchange and weaving movements. This is consistent with the definitions used to develop the equations.
- The accident rate should be allowed to vary by link rather than being a global input to accommodate work zones.
- The shoulder factor should be extended to include partial lane blockages. The staff have observed this phenomenon in the corridor where a four- to five-foot median shoulder exists: stopped vehicles protrude into the adjacent lane but not enough to cause the lane to be blocked completely. This led to relating shoulder factor to shoulder width rather than relying on the concept of a "usable" shoulder.

Integration With Current Planning Efforts

The staff expressed interest in applying the procedure to all freeway sections in the area where an incident management program was recommended by the Early Deployment Plan. Beyond studying the impacts of proposed incident management strategies, the MPO staff expressed interest in using the procedure as a basic operational tool. Specifically, they are concerned with delays during the major reconstruction that is now underway and would like a way of communicating the problem to the state DOT and local decision-makers. They also see the procedure as helpful in the long-range planning process where selected freeway corridors can be analyzed using forecasted traffic from their demand forecasting models.

4.3 Case Study Findings: Hartford, CT

4.3.1 Description of Corridor

The corridor selected by the Hartford MPO (Capital Region Council of Governments; CRCOG) for the case study is I-84 from near its junction with I-91 in downtown Hartford southwest for a distance of 9.25 miles. It is heavily used by commuter traffic as well as through traffic. An examination of 1996 HPMS data revealed the following characteristics for the corridor:

- Truck percentages are low (four percent in the peak hour, eight percent as a daily average).
- There are generally three lanes in each direction, but several segments have different numbers of lanes in each direction (lane imbalance).
- State-reported K- and D-factors are high, leading to an estimated 7.8 percent of AADT occurring in the peak hour and direction. This in turn leads to high peak V/C ratios for most of the segments (1.15 to 1.34).
- Interchanges are closely spaced; there are 12 interchanges in the 9.25 miles.
- Speed limits are very low for an Interstate highway; the majority of segments have a speed limit of 45 mph and a few have a speed limit of 40 mph. (Speed limits have been set at low levels because of the large number of interchanges and several alignment problems.)

The basic input data appear in Table 4.3. The capacity value originally supplied by CRCOG for basic three-lane sections was 5,742 vph. This resulted in very high AADT/C ratio for some sections. The capacity reported in HPMS for these same three-lane sections was 6,562 vph; this value was used to revise the calculations performed by CRCOG. Also, since the equations for both directions combined were used, the average number of lanes in the section was used (i.e., three in each direction).

Table 4.3 Basic Data for Hartford Study Corridor (I-84)

Links	Name (Milepost*)	AADT	Peak Period % in Peak Direction	Speed Limit	# Lanes (one-way)	One-way Capacity (VPH)	Link Length (miles)	Shoulders (B, 1 or N)	Recurring Bottleneck (Y or N)
1	53.24-54.19	74,590	38.00%	50	3	6,562	0.95	B	N
2	54.19-54.51	73,542	38.00%	50	3	6,562	0.32	B	N
3	54.51-55.09 (**54.97-55.09), 0.12 miles, 3/2**)	91,434	38.00%	50	3	6,562	0.58	B	Y
4	55.09-55.24	83,500	38.00%	50	3	6,562	0.15	B	N
5	55.24-55.99	92,587	38.00%	50	3	6,562	0.75	B	N
6	55.99-56.24	112,784	38.00%	50	3	6,562	0.25	B	N
7	56.24-59.3 (**57.91-58.35, 0.44 miles, 2/3; 58.35-58.37, 0.02 miles, 2/2**)	110,745	38.00%	50	3	6,562	3.06	B	N
8	59.3-59.42	111,400	38.00%	45	3	6,562	0.12	B	N
9	59.42-59.88	115,924	38.00%	45	3	6,562	0.46	B	N
10	59.88-60.51 (**59.97-60.46, 0.49 miles, 4/3; 60.46-60.50, 0.04 miles, 5/3**)	131,735	38.00%	45	3	6,562	0.63	B	N
11	60.51-60.82 (**60.79-60.82, 0.03 miles, 4/3**)	123,957	38.00%	40	3	6,562	0.31	B	N
12	60.82-61.13	141,800	38.00%	40	3	6,562	0.31	B	N
13	61.13-61.38 (**61.13-61.20, 0.07 miles, 4/3; 61.20-61.38, 0.18 miles, 5/3**)	160,138	38.00%	40	3	7,656	0.25	B	N
14	61.38-61.63 (**61.38-61.57, 0.19 miles, 4/3; 61.62-61.63, 0.01 miles overpass, 4/3**)	138,167	38.00%	40	3	6,562	0.25	B	N
15	61.63-61.88 (**61.63-61.87, 0.24 miles, 4/3**)	157,821	38.00%	40	3	6,562	0.25	B	N
16	61.88-61.99	158,100	38.00%	40	3	6,562	0.11	B	N
17	61.99-62.21 (**61.99-62.17, 0.18 miles, 4/3; 62.17-62.21, 0.04 miles, 2/3**)	140,177	38.00%	40	3	6,562	0.22	B	N
18	62.21-62.37	115,200	38.00%	40	2	4,375	0.16	B	Y
19	62.37-62.49	115,200	38.00%	40	2	4,375	0.12	B	N

* **Note:** Text in bold indicates lane imbalance.

4.3.2 Scenarios Analyzed

Due to limited staff time availability at CRCOG, only two scenarios were developed: a base case and the institution of an incident management program. In the latter scenario it was assumed that incident duration would be decreased by 10 minutes from the 38-minute default value (a 26 percent reduction).

4.3.3 Model Results

The base case resulted in the following statistics for the corridor, as shown in Table 4.4:

Table 4.4 Base Case Results for Hartford, I-84

	Hours	Percent
Daily		
Delay due to Incidents	1,095.94	3.46%
Delay due to Recurring Bottlenecks	9,285.04	29.31%
Uncongested Vehicle Hours of Travel	21,299.86	67.23%
Total	**31,680.83**	**100.00%**
Peak Period		
Delay due to Incidents	689.93	4.61%
Delay due to Recurring Bottlenecks	6,061.89	40.50%
Uncongested Vehicle Hours of Travel	8,215.66	54.89%
Total	**14,967.47**	**100.00%**

Delay in the corridor is dominated by a single but severe recurring bottleneck: Link 18/19, the interchange with I-91. Only 10 percent of queued delay is due to incidents because of this severe bottleneck (AADT/C ratio of over 13). There was one discrepancy between CRCOG's input data and HPMS: CRCOG coded usable shoulders on both sides of the highway while HPMS indicated 10-foot right shoulders (usable) and two- to three-foot left shoulders (unusable). If this situation is used, daily vehicle-hours due to incidents increase to 3,160 and peak period vehicle-hours increases to 1,982, roughly 25 percent of queued delay in both cases.

When incident duration was dropped to 28 minutes to account for the presence of an incident management program (assuming the originally coded values for usable shoulders on both sides is used), daily incident delay decreased to 595 vehicle-hours and peak period incident delay to 375 vehicle-hours, about a 45 percent decrease in incident-related delay. If usable shoulders are present on one side only, daily incident delay drops to 1,716 vehicle-hours and peak period incident delay to 1,076 vehicle hours, a 45 percent decrease in incident-related delay. However, in terms of *total* delay, the reduction is larger if shoulders are assumed on one side only: a 12 percent decrease as opposed to a four percent decrease.

4.3.4 MPO Staff Reactions

Ease of Use

As was the case with the Knoxville MPO, the CRCOG staff was impressed with the ease of applying the spreadsheet. However, if the spreadsheet had not already operationalized the equations and the Application Guidelines, they would have felt uncomfortable developing their own spreadsheet or applying the procedure manually. The frequent changing of the numbers of lanes in each direction was also identified as a problem for the current spreadsheet, which handles both directions combined. Unfortunately, the equations for individual directions were not imbedded in a spreadsheet for this study. The CRCOG would have felt more comfortable in applying the individual directions.

The staff expressed concern that the results were so sensitive to the identification of recurring bottlenecks. However, it is clear that the predominant form of congestion in this corridor is recurring (i.e., related to geometrics) and not due to incidents. Given this, the staff was not very interested in pursing incident management strategies in the corridor.

5.0 Study Plan for Arterial Incident Modeling

5.0 Study Plan for Arterial Incident Modeling

5.1 Introduction

The purpose of this section is to discuss potential enhancements to the incident impact procedure for predicting incident-related delays for signalized urban arterial streets. As discussed in Section 2.0, the procedure was modified to model incidents on urban streets. However, many assumptions in the model had to rely upon data collected for freeway facilities. Therefore, only a preliminary effort to model incidents on signalized arterial streets was attempted. This section begins with a discussion of arterial incident management history and issues, and a review of recent literature and limitations of the current incident modeling process. This is followed by a data collection plan to explore information missing from current literature and recommendations regarding model enhancements and validation.

5.1.1 Background on Arterial Incident Congestion Problems

The vast majority of incident-related research has centered on freeway incidents. However, no concentrated effort to look at surface street incidents occurred until after 1990. In 1996, the Federal Highway Administration (FHWA) and Oak Ridge National Laboratory (ORNL) sponsored a workshop on surface street incident detection in Scottsdale, Arizona. The purpose of the workshop was "to facilitate the development of a structured plan of research activities that will lead to the development, testing and evaluation of deployable surface street incident detection and management systems (SSIDMS) that are compatible with existing and future advanced traffic management systems (ATMS)." This research initiative was aimed at:

- Establishing a baseline of existing knowledge regarding the nature of surface street incidents and previous attempts at incident detection and management;
- Performing research, development and laboratory testing of detection algorithms, impact assessments and response strategies; and
- Supporting the deployment of promising SSIDMS technologies and strategies on a national basis.

Recognizing that the cost of travel delays associated with incidents exceeds $60 million per day nationally, a methodology to quantify surface street incident delay impacts could play a significant role in building the case for deploying SSIDMS technologies and strategies.

Though freeway and arterial incident categories have many similarities, anecdotal evidence suggests that many more non-disablement incidents occur on arterial roadways than on freeways. Unpredictable non-disablement incidents are caused by police traffic enforcement activity, medical or fire emergencies, and debris spills. Traffic restrictions are also caused by other activities including short-term construction, delivery vehicles, buses that stop in travel lanes, school zones and major police incidents. All of these activities are far more prevalent on arterial roadways than on freeways. Also, arterial accident rates are typically much higher than those of freeways, leading to a higher proportion of accident-related incidents, which tend to be the most severe form of incident.

5.1.2 Literature Review

Surface Street Incident Characteristics

Raub and Schofer (Reference 10) performed a study to quantify arterial street incident characteristics in suburban Chicago. Over 1,800 traffic incidents were recorded over a 28-day period between the hours of 6:00 a.m. and 10:00 p.m. each day. Based on a review of these records, up to 15 percent of all crashes may have been caused by previous incidents (secondary accidents). Of all incidents categorized, 35 percent were traffic crashes, 30 percent were traffic stops (i.e., police activity) and 27 percent were disabled vehicles. Table 5.1 summarizes these results.

Table 5.1 Distribution of Surface Street Incidents

Incident Type	Portion of Incidents
Traffic Crashes	35%
Traffic Stops	30%
Disabled Vehicles	27%
Fires	2%
Other	6%

Raub and Pfefer (Reference 11) performed a second study in suburban Chicago to quantify traffic flow characteristics past incidents. Saturation flow rates were measured for 15 incidents on four-lane urban arterial streets. Each incident included a single-lane blockage. These incidents reduced the saturation flow rate of the two-lane section by over 60 percent around accidents, and under 55 percent around disabled vehicles. The worst saturation flow rate observed for accidents was 1,230 vph (32 percent), while the worst for a disabled vehicle was 1,650 vph (43 percent) out of a normal saturation flow of 3,800 vph for both lanes. Disablement incidents produced relatively consistent flow reductions. Flow reductions around accidents were highly dependent on the amount of activity around the site, including the number and type of vehicles responding. More severe accidents with many response vehicles produced larger capacity reductions. Table 5.2 summarizes the range and average headways observed among six property-damage crashes, six injury crashes, and three disablement incidents in suburban Chicago. Table 5.3 shows the saturation flow rates that result from these headways.

Table 5.2 Range and Overall Average Time Headways per Incident (seconds per vehicle) Single Lane Blocking Incidents on Four-Lane Urban Arterial Streets

Type of Incident	Minimum	Average	Maximum
Property Damage Crashes	2.29	2.41	2.86
Injury Crashes	2.33	2.67	2.96
Disabled Vehicles	1.82	2.08	2.18

Source: Reference 11.

Table 5.3 Range and Overall Average Lane Capacity per Incident (vehicles per hour in remaining lane, percent of two-lane capacity) Single Lane Blocking Incidents on Four-Lane Urban Arterial Streets

Type of Incident	Minimum	Average	Maximum
Property Damage Crashes	1,260 (33%)	1,490 (39%)	1,570 (41%)
Injury Crashes	1,230 (32%)	1,350 (36%)	1,550 (41%)
Disabled Vehicles	1,650 (43%)	1,730 (46%)	1,980 (52%)

Source: Reference 11.

The study identified median type and truck mix as secondary sources of variation in observed mean headways. Two-way left turn lanes provide more operational flexibility around the incident site than raised medians or undivided two-way roadways. Having a large portion of trucks in the vehicle mix was noted to reduce flow rates. The study did not address the impact of incidents located on shoulders or off the arterial roadway, nor did it address incidents on two- or six-lane roadways, or incidents that affect both directions of flow on the arterial.

The average arterial incident capacity reduction factors measured above are not remarkably different from those reported in literature for freeways (Reference 7) or those developed as part of this study with NETSIM. For example, a single-lane blockage on a four-lane freeway is reported to have a net capacity that is 39 percent of the normal capacity of two lanes. This is the same as the reported average value for property damage crashes in Table 5.3. The reported net capacity for a single-lane blocking disablement on a four-lane freeway is 42 percent of the normal capacity of two lanes. This is only four percentage points lower than the reported value in Table 5.3, though, notably, it is also less than the observed minimum. However, only three incidents were involved in the development of the disablement-related traffic data in Tables 5.2 and 5.3.

5.1.3 Critique of Current Incident Modeling Approach As Applied to Arterials

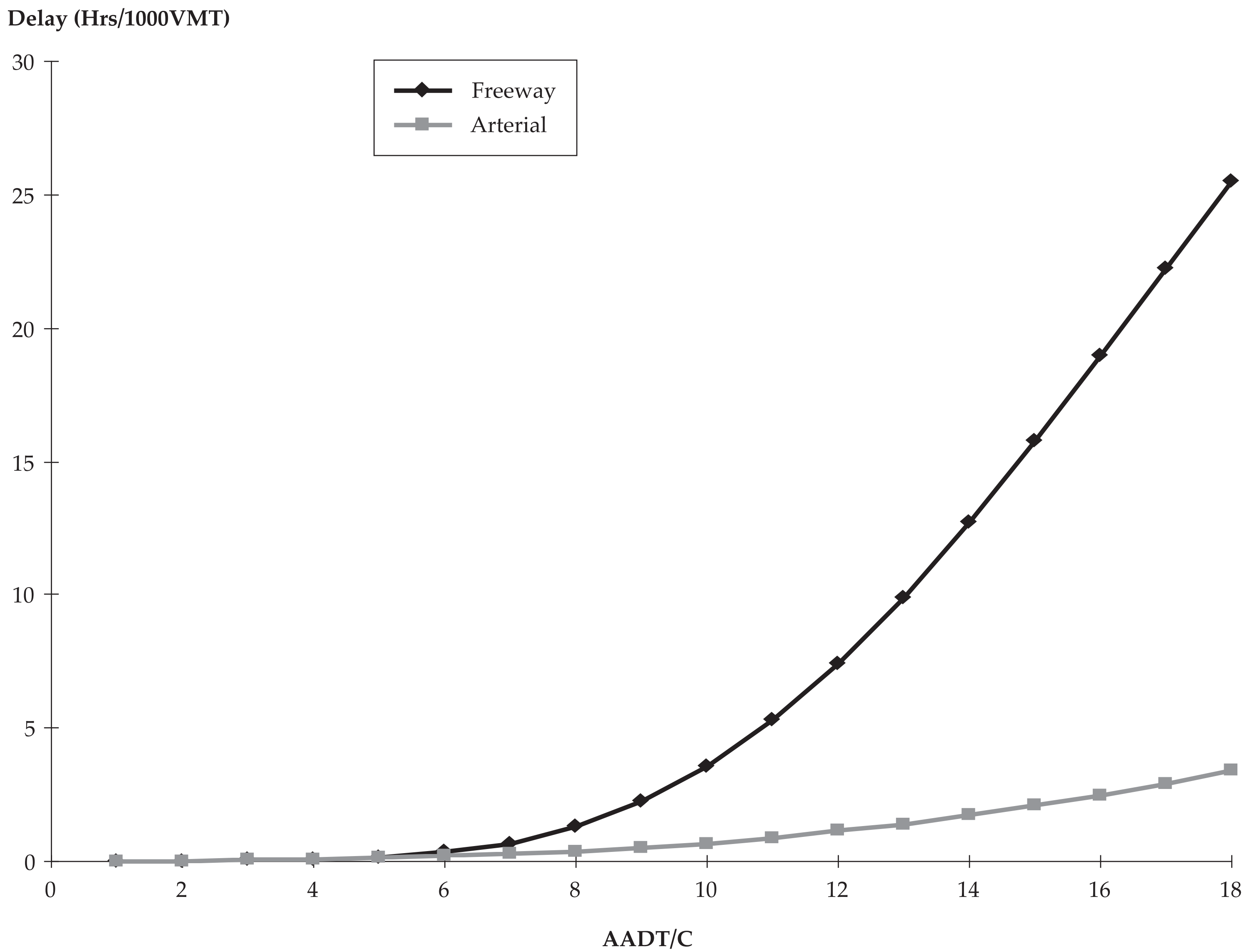
This section discusses various aspects of the current arterial street incident model and how the model might be enhanced to better account for noted deficiencies. As stated in Section 3.0, the lack of data on incident characteristics for arterials hindered the development of delay-prediction equations. The same data as for freeways were used with the following modifications: 1) the accident rate component of incident rate was changed to reflect arterial accident potential; 2) only lane blockage incidents were assumed to have an effect; and 3) capacity reduction due to lane blockages was computed as a function of distance from the signalized intersection. The accident rate increase would tend to increase arterial delay as compared to freeways, but VMT is lower on arterials at the same AADT/C ratio (due to lower arterial capacity). The second and third modifications would tend to decrease arterial delay compared to freeways. The net effect of these factors is that, *under this set of assumptions*, incident delay on arterials is less significant than for freeways (Figure 5.1). However, closer examination of the assumptions appears to be in order before the impact of arterial incidents can be dismissed. Specially, several topics should be pursued more vigorously.

Incident Type, Duration, and Blockage

In the current model, the distribution of incident type, duration, and lane blockage is assumed to follow that of freeways. The distribution of freeway incident types reported in the literature are markedly different than those of arterial streets. Distributions from the Chicago study could be used. However, variations in local police-enforcement policies may significantly affect the portion of "traffic stops" on a local basis. Since the effect of traffic stops is similar to disablements and other non-accident incidents, the current approach of allowing for separate designation of accident and other-incident rates should be appropriate for dealing with local conditions. Data on arterial street incidents from other cities, including more detailed breakdowns of incident types would add confidence to what is reported in the Chicago study. There are several aspects of incident blockage on arterials that are not known based on current literature:

- How frequent are incidents that result in capacity reductions in both directions of flow, or on all approaches to an intersection?
- If a full blockage occurs on a multilane arterial, for how long is the full blockage in place before at least one lane is opened?

Figure 5.1 Comparison of Freeway and Arterial Incident Delay *(Four-Lane Sections)*



- Is the distribution of incidents by capacity-reduction severity similar to that of freeways (shoulder, single-lane blocking, multi-lane blocking, etc.)?

- Does the hourly volume-to-capacity ratio affect arterial street accident rates?

Capacity Reduction Factors

The current methodology uses incident capacity reduction factors based on simulated data developed with NETSIM. However, when comparing arterial-street-accident and incident-capacity reductions from the Chicago study to the those developed with NETSIM, the portion of remaining capacity is similar. This suggests that altering the traffic-capacity-reduction factors based on arterial street incident traffic flow data would be among the least fruitful enhancements to the model.

Impact of Incident Location on Capacity Reduction

The current methodology uses a capacity transition function based on where an incident is located on a roadway link relative to the signalized intersection. The portion of capacity lost is related to the distance between the incident and the traffic signal at the downstream end of the link (the signal spacing is used as the link length). It may be desirable to further investigate the interaction between traffic signal location and incident location using microsimulation techniques. Some of the following considerations will come into play in this analysis:

- Since traffic on arterials flows in platoons, it is likely that a queue will develop upstream of any incident, including mid-block incidents far from signals. This will impose delays on traffic flows even if the queues from one platoon dissipate before the next platoon arrives. Also, this effect is as likely to contribute to secondary accidents as is congestion resulting from a queue that does not dissipate after each platoon passes.

- Incidents in the vicinity of intersections will affect capacity both upstream and downstream of the intersection. A parametric analysis of this phenomenon should be performed using microsimulation to better understand the spatial influence of lane blockages among four- and six-lane arterial streets. All "mid-block" signals modeled would be vulnerable to capacity-reduction effects both upstream and downstream of each intersection.

Impact of Non-Lane-Blocking Incidents

It is assumed that shoulder incidents have no impact on flow, and that there will always be places to pull these vehicles off the road on an arterial street, even if there are no shoulders, or if the roadway happens to have vertical curbs with no pull-off opportunities. Perhaps factors analogous to identifying the presence of left and/or right shoulders on freeways can be included. Some arterial streets, especially expressways, may have both left- and right-side shoulders. Roadways with two-way-left-turn lanes, or extensive left-turn-bays, may be said to have "left shoulders." Roadways with numerous driveways and other pull-out opportunities may be said to have "right shoulders." Given that two-thirds of incidents on arterial streets involve disabled vehicles and traffic stops, the presence or absence of "shoulder equivalents" would have a dramatic impact on predicted delays. It would be useful to develop a functional definition of "arterial-shoulder-equivalent" and develop procedures for characterizing the effectiveness of these shoulder substitutes. Other issue include:

- Under what conditions will a shoulder incident result in flow disruptions along an arterial street?
- Would a "left shoulder" arterial street incident affect both directions of traffic flow?

Impact of Incident Severity on Capacity Reduction

Incidents of different levels of severity are currently assigned the same capacity-reduction factor, based only on the number of lanes blocked. Capacity reductions could vary based on the nature of the incident and the amount of attention it draws. The literature provides clear evidence of lower section capacities under more severe incidents. The Chicago study provides enough information to modify roadway-section capacity depending on whether the incident is an injury accident, property damage accident or some other incident type. However, a deeper investigation of capacity impacts due to other incident types is not likely to affect results as much as some of the other factors mentioned in previous sections. Therefore, it is recommended that the Chicago data be used to establish relationships of accidents to other incident types.

Impact of Incidents on the Opposite Direction of Traffic Flow

Potential congestion from rubbernecking is not assumed to occur in the current model. Also, accidents involving bi-directional blockage are not assumed to occur. Incident situations that could be investigated and quantified include:

- Under what conditions does an incident on one side of a road affect the other direction of flow?
- What is the relative rate of incidents that create blockages in both directions on a street?
- How often would incidents block all approaches to an intersection, including side street approaches?
- If an incident blocks one lane in one direction on a two-lane street, what is the expected two-way capacity assuming no traffic management, or assuming a traffic management plan that rotates the use of the other lane using construction zone flagging techniques.

Impact of Incidents at Mid-block Signals

Incidents that occur at mid-block signals do not impose an impact any different from incidents that occur at signals for major intersections. Traffic signals along an arterial street typically serve cross streets with varying demand levels. Therefore, the green time to cycle time ratios available for main street traffic are higher at signals serving minor streets. Since mid-block signals have higher g/c ratios for through traffic on the main street, the capacity reduction associated with an incident at a mid-block signal would be less than that of a major intersection signal. The impact of this factor should be explored with a parametric analysis using microsimulation.

Lateral Location of Incident on Multilane Roadways

A disablement that occurs at a mid-block location while vehicles are moving is less likely to result in a lane blockage or at least a left-lane blockage than a disablement that occurs while a vehicle is in a standing queue at an intersection. If a vehicle breaks down while standing in a queue, it may be difficult to remove it from the roadway because it is surrounded by other queued vehicles. There may be a need to modify the incident impact distributions to account for "trapped disablements" that occur within queues upstream of traffic signals. Some sort of generalized modeling assumption may be appropriate to account for this effect.

5.2 Framing the Problem Sensitivity Analysis

Prior to obtaining field data for arterial incidents, a series of sensitivity tests should be made with the existing model to determine the range of delay impacts that can be expected due to incidents. The assumptions on how arterial incidents differ from freeway incidents can be examined by studying the factors identified in Section 5.1.3. In this way, in can be determined if the issue of arterial incidents is worth pursuing. At this point, we believe that they are, and the results of the sensitivity tests will identify the most critical factors and input data for further investigation.

5.3 Data Collection Approach

Like any modeling framework, the current approach consists of a series of algorithms that were developed by a variety of different means. These include analysis of empirical (field) data, analysis of synthetic data (usually developed using traffic simulation models), analytically derived algorithms based on established theories, and algorithms derived using "professional judgment." The modeling issues identified in Section 5.1.3 will require applications of all of these techniques to enhance the validity of the model.

5.3.1 Identification and Selection of Participating Local Agencies

Two key potential participants were identified as a source of assistance in obtaining and/or evaluating empirical data regarding arterial street incidents.

Northwestern University Evanston, Illinois

Staff members associated with Northwestern University in Illinois have already provided two key research papers regarding the nature of arterial street incidents. Their work, which involved cooperation among several jurisdictions in suburban Chicago, was summarized in Section 5.1.2. The previous knowledge and significant interest of these staff members could be an advantage in supporting continued work.

Montgomery County Transportation Management Center Montgomery County, Maryland

Montgomery County, Maryland has an established ATMS that includes an extensive array of surveillance detectors and video cameras. These automated data-collection elements may assist in detecting incidents and analysis of videotapes of incidents would reveal their impacts on traffic flow. A similar effort was performed to measure the saturation flow rates of freeway incidents using Maryland State Highway Administration's CHART freeway surveillance cameras.

5.3.2 Input Data

The Chicago database provides some additional input on the distribution of incident characteristics. (Distributions for 1) incident types; 2) lateral location by incident type, 3) lanes blocked by incident type; and 4) incident duration by incident type are the ones needed). Unlike freeway incidents, traffic stops (police enforcement activity) seem to dominate non-accident incidents in the data set. The portion of "traffic stops" in the incident mix may vary widely depending on police department policies regarding the location where enforcement occurs. For example, if jurisdictions require minor violation offenders to move their vehicles off of the road, the portion of stops would be small, and would consist only of stops involving potentially dangerous offenders. Also, the portion of disabled vehicles that remain in the roadway blocking traffic lanes is much smaller on arterial streets than on freeways. More data from other metropolitan areas would be useful as a measure of consistency among metropolitan areas.

There are no known capacity-reduction factors that apply to arterial roadways with two, six, or eight lanes. Also, there is no documented evidence of the capacity reduction of incidents on the opposite flow of traffic (i.e., "rubbernecking" by motorists traveling in the direction not affected by the incident). Finally, the capacity reduction effects of shoulder incidents is not known. Additional microsimulation experiments should be conducted to set capacity-reduction factors for these conditions.

- It is not known whether response times would be greater or less than those on freeways. Data to this effect would be useful.
- The impact of proximity to traffic signals could be studied more closely using some sort of parametric analysis with microsimulation.

5.3.3 Validation Data

Verifying non-recurring delay estimates from the model is unlikely to be possible based on current arterial street speed and delay detection technologies. Though some areas have experimented with probe vehicle data for average travel speed estimates, it is unlikely that any jurisdiction has both travel speed and incident log data necessary to facilitate a direct validation however, it may be possible to observe several arterial street incidents using surveillance cameras from Montgomery County, Maryland. Since many of these cameras have an adequate scope of vision, it may be possible to monitor the length of queue and measure the saturation flow rates past each incident from a camera recording while using upstream detector stations to measure inbound traffic flow rates. This data could then be used to validate model runs for individual incidents with the same characteristics.

5.4 Recommended Modeling Approach

This section outlines a potential enhanced approach for modeling arterial street incidents. Details regarding the specific procedures to be applied during each step would be developed as part of the data collection plan in the previous section along with additional literature review. It is conceivable that certain aspects of the model may be embellished or simplified based on data collection, calibration and validation results.

5.4.1 Data Requirements

The suggested data requirements for applying the enhanced model are listed below. Following the appropriate sensitivity analyses, it may be desirable to establish default values for some of the parameters, or to eliminate those parameters that require additional data collection but add little to model sensitivity. For example, a typical distribution of median types and egress opportunities could be determined based on HPMS data, or a typical injury/fatality to property damage accident ratio could be estimated based on HSIS data.

- Annual Average Daily Traffic Volume;
- Hourly Section Capacity;
- Traffic Signal Density;
- Section Length;
- Median Type (Raised, TWLTL or Left Shoulder, None);
- Egress Opportunities (Continuous or Right Shoulder, Intermittent, None);
- Injury/Fatal Accident Rate;
- Property Damage Accident Rate;

- Non-Accident Incident Rate; and
- Average Incident Duration.

5.4.2 Non-recurring Delay Modeling Process

A potential non-recurring delay modeling process is outlined in this section. Like the preliminary modeling process applied to the current model, the process would need to be repeated for a large number of days over a variety of factors. These could include number of lanes in each direction, AADT/C ratio, traffic signal density, and some measure of the distribution of traffic signal g/c ratios for main street traffic along the route. The steps are:

1. Predict the type of incident using sampling techniques and accident/incident rates provided as input data.

2. Depending on the type of incident, predict the lateral location of the incident in terms of number of lanes blocked, or location on left or right shoulder.

3. Predict the longitudinal location of the incident with respect to signalized intersections along the corridor.

4. If a shoulder incident is predicted, determine whether the effects of median type, egress opportunities, or location in signal queue would affect the ability to move the incident from through travel lanes.

5. Depending on severity and median characteristics, determine whether the incident will affect both directions of traffic flow.

6. Select the appropriate capacity-reduction factors for each direction of traffic flow based on the previously established incident characteristics and the number of through lanes on the arterial street.

7. Predict the duration of the incident based on the type of incident and the average incident duration provided as input data.

8. If volume exceeds the capacity of the bottleneck, build and dissipate a long-term queue based on the current modeling process and estimate total delay impacts. If volume is less than capacity, assume 75 percent of link traffic travels within the progression band at the normal saturation flow rate for the roadway. Estimate the queue and delay per cycle length assuming cycle lengths that vary from 80 to 120 seconds with the current link v/c ratio (see Table 5.4 below). Multiply cycle delay by the number of cycles in which the incident is present to predict total non-recurring delay.

Table 5.4 Assumed Cycle Lengths as a Function of V/C Ratio

Hourly V/C Ratio	Cycle Length (seconds)
0.0 - 0.6	80
0.6 - 0.7	90
0.7 - 0.8	100
0.8 - 0.9	110
> 0.9	120

5.5 Recommended Validation Approach

As discussed in Section 5.2.3, model validation would be limited to any data that could be collected regarding delay and incident impacts from a traffic management center, or synthetically derived data. Field data could be obtained from surveillance camera and roadway detector data using ATMS resources at Montgomery County (Maryland) Department of Transportation or another traffic management center. Using field-measured flow rates, incident characteristics, saturation flows and queue lengths; non-recurring delays would be estimated for use in validation against individual runs using the same traffic flow rates, incident characteristics and roadway geometry. Another approach would be to model incidents using the CORSIM microsimulation model to synthetically develop the same measures, and then apply the same characteristics and compare non-recurring delay estimates. A validation plan combining both of these methods will most likely be necessary to provide validation data on incidents with characteristics not observed in the field.

6.0 Summary of Findings and Recommendations

6.0 Summary of Findings and Recommendations

6.1 Development Summary and Major Findings

This project developed a procedure that estimates the impacts of incidents on traffic operations in a corridor. It is meant to be applied at the sketch planning level and requires only a minimum amount of input data. The final product is a set of equations that compute vehicle-hours of travel (VHT) for uncongested (unsaturated) conditions, incident conditions, and recurring bottlenecks. Separate equations were developed for each of the three components of total VHT by: direction of travel (a.m.-peak direction, p.m.-peak direction, and both direction combined) and by time period (weekday peak period and daily). The equations relate VHT to easily obtainable data: 1) number of lanes; 2) free flow speed; 3) AADT/C ratio; 4) total incident rate and the accident rate portion of total incident rate; 5) incident duration; 6) shoulder width; and 7) location of recurring bottlenecks. Even though the final product is a set of equations, the method used to develop them incorporates several advanced features, many of which are not found in other incident impact methodologies:

- **The approach is stochastic in nature, a feature that has several advantages.** First, it provides a realistic assignment of incident characteristics and captures those rare events that have a large effect (e.g., total freeway closures for long periods of time). Second, the effect of traffic variability can be modeled rather than relying on a static approach. Third, variability in delay estimates (i.e., reliability of travel time) can be directly assessed.

- **Temporal distributions that incorporate peak spreading and hourly variability are used to estimate demand.** The temporal distributions are based on data from over 700 locations around the country.

- **Queuing analysis is used to estimate the extent of congestion.** The concept of "vertical stacking" is used, but its tendency to underestimate queue extent is partially accounted for by including a factor for vehicles traversing the full length of the queued link.

- **The concept of bottleneck capacity is incorporated into the modeling procedure.** The analysis also considers capacity drops due to both recurring and incident bottlenecks. The bottleneck capacities were identified in a series of microscopic simulation experiments. Although not used for this analysis, queue speeds and densities were also determined as a function of bottleneck severity; these could prove useful in future applications where link-specific traffic measurements are considered.

- **The interaction between recurring and nonrecurring congestion is addressed.** In addition to estimating the effect of incidents solely, the approach imposes recurring delay on the process as well. This allows direct estimation of the proportion of delay due to each component, a problematic issue in the past.

- **Incident characteristics developed by Reference 7 were extended for this study.** The first extension was to make the accident rate component of total incident rate a function of congestion (V/C ratio). This accomplishes two things: 1) it gives a more realistic estimate of accidents; and 2) it partially accounts for secondary accidents since, once a queue has formed, the V/C ratio is higher. The reason that V/C is higher is the capacity drop feature. The second extension was to treat the presence of shoulders as an input variable rather than as an internal default value.

The procedure was developed with freeways as the emphasis. However, a preliminary set of equations for signalized arterials was also produced. Because the arterial equations are based on incident-related data from freeways and several assumptions about traffic flow, they should be applied with caution.

The procedure was validated against ITS surveillance data (loop detector) from freeway corridors in Seattle, WA; Denver, CO; Orlando, FL; and San Antonio, TX. The comparison of predicted versus observed VHT revealed that, in general, the procedure predicted higher values than computed with the field data: around 13 percent higher on average. Given that the loop detector data only measure conditions within the limits of the corridor (while the incident procedure allows long queues to extend indefinitely) and the limited number of days in the data (generally around two months, which may miss rare but severe events), the slight overestimation seems to be reasonable. Further, the validation only considered **total** VHT, not the change in VHT due to implementing incident management strategies, which is the main goal of the project.

A spreadsheet was developed based on the equations and Application Guidelines; this was used by the Hartford, CT and Knoxville, TN MPOs in demonstrating the use of the procedure. The spreadsheet model was well-received, which was fortuitous since the prospect of applying the multitude of equations manually was viewed as daunting. In addition to studying the effects of incident management strategies, planners also saw value in the procedure for other operational and planning analyses, such as the effect of workzones and post-processing future travel demand forecasts.

Although the primary purpose of the project was the development of a method to estimate incident impacts, several interesting aspects of the incident problem emerged when the method was applied.

- The method is highly sensitive to the identification of recurring bottlenecks. Allowing analysts to identify recurring bottlenecks rather than allowing the method to identify them is an extremely important aspect of the study. It is felt that this is more reflective of actual conditions in a corridor. If the estimation of total VHT or the split of VHT between recurring and nonrecurring sources is important, the number and location of recurring bottlenecks in the corridor is extremely significant. For example, at an AADT/C of 11, only 19 percent of queued (congested) delay is due to incidents if recurring bottlenecks occur every 1.5 miles; if they only occur every 10 miles, then 61 percent of queued delay is due to incidents. In the first case, the congestion from multiple recurring bottlenecks overwhelm incident delay. *This leads to the conclusion that urban areas can differ greatly in their congestion patterns depending on their individual conditions.* That is, a "one size fits all" approach for estimating the importance of incidents to total delay is untenable.

- If estimation of recurring congestion is not important to analysts, then the above discussion is moot. If so, analysts are primarily concerned with estimated changes in VHT due to incident-related strategies. In estimating incident delay, it was found that method is highly sensitive to the presence and width of shoulders on both sides of the highway. Therefore, the provision of shoulders or at least accident investigation sites (which function as shoulders for certain classes of incidents) can be viewed as an important congestion management strategy.

- Variability in travel time (VHT) was found to increase sharply with congestion. In the method, variability in travel time is due to both the occurrence of incidents and variability in day-to-day traffic volumes. At AADT/C ratios below eight, little variability was found. Above an AADT of eight, the amount of variability increases dramatically.

Finally, it is clear that the method developed here has potential application in many other models and procedures in addition to being a stand-alone tool for transportation planners. Some of these models and procedures are discussed in the next section.

6.2 Recommendations

Based on the work performed, several improvements and adaptations of the procedure are envisioned:

1. **Arterial incident impact procedures.** An obvious shortcoming of the procedure is in the area of arterial incidents. Section 6.0 outlines a strategy for collected the required data and adjusting the modeling procedure for arterial traffic conditions.

2. **Recommended model improvements.** The model used to develop the final equations could be improved in several ways.

   a. **Customized delay models for individual urban areas**. A key underpinning of the procedure is the use of national average temporal traffic distributions and hourly variability statistics. (These determine when volumes exceed capacity.) It might be useful to apply the model with area-specific data for these values in order to improve the accuracy of the procedure when it is applied to specific corridors. This task would basically apply the incident modeling procedures using local all the way through curve fitting. Alternately, consideration can be given to developing a family of temporal distributions instead of the single national average. Each distribution would then be put through the modeling procedure to develop separate equations. Urban areas would then use the equations for the distribution that most closely matches their conditions.

b. **Including the effects of weather in the model**. The final missing component of congestion is the affect that adverse weather has traffic flow. As with incidents, the stochastic framework of the model is ideally suited to studying weather effects. However, since weather varies substantially from area to area, it is likely that only customized runs or a family of representative weather conditions will be accurate enough. Also, relationships between weather conditions and capacity reductions (and possibly accident rate) will have to be established or borrowed from the literature. A purely hypothetical example of such a relationship would be: rain decreases freeway capacity by 10 percent, increases the accident rate by five percent, but rain after an extended dry spell increases accident rate by 15 percent. The current model framework can use these data, provided that they exist and are reliable.

c. **Modeling the effects of traffic diversion**. For severe incidents, it is likely that some amount of diversion will occur from the affected facility. Also, diversion, postponing trips, or making them by alternative modes is a goal of traveler information systems and the model could be made sensitive to this strategy if diversion was accommodated.

3. **Short-term traffic predictions for traffic management centers (TMCs)**. Several of the TMCs we have contacted on the current study have expressed interest in the results. There is an opportunity to provide a simple spreadsheet that predicts the short-term consequences of both incidents and recurring bottleneck breakdowns. This spreadsheet would differ from the one that operationalizes the equations from a planning perspective in that actual conditions would be modeled. The model would use local historical volume and capacity data as a basis, perhaps in combination with real-time data, and would allow the operator to indicate the where, when, and how of a traffic breakdown. The model would then predict queue lengths and delay at the end of different time intervals for the do-nothing case as well as for several scenarios. For example, the model could estimate the savings due to reducing incident duration by X minutes or diverting Y percent of traffic from the facility.

4. **Detailed incident traffic parameters from simulation**. A large amount of data was generated from the FRESIM and NETSIM runs (Appendices B and C) from which only a few key parameters were extracted. The generated data are a potentially rich source of information on the dynamics of traffic flow during and after (recovery period) for an incident. This information should be useful to other applications which deal with the effects of incidents on a more detailed basis (e.g., macroscopic simulation, incident detection algorithms, and TMC control software).

5. **Quantified relationships between transportation improvement strategies and the method's independent variables should be established**. The Application Guidelines (Appendix A) contain general guidance on how improvement strategies and the independent variables in the equations. However, to be more useful to planners applying the method, more specific guidance on expected changes in the input variables should be provided.

6. **The variability in travel time (VHT) should be studied more extensively with the model**. This is becoming an important aspect of congestion management and travel

demand forecasting, yet little is known about how travel time varies and what its effects are on trip-making. The method is well suited to providing estimates of variability (due to its stochastic nature) and could be used to estimate representative travel time variability in typical urban networks.

7. **The method could prove valuable to other applications and should be adapted for use by them**. Because they both operate at the sketch planning level, both the STEAM and IDAS models could take advantage of the relationships developed here. The HPMS and HERS models could also benefit in two ways. First, it would provide a way of estimating the impacts of incident management on national performance forecasts for the *Conditions and Performance Report* to Congress and when the HPMS and HERS models are used by states to perform transportation needs studies. Second, because the method provides estimates of both recurring and nonrecurring sources of congestion, it can be used as a basis for monitoring national congestion trends for general reporting and to meet the Government Performance and Review Act requirements. For all of these applications, the basic adjustment that needs to be made is the estimation of link-specific speeds rather than systemwide VHT as the primary output from the model.

8. **Improved speed/delay functions in travel demand forecasting (TDF) models**. Current estimation of speeds and travel times in TDF models is based on simplistic link performance functions that relate speed to V/C ratio; most are variants of the old BPR function. There are multiple shortcomings with this approach which lead to inaccuracies in speed estimation: 1) it only considers speeds in a single hour yet congestion now occurs in multiple hours; 2) the BPR-like formulation provides a crude estimation of speeds when V/C ratios exceed 1.0; 3) it doesn't consider queue spillbacks onto upstream links but rather assigns all delay to a single link; 4) due to the way assignments are made, bottlenecks are misplaced one link downstream; 5) incident effects are completely ignored; and 6) variability in travel time is not considered. The method developed by this project can address these issues, although many operational problems must be overcome in incorporating them into TDF models.

7.0 References

7.0 References

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Appendix A

Application Guidelines for Sketch Planning Incident Analysis

Application Guidelines for Sketch Planning Incident Analysis

■ Freeways

Introduction

The sketch planning procedure for estimating incident impacts is meant to be applied for an extended section of freeway that can be anywhere from two to 20+ miles in length. The following input data and calculations are required.

Step 1: Decide If Directional Analysis is Needed

If traffic conditions vary substantially by direction, then each direction should be analyzed separately. This determination can be made based on directional volumes or the nature of bottlenecks (e.g., lane imbalance). For example, a lane-drop may exist in one direction and not the other, or an interchange may function as bottleneck in only one direction. Essentially, if capacity and volumes are close to being the same in both directions, then the corridor can be analyzed using combined directions; otherwise directional analysis should be undertaken.

Step 2: Identify Recurring Bottlenecks

The recurring bottlenecks in the corridor must be identified by the user. Based on the analysis undertaken with the QSIM model, recurring bottlenecks can occur whenever AADT/C values exceed 8.0. These can be on-ramps, freeway-to-freeway merges, lane-drops, or work zones. Because the procedure is highly sensitive to the specification of recurring bottlenecks in the corridor, care should be taken to identify "true" bottlenecks from areas where traffic breaks down due to downstream conditions. For example, the queue from a "true" bottleneck may spread upstream and cause traffic flow in another on-ramp area to breakdown. It is possible to have several successive segments with AADT/C ratios greater than 8.0, yet only designate one of them as the "true" or "controlling" recurring bottleneck. Under no circumstances should two successive links be coded as recurring bottlenecks; only one will control traffic flow.

Step 3: Define Links

The corridor should be broken into links for separate analysis. Because AADT/C is the basis for delay prediction, links should be defined when either AADT or capacity changes significantly. Logical breakpoints include on-ramps, lane-drops, freeway-to-freeway merges, and workzones.

Step 4: Set Input Parameters

1. **Analysis Period:** Select peak period or daily analysis periods.

2. **Free Flow Speed (FFS):** For freeways, free flow speed is the common definition in practice: the speed of a vehicle under very light traffic conditions. Following guidance from *NCHRP 387*[1], the following equations should be used:

   $$FFS = (0.88 * SpeedLimit) + 14, \text{ for posted speed limits} > 50 \text{ mph} \quad (1)$$

   $$FFS = (0.79 * SpeedLimit) + 12, \text{ for posted speed limits} <= 50 \text{ mph} \quad (2)$$

3. **Annual Average Daily Traffic (AADT):** The AADT of a section or link is the same as defined in the *Traffic Monitoring Guide*. If a travel demand forecasting model (TDF) model is used and if the model predicts weekday traffic, then adjustments must be made to TDF link volumes to correspond with the AADT definition. If peak hour forecasts are made, they first must be converted to Annual Average Weekday Traffic (AWDT) by factoring:

   $$AAWT = \frac{PHV}{F_{PHV}} \quad (3)$$

where PHV is the forecasted peak-hour volume and F_{PHV} is the percent of daily traffic moving in the peak hour. If peak-hour forecasts are adjusted internally to correspond with design hour volumes (e.g., 30^{th} highest annual hour of traffic), then F_{PHV} should be set to the local K-factor. If peak-hour forecasts represent the average "typical" peak hour, then F_{PHV} should be based on the average peak hour percentage of traffic as determined from local continuous count stations. If local values are unavailable, the following default percentages may be used:[2]

[1] *Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications*, NCHRP Report 387, Transportation Research Board, 1997.

[2] *Development of Diurnal Traffic Distribution and Daily, Peak, and Off-peak Vehicle Speed Estimation Procedures for Air Quality Planning*, developed by COMSIS Corp. and SAIC for FHWA Office of Environment and Planning Work Order B-94-06, April 1996.

Highway Type	AADT/C Range	Default Peak-Hour Percent (One Direction)
	<= 7.5	0.0485
	7.5 < AADT/C <= 8.5	0.0469
Freeway	8.5 < AADT/C <= 9.5	0.0459
	9.5 < AADT/C <= 10.5	0.0438
	10.5 < AADT/C <= 11.5	0.0414
	11.5 < AADT/C <= 12.5	0.0390
	> 12.5	(see Equation 4)
	<= 7.5	0.0483
	7.5 < AADT/C <= 8.5	0.0466
Nonfreeway	8.5 < AADT/C <= 9.5	0.0455
	9.5 < AADT/C <= 10.5	0.0436
	10.5 < AADT/C <= 11.5	0.0414
	11.5 < AADT/C <= 12.5	0.0392
	> 12.5	(see Equation 4)

$$\text{Peak hr pct} = \frac{(0.0392 * (24 - AADT/C)) + ((1/48) * (AADT/C - 12))}{12} \quad (4)$$

For TDF models, if volumes are based on one-way links, then these links must be combined to represent two-way flow, i.e., the one-way AAWTs should be added.

Once two-way AAWT is obtained, it must be converted to AADT by dividing by the ratio of AAWT/AADT:

$$AADT = \frac{AAWT}{F_{AWDT}} \quad (5)$$

where: F_{AWDT} is the area-wide ratio of AAWT/AADT.

The default value for F_{AWDT} is 1.0757.

If directional analysis is chosen, AADT should still be computed on the basis of both directions combined (to be consistent with how the equations were developed). Thus, if one direction of a freeway has an AADT value of 50,000 vehicles per day (vpd) and the other has an AADT of 60,000, the AADTs to use in the equations are 100,000 and 120,000, respectively.

4. **Capacity:** The capacity for all **through/general purpose lanes only** should be calculated. Do not consider extended acceleration lanes and lanes added to improve the functioning of interchange areas. If the area is a workzone, then capacity needs to account for the nature of the work zone. For all facilities, capacity is based on the *Highway Capacity Manual (HCM)* capacity for the peak hour. Freeway capacity for the speed/delay models is the same as defined by the *HCM*: the maximum sustainable flow rate past a point on the highway (i.e., flow rate at Level of Service E). All attempts should be made to follow Chapter 3 of the *HCM* in computing this value. If

it is not available, then the following calculations, based on Equation 11-1 from *NCHRP 387* can be made.

$$\text{Capacity (vph)} = \text{IdealCap} * N * \text{FHV} * \text{PHF} \quad (6)$$

where:

IdealCap = 2,400 pcphpl if free flow speed >= 70 mph;
2,300 otherwise
N = number of through lanes
F_{HV} = heavy vehicle adjustment factor
= 1.0/(1.0 + 0.5 HV) for level terrain
= 1.0/(1.0 + 2.0 HV) for rolling terrain
= 1.0/(1.0 + 5.0 HV) for mountainous terrain (rare in urban areas)
HV = daily proportion of trucks and busses in traffic stream
PHF = ratio of peak 15-min flow rate to average hourly rate

The PHF factor should be chosen with care because the default value recommended by *NCHRP 387* (0.90) can have a significant influence on capacity. Examination of freeway surveillance data from Orlando (I-4) and Denver (I-25) show that for these urban interstates the PHF is approximately 0.95. Further, if local evidence exists that the ideal capacities given above can be sustained for hour-long periods, then the PHF should be set to 1.0.

HV should be computed as a composite average for the corridor to avoid having capacity vary from section to section.

In the predictive equations, capacity is the sum of the one-way capacities. Thus, assuming the result of Equation 6 is 2,100 vph and there are three lanes in each direction, capacity in the AADT/C term of the equations is (6 x 2,100 = 12,600). If directional analysis is chosen capacity should still be computed on the basis of both directions combined. Continuing the example, if the freeway segment has three lanes is one direction and two in the other, then capacities in the AADT/C term are 6,300 and 4,200, respectively.

5. **AADT/C:** For base/current year conditions, if AADT/C exceeds 13.0, then both AADT and capacity should be checked for accuracy. (AADT/C rarely exceeds 14.0 for existing facilities.) Under no conditions, including forecasted future volumes, should AADT/C exceed 18.0.

6. **Incident Rate Factor:** If the incident rate of the facility is known, it should be used in the equations. It is computed as:

$$\text{IncRateFac} = \text{(Facility Incident Rate)/(Default Incident Rate)} \quad (7)$$

Here, the incident rate includes all forms of incidents, even minor ones. The types considered in the default model are: 1) abandoned vehicles, 2) accidents (crashes), 3) debris on roadway, 4) vehicle breakdowns (mechanical trouble, stalled vehicles, flat tires), and 5) "other" (vehicles parked without having a breakdown). If information on **all** of these types are not available, then the analyst should either use the default incident rate or can factor their data using the distribution of incident types information provided in Chapter 3.

Note that the selection of the Incident Rate, Accident Rate, and Duration Factors (see below) are based on comparison to the default values. (If these are not known for the facility being analyzed, they should be set to 1.0.) Because individual links on the facility will usually have different AADT/C ratios, the Incident Rate Factor should be developed for each individual link (Table A.1 offers guidance.)

Table A.1 Default Accident and Incident Rates by AADT/C

AADT/C	Accident Rate (per MVMT)	Total Incident Rate (per MVMT)
1	1.066	9.611
2	1.069	9.614
3	1.075	9.620
4	1.086	9.631
5	1.105	9.650
6	1.132	9.677
7	1.172	9.717
8	1.220	9.765
9	1.275	9.820
10	1.345	9.890
11	1.414	9.959
12	1.518	10.063
13	1.583	10.128
14	1.657	10.202
15	1.709	10.254
16	1.760	10.305
17	1.810	10.355
18	1.853	10.398

7. **Accident Rate Factor:** Accidents are a subset of total incidents. As with the incident rate factor, if the accident rate of the facility is known, it should be used in the equations. It is computed as:

$$AccRateFac = (\text{Facility Accident Rate}/\text{Default Accident Rate}) - 1.0 \qquad (8)$$

The Accident Rate Factor is developed differently than the other factors. It essentially measures the deviation of the facility-specific rate from the default accident rate that is imbedded in the overall incident rate. In other words, it is used to adjust the calculated incident delay to account for accident rates that are higher or lower than the default. Therefore, the results of the equation for accidents only should be added to the results of the equation for incidents (see Step 6 below).

Since accident rate varies by traffic volume it should be computed for each link based on its AADT/C level and the values in Table A.1. *To avoid double counting, either the total incident rate* ***or*** *the accident rate should be adjusted for accidents, but not both.* For example, if the accident rate of a facility is known but not the incident rate, the default incident rate should be used and the accident rate factor adjusted as shown in Equation 8. If both are known, it is recommended that the incident rate factor only be adjusted.

8. **Duration Factor:** For incident duration, the overall weighted average duration of all incidents for the default case is 38.0 minutes. The duration factor is then:

   DurFac = (target mean incident duration)/38.0 (9)

9. **Shoulder Factor:** The ability of shoulders to shelter disabled vehicles has a strong influence on incident-related delay. Therefore, shoulder widths must be wide enough to store disabled vehicles without them encroaching on the adjacent travel lanes. However, it is possible that narrow shoulders can cause a stopped vehicle to encroach into the adjacent travel lane without causing that lane to be completely blocked. Therefore, values for the Shoulder Factor are computed as a function of shoulder width for right and left shoulders individually:

Shoulder Width	Shoulder Factor (Left and Right)
<= 3 ft	0.0
4-5 ft	0.5
6+ ft	1.0

The shoulder factor for use in the equations is then:

ShldFac = {SF(left) + SF(right)}/2 (10)

10. **Link Length:** The length of the link in miles (to the nearest tenth) should be noted. Link length is used in VMT calculations.

11. **Percent of Annual VMT in the peak period:** This data item is used only if the peak period is used as the time period of analysis. The peak period is defined as weekdays between the hours 6:00 to 10: A.M. and 3:00 to 7:00 P.M. If locally defined values are unavailable, the defaults in Table A.2 may be used. In developing weekday peak period VMT, it is necessary to account for both weekdays and weekends. A simple approximation would be:

    PPVMT = (PPVOL/AWDT) * (5/7) * (AWDT/AADT) (11)

where:

PPVMT	=	percent of annual VMT in the weekday peak period
PPVOL	=	average peak period volumes

AWDT = annual average weekday traffic
(5/7) = ratio of weekdays to total days in the year

As before, an average approximation of AWDT/AADT is 1.0757.

Table A.2 VMT Proportions for Freeways (Both Directions Combined)

AADT/C	Percent of Traffic in Peak Hour	Percent of Traffic in Peak Period
1	0.0787	0.3844
2	0.0786	0.3844
3	0.0788	0.3847
4	0.0789	0.3852
5	0.0789	0.3845
6	0.0784	0.3842
7	0.0787	0.3844
8	0.0768	0.3830
9	0.0745	0.3814
10	0.0718	0.3777
11	0.0619	0.3720
12	0.0620	0.3644
13	0.0602	0.3497
14	0.0579	0.3339
15	0.0557	0.3188
16	0.0533	0.3045
17	0.0509	0.2925
18	0.0489	0.2823

Step 5: Calculate VMT and Hours per Vehicle-Mile for Uncongested (H_u) and Incident (H_i) Conditions

For each link, H_u and H_i are estimated using the appropriate equations. VMT is calculated as the AADT times the link length in miles if the daily time period is used for the analysis. If the peak period is used, then VMT is AADT times link length times the proportion of VMT during the peak period (use Table A.2 if local values are unavailable).

Step 6: Calculate the Change in Hi Due to Deviation From the Default Accident Rate (Ha)

If the accident rate of the facility is known, then H_i should be adjusted to account for the actual accident rate of the facility by adding H_a to H_i. Note that in Equation 8 if the actual rate is lower than the default rate, H_a is negative.

Step 7: Calculate Hours per Vehicle (Hr) and Number of Vehicle (Vr) for Each Recurring Bottleneck

For each recurring bottleneck, H_r is calculated using the appropriate equation. V_r is set equal to the AADT of the link if the analysis period is daily. For the peak period, AADT is multiplied by the proportion of VMT during the peak period to derive V_r.

Step 8: Calculate Baseline Vehicle-Hours of Travel (VHT) for Entire Corridor (Extended Segment of Highway)

For the facility being analyzed, the total VHT for the corridor should be computed as:

$$\text{Total VHT} = \sum_{l} ((H_{u(l)} + H_{i(l)}) * VMT_l) + \sum_{b} H_{r(b)} * V_{r(b)} \quad (11)$$

where: *l* refers to individual links and *b* refers to recurring bottlenecks.

If desired, the user can also track the proportion of VHT due to incidents (VHT_i), recurring bottlenecks (VHT_r), and uncongested travel (VHT_u) by breaking out the terms in Equation 11. For any given link:

$$VHTu = Hu * VMT \quad (12)$$
$$VHTi = Hi * VMT \quad (13)$$
$$VHTr = Hr * Vr \quad (14)$$

The analyst is cautioned that VHT_i and VHT_r are measures of systemwide delay due to queuing while VHT_u is the total vehicle-hours of travel for vehicles traversing the segment, and, therefore, is not true delay. The delay incurred by vehicles for unqueued can be found by computing VHT under ideal or "desired" speeds for the segment (e.g., VHT at the free flow speed, VHT_{ffs}) and subtracting it from VHT_u. Then,

$$\text{Total vehicle-hours of delay} = VHT_i + VHT_r + (VHT_u - VHT_{ffs}) \quad (15)$$

Nearly all of the delay imbedded in VHT_u is volume-related: the updated BPR curve predicts noticeable delay when V/C ratios exceed 0.75. Only a small amount of the delay is due to the capacity-reducing effect of incidents. The reason for incident's small influence on unqueued delay is that high volumes occur every day and incidents happen infrequently. The delay portion of VHT_u (the last term in equation 15) can either be kept separate from queued delay or can be counted as recurring delay, ignoring the small (less than one percent) contribution from incidents.

Step 9: Determine the Effects of Incident Management and Transportation Improvement Strategies on the Input Variables

Improvement strategies that have an effect on the input variables in the model will produce different delay estimates. General guidance is provided in Table A.3 for a variety of improvement types, including capital improvements, incident management, and ITS strategies. Note that for AADT/C, strategies can affect either AADT or capacity. Because it is difficult to quantify specific changes due to strategies in many cases, the user should perform sensitivity analysis using several reasonable levels. For example, in examining the effect of an incident management program, the user might select several different reduction levels for study, say, 10, 20, and 30 percent reductions in incident duration. The equations would then be applied with the original duration factor being reduced by these percents. A brief discussion of the strategies and their affects follows.

Closed Circuit Television (CCTV) Surveillance: Primarily used for incident verification and incident detection to a lesser degree. Main effect will be reduction of incident duration. A possible additional effect is a reduction in secondary accidents due to shorter durations of primary accidents. However, this effect is already partially accounted for within the model and no adjustments are recommended.

Service Patrols: Main effect is the reduction in the incident response component of total incident duration. In some cases, emergency or police vehicles parked on or near the freeway may have a small negative effect on drivers speeds (as reflected by a lower free flow speed) but this effect should not be used unless there is compelling local evidence to the contrary.

Automated Incident Detection: Strategies include incident detection algorithms applied to traffic surveillance data and free cellular phone calls to report incidents. The effect is a reduction in total incident duration.

Computer-Aided Dispatch: This is the automated control of incident response strategies. The effect is a reduction in total incident duration.

Shoulder Widening: The *HCM* reports that shoulder widening up to a point will increase capacity. If the widening is large enough to qualify as a "usable shoulder" for sheltering disabled vehicles, then the shoulder factor will also be affected. Shoulder widening may also lower accident rates, although viable safety relationships for shoulders on urban freeways are scarce.

Interchange Reconfiguration: Reconstructing an interchange can lead to a substantial increase in the capacity of the segment due to elimination of weaving problems and the addition of extra lanes for short distances. The *HCM* should be consulted to estimate the increase in capacity, if any. For many planning applications, detailed before and after capacity calculations based on weaving or complex ramp configurations are not performed the basic freeway lane capacities are used (e.g., Equation 6 above). Therefore, care should be taken in estimating any capacity increase due to interchange configuration as well as many other operational improvements. One approach would be to estimate the percent increase in capacity due to an operational improvement and apply that to the base capacity; even if the absolute value of capacity is off, the relative delay decrease should be representative of actual conditions.

Table A.3 Effects of Transportation Improvement Strategies on Model Inputs

Strategy	FFS	DurFac	AADT/C	ShldFac	AccRateFac	IncRateFac
CCTV Surveillance	0	**3**	0	0	0	0
Service Patrols	-1[1] - 0	**3**	0	0	0	0
Automated Detection (e.g., free cell phone calls)	0	**3**	0	0	0	0
Computer-aided dispatch for incident response	0	**3**	0	0	0	0
Shoulder widening	0	0	**0-2**	**3**	1	0
Interchange reconfiguration	**0-2**	0	**1-3**	0	**0-3**	0
Accident investigation sites	0	0	0	**1-3**	0	0
Realignment/reconstruction	**0-3**	0	**1-3**	0	**0-2**	0
Safety inspection programs	0	0	0	0	0-1	1-2
Corridor congestion relief	0	0	**1-3**	0	0	0
Demand management	0	0	**1-3**	0	0	0
Lane addition	0	0	**3**	0	0	0
Ramp metering	0	0	**1-3**	0	**0-3**	0
En-route traveler information	0	0	**0-3**	0	1[2]	0

[1] Possible negative effect due to onlooker delay in opposite direction.

+3 to +1 High to low beneficial effect likely
0 No net effect likely
-1 to -3 Low to high adverse effect likely

In some cases, interchange reconfiguration can also lead to a small increase in the free flow speed; if the reconfiguration allows an increase in the posted speed limit, then Equations (1) or (2) can be used to calculate the new free flow speed.

Accident Investigation Sites: In the context of sketch planning, this improvement may be thought of as a shoulder widening to accommodate disabled vehicles involved in an accident (assuming shoulders were not wide enough initially). However, a subset of accidents will be too severe to allow use of these sites. On the other hand, vehicles involved in other incidents (vehicle breakdowns, flat tires) could use the sites as refuge. Examination of crash severity data from the 1993 General Estimates System (GES) show that only 14 percent of urban Interstate crashes involve a fatality, an "incapacitating" injury, or a "nonincapacitating" injury. The remaining 86 percent are either no injury or possible injury; these are the crashes assumed to take advantage of the investigation site. If 25 percent of the remaining (noncrash) incidents is assumed to use the site, the adjusted shoulder factor is:

$$ShldFac/ = (ShldFac + N) * \{(0.86 * AR/IR) + (0.25 * (1 - AR/IR))\} \quad (16)$$

where:

ShldFac	=	original shoulder factor
N	=	0.5 if sites are installed on one side of the freeway
	=	1.0 if sites are installed on both sides
AR	=	accident rate (use Table A.1 as a default)
IR	=	total incident rate, including accident rate (use Table A.1 as a default)

If local experience indicates that more than 25 percent of noncrash incidents would use the site, then this factor should be increased. For example, consider a situation the original shoulder factor is 0 (no "usable" shoulders), the AADT/C of the link is 10, an accident investigation site is constructed on one side of the freeway, and the default accident and incident rates from Table A.1 are used. The calculation is:

$$\begin{aligned} ShldFac/ &= (0 + 0.5) * \{(0.86 * (1.345/9.890)) + (0.25 * (1 - (1.345/9.890)))\} \\ &= 0.5 * \{0.3330) \\ &= 0.1665 \end{aligned}$$

Note that the effect of this improvement is less than if "usable" shoulders were added for the full length of the link, i.e., the adjusted shoulder factor would have been 0.5 in that case.

Realignment/Reconstruction: The same effects as for interchange reconfiguration are indicated.

Vehicle Safety Inspection Programs: These are felt to be the only activity that could possibly have an effect on noncrash incidents. The theory is that by improving vehicle condition, breakdowns are less likely. Unless local evidence suggest otherwise, it is recommended that the effect of these programs be ignored.

Demand Management: These strategies include Transportation Control Measures instituted for air quality reasons as well as many other strategies (e.g., ridesharing). Their effect is to either eliminate trips or to shift them from peak travel times. If trips are eliminated because of demand management, then an estimate should be made of how many of these trips would be using the facility in question, and AADT should be reduced. If trips are shifted out of the peak hour or peak period to other times, analysis is more difficult. The most direct way of handling this is to reduce the amount of VMT in the peak hour or period, but this is not always possible. Some demand strategies shift trips from the peak **hour** into adjacent hours (peak spreading). However, recall that the peak period for the model is four hours in the morning and four hours in the afternoon. It is therefore not possible to adjust peak period VMT for this case. A similar situation occurs for daily analysis; the shifting of trips will also reduce delay for daily analysis by reducing delays in the peak period. In cases where VMT can not be adjusted, it is recommended that AADT be adjusted as an indirect way of handling the peak VMT shift within the model. For the purpose of planning applications, it can be assumed that the shift affects only recurring delay total daily trips are the same so the same number of incidents can be expected. (This is not strictly true since accident potential in the model is assumed to increase with congestion.) Therefore, AADT in the AADT/C term **for the recurring delay equation only** should be adjusted. For the sake of simplicity, the following recommendations are made:

Effect of Demand Management	Peak Period Analysis	Daily Analysis
Eliminate trips	Reduce AADT by percent of trips eliminated for the facility	Reduce AADT by percent of trips eliminated for the facility
Move trips from peak hour into other hours in the peak period	Reduce AADT in recurring delay eq. only by the percent of trips shifted for the facility	Reduce AADT in recurring delay eq. only by the percent of trips shifted for the facility
Move trips from peak period to off-peak periods	Reduce peak period VMT by the percent of trips shifted for the facility (e.g., Table A.2)	Reduce AADT in recurring delay eq. only by the percent of trips shifted for the facility

Lane Addition: Basically, a capacity improvement, the same effects as for interchange reconfiguration are indicated.

Ramp Metering: Locations where ramp metering has been installed generally report an increase in capacity and a corresponding decrease in delay **for the freeway**. (Analysts should be aware that additional delay is usually sustained by vehicles on the on-ramp, and spillbacks onto adjacent arterial streets can occur.) There is also some evidence that accident potential is reduced by ramp metering, presumably because of smoother merge operations and less turbulent mainline flow.

En-Route Traveler Information: The effects of traveler information systems are similar to demand management, except that the they tend to be more dynamic. That is, diversions from the freeway only occur when congestion reaches a certain level.

Step 10: Repeat Steps 5 through 8

For the selected strategy(s), repeat the delay calculations and note the difference; this is the delay savings due to the strategy(s).

Appendix B

FRESIM Experiment Results

SKETCH METHODS FOR ESTIMATING INCIDENT-RELATED IMPACTS

TECHNICAL MEMORANDUM

FRESIM Experiment Results

1. Introduction

The purpose of this Memorandum is to document the results of the FRESIM experiments. These experiments were conducted for three reasons:

1. To determine the influence of incident location relative to a recurring bottleneck (i.e., an on-ramp). It was postulated that if incidents occurred upstream from the on-ramp merge area, then total flow at the incident location is less than the total bottleneck volume, which is the sum of the mainline and ramp volumes. Further, an incident upstream from the merge area would tend to meter flow into the recurring bottleneck and improve its performance (at the expense of transferring delay to the freeway upstream). On the other hand, if an incident occurred *within or close to* the merge area, it was postulated that the turbulence caused by normally merging vehicles compounded by lane changing and rubbernecking to avoid the incident would lead to a more severe "combined" bottleneck.

2. To develop traffic parameters for use within the QSIM model. In addition to the information on incident location from (1) above, basic data on incident flow rates (i.e., capacity reduction due to incidents) and the speed of vehicles in queues caused by incidents needed to be developed.

3. To develop estimates of delay under recurring and nonrecurring conditions. The FRESIM results can be used in addition to field data to calibrate QSIM. Also, simplified delay equations can be developed from FRESIM results to estimate the effect of isolated incidents.

2. Experimental Design

The design of the initial experiment is shown in Figure 1. The factors under study included V/C ratio, incident location relative to the on-ramp, incident duration, and ramp volume percentage. Four consecutive hours representing the afternoon peak period were simulated with Hour 2 being the highest hour in the peak period. The incident began at the start of Hour 2. The volumes for each hour were determined from the temporal distributions developed for HPMS.

The full experiment is shown in Table 1. Note that for the base case (incident duration = 0), location is irrelevant. Also note that for the higher volume cases, only partial results were obtained due to the queues backing up beyond the extent of the upstream freeway (six miles). Based on these results, a congestion sub-experiment was established that including not only more upstream storage but additional time periods as well. (Queues consume both time and space and the extra time was needed to allow them to dissipate.) The total freeway length for the sub-experiment was 22 miles and eight hours were simulated. V/C ratios included in the sub-experiment were 1.0, 1.1 and 1.2; ramp percentage and incident duration and location were the same as for the main experiment. In addition, two other factors were included. First, the lane where the incident occurred was varied. Second, a truck percentage factor was included (0 percent as before and 10 percent). This was done because previous work with FRESIM had revealed that as V/C increases up to 1.0, the influence of trucks is greater than the *Highway Capacity Manual's* constant passenger car equivalents. Therefore, it was postulated that in queues (i.e., V/C ratios greater than 1.0), this phenomenon would continue.

3. Simulation Results

Table 2 through 4 show a convenient way to display the FRESIM results for individual runs. These tables highlight the three main traffic parameters of interest: speed, volume, and density. Traffic flows from left-to-right in these diagrams and the on-ramp is connected at Node 190. In Table 2, the incident is highlighted in time and space; it occurs upstream of the on-ramp merge area.) Note that even after the incident ends, a substantial queue has been built that requires almost another two hours to clear. Another aspect of queue dynamics is also displayed in Table 2. After the incident has ended, a wave of vehicles is now delivered to the recurring bottleneck. (Our previous work with FRESIM showed that the queue clearance flow is very high – around 2,400 pcphpl.) This abnormally high volume then causes the recurring bottleneck to exceed capacity, leading to low-freeway speeds between the old incident location and the on-ramp. It also causes the queue to dissipate much more slowly than if no bottleneck (on-ramp) was present; our earlier work showed that after an incident is cleared (in the absence of another bottleneck), a "transition" period ensues with the high-clearance flows noted above and speeds of around 40 mph. Thus, it is clear that in the upstream location case, which was originally thought to be relatively benign, there is an interaction between incidents and recurring bottlenecks that must be accounted for within QSIM.

Delay statistics for the two experiments are reported in Tables 5 and 6. Data cannot be compared between the tables because the network and simulation time were expanded for the congestion sub-experiment; only within-table comparisons should be made. Table 5 clearly shows that delay increases with V/C ratio and incident duration, as should be expected. Delay was also found to lower when the incident occurred upstream from the bottleneck (Locations A, B, and C). There also appears to be an interaction between incident location and ramp percentage: if the incident occurs upstream, then a higher ramp percentage results in less delay. (More vehicles traverse the ramp versus the mainline in this case.) However, if the incident occurs within the merge area, then delay increases with increasing ramp percentage. (Ramp vehicles are now exposed to incident conditions.)

Table 6 shows the results from the congestion sub-experiment. Two caveats must be stated in conjunction with these data. First, incident runs with V/C ratios of 1.2 could not be completed because the vehicle limitation in FRESIM was reached. Second, for the most severe cases displayed (V/C = 1.1 and incident duration = 60 minutes), the queues still haven't dissipated after the simulation ends. The trends in the congestion case are complicated than for the uncongested case because of the queues that have already built prior to the incident occurring. Looking at the total delay first, it is clear that the expected influence of truck percentage on FRESIM results is present: total delay is much higher when 10 percent trucks are in the traffic stream, even when the total number of vehicles is adjusted to maintain a constant V/C level. Ramp percentage has a very strong effect on delay, especially for the case where no incidents are present. Also, the lane in which the incident occurs does not have a significant influence on delay. Looking at incident-related delay, the results are less tidy. It appears that as recurring congestion worsens, the influence of incidents that occur upstream from the on-ramp becomes small in comparison to on-ramp-related delay. Two possible explanations are offered for this occurrence. First, given that flow has already broken down, an upstream incident has little effect on the section's flow characteristics; the two bottlenecks are not additive. Second, an upstream incident will temporarily improve flow at the on-ramp due to the metering effect; this is particularly important in the high-ramp percentage cases.

4. Traffic Parameters for QSIM

All of the evidence from the FRESIM results indicates that bottlenecks have different levels of severity in terms of their impact on traffic flow. "Bottleneck severity" can be defined as a combination of demand V/C ratio, ramp percentage, truck percentage, and incident location. The evidence is further corroborated by checking the two key parameters for use within QSIM: bottleneck flow rates and queue speeds (Tables 7 and 8). Table 7 clearly shows that when there is little recurring congestion, as bottleneck severity increases, queue speeds and flow rates decrease. For a given V/C and incident duration, queue speeds for upstream incidents increase as ramp percentage increases. This is because a greater proportion of vehicles avoid the incident because they enter via the on-ramp. Conversely, queue speeds for merge-area incidents decrease with increasing ramp percentage because all vehicles (mainline and ramp) are now exposed to the incident. From these results, it can be concluded that it is the *interaction* of ramp percentage and incident location (rather than these factors individually) that defines bottleneck severity, along with V/C and incident duration.

For traffic flow already under the influence of recurring congestion, the decrease in queue speeds is less dramatic; speeds are already low because of the recurring bottleneck. However, queue speeds for merge-area incidents are roughly half as for upstream incidents. The influence of truck percentage on queue speeds for upstream incidents is as expected given the previous results, namely, speeds decrease slightly with increasing truck percentage. However, queue speeds as a function of truck percentage for merge-area incidents is at first perplexing: where ramp proportion is 30 percent, queue speeds are actually higher for the 10 percent truck case, even though bottleneck flow rates are much lower. However, further review revealed that densities for the 0 percent truck case were much higher: 170 vplm versus 125 vplm for the 10 percent truck case. We previously noted the disparity between FRESIM and the *Highway Capacity Manual* in the effect of trucks on trucks on traffic flow. However, it can not be stated with certainty which is more reflective of reality. Intuitively, it makes sense that as congestion builds, the performance characteristics of trucks (low acceleration, greater breaking distances) have a greater influence on surrounding traffic than under free flow conditions. However, without field verification, it is also possible that the results obtained here are an artifact of FRESIM's internal truck performance relationships. Given the discrepancies between FRESIM and the *Highway Capacity Manual* for the influence of trucks, it is probably worthwhile to ignore the truck percentage and factor and focus on the all passenger car runs for the purpose of providing traffic parameters to QSIM.

5. Modifications to QSIM

The data in Tables 7 and 8 serve as the basis for modifying QSIM to account for "bottleneck severity." The following recommendations for changes to QSIM are made.

- Ramp percentage has a strong effect on traffic flow through the bottleneck. Therefore, when QSIM is used to derive the final relationships, ramp percentage should be varied as one of the experimental factors. This is in addition to the factors of AADT/C, average incident rate, and average incident duration previously defined.

- Incident location – either upstream of or within the on-ramp merge area – should be included within QSIM. Typical merge areas on freeways are 500 to 1,000 feet in length. Therefore, all other things being equal, the probability of an incident occurring within the merge area is the length of the merge area divided by the total length of the study segment. However, all things are not equal. Crashes, the most severe form of incident, tend to concentrate in merge areas where vehicle conflicts and total volumes are higher than upstream segments. The higher volume of merge areas also would also increase the likelihood of noncrash incidents. Therefore, we recommend that incident location be determined stochastically within QSIM after the type of incident is determined. The sequence of events in QSIM for determining incident characteristics (all done stochastically) is then:

  1. determine if an incident occurs during the time period
  2. if so, determine the type of incident
  3. determine the incident location (merge area or not)
  4. determine if lanes or shoulders are blocked
  5. if lanes are blocked, determine how many
  6. determine incident duration

  If the incident is a crash, the probability of it occurring within the merge area can be determined from analyzing GES or state accident databases, both of which we have on hand. (We will consider the percent of crashes which occur at interchanges versus noninterchange locations in urban areas.) If the incident is a noncrash, then the probability of it occurring within the merge area is:

$$\frac{750 * Vt}{L * Vt * R}$$

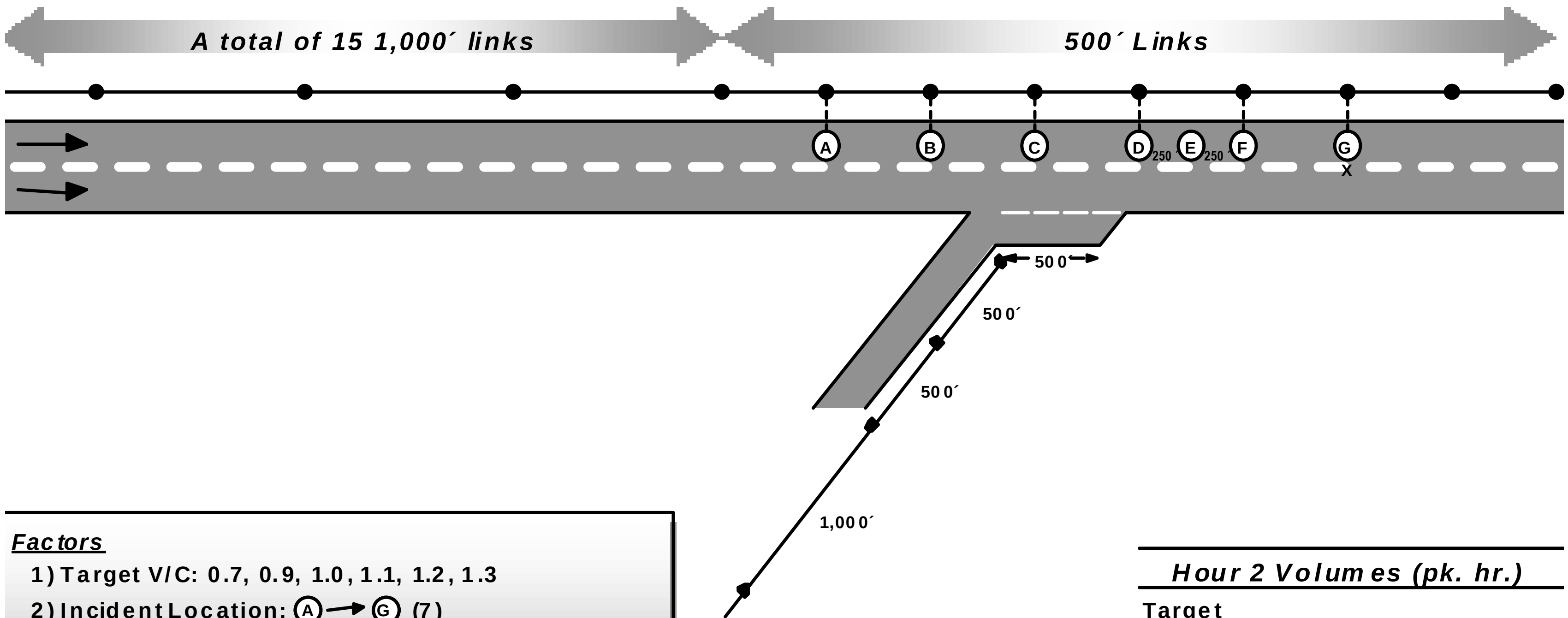
Where:	750	=	average length of an on-ramp merge area
	Vt	=	total volume of the segment
	L	=	length of the test segment
	R	=	ramp percentage.

- The concept of "bottleneck severity" should be used in conjunction with incidents, with the data in Tables 7 and 8 used to assign queue speeds and flow rates. The following procedure is recommended.

  For incidents upstream of the merge area: The percent of total volume experiencing the effect of the incident is 1.0 minus the ramp percentage; this volume should be subjected to incident traffic parameters. The volume now relieved of the recurring congestion bottleneck is the ramp percentage; this volume should move at the free flow speed.

  For incidents in the ramp area: The total volume should be subjected to the incident traffic parameters.

  For the transition period: This is the period after the incident has ended and the queue has not yet dissipated. If a queue developed as a result of the incident, then when it the incident ends, a wave of vehicles is delivered to the on-ramp. This wave is large enough to exceed the capacity of the on-ramp, even under very low on-ramp volumes. Therefore, once the incident has ended and assuming that a queue has been built, the recurring bottleneck capacity (currently 2,000 pcphpl) and queue speed (currently 15.5 mph) should be used until the queue dissipates.



Factors

1) Target V/C: 0.7, 0.9, 1.0, 1.1, 1.2, 1.3
2) Incident Location: (A) → (G) (7)
3) Incident Duration: 0, 15, 30, 60 minutes
4) Ramp Volume Percentage (10%, 20%, 30%)

- Simulate 4 hours
- Incident begins at beginning of hour 2
- Incident blocks right most lane and is 70 feet long
- Output @ 15 minute intervals
- 0% trucks
- FFS = 60 mph
- Rubberneck = 10%

Hour 1 volumes = 94% (Hour 2)
Hour 3 volumes = 98% (Hour 2)
Hour 4 volumes = 84% (Hour 2)

Hour 2 Volumes (pk. hr.)

Target V/C*	Mainline	Ramp**	Total
0.7	2,520	630	3,150
0.9	3,240	810	4,050
1.0	3,600	900	4,500
1.1	3,960	990	4,950
1.2	4,320	1,080	5,400
1.3	4,450	1,350	5,800

* Assume C = 2,250
** @ 20% of mainline

Figure 1. FRESIM Incident Experiment

Table 1. Main Experimental Design

		RAMP PERCENTAGE																				
		10							20							30						
		LOCATION							LOCATION							LOCATION						
		A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
		SIMUL	SIMUL	SIMUL	SIMUL	SIMUL	SIMUL	SIMUL	SIMUL	SIMUL	SIMUL	SIMUL	SIMUL	SIMUL	SIMUL	SIMUL	SIMUL	SIMUL	SIMUL	SIMUL	SIMUL	SIMUL
		COMPL?	COMPL?	COMPL?	COMPL?	COMPL?	COMPL?	COMPL?	COMPL?	COMPL?	COMPL?	COMPL?	COMPL?	COMPL?	COMPL?	COMPL?	COMPL?	COMPL?	COMPL?	COMPL?	COMPL?	COMPL?
V/C	DURATION																					
0.7	0	XXX	.	.	.	.	.	.	XXX	.	.	.	.	.	.	XXX	.	.	.	.	.	.
	15	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
	30	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
	60	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
0.9	0	XXX	.	.	.	.	.	.	XXX	.	.	.	.	.	.	XXX	.	.	.	.	.	.
	15	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
	30	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
	60	XXX	XXX	XXX	(part)	(part)	(part)	(part)	XXX	XXX	XXX	(part)	(part)	(part)	(part)	XXX	XXX	XXX	(part)	(part)	XXX	XXX
1	0	XXX	.	.	.	.	.	.	XXX	.	.	.	.	.	.	XXX	.	.	.	.	.	.
	15	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
	30	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
	60	(part)	(part)	(part)	(part)	(part)	(part)	(part)	XXX	XXX	XXX	(part)	(part)	(part)	(part)	XXX	XXX	XXX	(part)	(part)	(part)	(part)
1.1	0	XXX	.	.	.	.	.	.	XXX	.	.	.	.	.	.	XXX	.	.	.	.	.	.
	15	XXX	XXX	XXX	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	XXX	XXX	XXX	(part)	(part)	(part)	(part)
	30	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)
	60	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)
1.2	0	(part)	.	.	.	.	.	.	(part)	.	.	.	.	.	.	(part)	.	.	.	.	.	.
	15	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)
	30	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)
	60	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)
1.3	0	(part)	.	.	.	.	.	.	(part)	.	.	.	.	.	.	(part)	.	.	.	.	.	.
	15	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)
	30	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)
	60	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)	(part)

Table 2. Example of FRESIM Output – Speed

V/C: 0.9,
RAMP PERCENT: 20,
DURATION: 30,
AND LOCATION: B

NODE1

HOUR	MIN	10 SPEED (mph)	20 SPEED (mph)	30 SPEED (mph)	40 SPEED (mph)	50 SPEED (mph)	60 SPEED (mph)	70 SPEED (mph)	80 SPEED (mph)	90 SPEED (mph)	100 SPEED (mph)	110 SPEED (mph)	120 SPEED (mph)	130 SPEED (mph)	140 SPEED (mph)	150 SPEED (mph)	160 SPEED (mph)	170 SPEED (mph)	180 SPEED (mph)	190 SPEED (mph)	200 SPEED (mph)	210 SPEED (mph)	220 SPEED (mph)	230 SPEED (mph)
12	15	57.0	55.9	55.3	54.6	54.3	54.6	54.4	54.9	54.7	54.7	54.4	54.9	54.6	54.2	54.6	53.4	51.6	51.2	45.6	46.5	52.6	53.9	55.1
	30	57.1	56.0	55.6	55.5	55.4	55.6	55.3	55.2	54.9	55.0	55.6	54.7	54.8	54.9	54.5	52.5	51.5	51.7	44.7	46.8	51.6	54.0	55.8
	45	56.8	55.6	55.3	55.3	55.1	54.9	54.7	54.9	55.1	54.8	54.9	55.1	54.8	54.9	54.6	53.2	51.6	51.1	42.8	45.9	51.4	52.7	54.8
13	0	57.1	55.5	54.9	54.3	54.6	54.5	54.5	54.5	54.3	54.0	54.2	54.3	54.2	54.2	54.1	52.1	50.5	50.6	44.8	45.9	52.2	53.5	55.2
	15	56.2	55.0	54.9	54.7	54.8	54.4	54.6	54.6	45.9	**33.8**	**25.5**	**19.7**	**15.4**	**12.0**	**9.7**	**9.1**	**8.3x**	40.6	54.3	56.1	57.2	57.3	57.3
	30	56.4	55.1	54.8	**31.2**	**15.0**	**12.6**	**10.5**	**8.9**	**7.8**	**7.7**	**7.7**	**7.7**	**7.7**	**7.6**	**7.7**	**7.6**	**8.3x**	40.0	54.6	56.3	57.2	57.2	56.9
	45	56.4	49.9	19.8	12.0	13.1	13.6	14.0	14.5	15.1	15.7	16.3	16.9	17.6	18.4	19.0	19.8	20.5	21.8	23.9	40.0	50.4	52.3	54.2
14	0	56.8	51.3	21.9	19.8	19.8	19.9	20.0	20.0	20.0	20.0	20.1	20.0	20.0	20.0	20.1	20.0	20.0	20.2	22.2	39.3	50.0	51.8	53.7
	15	56.3	54.9	38.5	20.1	19.9	19.9	19.9	19.9	20.0	20.0	20.0	20.0	20.0	19.9	19.9	19.9	20.0	20.0	22.1	38.9	49.1	51.4	54.2
	30	56.4	55.4	54.9	31.4	20.2	20.2	20.2	20.1	20.0	19.9	19.9	19.9	19.9	19.9	19.8	19.8	19.8	19.7	21.9	38.6	50.4	51.5	54.0
	45	56.7	55.6	54.9	54.3	41.0	29.3	23.7	21.1	20.0	19.8	19.9	19.9	19.9	19.9	19.8	19.9	20.1	20.1	22.0	38.8	50.1	51.5	53.4
15	0	56.4	55.3	54.7	54.2	54.2	54.4	54.5	54.0	45.4	32.0	25.4	21.2	19.6	19.4	19.5	19.6	19.6	19.7	21.9	38.2	49.2	52.5	55.1
	15	57.2	55.9	55.3	55.1	54.8	55.0	54.8	54.5	54.5	54.5	54.6	53.0	42.5	33.5	29.7	28.2	27.0	26.2	28.1	42.8	52.3	53.4	55.2
	30	57.0	55.6	55.0	54.7	55.0	54.6	54.8	54.6	54.5	54.5	54.3	54.5	54.4	54.3	53.8	51.2	49.2	50.2	47.7	48.8	53.6	54.4	55.5
	45	57.5	56.2	55.6	55.1	55.1	55.3	55.3	54.9	55.0	55.1	55.1	55.1	55.3	55.2	55.2	54.5	52.8	51.8	50.1	49.9	54.0	54.3	55.0
16	0	57.1	56.0	55.6	55.4	55.5	55.3	55.4	55.4	54.8	54.8	54.7	54.9	54.9	55.0	54.9	53.9	53.0	53.4	50.7	50.3	53.8	55.1	55.9

Table 3. Example of FRESIM Output – Volume

V/C: 0.9,
RAMP PERCENT: 20,
DURATION: 30,
AND LOCATION: B

		NODE1																						
		10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230
		HRLY	HRLY	HRLY	HRLY	HRLY	HRLY	HRLY	HRLY	HRLY	HRLY	HRLY	HRLY	HRLY	HRLY	HRLY	HRLY	HRLY	HRLY	HRLY	HRLY	HRLY	HRLY	HRLY
		VOL	VOL	VOL	VOL	VOL	VOL	VOL	VOL	VOL	VOL	VOL	VOL	VOL	VOL	VOL	VOL	VOL	VOL	VOL	VOL	VOL	VOL	VOL
HOUR	MIN																							
	30	3028	3026	3018	2998	3016	3046	3070	3074	3084	3102	3088	3074	3060	3030	3016	3014	3006	2994	3742	3750	3760	3770	3782
	45	3044	3034	3034	3060	3058	3042	3020	3012	3016	3010	3028	3042	3038	3028	3024	3042	3068	3084	3832	3812	3790	3760	3736
13	0	3042	3056	3042	3048	3068	3064	3062	3048	3040	3012	2982	2988	3022	3054	3052	3024	2992	2984	3786	3822	3840	3852	3856
	15	3226	3202	3202	3194	3178	3168	3162	3166	3108	2998	2848	2666	2492	2338	2200	2106	2056	2030	2820	2818	2812	2812	2824
	30	3242	3238	3238	2932	2538	2396	2260	2110	2012	1990	1994	1994	1988	1984	1984	1982	1976	1978	2790	2786	2788	2788	2786
	45	3240	3170	2880	2724	2814	2876	2940	3000	3060	3128	3196	3262	3334	3408	3482	3540	3570	3552	4304	4264	4246	4230	4214
14	0	3228	3310	3470	3536	3530	3530	3532	3536	3540	3540	3538	3530	3516	3508	3508	3506	3504	3510	4324	4322	4322	4326	4326
	15	3170	3168	3310	3492	3534	3542	3542	3542	3542	3540	3542	3550	3558	3558	3548	3542	3544	3540	4332	4332	4330	4328	4336
	30	3168	3162	3156	3366	3578	3580	3580	3576	3570	3562	3556	3552	3550	3550	3546	3544	3542	3542	4334	4326	4324	4330	4330
	45	3168	3176	3184	3180	3204	3270	3374	3482	3536	3554	3558	3558	3556	3548	3542	3538	3540	3538	4322	4330	4338	4334	4330
15	0	3174	3168	3158	3148	3148	3180	3178	3170	3220	3304	3410	3492	3514	3514	3520	3526	3526	3528	4324	4320	4324	4324	4314
	15	2720	2764	2812	2866	2918	2908	2898	2896	2884	2868	2826	2834	2944	3070	3180	3260	3308	3362	4106	4142	4144	4152	4164
	30	2722	2716	2698	2680	2678	2696	2708	2708	2708	2732	2772	2794	2768	2736	2726	2722	2708	2674	3326	3318	3308	3300	3300
	45	2716	2722	2730	2738	2726	2718	2722	2704	2698	2678	2654	2658	2672	2684	2690	2698	2720	2760	3462	3478	3492	3506	3522
16	0	2720	2716	2696	2700	2730	2734	2716	2728	2742	2760	2770	2718	2678	2692	2710	2694	2664	2636	3292	3282	3284	3294	3304

Note: 15-minute volumes have been converted to hourly volumes for comparison

Table 4. Example of FRESIM Output – Density

V/C: 0.9,
RAMP PERCENT: 20,
DURATION: 30,
AND LOCATION: B

		NODE1																						
		10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230
		DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)	DENSI-TY (vplm)
HOUR	MIN																							
12	15	27	27	28	28	28	28	28	27	27	27	28	28	28	28	28	28	29	29	41	40	36	35	35
	30	27	27	27	27	27	27	28	28	28	28	28	28	28	28	28	29	29	29	42	40	36	35	34
	45	27	27	27	28	28	28	28	27	27	27	28	28	28	28	28	29	30	30	45	41	37	36	34
13	0	27	28	28	28	28	28	28	28	28	28	27	28	28	28	28	29	30	29	42	42	37	36	35
	15	29	29	29	29	29	29	29	29	34	44	56	68	81	98	114	116	124	25	26	25	25	25	25
	30	29	29	30	47	84	95	108	119	130	130	130	130	130	130	129	130	118	25	26	25	24	24	24
	45	29	32	73	113	107	106	105	104	102	100	98	97	95	93	91	90	87	81	90	53	42	40	39
14	0	28	32	79	89	89	89	88	88	88	88	88	88	88	88	87	88	88	87	97	55	43	42	40
	15	28	29	43	87	89	89	89	89	89	89	89	89	89	89	89	89	89	88	98	56	44	42	40
	30	28	29	29	54	88	89	89	89	89	89	89	89	89	89	89	89	89	90	99	56	43	42	40
	45	28	29	29	29	39	56	71	82	88	90	90	89	89	89	89	89	88	88	98	56	43	42	41
15	0	28	29	29	29	29	29	29	29	35	52	67	82	90	90	90	90	90	90	99	57	44	41	39
	15	24	25	25	26	27	26	26	27	26	26	26	27	35	46	54	58	61	64	73	48	40	39	38
	30	24	24	25	25	24	25	25	25	25	25	26	26	25	25	25	27	28	27	35	34	31	30	30
	45	24	24	25	25	25	25	25	25	25	24	24	24	24	24	24	25	26	27	35	35	32	32	32
16	0	24	24	24	24	25	25	25	25	25	25	25	25	24	24	25	25	25	25	32	33	31	30	30

Table 5. Delay Estimates, Main Experiment

(DELAY IS IN HOURS PER 1000 VEHICLE-MILES)

		RAMP PERCENT																				
		10							20							30						
		LOCATION							LOCATION							LOCATION						
V/C	DURATION	A INCID DELAY	B INCID DELAY	C INCID DELAY	D INCID DELAY	E INCID DELAY	F INCID DELAY	G INCID DELAY	A INCID DELAY	B INCID DELAY	C INCID DELAY	D INCID DELAY	E INCID DELAY	F INCID DELAY	G INCID DELAY	A INCID DELAY	B INCID DELAY	C INCID DELAY	D INCID DELAY	E INCID DELAY	F INCID DELAY	G INCID DELAY
0.7	15	0.553	0.564	0.570	1.010	1.046	0.983	0.705	0.406	0.372	0.339	1.553	1.278	1.288	1.116	0.120	0.099	0.093	1.479	1.536	1.550	1.252
	30	2.158	2.141	2.215	4.180	4.161	3.907	3.495	1.529	1.445	1.440	6.265	5.073	5.117	4.321	0.552	0.464	0.381	5.842	5.881	5.861	4.976
0.9	15	2.190	2.487	2.208	3.750	3.673	3.678	3.373	2.474	2.545	2.569	7.345	6.654	7.200	6.316	1.422	1.580	1.637	9.057	8.750	8.061	7.305
	30	8.350	8.675	8.190	12.228	11.897	11.387	11.516	8.810	8.555	9.440	20.901	20.180	20.285	19.264	5.401	5.414	5.523	26.701	25.603	24.855	23.161
1	15	9.827	9.811	9.882	11.481	11.591	11.808	11.178	9.920	9.365	10.041	17.306	18.044	17.310	16.641	8.052	8.940	7.707	22.438	22.428	22.390	21.878
	30	14.621	14.473	14.542	17.349	17.238	17.087	16.786	17.496	17.753	17.642	23.304	23.197	22.982	22.421	16.321	14.805	15.627	31.611	31.543	31.631	30.972

		RAMP PERCENT																				
		10							20							30						
		LOCATION							LOCATION							LOCATION						
V/C	DURATION	A TOTAL DELAY	B TOTAL DELAY	C TOTAL DELAY	D TOTAL DELAY	E TOTAL DELAY	F TOTAL DELAY	G TOTAL DELAY	A TOTAL DELAY	B TOTAL DELAY	C TOTAL DELAY	D TOTAL DELAY	E TOTAL DELAY	F TOTAL DELAY	G TOTAL DELAY	A TOTAL DELAY	B TOTAL DELAY	C TOTAL DELAY	D TOTAL DELAY	E TOTAL DELAY	F TOTAL DELAY	G TOTAL DELAY
0.7	15	1.830	1.842	1.848	2.288	2.323	2.261	1.983	1.585	1.551	1.519	2.732	2.458	2.467	2.296	1.090	1.069	1.063	2.449	2.506	2.520	2.222
	30	3.436	3.418	3.492	5.458	5.439	5.185	4.773	2.709	2.625	2.619	7.445	6.253	6.297	5.501	1.522	1.434	1.351	6.812	6.851	6.831	5.946
0.9	15	4.008	4.305	4.027	5.568	5.491	5.497	5.191	4.192	4.263	4.287	9.063	8.372	8.918	8.034	3.008	3.166	3.222	10.642	10.335	9.646	8.891
	30	10.169	10.493	10.009	14.046	13.716	13.205	13.335	10.528	10.273	11.158	22.619	21.898	22.003	20.982	6.986	6.999	7.108	28.286	27.189	26.441	24.747
1	15	11.954	11.938	12.009	13.607	13.718	13.935	13.304	16.691	16.135	16.812	24.077	24.814	24.080	23.411	16.839	17.726	16.493	31.225	31.215	31.176	30.665
	30	16.748	16.600	16.668	19.476	19.365	19.214	18.913	24.266	24.524	24.412	30.074	29.967	29.752	29.191	25.107	23.592	24.413	40.398	40.330	40.418	39.758

Table 6 Delay Estimates, Congestion Sub-Experiment

(DELAY IS IN HOURS PER 1000 VEHICLE-MILES)

V/C	LANE_NUM	TRK_PCT	DURATION	RAMP PERCENT 10, LOCATION A, INCID DELAY	10 C INCID DELAY	10 E INCID DELAY	10 G INCID DELAY	RAMP PERCENT 20, LOCATION A, INCID DELAY	20 C INCID DELAY	20 E INCID DELAY	20 G INCID DELAY	RAMP PERCENT 30, LOCATION A, INCID DELAY	30 C INCID DELAY	30 E INCID DELAY	30 G INCID DELAY
1	0	0	0	0.000	.	.	.	.	.	.	.	.	.	.	.
		10	0	.	.	.	.	0.000	.	.	.	0.000	.	.	.
	1	0	30	3.545	3.613	5.441	4.857	3.564	3.652	7.444	6.865	3.539	3.513	9.358	8.936
			60	9.219	9.082	13.012	12.231	7.967	8.605	16.887	15.310	6.637	6.511	19.598	18.661
		10	15	0.413	0.343	1.693	1.671	1.010	1.010	2.324	1.666	1.319	1.499	5.170	5.446
			30	3.640	3.704	5.859	5.720	2.826	2.587	7.737	7.182	2.511	3.044	10.347	9.596
			60	10.391	10.346	13.797	13.329	8.258	7.627	16.967	16.032	5.882	4.926	17.057	17.038
1.1	0	0	0	0.000	.	.	.	0.000	.	.	.	0.000	.	.	.
		10	0	0.000	.	.	.	0.000	.	.	.	0.000	.	.	.
	1	0	15	3.170	3.159	4.189	4.126	3.252	3.205	5.658	5.633	2.125	2.539	6.043	5.699
			30	6.495	6.759	8.724	8.250	5.957	6.076	10.882	10.524	3.610	3.630	12.072	11.079
			60	11.638	11.732	.	.	11.094	11.172	19.920	18.908	6.963	7.000	23.194	22.276
		10	15	5.778	4.220	.	5.475	3.215	2.146	.	6.836	0.010	0.657	.	3.818
			30	6.935	6.942	.	7.818	5.997	6.372	.	10.973	0.444	0.532	.	.
			60	.	.	.	.	.	10.995	.	.	.	3.173	.	.
	2	0	15	3.147	3.366	4.246	4.475	3.072	3.602	6.411	5.910	2.011	2.947	6.397	5.953
			30	6.621	7.083	8.200	8.428	6.175	7.148	11.838	10.968	3.721	5.243	11.106	9.797
			60	11.578	11.902	.	.	11.484	13.079	.	19.451	7.032	9.724	.	.

Table 6. (Cont.)

V/C	LANE_NUM	TRK_PCT	DURATION	RAMP PERCENT 10, LOCATION A, TOTAL DELAY	10, C, TOTAL DELAY	10, E, TOTAL DELAY	10, G, TOTAL DELAY	20, LOCATION A, TOTAL DELAY	20, C, TOTAL DELAY	20, E, TOTAL DELAY	20, G, TOTAL DELAY	30, LOCATION A, TOTAL DELAY	30, C, TOTAL DELAY	30, E, TOTAL DELAY	30, G, TOTAL DELAY
1	0	0	0	2.047	.	.	.	.	.	.	.	.	.	.	.
		10	0	.	.	.	.	11.533	.	.	.	16.150	.	.	.
	1	0	30	5.592	5.660	7.489	6.904	6.098	6.185	9.977	9.398	6.473	6.447	12.291	11.869
			60	11.267	11.129	15.059	14.278	10.500	11.138	19.420	17.843	9.570	9.444	22.532	21.594
		10	15	7.047	6.976	8.327	8.304	11.533	11.450	13.857	13.199	17.469	17.648	21.320	21.595
			30	10.274	10.337	12.492	12.354	14.360	14.120	19.270	18.715	18.661	19.194	26.497	25.746
			60	17.024	16.979	20.431	19.962	19.791	19.160	28.500	27.565	22.032	21.076	33.207	33.188
1.1	0	0	0	5.367	.	.	.	8.582	.	.	.	12.472	.	.	.
		10	0	12.449	.	.	.	21.404	.	.	.	34.417	.	.	.
	1	0	15	8.537	8.525	9.556	9.493	11.834	11.787	14.240	14.214	14.597	15.012	18.515	18.172
			30	11.862	12.126	14.091	13.617	14.538	14.658	19.463	19.106	16.082	16.103	24.544	23.552
			60	17.005	17.099	.	.	19.676	19.754	28.501	27.489	19.435	19.472	35.667	34.749
		10	15	18.227	16.669	.	17.925	24.620	23.551	.	28.240	34.057	35.075	.	38.236
			30	19.385	19.391	.	20.267	27.401	27.776	.	32.378	34.862	34.950	.	.
			60	.	.	.	.	.	32.400	.	.	.	37.591	.	.
	2	0	15	8.513	8.733	9.612	9.842	11.653	12.184	14.993	14.492	14.484	15.420	18.869	18.426
			30	11.988	12.450	13.566	13.795	14.756	15.730	20.420	19.550	16.193	17.715	23.578	22.269
			60	16.945	17.268	.	.	20.066	21.661	.	28.032	19.504	22.196	.	.

Note: The network and time span over which delay is calculated for the congestion sub-experiment are longer than for the main experiment. Therefore, statistics reported between Tables 5 and 6 are not comparable.

Table 7. Incident Bottleneck Flow Rates and Queue Speeds, Main Experiment

V_C	DURATION	RAMP_PCT 10, LOCATION UPSTREAM, SPEED (mph)	RAMP_PCT 10, LOCATION DOWNSTREAM, SPEED (mph)	RAMP_PCT 20, LOCATION UPSTREAM, SPEED (mph)	RAMP_PCT 20, LOCATION DOWNSTREAM, SPEED (mph)	RAMP_PCT 30, LOCATION UPSTREAM, SPEED (mph)	RAMP_PCT 30, LOCATION DOWNSTREAM, SPEED (mph)
0.7	15	17.2	11.6	20.7	9.4	36.6	8.9
	30	13.1	8.1	14.3	6.3	27.2	5.5
	60	11.6	6.8	12.3	5.2	17.5	4.4
0.9	15	13.7	9.5	14.4	6.9	17.3	5.8
	30	11.9	7.5	12.3	5.2	13.5	3.9
	60	11.0	6.6	11.4	4.5	12.1	3.2
1	15	13.0	7.9	14.2	6.1	15.3	4.7

V_C	DURATION	RAMP_PCT 10, LOCATION UPSTREAM, VEHs (vph)	RAMP_PCT 10, LOCATION DOWNSTREAM, VEHs (vph)	RAMP_PCT 20, LOCATION UPSTREAM, VEHs (vph)	RAMP_PCT 20, LOCATION DOWNSTREAM, VEHs (vph)	RAMP_PCT 30, LOCATION UPSTREAM, VEHs (vph)	RAMP_PCT 30, LOCATION DOWNSTREAM, VEHs (vph)
0.7	15	2015	1892	1924	1872	2023	1872
	30	2009	1862	1960	1860	2014	1854
	60	2014	1827	1989	1859	2004	1856
0.9	15	1999	1956	2033	1856	1967	1800
	30	1995	1924	2006	1827	1980	1814
	60	1997	1912	1998	1818	1992	1814
1	15	2005	1896	2027	1884	1988	1860

Table 8. Incident Bottleneck Flow Rates and Queue Speeds, Congestion Sub-Experiment

		RAMP_PCT											
		10				20				30			
		TRK_PCT				TRK_PCT				TRK_PCT			
		0		10		0		10		0		10	
		LOCATION		LOCATION		LOCATION		LOCATION		LOCATION		LOCATION	
		UPSTREAM	DOWNSTREAM	UPSTREAM	DOWNSTREAM	UPSTREAM	DOWNSTREAM	UPSTREAM	DOWNSTREAM	UPSTREAM	DOWNSTREAM	UPSTREAM	DOWNSTREAM
		SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED
		(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)
V_C	DURATION												
1	15	.	.	10.4	6.5	.	.	9.9	5.0	.	.	9.8	5.9
	30	11.6	6.4	9.7	5.6	11.5	4.5	9.7	4.3	12.2	3.6	9.9	5.2
	60	10.9	5.7	9.4	5.4	11.0	4.0	9.5	4.0	11.4	2.9	9.8	5.5
1.1	15	11.1	6.6	10.4	.	11.4	4.8	9.9	.	10.9	3.3	9.4	.
	30	10.8	5.8	9.8	.	11.1	4.1	9.6	.	11.0	2.7	9.7	.
	60	10.6	5.3	8.5	5.3	10.9	3.7	8.6	4.1	11.0	2.5	9.1	5.6

Table 8 (Cont.)

		RAMP_PCT											
		10				20				30			
		TRK_PCT				TRK_PCT				TRK_PCT			
		0		10		0		10		0		10	
		LOCATION		LOCATION		LOCATION		LOCATION		LOCATION		LOCATION	
		UPSTREAM	DOWNSTREAM	UPSTREAM	DOWNSTREAM	UPSTREAM	DOWNSTREAM	UPSTREAM	DOWNSTREAM	UPSTREAM	DOWNSTREAM	UPSTREAM	DOWNSTREAM
		VEHs	VEHs	VEHs	VEHs	VEHs	VEHs	VEHs	VEHs	VEHs	VEHs	VEHs	VEHs
		(pcph)	(pcph)	(pcph)	(pcph)	(pcph)	(pcph)	(pcph)	(pcph)	(pcph)	(pcph)	(pcph)	(pcph)
V_C	DURATION												
1	15	.	.	1876	1825	.	.	1820	1807	.	.	1807	1781
	30	1998	1849	1804	1779	1985	1858	1825	1804	1981	1875	1823	1816
	60	1985	1835	1782	1788	1975	1837	1784	1778	1996	1870	1824	1802
1.1	15	2007	1888	1863	.	2037	1910	1797	.	1985	1898	1761	.
	30	2005	1865	1793	.	2010	1888	1799	.	2001	1869	1763	.
	60	2008	1855	1755	1779	1999	1860	1790	1825	1997	1872	1771	1742

Appendix C

NETSIM Experiment Results

SKETCH METHODS FOR ESTIMATING INCIDENT-RELATED IMPACTS

TECHNICAL MEMORANDUM

NETSIM Experiment Results

1. Introduction

The purpose of this Memorandum is to document the results of the NETSIM experiments. As with the FRESIM experiments, these experiments were conducted for three reasons:

1. To determine the influence of incident location relative to a recurring bottleneck. In the case of a freeway (as shown in the previous FRESIM results), the recurring bottleneck was assumed to be an on-ramp. In the case of arterials studied here with NETSIM, the recurring bottleneck is a signalized intersection. It was postulated that if incidents occurred at midblock locations some distance from the signalized intersection, the effect would be less than if the intersection itself was blocked by the incident. Also, an incident upstream from the merge area would tend to meter flow into the recurring bottleneck (intersection). On the other hand, if an incident occurred *within or close to* the intersection, it was postulated that the loss of capacity at the "processing point" would lead to a more severe bottleneck.

2. To develop traffic parameters for use within the QSIM model. In addition to the information on incident location from (1) above, basic data on incident flow rates (i.e., capacity reduction due to incidents) and the speed of vehicles in queues caused by incidents needed to be developed.

3. To develop estimates of delay under recurring and nonrecurring conditions. The NETSIM results can be used in addition to field data to calibrate QSIM. Also, simplified delay equations can be developed from NETSIM results to estimate the effect of isolated incidents.

2. Experimental Design

The design of signalized arterial experiment is less detailed than the one conducted for freeways. Three factors were studied: 1) Midblock traffic volume; 2) Incident location; and 3) Incident duration. Four consecutive hours representing the afternoon-peak period were simulated with Hour 2 being the highest hour in the peak period. The incident began at the start of Hour 2 and blocked a single lane of the two lanes in one direction. The volumes for each hour were determined from the temporal distributions developed for HPMS. The experiment and the test network are shown in Figure 1. Mid-block volume levels shown in Figure 1 proved difficult to achieve, therefore, volumes of 750, 1,000, 1,050, 1,100, and 1,150 pcphpl were used.

3. Simulation Results

Total delay estimates for the experiment are shown in Table 1. (These are the absolute number of hours per 1,000 vehicle-miles; they are not measured relative to the free flow speed or "ideal arterial speed.") Note that for the base case (incident duration = 0), location is irrelevant. Incident-related delay only (total delay minus the delay for no incidents) is given in Table 2. Several observations can be made about the data in Table 2:

- Random variation in the simulation results, which we have found **not** to be a problem for FRESIM, seems to be present in the data shown in Table 2. In particular, the results for Location I appear counter to the general trends exhibited. For completeness, we plan to re-run the experiment with a different random number seed and will average the delay from the two runs. *However, the effect of random variation in the results presented here is not large enough to prevent the extraction of traffic parameters for QSIM.*

- The effect of incident location is sharply defined: at Locations A and B (at the intersection and 50 feet upstream, respectively) incident delay is the highest. For a given test volume level, delay decreases at first and then increases as the incident moves further upstream. Further review of the data using time/space diagrams (the Appendix) shows the reason for the upturn: the queues spillback to consume the first intersection in the network.

- Incident-related delay is nonlinear with respect to volume and to a lesser degree with incident duration. For example, consider an incident duration of 30 minutes in Table 2. For Locations D through J, incident delay increases from practically zero to around 30 hours per 1,000 vehicle-miles traveled. Delay also doubles (or triples) as volume increases from 1,000 vphpl to 1,150 vphpl. These results have strong implications for incident management programs – small reductions in demand volumes (through traveler information-induced diversion) and incident durations (through effective incident detection/response) can lead to large decreases in delay on arterials.

4. Traffic Parameters for QSIM

As with the FRESIM results for freeways, the concept of "bottleneck severity" appears to hold for signalized arterials. Table 3 shows the flow rates (vph) on the link immediately downstream of the one-lane blockage incident and Table 4 shows the speeds in the queue immediately upstream of the incident. The same general trend that was found for incident delay emerges: 1) capacities are most restricted when the incident occurs at or near the signalized intersection; and 2) capacities increase as the incident moves upstream from the intersection, up to the point where the queue spills back to the upstream intersection and restricts flow on the segment. Based on these data, the following bottleneck capacities and queue speeds should be used for QSIM.

Distance to Intersection	Capacity (pcphpl)	Queue speed (mph)
Within 10 ft. of intersection	850	1.7
11-50 ft.	1,000	2.0
51-100 ft.	1,300	2.8
101-150 ft.	1,500	3.4
151-200 ft.	1,650	3.8
210+ ft.	1,750	4.5

Note that within QSIM, the intersection is located at the downstream end of the test segment. **Further, if the queue that is created exceeds the signal spacing (which means that spillback to an upstream intersection occurs), the capacity should be lowered to 1,500 pcphpl if it is not already at or below that level.**

5. Modifications to QSIM

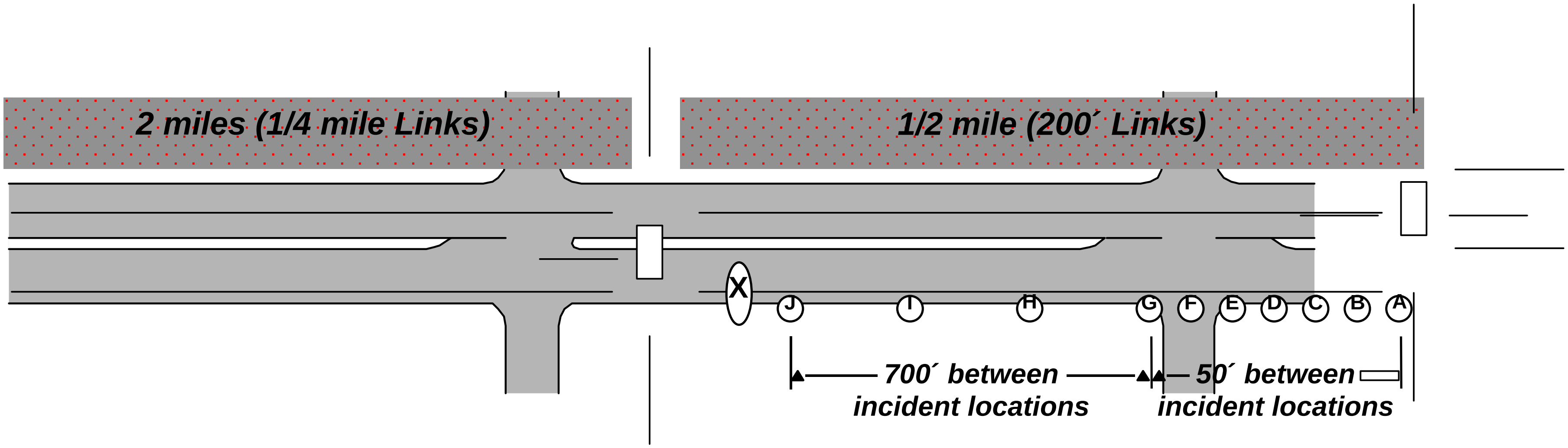
As with freeways, it is apparent that incident location relative to a recurring bottleneck has a profound effect on traffic flow. Therefore, the incident location should be determined probabilistically as with the other incident characteristics. Except for crashes, incidents have an equal probability of occurring along a segment. Crashes tend to be concentrated at intersections. The sequence of events in QSIM for determining incident characteristics (all done stochastically) is then:

1. determine if an incident occurs during the time period
2. if so, determine the type of incident
3. determine the incident location (distance from intersection)
4. determine if lanes or shoulders are blocked
5. if lanes are blocked, determine how many
6. determine incident duration

If the incident is a crash, the probability of it occurring at the intersection can be determined from analyzing GES or state accident databases, both of which we have on hand. If the incident is a noncrash, then location will be determined assuming a uniform distribution along the segment.

<u>For the transition period:</u> This is the period after the incident has ended and the queue has not yet dissipated. Once the incident has ended and assuming that a queue has been built, the original intersection capacity and queue speed (currently 8.5 mph) should be used until the queue dissipates.

Figure 1. NETSIM Incident Experiment



Experimental Factors

- Incident Location: [illegible] (10)
- Incident Duration: 0, 1[illegible], 30, [illegible]0 minutes
- Traffic Volumes @X: 750, 1,000, 1,250, 1,500, 1,750 vphpl
- Same hourly distribution as for FRESIM experiment

Simulation Parameters

- FFS = 45mph
- Simulate 4 hours; output @ 15 minutes
- Signal offset = 40 seconds
- 0% trucks
- C = 60 seconds; G/C of mainline = 50%
- Develop turning movements to match experimental volumes

Table 1. Total Delay for NETSIM Experiment

(Delay is in Hours per 1,000 VMT)

	DURATION																		
	0				15					30					60				
	VOLUME				VOLUME					VOLUME					VOLUME				
	750	1050	1100	1150	750	1000	1050	1100	1150	750	1000	1050	1100	1150	750	1000	1050	1100	1150
	TOTAL DELAY	TOTAL DELAY	TOTAL DELAY	TOTAL DELAY	TOTAL DELAY	TOTAL DELAY	TOTAL DELAY	TOTAL DELAY	TOTAL DELAY	TOTAL DELAY	TOTAL DELAY	TOTAL DELAY	TOTAL DELAY	TOTAL DELAY	TOTAL DELAY	TOTAL DELAY	TOTAL DELAY	TOTAL DELAY	TOTAL DELAY
LOCATION																			
A	29.0	32.5	31.4	32.4	33.6	.	50.8	48.7	54.7	47.3	.	65.0	81.6	103.1	90.8	.	139.6	168.1	187.8
B	.	.	.	.	33.0	.	41.1	45.3	55.1	43.5	.	65.8	72.1	94.3	78.1	87.5	122.1	145.1	172.5
C	.	.	.	.	29.6	41.3	40.4	41.8	48.0	31.8	52.4	53.4	64.0	90.0	47.1	74.9	91.0	111.8	154.3
D	.	.	.	.	29.4	38.2	37.0	40.2	45.6	30.0	48.1	45.3	55.9	71.1	30.4	61.4	70.9	98.4	135.6
E	.	.	.	.	29.1	35.8	34.2	36.5	43.3	29.4	45.8	42.7	49.3	60.6	29.7	63.7	58.3	84.5	108.5
F	.	.	.	.	29.0	34.5	33.6	34.2	39.5	29.3	43.6	40.0	42.9	53.2	29.6	58.8	54.0	62.3	84.9
G	.	.	.	.	29.3	34.1	31.9	35.5	44.7	29.7	41.0	35.5	44.5	71.4	30.7	56.5	46.8	60.1	127.9
H	.	.	.	.	29.2	32.9	34.1	37.7	44.4	29.7	36.7	45.7	50.5	56.6	30.6	50.3	70.8	81.3	98.5
I	.	.	.	.	29.3	33.2	32.0	38.6	44.9	29.6	36.8	34.1	51.1	70.1	30.3	49.9	36.1	82.3	122.6
J	.	.	.	.	29.5	33.2	38.4	39.8	47.2	30.5	36.4	49.3	57.4	56.5	34.0	48.6	76.7	105.1	93.7

Table 2. Incident-Related Delay for NETSIM Experiment

(Delay is in Hours per 1,000 VMT)

	DURATION 15					DURATION 30					DURATION 60				
	VOLUME					VOLUME					VOLUME				
	750	1000	1050	1100	1150	750	1000	1050	1100	1150	750	1000	1050	1100	1150
	INCID DELAY	INCID DELAY	INCID DELAY	INCID DELAY	INCID DELAY	INCID DELAY	INCID DELAY	INCID DELAY	INCID DELAY	INCID DELAY	INCID DELAY	INCID DELAY	INCID DELAY	INCID DELAY	INCID DELAY
LOCATION															
A	4.2	.	19.8	17.1	22.2	17.9	.	34.0	50.0	70.6	61.4	.	108.6	136.5	155.3
B	3.6	.	10.1	13.7	22.6	14.1	.	34.8	40.5	61.8	48.7	58.1	91.1	113.5	140.0
C	0.2	11.9	9.4	10.2	15.5	2.4	23.0	22.4	32.4	57.5	17.7	45.5	60.0	80.2	121.8
D	0.0	8.8	6.0	8.6	13.1	0.6	18.7	14.3	24.3	38.6	1.0	32.0	39.9	66.8	103.1
E	0.0	6.4	3.2	4.9	10.8	0.0	16.4	11.7	17.7	28.1	0.3	34.3	27.3	52.9	76.0
F	0.0	5.1	2.6	2.6	7.0	0.0	14.2	9.0	11.3	20.7	0.2	29.4	23.0	30.7	52.4
G	0.0	4.7	0.9	3.9	12.2	0.3	11.6	4.5	12.9	38.9	1.3	27.1	15.8	28.5	95.4
H	0.0	3.5	3.1	6.1	11.9	0.3	7.3	14.7	18.9	24.1	1.2	20.9	39.8	49.7	66.0
I	0.0	3.8	1.0	7.0	12.4	0.2	7.4	3.1	19.5	37.6	0.9	20.5	5.1	50.7	90.1
J	0.1	3.8	7.4	8.2	14.7	1.1	7.0	18.3	25.8	24.0	4.6	19.2	45.7	73.5	61.2

Table 3. Bottleneck Flow Rates, Arterial Incidents

	DURATION														
	15					30					60				
	DEMAND VOLUME (vphpl)					DEMAND VOLUME (vphpl)					DEMAND VOLUME (vphpl)				
	750	1000	1050	1100	1150	750	1000	1050	1100	1150	750	1000	1050	1100	1150
LOCATION	HRLY VOLUME	HRLY VOLUME	HRLY VOLUME	HRLY VOLUME	HRLY VOLUME	HRLY VOLUME	HRLY VOLUME	HRLY VOLUME	HRLY VOLUME	HRLY VOLUME	HRLY VOLUME	HRLY VOLUME	HRLY VOLUME	HRLY VOLUME	HRLY VOLUME
A	808	.	928	852	880	794	.	832	844	846	820	.	821	820	859
B	912	.	1080	968	996	944	.	998	982	1000	969	1035	996	1015	988
C	1292	1312	1304	1308	1308	1296	1288	1294	1264	1280	1280	1280	1299	1289	1299
D	1420	1484	1524	1516	1500	1450	1456	1544	1502	1532	1476	1457	1553	1537	1529
E	1448	1592	1676	1668	1692	1476	1590	1694	1676	1712	1497	1591	1723	1663	1693
F	1416	1648	1784	1848	1732	1452	1632	1756	1830	1780	1480	1647	1789	1839	1799
G	1436	1696	1900	1696	1508	1446	1682	1878	1794	1518	1475	1680	1915	1809	1471
H	1456	1804	1616	1592	1544	1452	1782	1496	1586	1596	1496	1788	1503	1567	1552
I	1448	1776	1960	1460	1524	1462	1798	2004	1514	1554	1464	1796	2063	1585	1544
J	1404	1820	1316	1504	1588	1408	1820	1380	1458	1650	1417	1844	1433	1425	1689

Table 4. Queue Speeds, Arterial Incidents

	DURATION														
	15					30					60				
	DEMAND VOLUME (vphpl)					DEMAND VOLUME (vphpl)					DEMAND VOLUME (vphpl)				
	750	1000	1050	1100	1150	750	1000	1050	1100	1150	750	1000	1050	1100	1150
	QUEUE	QUEUE	QUEUE	QUEUE	QUEUE	QUEUE	QUEUE	QUEUE	QUEUE	QUEUE	QUEUE	QUEUE	QUEUE	QUEUE	QUEUE
	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED
LOCATION															
A	2.2	.	2.2	1.9	2.0	1.8	.	1.8	1.7	1.8	1.7	.	1.7	1.6	1.7
B	2.4	.	2.6	2.2	2.2	2.1	.	2.2	2.0	2.1	2.0	2.2	2.1	2.0	2.0
C	7.6	3.3	3.3	2.9	3.1	4.0	2.9	2.9	2.7	2.7	3.3	2.8	2.7	2.6	2.7
D	12.8	3.9	4.1	3.6	3.6	9.4	3.4	3.6	3.3	3.3	11.1	3.2	3.4	3.2	3.2
E	21.6	4.4	4.9	4.2	4.3	21.9	3.8	4.1	3.8	3.9	20.6	3.6	3.9	3.6	3.7
F	25.5	4.8	5.2	4.9	4.2	22.7	4.0	4.2	4.3	3.9	23.4	3.9	4.1	4.1	3.9
G	20.5	8.7	9.9	5.6	4.3	18.6	5.2	5.9	4.6	3.6	18.9	4.5	5.2	4.4	3.3
H	29.2	14.0	6.2	5.1	4.4	20.5	7.0	4.0	4.0	3.8	21.0	5.5	3.6	3.7	3.5
I	21.8	12.1	12.6	4.4	4.3	22.9	6.5	7.5	3.7	3.7	21.8	5.4	7.1	3.7	3.5
J	17.8	15.4	4.6	4.8	4.8	11.4	8.0	3.6	3.7	4.1	9.0	6.1	3.4	3.3	4.0

Table 5. Time/Space Diagrams for Selected Arterial Incidents

VOLUME (VPHPL): 1050,
DURATION: 0,
AND LOCATION: A

		NODE1																							
		60	70	80	90	100	110	120	130	140	150	160	170	180	190	191	192	201	202	203	210	211	212	213	220
		SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)	SPEED (mph)
HOUR	MINUTE																								
0	30	39.7	40.1	24.0	26.3	36.2	40.0	39.7	39.3	39.1	38.8	38.4	38.0	37.8	34.8	45.0	43.9	39.7	27.1	18.9	12.8	7.5	7.1	4.8	26.7
	45	40.6	40.4	24.4	26.2	36.0	40.5	40.2	39.9	39.7	39.3	38.9	38.8	38.9	36.9	45.0	44.8	34.8	22.1	14.6	10.9	7.2	7.0	4.8	27.3
1	0	41.8	41.7	25.2	26.0	35.9	40.5	40.2	40.0	39.7	39.4	39.1	38.7	38.8	36.2	45.0	40.4	33.6	24.5	18.1	15.0	8.8	7.9	5.2	25.5
	15	39.0	38.8	23.2	26.0	35.6	39.4	39.0	38.5	38.3	37.9	37.6	37.5	37.3	35.0	45.0	43.8	33.5	19.9	12.3	9.2	6.1	6.4	4.7	26.7
	30	39.3	39.0	23.1	26.1	35.4	39.3	38.7	38.4	38.2	37.7	37.5	37.3	37.3	34.6	45.0	43.2	33.6	18.3	11.9	9.0	5.9	6.3	4.5	26.0
	45	41.0	40.8	24.6	26.2	35.8	39.8	39.4	39.2	39.3	38.9	38.4	38.2	38.0	35.4	44.1	34.8	22.2	15.2	11.2	9.6	6.9	6.8	4.7	27.1
2	0	39.8	39.3	23.5	26.0	35.3	39.5	39.1	38.5	38.3	37.8	37.4	37.2	37.1	34.7	45.0	43.2	36.1	20.6	13.1	9.8	6.3	6.6	4.7	26.3
	15	40.6	40.6	22.7	26.2	36.0	40.4	40.0	39.4	39.4	39.1	38.8	38.5	38.6	36.4	45.0	43.1	31.4	19.5	13.1	10.4	6.8	7.1	4.8	27.0
	30	41.7	41.3	23.8	26.0	36.1	40.4	39.8	39.3	38.8	38.4	38.1	37.9	37.8	35.0	45.0	43.6	34.3	21.5	15.0	12.5	7.9	7.8	5.1	26.0
	45	39.6	39.4	23.6	26.1	35.5	39.6	39.3	38.9	38.6	38.2	37.8	37.6	37.2	33.2	36.7	26.5	19.0	14.8	10.8	9.6	6.6	6.9	4.6	26.1
3	0	41.4	40.9	23.3	25.9	35.9	40.6	40.2	39.7	39.4	39.0	38.6	38.3	38.3	35.4	45.0	40.7	33.0	20.1	13.4	10.4	7.0	7.1	4.9	26.9
	15	40.4	39.9	22.5	25.7	35.7	40.2	39.9	39.3	39.2	38.8	38.6	38.3	38.0	35.2	45.0	45.0	44.3	28.5	21.4	15.1	9.0	7.6	4.6	26.1
	30	41.5	41.3	23.7	26.1	35.9	40.2	39.7	39.3	39.2	38.6	38.5	38.3	38.2	35.9	45.0	45.0	45.0	30.5	23.3	15.5	9.7	7.7	4.7	25.5
	45	41.5	41.9	25.3	26.2	35.6	40.2	39.8	39.6	39.7	39.4	39.2	39.0	38.9	36.8	45.0	45.0	44.8	29.9	22.4	17.5	9.7	7.9	4.6	25.7
4	0	39.7	39.4	21.6	25.5	35.8	39.5	39.1	38.7	38.5	38.2	37.8	37.5	37.4	35.3	45.0	45.0	45.0	30.8	21.1	14.2	8.3	7.1	4.4	26.0

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: A

NODE1

HOUR	MINUTE	60 SPEED (mph)	70 SPEED (mph)	80 SPEED (mph)	90 SPEED (mph)	100 SPEED (mph)	110 SPEED (mph)	120 SPEED (mph)	130 SPEED (mph)	140 SPEED (mph)	150 SPEED (mph)	160 SPEED (mph)	170 SPEED (mph)	180 SPEED (mph)	190 SPEED (mph)	191 SPEED (mph)	192 SPEED (mph)	201 SPEED (mph)	202 SPEED (mph)	203 SPEED (mph)	210 SPEED (mph)	211 SPEED (mph)	212 SPEED (mph)	213 SPEED (mph)	220 SPEED (mph)
0	30	41.8	41.7	26.1	26.1	38.9	41.0	41.3	40.7	40.4	40.3	40.3	40.1	40.3	39.9	45.0	45.0	45.0	32.0	27.7	20.7	11.8	7.3	5.2	26.5
	45	41.3	41.0	22.7	26.1	38.3	40.1	40.2	40.0	39.8	39.7	39.6	39.2	39.2	39.0	45.0	45.0	45.0	32.2	28.5	20.3	10.3	6.7	4.8	25.2
1	0	41.4	41.1	24.0	26.2	38.4	40.5	40.4	40.3	40.4	40.1	40.4	40.4	40.7	40.6	45.0	45.0	45.0	31.7	27.9	18.6	10.8	6.4	4.7	26.4
	15	40.5	40.0	16.3	8.3	7.8	6.6	5.8	5.0	4.4	3.9	3.6	2.9	2.5	2.3	2.1	2.1	2.0	1.9	1.7	1.7	1.7	1.5	1.7	24.7
	30	41.1	15.2	2.5	1.8	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.8	1.5	1.8	25.4
	45	41.1	6.6	2.9	8.4	5.4	5.1	5.0	5.1	5.1	5.1	5.1	5.3	5.3	5.3	5.3	5.4	5.4	5.1	5.6	5.2	5.5	5.6	4.9	24.9
2	0	40.6	40.2	6.3	17.8	9.7	6.4	5.3	5.4	5.4	5.3	5.3	5.4	5.5	5.4	5.4	5.5	5.4	5.4	5.2	5.2	5.2	5.5	4.8	24.6
	15	41.1	41.3	24.5	25.4	35.1	23.5	13.6	10.7	9.2	7.4	6.0	5.6	5.7	5.7	5.6	5.7	5.5	5.4	5.7	5.3	5.7	5.6	5.0	24.9
	30	41.2	41.2	23.6	25.3	38.0	40.6	41.0	40.8	40.6	40.4	39.7	27.5	19.9	15.3	14.1	13.5	11.9	10.3	9.4	7.7	6.7	6.1	5.1	25.6
	45	40.9	40.6	22.3	26.0	38.5	40.8	40.8	40.4	40.0	39.7	39.8	39.6	39.7	40.5	45.0	45.0	38.9	25.0	19.6	13.1	9.6	6.1	5.0	25.9
3	0	41.4	41.2	23.7	26.2	38.4	40.6	40.3	39.8	39.6	39.6	39.5	39.2	39.3	38.8	45.0	40.5	32.1	22.9	16.4	13.5	9.5	6.3	5.0	25.0
	15	42.2	42.0	26.9	26.2	39.1	41.0	41.0	40.7	40.6	40.6	40.4	40.4	40.7	41.4	45.0	45.0	45.0	32.9	26.3	16.6	10.2	6.4	4.9	26.4
	30	41.5	41.9	25.4	26.1	39.1	41.7	41.8	41.6	41.4	41.4	41.3	41.3	41.4	41.8	45.0	45.0	45.0	33.3	30.3	21.7	13.1	6.7	5.0	25.8
	45	41.9	41.4	24.8	25.8	38.5	41.1	41.1	40.8	40.8	40.9	40.8	40.5	40.9	40.9	45.0	45.0	45.0	33.2	29.7	22.0	14.8	7.5	5.0	26.1
4	0	40.8	40.4	24.2	26.0	37.9	40.0	40.0	40.0	39.7	39.5	39.5	39.5	39.8	39.4	45.0	45.0	45.0	34.1	32.4	25.8	15.7	8.0	4.9	24.8

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: B

		NODE1																							
		60	70	80	90	100	110	120	130	140	150	160	170	180	190	191	192	201	202	203	210	211	212	213	220
		SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED
		(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)
HOUR	MINUTE																								
0	30	41.8	41.7	26.1	26.1	38.9	41.0	41.3	40.7	40.4	40.3	40.3	40.1	40.3	39.9	45.0	45.0	45.0	32.0	27.7	20.7	11.8	7.3	5.2	26.5
	45	41.3	41.0	22.7	26.1	38.3	40.1	40.2	40.0	39.8	39.7	39.6	39.2	39.2	39.0	45.0	45.0	45.0	32.2	28.5	20.3	10.3	6.7	4.8	25.2
1	0	41.4	41.1	24.0	26.2	38.4	40.5	40.4	40.3	40.4	40.1	40.4	40.4	40.7	40.6	45.0	45.0	45.0	31.7	27.9	18.6	10.8	6.4	4.7	26.4
	15	40.4	39.9	19.9	13.1	12.1	10.0	8.2	7.0	6.1	5.2	4.7	4.2	3.4	3.0	2.8	2.8	2.7	2.6	2.3	2.5	2.1	2.6	3.8	26.4
	30	41.4	15.5	2.8	2.0	1.9	1.9	1.9	1.9	1.8	1.8	1.8	1.9	1.8	1.8	1.8	1.8	1.8	1.7	1.8	1.8	1.7	2.1	3.3	26.5
	45	40.7	5.1	2.7	8.6	6.0	5.1	4.9	5.0	5.0	5.0	5.1	5.1	5.2	5.1	5.2	5.2	5.2	5.0	5.0	5.1	5.2	5.2	4.8	24.9
2	0	40.7	28.2	4.6	25.0	22.7	8.8	5.8	5.6	5.5	5.6	5.6	5.6	5.7	5.5	5.6	5.6	5.5	5.4	5.3	5.2	5.3	5.6	4.9	25.8
	15	41.2	40.8	23.2	25.7	29.1	12.9	8.3	6.6	6.0	5.4	5.4	5.4	5.3	5.3	5.5	5.4	5.3	5.4	5.2	5.2	5.4	5.4	4.8	25.2
	30	41.4	41.1	24.0	25.4	38.2	40.5	40.9	40.4	38.9	27.6	16.0	12.0	10.2	9.3	9.0	8.5	7.6	7.1	6.7	5.9	5.5	5.3	4.7	24.6
	45	41.6	41.6	24.8	25.7	38.3	41.0	41.2	41.0	41.0	40.6	40.3	40.4	40.8	41.9	45.0	41.9	35.0	23.2	14.5	11.0	8.0	6.3	5.1	25.8
3	0	41.2	41.5	23.3	26.1	38.5	40.7	40.8	40.6	40.5	40.2	40.1	40.0	40.3	40.4	45.0	44.7	40.3	25.1	20.1	13.0	9.2	6.1	5.1	26.0
	15	42.6	42.3	28.1	26.1	37.9	40.2	40.3	40.0	39.8	39.7	39.7	39.2	39.5	38.9	45.0	45.0	45.0	32.7	27.5	19.6	12.2	7.5	4.9	26.0
	30	42.0	41.9	26.6	26.4	39.3	41.7	41.8	41.5	41.3	41.0	40.9	40.8	40.9	41.4	45.0	45.0	45.0	28.6	26.0	20.3	12.4	7.3	5.0	24.7
	45	41.8	41.4	24.1	26.2	38.5	40.5	40.6	40.4	40.4	40.7	40.3	40.1	40.3	40.9	45.0	45.0	45.0	33.7	33.1	30.1	21.1	8.9	5.1	25.7
4	0	40.5	40.3	23.8	26.2	38.4	40.0	40.0	40.2	40.1	39.8	39.8	39.8	39.8	38.9	45.0	45.0	45.0	33.7	31.9	24.5	12.9	6.9	4.4	24.0

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: C

		NODE1																						
		60	70	80	90	100	110	120	130	140	150	160	170	180	190	191	192	201	202	203	210	211	212	213	220
		SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED
		(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)
HOUR	MINUTE																								
0	30	41.8	41.7	26.1	26.1	38.9	41.0	41.3	40.7	40.4	40.3	40.3	40.1	40.3	39.9	45.0	45.0	45.0	32.0	27.7	20.7	11.8	7.3	5.2	26.5
	45	41.3	41.0	22.7	26.1	38.3	40.1	40.2	40.0	39.8	39.7	39.6	39.2	39.2	39.0	45.0	45.0	45.0	32.2	28.5	20.3	10.3	6.7	4.8	25.2
1	0	41.4	41.1	24.0	26.2	38.4	40.5	40.4	40.3	40.4	40.1	40.4	40.4	40.7	40.6	45.0	45.0	45.0	31.7	27.9	18.6	10.8	6.4	4.7	26.4
	15	40.6	40.0	22.6	24.3	23.1	16.9	12.4	10.0	8.4	6.8	6.0	5.2	4.5	3.6	3.5	3.5	3.3	3.1	3.2	2.7	3.2	6.1	3.6	26.5
	30	41.1	40.7	4.5	2.8	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.5	2.4	2.5	2.5	2.5	2.6	2.4	3.0	6.1	3.7	26.7
	45	40.9	37.0	4.0	14.2	8.7	5.9	5.5	5.6	5.5	5.5	5.4	5.4	5.6	5.5	5.7	5.6	5.5	5.5	5.4	5.3	5.8	5.7	5.1	24.9
2	0	40.6	40.3	21.2	24.9	26.4	15.3	11.4	7.8	6.1	5.7	5.6	5.8	5.9	5.8	5.8	5.8	5.7	5.7	5.7	5.4	5.7	5.5	5.1	25.1
	15	40.9	40.8	24.7	25.6	38.2	40.8	40.5	39.8	37.8	26.6	16.1	11.1	9.2	8.5	8.0	7.3	6.4	5.9	5.8	5.5	5.6	5.5	5.1	25.4
	30	41.2	41.4	24.4	25.7	38.1	40.5	40.6	40.6	40.2	40.0	39.9	40.0	40.2	39.1	45.0	44.6	37.5	24.9	24.3	16.6	11.5	7.0	5.4	25.2
	45	41.0	41.0	24.2	25.7	38.5	40.6	40.4	40.0	39.9	39.6	39.3	39.1	39.5	39.8	45.0	45.0	44.9	30.9	23.9	15.6	9.7	6.7	5.0	24.5
3	0	40.9	41.3	24.0	25.8	38.1	40.5	40.5	40.6	40.4	40.1	40.0	39.8	40.1	39.9	45.0	45.0	44.4	28.4	22.6	15.9	10.4	6.7	5.2	25.3
	15	42.1	41.4	24.0	26.1	38.6	41.0	41.1	41.2	41.2	40.8	40.9	41.0	41.0	41.3	45.0	45.0	45.0	32.6	27.7	18.8	11.4	6.2	4.8	25.5
	30	41.9	41.7	25.8	26.4	39.2	41.4	41.9	41.7	41.4	41.0	40.9	40.7	40.9	41.8	45.0	45.0	45.0	33.9	32.1	24.6	13.8	7.2	5.0	25.5
	45	41.9	41.4	24.7	25.6	38.1	40.3	40.7	40.2	40.1	39.9	39.8	39.7	39.7	39.0	45.0	45.0	45.0	33.8	32.4	24.5	14.4	8.6	5.1	25.7
4	0	40.7	40.5	24.4	26.0	37.8	39.9	40.0	39.9	39.5	39.3	39.3	39.1	39.4	39.0	45.0	45.0	45.0	32.4	29.7	24.7	13.6	7.3	5.1	25.3

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: D

		NODE1																							
		60	70	80	90	100	110	120	130	140	150	160	170	180	190	191	192	201	202	203	210	211	212	213	220
		SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED
		(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)
HOUR	MINUTE																								
0	30	41.8	41.7	26.1	26.1	38.9	41.0	41.3	40.7	40.4	40.3	40.3	40.1	40.3	39.9	45.0	45.0	45.0	32.0	27.7	20.7	11.8	7.3	5.2	26.5
	45	41.3	41.0	22.7	26.1	38.3	40.1	40.2	40.0	39.8	39.7	39.6	39.2	39.2	39.0	45.0	45.0	45.0	32.2	28.5	20.3	10.3	6.7	4.8	25.2
1	0	41.4	41.1	24.0	26.2	38.4	40.5	40.4	40.3	40.4	40.1	40.4	40.4	40.7	40.6	45.0	45.0	45.0	31.7	27.9	18.6	10.8	6.4	4.7	26.4
	15	40.4	40.1	22.6	25.9	37.7	38.9	27.1	17.5	13.0	10.0	7.8	6.4	5.6	5.1	4.3	4.0	4.0	3.8	3.5	4.0	7.6	5.7	4.0	25.1
	30	41.1	41.0	14.3	5.4	4.3	3.7	3.4	3.3	3.3	3.2	3.2	3.2	3.1	3.0	3.1	3.0	3.1	3.2	2.9	3.7	8.6	6.4	4.3	26.7
	45	41.1	41.5	11.9	14.7	9.1	7.1	5.9	5.4	5.3	5.3	5.3	5.4	5.4	5.4	5.5	5.4	5.3	5.3	5.4	5.1	5.4	5.2	4.8	25.0
2	0	40.3	40.0	24.1	25.5	38.2	40.2	39.8	38.2	27.2	17.8	11.4	7.4	6.7	6.3	6.1	5.9	5.7	5.8	5.7	5.5	5.7	5.6	5.0	25.7
	15	40.9	40.8	24.8	25.7	38.2	40.9	40.8	40.5	40.4	40.1	40.0	39.6	40.2	39.7	45.0	41.9	36.0	21.9	16.5	11.8	8.3	6.3	5.0	25.4
	30	41.3	41.0	23.9	25.3	38.0	40.7	40.9	40.7	40.7	40.5	40.4	40.6	41.1	40.6	45.0	45.0	45.0	33.3	29.5	19.9	11.6	7.3	5.5	25.1
	45	41.7	41.5	25.4	26.2	38.5	40.5	40.7	40.5	40.4	40.0	39.8	39.7	40.1	40.8	45.0	45.0	40.0	25.7	19.3	12.7	8.2	6.1	5.1	25.7
3	0	41.4	41.4	23.9	26.0	38.6	40.8	40.5	40.5	40.3	39.8	39.9	39.8	40.1	40.4	45.0	45.0	45.0	32.8	30.1	19.4	11.2	6.6	5.2	25.9
	15	41.9	41.9	27.1	26.1	38.4	40.6	40.7	40.8	40.4	40.2	40.1	40.1	40.3	39.5	45.0	45.0	45.0	33.4	30.3	19.5	11.1	7.3	5.5	26.8
	30	42.0	42.1	25.9	26.1	38.8	41.6	41.7	41.6	41.3	41.1	41.2	41.2	41.1	41.4	45.0	45.0	45.0	32.7	31.4	21.2	14.1	8.3	4.9	25.1
	45	41.8	41.5	24.0	25.8	38.6	41.3	41.9	41.8	41.6	41.5	41.4	41.4	41.5	41.2	45.0	45.0	45.0	34.1	32.4	27.6	16.5	7.5	5.1	25.5
4	0	40.5	40.4	24.7	26.2	38.3	40.3	40.7	40.4	40.2	40.0	39.9	39.9	40.1	39.8	45.0	45.0	45.0	33.3	31.2	23.5	13.3	7.2	5.2	26.7

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: E

		NODE1																							
		60	70	80	90	100	110	120	130	140	150	160	170	180	190	191	192	201	202	203	210	211	212	213	220
		SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED
		(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)
HOUR	MINUTE																								
0	30	41.8	41.7	26.1	26.1	38.9	41.0	41.3	40.7	40.4	40.3	40.3	40.1	40.3	39.9	45.0	45.0	45.0	32.0	27.7	20.7	11.8	7.3	5.2	26.5
	45	41.3	41.0	22.7	26.1	38.3	40.1	40.2	40.0	39.8	39.7	39.6	39.2	39.2	39.0	45.0	45.0	45.0	32.2	28.5	20.3	10.3	6.7	4.8	25.2
1	0	41.4	41.1	24.0	26.2	38.4	40.5	40.4	40.3	40.4	40.1	40.4	40.4	40.7	40.6	45.0	45.0	45.0	31.7	27.9	18.6	10.8	6.4	4.7	26.4
	15	40.3	39.8	22.0	26.1	38.2	40.7	39.9	36.3	21.8	16.1	11.6	8.6	6.7	5.8	5.5	5.0	4.6	3.9	4.7	10.6	8.1	6.2	4.2	24.5
	30	41.1	40.8	23.4	15.3	10.2	6.1	4.7	4.0	3.7	3.6	3.5	3.5	3.5	3.4	3.4	3.5	3.6	3.3	4.1	10.5	7.9	6.1	4.4	26.2
	45	40.9	41.1	21.6	13.8	10.8	8.6	7.0	6.1	5.5	5.3	5.3	5.4	5.4	5.2	5.2	5.2	5.2	5.0	5.3	5.2	5.2	5.2	4.6	24.6
2	0	40.7	40.4	22.6	25.9	38.2	40.1	39.9	39.2	34.0	21.4	13.3	9.2	7.3	6.6	6.6	6.6	6.1	6.1	5.7	5.7	5.9	5.6	5.2	25.1
	15	41.0	41.1	24.6	25.5	37.8	40.5	40.5	40.3	40.3	40.3	40.2	39.9	40.0	39.8	45.0	38.4	34.1	24.9	20.9	15.6	9.1	6.3	5.2	25.6
	30	41.6	41.3	24.2	25.6	37.6	40.2	40.1	40.0	39.7	39.6	39.6	39.7	39.9	39.0	45.0	45.0	45.0	33.4	28.2	20.9	11.3	7.1	5.3	25.3
	45	41.2	41.1	24.1	25.7	37.9	40.4	40.3	40.1	39.8	39.7	39.3	39.6	40.2	41.1	45.0	43.6	36.6	24.3	17.2	12.1	8.4	6.0	5.0	25.9
3	0	41.4	41.5	23.7	26.1	38.4	40.8	41.0	40.7	40.5	40.2	40.0	40.0	40.1	39.8	45.0	42.0	35.2	22.4	17.7	12.0	8.5	5.9	5.0	26.3
	15	42.0	41.7	26.8	26.5	39.0	41.5	41.6	41.6	41.2	41.1	41.2	40.9	40.8	41.1	45.0	45.0	45.0	31.6	25.0	16.9	11.1	6.8	4.8	24.8
	30	42.1	42.0	25.7	26.2	39.0	41.6	41.8	41.6	41.3	41.3	41.2	41.2	41.2	40.8	45.0	45.0	45.0	34.0	32.4	26.3	15.3	8.4	4.9	24.4
	45	41.8	41.5	24.7	25.8	38.4	40.8	40.9	40.8	40.7	40.4	40.6	40.4	40.5	39.8	45.0	45.0	45.0	33.9	32.0	23.1	13.8	7.9	5.0	25.5
4	0	40.3	39.8	24.5	25.7	38.3	40.5	40.4	40.5	40.1	40.1	40.2	40.2	40.2	40.2	45.0	45.0	45.0	32.1	29.4	23.6	14.1	6.9	4.8	25.5

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: F

		NODE1																							
		60	70	80	90	100	110	120	130	140	150	160	170	180	190	191	192	201	202	203	210	211	212	213	220
		SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED
		(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)
HOUR	MINUTE																								
0	30	41.8	41.7	26.1	26.1	38.9	41.0	41.3	40.7	40.4	40.3	40.3	40.1	40.3	39.9	45.0	45.0	45.0	32.0	27.7	20.7	11.8	7.3	5.2	26.5
	45	41.3	41.0	22.7	26.1	38.3	40.1	40.2	40.0	39.8	39.7	39.6	39.2	39.2	39.0	45.0	45.0	45.0	32.2	28.5	20.3	10.3	6.7	4.8	25.2
1	0	41.4	41.1	24.0	26.2	38.4	40.5	40.4	40.3	40.4	40.1	40.4	40.4	40.7	40.6	45.0	45.0	45.0	31.7	27.9	18.6	10.8	6.4	4.7	26.4
	15	40.5	40.1	22.4	26.1	37.9	40.0	39.7	39.6	38.9	33.0	18.4	11.7	8.1	6.3	5.5	4.7	4.4	5.0	12.9	11.3	8.0	6.0	4.4	25.4
	30	41.3	41.0	25.4	26.0	28.3	12.9	7.1	5.2	4.6	3.9	3.6	3.6	3.5	3.4	3.6	3.5	3.4	4.3	12.8	10.9	7.7	6.0	4.5	25.8
	45	41.0	41.3	25.4	26.2	28.7	16.9	11.2	7.2	6.5	5.9	5.6	5.5	5.5	5.3	5.5	5.4	5.3	5.4	5.4	5.2	5.4	5.4	4.8	24.1
2	0	40.2	40.3	23.7	25.8	38.2	40.1	40.2	40.0	39.6	38.5	30.4	21.7	15.8	10.5	8.3	6.6	6.1	5.8	5.6	5.3	5.2	5.4	4.7	24.5
	15	41.1	41.3	23.8	25.5	38.4	40.9	40.7	40.4	40.5	40.4	40.6	40.2	40.5	40.4	45.0	45.0	44.1	28.9	20.8	13.5	8.9	6.5	5.1	25.2
	30	41.5	41.1	24.5	25.7	38.8	41.1	41.2	40.9	40.7	40.4	40.4	40.4	40.6	40.5	45.0	45.0	45.0	30.5	22.5	14.9	9.6	6.9	5.4	25.7
	45	41.6	41.3	25.5	26.2	38.7	41.0	40.9	40.8	40.5	40.3	40.1	40.1	40.4	40.9	45.0	44.6	41.6	26.4	18.0	12.4	8.5	6.0	4.9	24.3
3	0	41.4	41.7	24.3	26.0	38.2	40.6	40.5	40.1	39.8	39.8	39.6	39.5	39.8	39.0	45.0	45.0	45.0	28.3	22.7	16.2	9.3	5.6	4.8	25.3
	15	42.4	41.7	26.5	26.3	38.7	40.7	40.9	40.3	40.2	40.1	39.6	39.4	39.5	39.0	45.0	45.0	45.0	32.8	30.8	21.0	10.8	6.3	4.7	25.2
	30	41.8	42.0	25.7	26.2	39.3	41.8	42.0	41.7	41.5	41.4	41.3	41.1	41.3	41.9	45.0	45.0	45.0	34.1	32.4	24.5	13.5	7.7	5.2	25.0
	45	41.9	41.6	24.4	25.8	38.4	41.1	41.5	41.2	41.3	41.3	41.0	41.1	41.2	41.7	45.0	45.0	45.0	34.1	33.6	27.1	15.5	7.8	5.0	26.9
4	0	40.6	40.3	24.7	26.5	38.3	39.9	40.4	40.0	39.7	39.7	39.3	39.4	39.2	38.7	45.0	45.0	45.0	33.4	31.3	23.8	14.8	7.7	5.0	25.8

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: G

HOUR	MINUTE	NODE1 60 SPEED (mph)	70 SPEED (mph)	80 SPEED (mph)	90 SPEED (mph)	100 SPEED (mph)	110 SPEED (mph)	120 SPEED (mph)	130 SPEED (mph)	140 SPEED (mph)	150 SPEED (mph)	160 SPEED (mph)	170 SPEED (mph)	180 SPEED (mph)	190 SPEED (mph)	191 SPEED (mph)	192 SPEED (mph)	201 SPEED (mph)	202 SPEED (mph)	203 SPEED (mph)	210 SPEED (mph)	211 SPEED (mph)	212 SPEED (mph)	213 SPEED (mph)	220 SPEED (mph)
0	30	41.8	41.7	26.1	26.1	38.9	41.0	41.3	40.7	40.4	40.3	40.3	40.1	40.3	39.9	45.0	45.0	45.0	32.0	27.7	20.7	11.8	7.3	5.2	26.5
	45	41.3	41.0	22.7	26.1	38.3	40.1	40.2	40.0	39.8	39.7	39.6	39.2	39.2	39.0	45.0	45.0	45.0	32.2	28.5	20.3	10.3	6.7	4.8	25.2
1	0	41.4	41.1	24.0	26.2	38.4	40.5	40.4	40.3	40.4	40.1	40.4	40.4	40.7	40.6	45.0	45.0	45.0	31.7	27.9	18.6	10.8	6.4	4.7	26.4
	15	40.4	39.8	22.0	26.2	38.2	40.3	40.1	39.8	39.6	39.2	34.2	17.3	8.5	6.3	5.7	4.9	6.8	18.9	17.6	11.8	8.1	6.1	4.6	25.1
	30	40.9	40.8	25.2	26.3	38.2	39.8	37.9	29.3	15.0	6.9	4.6	4.0	3.8	3.8	3.8	3.8	5.9	17.5	14.5	9.8	7.1	6.2	4.5	25.7
	45	41.2	41.1	25.1	26.7	39.0	40.7	36.3	23.0	18.3	15.9	12.7	9.7	8.6	7.9	7.9	7.8	7.3	6.9	7.2	6.4	6.4	6.1	5.3	25.6
2	0	40.4	40.2	23.8	25.8	37.8	40.1	39.9	39.8	39.7	39.4	39.3	39.1	39.4	39.3	45.0	45.0	42.2	26.5	19.1	12.3	8.9	6.5	5.1	25.0
	15	40.9	41.0	24.8	25.7	38.5	41.0	40.7	40.0	40.0	40.2	40.1	39.8	39.9	39.6	45.0	45.0	45.0	32.2	25.9	15.9	9.5	6.3	5.1	25.5
	30	41.2	41.1	24.3	25.5	38.4	40.7	40.8	40.7	40.3	40.2	40.1	39.8	40.1	39.1	45.0	45.0	45.0	29.7	22.5	16.6	10.9	6.9	5.4	24.9
	45	41.0	40.8	23.0	25.5	38.5	41.3	41.7	41.4	41.1	40.9	40.9	40.9	41.2	42.2	45.0	45.0	45.0	30.1	19.6	12.6	8.6	6.2	5.2	26.7
3	0	41.3	41.4	24.5	26.0	37.9	40.2	40.3	39.8	39.5	39.4	39.3	39.3	39.7	39.3	45.0	45.0	45.0	28.3	23.2	14.0	9.3	6.2	4.8	24.8
	15	42.5	42.1	27.1	26.3	38.7	40.4	40.4	40.1	39.9	39.7	39.4	39.3	39.5	39.1	45.0	45.0	45.0	33.4	28.9	19.3	12.2	7.7	4.8	25.6
	30	41.9	42.0	25.9	26.5	39.3	41.8	42.0	41.7	41.4	41.0	40.8	40.7	40.9	40.7	45.0	45.0	45.0	32.4	29.1	21.5	13.5	7.9	5.1	25.5
	45	41.9	41.7	24.1	26.1	38.6	41.1	41.0	41.1	40.5	40.6	40.4	40.4	40.7	41.1	45.0	45.0	45.0	34.1	32.9	27.6	14.7	7.5	4.9	25.6
4	0	40.4	40.5	21.3	25.4	38.3	40.3	40.2	40.3	40.1	40.0	39.7	39.9	40.1	39.3	45.0	45.0	45.0	33.1	29.7	21.5	11.7	6.7	4.5	26.1

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: H

		NODE1																							
		60	70	80	90	100	110	120	130	140	150	160	170	180	190	191	192	201	202	203	210	211	212	213	220
		SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED
		(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)
HOUR	MINUTE																								
0	30	41.8	41.7	26.1	26.1	38.9	41.0	41.3	40.7	40.4	40.3	40.3	40.1	40.3	39.9	45.0	45.0	45.0	32.0	27.7	20.7	11.8	7.3	5.2	26.5
	45	41.3	41.0	22.7	26.1	38.3	40.1	40.2	40.0	39.8	39.7	39.6	39.2	39.2	39.0	45.0	45.0	45.0	32.2	28.5	20.3	10.3	6.7	4.8	25.2
1	0	41.4	41.1	24.0	26.2	38.4	40.5	40.4	40.3	40.4	40.1	40.4	40.4	40.7	40.6	45.0	45.0	45.0	31.7	27.9	18.6	10.8	6.4	4.7	26.4
	15	40.6	40.0	22.6	26.1	38.0	40.1	37.4	24.3	16.8	11.1	8.0	6.2	5.5	4.3	3.8	4.1	21.7	30.1	24.9	17.0	10.2	6.3	4.3	25.1
	30	41.2	40.8	13.9	4.7	3.8	3.3	3.0	2.8	2.8	2.8	2.8	2.8	2.8	2.7	2.6	3.2	22.4	32.7	29.9	19.7	11.4	6.6	3.9	25.5
	45	40.9	41.5	10.5	12.6	7.7	6.3	5.6	5.5	5.5	5.5	5.5	5.6	5.7	5.6	5.6	5.6	5.6	5.5	5.5	5.4	5.6	5.3	4.9	25.1
2	0	40.5	40.2	22.0	25.6	38.0	39.5	33.5	21.1	11.9	8.9	6.9	5.8	5.7	5.4	5.6	5.4	5.5	5.5	5.5	5.2	5.5	5.2	4.9	24.7
	15	41.3	41.2	24.3	25.5	38.1	40.6	40.7	40.8	40.8	40.9	40.6	40.3	36.4	30.7	25.4	19.0	16.0	14.0	11.0	9.0	7.0	6.0	5.1	25.9
	30	41.1	41.1	24.6	25.5	38.0	40.6	40.6	40.6	40.2	39.9	39.8	39.8	40.1	39.8	45.0	45.0	45.0	32.6	27.3	19.1	11.6	7.6	5.8	25.9
	45	41.5	41.6	25.9	26.0	38.2	40.7	40.7	40.6	40.3	39.8	39.6	39.4	39.8	40.0	45.0	45.0	40.8	25.7	19.4	13.1	8.4	6.2	5.1	24.8
3	0	41.6	41.6	23.3	26.1	38.3	40.3	40.4	40.3	40.0	39.8	39.9	39.7	39.9	39.3	45.0	45.0	45.0	32.1	27.6	16.5	9.8	6.6	5.1	25.0
	15	42.0	41.5	25.8	26.4	38.5	40.7	40.6	40.2	39.9	39.7	39.7	39.4	39.6	39.3	45.0	45.0	45.0	33.7	29.9	20.4	11.6	7.5	5.0	24.2
	30	42.0	42.2	26.5	26.6	39.2	41.5	41.6	41.3	41.0	40.9	40.9	40.9	40.7	40.5	45.0	45.0	45.0	33.9	31.4	22.4	13.2	7.0	4.8	25.2
	45	41.8	41.6	24.0	26.0	38.5	40.9	41.1	41.0	41.3	40.8	40.8	40.6	40.9	41.3	45.0	45.0	45.0	33.8	30.6	25.4	14.7	7.8	5.3	26.4
4	0	40.4	40.4	24.8	26.6	38.2	39.8	39.8	39.7	39.5	39.5	39.4	39.4	39.5	39.0	45.0	45.0	45.0	33.4	30.6	25.5	13.5	6.7	4.8	26.7

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: I

		NODE1																							
		60	70	80	90	100	110	120	130	140	150	160	170	180	190	191	192	201	202	203	210	211	212	213	220
		SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED
		(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)
HOUR	MINUTE																								
0	30	41.8	41.7	26.1	26.1	38.9	41.0	41.3	40.7	40.4	40.3	40.3	40.1	40.3	39.9	45.0	45.0	45.0	32.0	27.7	20.7	11.8	7.3	5.2	26.5
	45	41.3	41.0	22.7	26.1	38.3	40.1	40.2	40.0	39.8	39.7	39.6	39.2	39.2	39.0	45.0	45.0	45.0	32.2	28.5	20.3	10.3	6.7	4.8	25.2
1	0	41.4	41.1	24.0	26.2	38.4	40.5	40.4	40.3	40.4	40.1	40.4	40.4	40.7	40.6	45.0	45.0	45.0	31.7	27.9	18.6	10.8	6.4	4.7	26.4
	15	40.4	40.0	21.6	25.8	38.0	40.5	39.9	40.0	39.8	38.3	28.3	14.2	7.9	5.5	7.0	20.0	20.9	16.0	11.5	8.9	6.9	5.8	4.5	24.8
	30	41.4	41.2	26.0	26.3	38.3	40.3	40.1	38.5	29.5	11.5	5.1	4.3	4.4	4.2	6.6	20.7	23.2	17.5	11.8	8.4	6.5	5.8	4.6	25.3
	45	41.2	41.0	25.9	26.4	38.4	40.9	41.0	40.6	39.8	37.9	28.5	23.5	17.4	14.6	12.5	10.7	9.6	9.1	8.1	7.8	6.7	6.2	5.2	26.1
2	0	40.3	40.3	23.9	25.7	38.0	40.5	40.2	40.1	39.9	39.7	39.2	39.2	39.3	39.0	45.0	45.0	43.0	27.1	20.3	13.6	9.0	6.7	5.0	24.6
	15	41.1	40.6	24.8	25.7	38.0	40.6	40.3	40.2	39.9	39.8	39.7	39.6	39.9	38.8	45.0	44.8	38.9	21.8	16.9	10.9	7.3	5.4	4.6	24.4
	30	41.4	41.3	24.1	25.8	38.4	40.7	40.8	40.6	40.6	40.2	40.0	40.2	40.3	40.0	45.0	45.0	45.0	32.1	27.8	17.9	10.8	7.2	5.5	25.4
	45	40.9	40.7	22.3	25.8	37.9	40.1	40.0	39.7	39.3	38.8	38.9	38.8	39.0	38.8	45.0	45.0	43.8	25.0	17.9	12.6	9.1	6.1	5.1	24.9
3	0	41.1	41.4	24.4	26.1	39.1	41.0	40.9	40.7	40.5	40.4	40.1	39.9	39.9	39.6	45.0	39.8	28.6	16.5	12.9	11.3	8.0	6.1	4.8	25.3
	15	42.4	42.1	27.6	26.3	38.1	40.3	40.6	40.8	40.5	40.4	40.3	39.9	40.1	39.1	45.0	45.0	45.0	33.6	28.8	20.4	13.2	7.1	5.2	26.2
	30	41.9	41.9	25.9	26.4	39.4	41.7	41.3	41.4	41.3	41.1	41.1	40.9	41.0	41.1	45.0	45.0	45.0	33.7	29.4	21.0	12.8	6.7	4.6	25.6
	45	41.8	41.6	24.5	26.0	38.1	40.5	40.6	40.5	40.2	40.1	40.1	39.9	40.1	40.1	45.0	45.0	45.0	33.5	31.7	27.6	17.5	8.1	5.1	25.3
4	0	40.8	40.4	24.8	26.5	38.2	40.0	40.4	40.1	39.8	39.7	39.6	39.4	39.6	38.4	45.0	45.0	45.0	31.7	28.7	22.6	13.9	7.2	4.6	25.2

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: J

		NODE1																							
		60	70	80	90	100	110	120	130	140	150	160	170	180	190	191	192	201	202	203	210	211	212	213	220
		SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED	SPEED
		(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)	(mph)
HOUR	MINUTE																								
0	30	41.8	41.7	26.1	26.1	38.9	41.0	41.3	40.7	40.4	40.3	40.3	40.1	40.3	39.9	45.0	45.0	45.0	32.0	27.7	20.7	11.8	7.3	5.2	26.5
	45	41.3	41.0	22.7	26.1	38.3	40.1	40.2	40.0	39.8	39.7	39.6	39.2	39.2	39.0	45.0	45.0	45.0	32.2	28.5	20.3	10.3	6.7	4.8	25.2
1	0	41.4	41.1	24.0	26.2	38.4	40.5	40.4	40.3	40.4	40.1	40.4	40.4	40.7	40.6	45.0	45.0	45.0	31.7	27.9	18.6	10.8	6.4	4.7	26.4
	15	40.7	40.0	20.6	15.7	12.9	10.9	9.2	7.6	6.4	5.5	4.9	4.3	3.5	3.4	23.2	27.5	42.4	31.3	30.8	23.3	12.9	6.6	3.9	25.4
	30	41.3	40.9	5.6	3.4	3.0	3.0	2.9	3.0	3.0	3.0	3.0	2.9	2.9	3.1	22.6	27.3	43.8	32.4	25.7	17.2	11.3	6.9	4.2	26.2
	45	40.9	40.8	5.2	15.9	16.3	10.8	6.9	5.8	5.6	5.8	6.0	5.9	5.9	5.8	6.1	5.9	5.7	5.6	5.8	5.4	5.5	5.7	5.1	25.2
2	0	40.4	40.1	24.1	25.4	37.9	37.6	26.3	18.9	11.0	6.5	5.6	5.6	5.8	5.6	5.7	5.6	5.5	5.5	5.4	5.2	5.5	5.2	4.9	25.4
	15	41.0	41.0	24.3	25.3	38.0	40.4	40.8	40.7	40.1	37.0	22.8	14.6	10.7	9.6	8.9	8.2	7.9	7.1	6.7	6.6	6.0	5.7	5.1	25.0
	30	41.3	41.3	24.1	25.3	38.1	40.8	40.8	41.0	41.1	41.1	40.9	40.7	41.0	41.3	45.0	45.0	45.0	33.3	27.0	16.6	9.7	6.1	5.1	25.3
	45	41.1	41.0	23.5	25.7	38.4	40.4	40.7	40.3	40.2	40.1	39.9	39.9	39.8	39.6	45.0	45.0	44.7	26.8	19.8	13.3	8.6	6.5	5.0	25.5
3	0	41.2	41.1	23.6	25.7	38.6	40.8	40.5	40.0	40.0	39.9	39.7	39.3	39.4	39.1	45.0	40.8	36.7	21.8	17.6	11.6	8.0	6.0	4.8	25.8
	15	42.2	42.0	26.9	26.0	38.5	40.5	40.6	40.7	40.4	40.3	40.0	40.1	40.1	39.4	45.0	45.0	45.0	33.9	31.6	24.0	12.7	7.0	4.9	24.2
	30	41.7	42.1	25.1	26.1	39.3	41.8	41.8	41.3	41.3	41.3	41.3	41.3	41.3	41.1	45.0	45.0	45.0	32.9	32.2	25.9	13.3	7.3	5.0	24.9
	45	41.8	41.4	24.3	25.9	38.4	40.9	40.8	40.7	40.5	40.3	40.3	40.1	40.4	40.4	45.0	45.0	45.0	33.2	30.0	24.3	15.5	8.4	5.0	24.7
4	0	40.7	40.7	24.5	26.8	38.1	39.7	40.1	39.9	39.7	39.3	39.2	39.4	39.3	38.4	45.0	45.0	45.0	33.0	29.9	23.1	16.3	7.5	5.0	25.6

VOLUME (VPHPL): 1050,
DURATION: 0,
AND LOCATION: A

		NODE1																							
		60	70	80	90	100	110	120	130	140	150	160	170	180	190	191	192	201	202	203	210	211	212	213	220
		VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH
		(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)
HOUR	MINUTE																								
0	30	1452	1456	1460	1964	1976	1976	1976	1972	1976	1968	1960	1964	1988	1996	2004	2004	2008	2008	2012	2012	2016	2008	2008	2144
	45	1280	1244	1280	1984	1984	1980	1980	1984	1988	1984	1988	1988	1988	1988	1988	1988	1988	1988	1984	1980	1976	1968	1964	2060
1	0	1408	1412	1384	1964	1956	1960	1956	1960	1956	1960	1960	1952	1928	1928	1928	1928	1928	1932	1940	1940	1936	1944	1948	2064
	15	1416	1412	1456	2112	2116	2116	2116	2108	2112	2116	2112	2120	2132	2128	2120	2116	2104	2096	2088	2088	2092	2096	2096	2220
	30	1456	1456	1408	2060	2056	2060	2052	2056	2048	2044	2052	2036	2044	2040	2036	2032	2040	2036	2032	2032	2028	2020	2020	2160
	45	1384	1416	1396	2048	2052	2048	2052	2052	2064	2060	2060	2076	2080	2088	2100	2108	2108	2108	2108	2104	2108	2112	2108	2216
2	0	1444	1440	1480	2164	2160	2160	2164	2156	2144	2152	2140	2128	2116	2104	2092	2088	2088	2088	2088	2088	2084	2084	2084	2212
	15	1332	1336	1328	2036	2044	2048	2044	2056	2060	2060	2060	2060	2068	2072	2076	2080	2072	2080	2084	2088	2096	2096	2092	2188
	30	1256	1228	1228	2060	2056	2052	2056	2044	2048	2052	2060	2072	2076	2080	2088	2088	2096	2096	2088	2088	2080	2080	2076	2208
	45	1416	1396	1416	2080	2080	2080	2084	2092	2088	2084	2084	2080	2080	2080	2076	2064	2052	2036	2040	2036	2036	2036	2040	2144
3	0	1356	1372	1372	2064	2072	2072	2064	2060	2056	2056	2052	2044	2028	2024	2024	2032	2044	2060	2068	2080	2084	2088	2092	2196
	15	1308	1328	1284	1736	1728	1728	1736	1736	1748	1740	1748	1760	1776	1784	1788	1788	1788	1792	1796	1796	1804	1804	1808	1912
	30	1164	1160	1204	1796	1792	1792	1788	1792	1792	1796	1792	1792	1792	1792	1788	1788	1792	1792	1792	1788	1780	1776	1768	1860
	45	1228	1224	1196	1736	1748	1748	1752	1744	1744	1748	1744	1740	1736	1736	1740	1744	1744	1744	1744	1748	1752	1748	1752	1880
4	0	1300	1320	1288	1768	1764	1768	1772	1780	1772	1776	1784	1788	1792	1792	1788	1784	1784	1776	1760	1752	1744	1748	1748	1840

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: A

HOUR	MINUTE	NODE1																							
		60	70	80	90	100	110	120	130	140	150	160	170	180	190	191	192	201	202	203	210	211	212	213	220
		VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH
		(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)
0	30	1464	1460	1436	1976	1976	1976	1968	1976	1980	1984	1984	1984	1984	1992	1988	1988	1984	1976	1984	1984	1980	1980	1980	2104
	45	1268	1272	1272	1904	1896	1896	1900	1892	1884	1880	1876	1868	1872	1868	1876	1876	1880	1888	1888	1892	1892	1892	1884	1988
1	0	1392	1364	1396	1908	1920	1916	1916	1924	1932	1932	1932	1936	1928	1928	1924	1916	1912	1912	1908	1912	1920	1928	1932	2056
	15	1460	1484	1236	1648	1572	1516	1436	1380	1308	1224	1140	1060	996	968	948	928	904	888	868	848	832	808	800	944
	30	1400	1124	884	864	864	876	888	856	852	856	856	860	852	856	852	860	860	852	860	860	860	864	864	1004
	45	1408	1688	1756	2260	2340	2352	2360	2384	2396	2416	2440	2436	2444	2440	2444	2436	2444	2456	2456	2468	2472	2480	2488	2568
2	0	1440	1424	1820	2428	2412	2416	2412	2408	2416	2420	2416	2424	2408	2408	2404	2412	2408	2404	2400	2404	2400	2400	2396	2520
	15	1344	1372	1380	2136	2140	2172	2236	2300	2356	2412	2480	2472	2504	2504	2504	2504	2504	2508	2516	2508	2516	2512	2520	2616
	30	1228	1212	1216	2020	2016	2012	2008	2004	1996	1992	1992	2068	2124	2148	2172	2188	2212	2224	2236	2248	2248	2256	2252	2388
	45	1444	1428	1392	2148	2152	2152	2152	2148	2152	2152	2152	2148	2144	2140	2140	2140	2128	2120	2116	2116	2116	2112	2112	2224
3	0	1356	1372	1392	2052	2056	2064	2060	2068	2064	2060	2060	2072	2068	2080	2084	2088	2100	2108	2112	2108	2108	2116	2116	2204
	15	1296	1308	1316	1996	2000	1996	1996	1996	2008	2012	2004	2004	2012	2012	2012	2008	1996	1988	1984	1988	1996	2000	2000	2100
	30	1152	1128	1156	1804	1804	1804	1816	1812	1800	1804	1808	1804	1804	1804	1804	1808	1820	1828	1824	1816	1808	1808	1816	1952
	45	1212	1232	1196	1840	1844	1852	1844	1840	1844	1844	1848	1852	1852	1852	1848	1844	1836	1832	1836	1836	1836	1828	1820	1904
4	0	1308	1284	1324	1820	1812	1812	1812	1824	1828	1824	1824	1820	1816	1804	1804	1800	1808	1812	1816	1824	1828	1828	1828	1940

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: B

		NODE1																							
		60 VPH (adj)	70 VPH (adj)	80 VPH (adj)	90 VPH (adj)	100 VPH (adj)	110 VPH (adj)	120 VPH (adj)	130 VPH (adj)	140 VPH (adj)	150 VPH (adj)	160 VPH (adj)	170 VPH (adj)	180 VPH (adj)	190 VPH (adj)	191 VPH (adj)	192 VPH (adj)	201 VPH (adj)	202 VPH (adj)	203 VPH (adj)	210 VPH (adj)	211 VPH (adj)	212 VPH (adj)	213 VPH (adj)	220 VPH (adj)
HOUR	MINUTE																								
0	30	1464	1460	1436	1976	1976	1976	1968	1976	1980	1984	1984	1984	1984	1992	1988	1988	1984	1976	1984	1984	1980	1980	1980	2104
	45	1268	1272	1272	1904	1896	1896	1900	1892	1884	1880	1876	1868	1872	1868	1876	1876	1880	1888	1888	1892	1892	1892	1884	1988
1	0	1392	1364	1396	1908	1920	1916	1916	1924	1932	1932	1932	1936	1928	1928	1924	1916	1912	1912	1908	1912	1920	1928	1932	2056
	15	1460	1484	1316	1892	1820	1784	1716	1628	1548	1488	1404	1320	1248	1224	1200	1180	1156	1136	1124	1104	1084	1072	1080	1216
	30	1400	1156	840	956	956	920	904	932	944	920	928	932	940	928	928	928	924	928	920	924	920	916	916	1072
	45	1408	1584	1556	2188	2256	2316	2344	2340	2352	2376	2376	2384	2384	2392	2396	2400	2412	2416	2428	2432	2440	2448	2432	2500
2	0	1440	1500	1944	2528	2532	2520	2512	2508	2500	2480	2476	2464	2468	2472	2464	2464	2460	2452	2444	2440	2448	2448	2460	2588
	15	1344	1368	1420	2152	2156	2184	2248	2312	2368	2404	2400	2408	2420	2412	2420	2416	2416	2424	2432	2436	2428	2428	2424	2520
	30	1228	1216	1216	1996	1988	1988	1992	1984	1988	2028	2112	2184	2240	2268	2288	2312	2336	2348	2360	2364	2376	2380	2372	2504
	45	1444	1420	1376	2132	2124	2116	2112	2112	2112	2100	2100	2104	2104	2112	2116	2120	2120	2116	2116	2120	2124	2128	2140	2264
3	0	1356	1376	1412	2104	2104	2112	2116	2108	2108	2124	2128	2124	2120	2120	2120	2116	2112	2116	2116	2116	2104	2092	2088	2168
	15	1292	1308	1312	1856	1860	1864	1856	1872	1868	1860	1860	1868	1872	1868	1864	1860	1852	1844	1844	1848	1860	1872	1880	1984
	30	1156	1128	1156	1820	1824	1824	1832	1828	1832	1840	1836	1832	1832	1836	1840	1848	1860	1868	1868	1868	1868	1868	1868	1984
	45	1212	1232	1196	1716	1720	1712	1708	1712	1700	1704	1704	1708	1704	1692	1684	1676	1672	1672	1672	1668	1664	1664	1660	1780
4	0	1308	1280	1324	1784	1776	1788	1780	1772	1792	1792	1796	1784	1780	1792	1792	1788	1780	1776	1776	1780	1780	1780	1780	1888

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: C

		NODE1																							
		60	70	80	90	100	110	120	130	140	150	160	170	180	190	191	192	201	202	203	210	211	212	213	220
		VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH
		(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)
HOUR	MINUTE																								
0	30	1464	1460	1436	1976	1976	1976	1968	1976	1980	1984	1984	1984	1984	1992	1988	1988	1984	1976	1984	1984	1980	1980	1980	2104
	45	1268	1272	1272	1904	1896	1896	1900	1892	1884	1880	1876	1868	1872	1868	1876	1876	1880	1888	1888	1892	1892	1892	1884	1988
1	0	1392	1364	1396	1908	1920	1916	1916	1924	1932	1932	1932	1936	1928	1928	1924	1916	1912	1912	1908	1912	1920	1928	1932	2056
	15	1460	1484	1444	2108	2040	1976	1916	1852	1780	1700	1624	1548	1480	1448	1420	1404	1380	1360	1344	1324	1308	1304	1308	1448
	30	1400	1404	996	1276	1284	1288	1284	1276	1268	1288	1284	1280	1280	1276	1280	1280	1280	1280	1284	1280	1280	1284	1288	1428
	45	1408	1408	1780	2436	2480	2488	2488	2496	2512	2500	2496	2500	2516	2520	2524	2528	2540	2552	2560	2568	2572	2564	2552	2632
2	0	1428	1428	1484	2276	2288	2352	2416	2468	2520	2548	2556	2552	2548	2556	2552	2548	2540	2536	2528	2532	2536	2528	2532	2656
	15	1356	1368	1376	2240	2236	2236	2224	2224	2236	2276	2356	2436	2500	2528	2548	2556	2560	2556	2556	2556	2560	2564	2560	2660
	30	1224	1216	1216	1996	2000	1988	2004	2012	2000	2008	1992	1992	1980	1976	1984	2000	2020	2032	2048	2056	2052	2048	2052	2180
	45	1448	1424	1392	2124	2116	2120	2112	2104	2112	2108	2116	2116	2124	2128	2128	2120	2108	2104	2100	2100	2100	2112	2108	2220
3	0	1356	1372	1392	2100	2104	2108	2112	2116	2120	2120	2120	2120	2120	2116	2112	2116	2124	2132	2132	2120	2116	2112	2108	2200
	15	1296	1308	1312	1908	1916	1912	1908	1904	1900	1904	1908	1912	1916	1916	1920	1916	1904	1904	1908	1924	1936	1940	1952	2064
	30	1152	1128	1156	1824	1812	1808	1812	1812	1804	1800	1804	1804	1804	1808	1808	1816	1832	1832	1824	1816	1808	1812	1816	1944
	45	1216	1232	1200	1720	1736	1740	1736	1732	1740	1744	1740	1736	1736	1736	1732	1724	1716	1712	1712	1716	1724	1724	1720	1804
4	0	1304	1284	1320	1864	1864	1868	1876	1880	1880	1876	1868	1868	1860	1852	1852	1848	1848	1852	1860	1864	1864	1864	1860	1968

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: D

		NODE1																						
		60	70	80	90	100	110	120	130	140	150	160	170	180	190	191	192	201	202	203	210	211	212	213	220
		VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH
		(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)
HOUR	MINUTE																								
0	30	1464	1460	1436	1976	1976	1976	1968	1976	1980	1984	1984	1984	1984	1992	1988	1988	1984	1976	1984	1984	1980	1980	1980	2104
	45	1268	1272	1272	1904	1896	1896	1900	1892	1884	1880	1876	1868	1872	1868	1876	1876	1880	1888	1888	1892	1892	1892	1884	1988
1	0	1392	1364	1396	1908	1920	1916	1916	1924	1932	1932	1932	1936	1928	1928	1924	1916	1912	1912	1908	1912	1920	1928	1932	2056
	15	1460	1480	1440	2132	2132	2132	2104	2020	1948	1900	1816	1736	1672	1640	1620	1600	1576	1560	1544	1528	1524	1520	1528	1672
	30	1400	1412	1276	1712	1636	1592	1556	1564	1552	1536	1540	1544	1556	1560	1556	1560	1564	1560	1564	1564	1564	1560	1556	1692
	45	1388	1400	1568	2160	2220	2272	2340	2408	2444	2432	2432	2436	2432	2432	2432	2428	2428	2432	2440	2440	2436	2432	2432	2512
2	0	1436	1428	1416	2144	2156	2156	2148	2144	2192	2268	2348	2416	2480	2512	2532	2540	2540	2540	2532	2540	2536	2536	2532	2656
	15	1368	1372	1376	2108	2108	2108	2108	2112	2112	2104	2100	2108	2108	2108	2116	2132	2148	2160	2160	2160	2164	2164	2160	2272
	30	1224	1216	1220	2132	2132	2132	2132	2132	2132	2140	2144	2132	2128	2124	2120	2120	2128	2128	2144	2152	2152	2156	2160	2268
	45	1448	1424	1380	2148	2148	2148	2148	2148	2144	2136	2140	2132	2136	2140	2144	2148	2144	2148	2144	2140	2144	2144	2144	2272
3	0	1356	1372	1404	2084	2084	2076	2080	2084	2080	2084	2076	2088	2084	2084	2084	2084	2088	2088	2092	2080	2076	2072	2072	2156
	15	1296	1308	1312	1924	1932	1940	1940	1936	1932	1940	1944	1952	1956	1952	1952	1948	1936	1932	1928	1940	1948	1956	1960	2072
	30	1152	1128	1156	1804	1800	1800	1804	1804	1816	1804	1800	1796	1796	1800	1800	1804	1816	1820	1824	1828	1824	1828	1828	1940
	45	1208	1232	1196	1744	1744	1744	1736	1740	1736	1748	1748	1748	1748	1748	1744	1744	1740	1736	1728	1720	1720	1720	1724	1836
4	0	1308	1280	1324	1948	1952	1944	1936	1936	1936	1936	1940	1944	1940	1936	1936	1928	1924	1924	1928	1932	1936	1932	1928	2020

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: E

		NODE1																							
		60	70	80	90	100	110	120	130	140	150	160	170	180	190	191	192	201	202	203	210	211	212	213	220
		VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH
		(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)
HOUR	MINUTE																								
0	30	1464	1460	1436	1976	1976	1976	1968	1976	1980	1984	1984	1984	1984	1992	1988	1988	1984	1976	1984	1984	1980	1980	1980	2104
	45	1268	1272	1272	1904	1896	1896	1900	1892	1884	1880	1876	1868	1872	1868	1876	1876	1880	1888	1888	1892	1892	1892	1884	1988
1	0	1392	1364	1396	1908	1920	1916	1916	1924	1932	1932	1932	1936	1928	1928	1924	1916	1912	1912	1908	1912	1920	1928	1932	2056
	15	1460	1484	1440	2156	2152	2156	2152	2144	2096	2028	1952	1872	1804	1772	1748	1736	1712	1692	1680	1676	1676	1672	1672	1800
	30	1400	1404	1368	1992	1928	1848	1776	1724	1696	1696	1716	1728	1724	1720	1720	1716	1712	1712	1712	1712	1712	1712	1716	1868
	45	1408	1408	1476	2064	2128	2216	2284	2340	2400	2396	2372	2360	2380	2384	2388	2388	2396	2400	2404	2396	2380	2376	2364	2452
2	0	1436	1428	1424	2200	2196	2188	2196	2196	2204	2264	2340	2412	2472	2508	2528	2548	2560	2556	2556	2556	2564	2560	2568	2688
	15	1348	1368	1372	2140	2140	2140	2128	2120	2124	2136	2140	2148	2148	2148	2152	2156	2168	2184	2192	2196	2196	2200	2200	2304
	30	1228	1216	1212	2040	2052	2048	2060	2068	2064	2060	2052	2052	2048	2044	2040	2036	2036	2040	2044	2052	2060	2064	2072	2180
	45	1444	1428	1392	2132	2120	2128	2124	2120	2128	2132	2144	2140	2136	2140	2144	2136	2116	2100	2084	2076	2068	2056	2048	2176
3	0	1356	1368	1392	2084	2088	2084	2088	2092	2080	2080	2076	2084	2084	2084	2084	2096	2116	2132	2148	2148	2148	2156	2152	2244
	15	1292	1308	1316	1888	1888	1896	1900	1900	1904	1908	1912	1912	1916	1916	1916	1912	1900	1892	1888	1896	1900	1896	1908	2012
	30	1156	1128	1156	1804	1800	1788	1788	1780	1780	1776	1772	1772	1776	1776	1776	1780	1792	1800	1804	1804	1808	1820	1816	1932
	45	1216	1232	1200	1748	1756	1764	1756	1760	1772	1776	1780	1780	1780	1776	1772	1760	1756	1752	1752	1740	1732	1724	1720	1828
4	0	1308	1280	1320	1884	1888	1884	1884	1892	1892	1880	1872	1860	1856	1856	1852	1856	1852	1848	1848	1860	1868	1876	1880	1996

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: F

HOUR	MINUTE	NODE1 60 VPH (adj)	70 VPH (adj)	80 VPH (adj)	90 VPH (adj)	100 VPH (adj)	110 VPH (adj)	120 VPH (adj)	130 VPH (adj)	140 VPH (adj)	150 VPH (adj)	160 VPH (adj)	170 VPH (adj)	180 VPH (adj)	190 VPH (adj)	191 VPH (adj)	192 VPH (adj)	201 VPH (adj)	202 VPH (adj)	203 VPH (adj)	210 VPH (adj)	211 VPH (adj)	212 VPH (adj)	213 VPH (adj)	220 VPH (adj)
0	30	1464	1460	1436	1976	1976	1976	1968	1976	1980	1984	1984	1984	1984	1992	1988	1988	1984	1976	1984	1984	1980	1980	1980	2104
	45	1268	1272	1272	1904	1896	1896	1900	1892	1884	1880	1876	1868	1872	1868	1876	1876	1880	1888	1888	1892	1892	1892	1884	1988
1	0	1392	1364	1396	1908	1920	1916	1916	1924	1932	1932	1932	1936	1928	1928	1924	1916	1912	1912	1908	1912	1920	1928	1932	2056
	15	1460	1484	1440	2112	2112	2112	2112	2108	2104	2088	2012	1952	1892	1860	1840	1820	1796	1784	1784	1780	1780	1776	1776	1904
	30	1400	1400	1428	2068	2044	1980	1908	1860	1808	1748	1752	1740	1736	1736	1732	1732	1728	1724	1728	1728	1728	1728	1732	1876
	45	1408	1412	1424	2056	2080	2152	2216	2256	2316	2392	2416	2408	2416	2416	2424	2428	2432	2436	2420	2416	2408	2400	2396	2484
2	0	1440	1428	1408	2108	2100	2096	2100	2100	2080	2076	2128	2204	2268	2304	2324	2344	2372	2380	2392	2392	2388	2392	2384	2508
	15	1344	1368	1376	2108	2112	2112	2112	2120	2132	2136	2136	2144	2140	2140	2140	2140	2128	2124	2112	2108	2108	2108	2112	2216
	30	1228	1212	1216	2148	2148	2156	2156	2148	2148	2140	2132	2124	2128	2124	2120	2120	2132	2140	2156	2168	2180	2184	2196	2320
	45	1444	1428	1392	2128	2124	2120	2128	2132	2140	2140	2136	2140	2132	2128	2128	2132	2128	2124	2120	2108	2108	2100	2088	2204
3	0	1356	1368	1392	2044	2048	2052	2044	2048	2036	2044	2056	2060	2060	2068	2072	2072	2072	2076	2080	2088	2080	2088	2084	2164
	15	1292	1312	1316	1860	1864	1856	1860	1864	1872	1872	1872	1868	1876	1876	1876	1868	1860	1856	1852	1856	1864	1868	1876	1984
	30	1156	1128	1156	1828	1824	1832	1828	1820	1824	1820	1816	1820	1820	1820	1820	1828	1840	1844	1848	1848	1848	1844	1848	1964
	45	1216	1232	1200	1700	1704	1700	1704	1700	1696	1704	1704	1700	1696	1692	1684	1672	1668	1664	1664	1660	1660	1660	1660	1772
4	0	1308	1284	1320	1848	1848	1852	1852	1860	1860	1852	1856	1860	1860	1860	1864	1864	1860	1864	1864	1868	1868	1864	1868	1972

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: G

HOUR	MINUTE	NODE1 60 VPH (adj)	70 VPH (adj)	80 VPH (adj)	90 VPH (adj)	100 VPH (adj)	110 VPH (adj)	120 VPH (adj)	130 VPH (adj)	140 VPH (adj)	150 VPH (adj)	160 VPH (adj)	170 VPH (adj)	180 VPH (adj)	190 VPH (adj)	191 VPH (adj)	192 VPH (adj)	201 VPH (adj)	202 VPH (adj)	203 VPH (adj)	210 VPH (adj)	211 VPH (adj)	212 VPH (adj)	213 VPH (adj)	220 VPH (adj)
0	30	1464	1460	1436	1976	1976	1976	1968	1976	1980	1984	1984	1984	1984	1992	1988	1988	1984	1976	1984	1984	1980	1980	1980	2104
	45	1268	1272	1272	1904	1896	1896	1900	1892	1884	1880	1876	1868	1872	1868	1876	1876	1880	1888	1888	1892	1892	1892	1884	1988
1	0	1392	1364	1396	1908	1920	1916	1916	1924	1932	1932	1932	1936	1928	1928	1924	1916	1912	1912	1908	1912	1920	1928	1932	2056
	15	1456	1484	1432	2120	2124	2132	2116	2112	2108	2112	2108	2056	1988	1956	1932	1916	1908	1900	1900	1892	1888	1880	1880	2012
	30	1404	1404	1432	2116	2112	2108	2120	2048	1988	1920	1868	1856	1852	1852	1852	1852	1852	1856	1852	1856	1856	1856	1860	2004
	45	1408	1404	1424	2060	2052	2052	2044	2108	2172	2236	2288	2356	2436	2472	2500	2516	2520	2516	2516	2516	2516	2520	2524	2620
2	0	1416	1428	1416	2132	2136	2128	2140	2140	2144	2140	2136	2128	2128	2124	2124	2128	2132	2136	2144	2144	2144	2140	2140	2276
	15	1368	1372	1368	2128	2128	2132	2132	2140	2128	2136	2148	2156	2156	2160	2160	2164	2164	2168	2168	2168	2160	2156	2144	2228
	30	1228	1216	1220	2140	2144	2148	2148	2136	2136	2128	2124	2116	2116	2112	2108	2104	2108	2108	2108	2108	2116	2120	2128	2240
	45	1444	1428	1392	2112	2108	2116	2116	2132	2132	2132	2124	2132	2124	2124	2120	2120	2116	2116	2108	2112	2112	2108	2104	2224
3	0	1356	1368	1392	2044	2048	2040	2040	2032	2044	2048	2052	2052	2056	2056	2064	2068	2072	2072	2080	2072	2068	2072	2072	2160
	15	1292	1308	1316	1864	1860	1860	1856	1856	1848	1852	1856	1852	1856	1860	1860	1848	1840	1836	1832	1840	1848	1856	1856	1972
	30	1156	1128	1156	1812	1812	1808	1812	1816	1820	1804	1800	1804	1804	1800	1800	1812	1820	1824	1828	1828	1828	1828	1832	1944
	45	1216	1232	1200	1744	1752	1756	1748	1748	1740	1756	1760	1752	1740	1732	1728	1724	1720	1720	1712	1704	1696	1692	1696	1812
4	0	1308	1280	1320	1824	1816	1820	1832	1816	1828	1824	1824	1828	1820	1820	1824	1828	1832	1828	1828	1836	1844	1836	1832	1932

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: H

		NODE1																							
		60	70	80	90	100	110	120	130	140	150	160	170	180	190	191	192	201	202	203	210	211	212	213	220
		VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH
		(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)
HOUR	MINUTE																								
0	30	1464	1460	1436	1976	1976	1976	1968	1976	1980	1984	1984	1984	1984	1992	1988	1988	1984	1976	1984	1984	1980	1980	1980	2104
	45	1268	1272	1272	1904	1896	1896	1900	1892	1884	1880	1876	1868	1872	1868	1876	1876	1880	1888	1888	1892	1892	1892	1884	1988
1	0	1392	1364	1396	1908	1920	1916	1916	1924	1932	1932	1932	1936	1928	1928	1924	1916	1912	1912	1908	1912	1920	1928	1932	2056
	15	1460	1484	1432	2116	2116	2116	2112	2040	1964	1892	1828	1756	1684	1652	1628	1612	1616	1616	1616	1612	1608	1608	1612	1752
	30	1400	1400	1196	1584	1524	1464	1392	1384	1384	1392	1384	1376	1380	1384	1380	1380	1376	1376	1380	1384	1388	1384	1388	1540
	45	1408	1412	1664	2308	2356	2420	2484	2508	2516	2504	2492	2500	2504	2508	2520	2520	2500	2484	2476	2460	2452	2444	2440	2508
2	0	1432	1424	1416	2072	2080	2072	2076	2128	2192	2272	2352	2416	2452	2448	2444	2444	2448	2452	2448	2448	2448	2452	2448	2572
	15	1352	1372	1360	2064	2064	2072	2080	2076	2072	2060	2064	2076	2112	2144	2168	2192	2208	2220	2228	2236	2236	2236	2236	2340
	30	1228	1216	1224	2120	2116	2120	2120	2124	2120	2128	2124	2112	2108	2100	2100	2100	2104	2104	2108	2112	2120	2112	2116	2244
	45	1444	1424	1376	2132	2128	2124	2128	2124	2132	2128	2120	2128	2128	2136	2136	2136	2132	2128	2124	2128	2128	2144	2140	2260
3	0	1356	1372	1412	2076	2084	2080	2068	2064	2068	2068	2076	2080	2080	2080	2080	2080	2080	2080	2076	2068	2060	2056	2056	2136
	15	1296	1308	1312	1888	1892	1900	1892	1904	1900	1896	1900	1896	1900	1896	1888	1876	1876	1880	1888	1896	1904	1900	1904	2020
	30	1152	1128	1156	1776	1776	1776	1788	1780	1788	1796	1788	1792	1792	1796	1804	1816	1820	1820	1820	1820	1820	1824	1820	1916
	45	1212	1232	1204	1832	1832	1832	1832	1836	1836	1832	1836	1828	1808	1800	1796	1796	1788	1784	1780	1780	1776	1772	1772	1912
4	0	1308	1280	1316	1808	1808	1800	1804	1808	1804	1804	1812	1816	1832	1832	1824	1820	1812	1812	1812	1808	1812	1820	1824	1928

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: I

NODE1

HOUR	MINUTE	60 VPH (adj)	70 VPH (adj)	80 VPH (adj)	90 VPH (adj)	100 VPH (adj)	110 VPH (adj)	120 VPH (adj)	130 VPH (adj)	140 VPH (adj)	150 VPH (adj)	160 VPH (adj)	170 VPH (adj)	180 VPH (adj)	190 VPH (adj)	191 VPH (adj)	192 VPH (adj)	201 VPH (adj)	202 VPH (adj)	203 VPH (adj)	210 VPH (adj)	211 VPH (adj)	212 VPH (adj)	213 VPH (adj)	220 VPH (adj)
0	30	1464	1460	1436	1976	1976	1976	1968	1976	1980	1984	1984	1984	1984	1992	1988	1988	1984	1976	1984	1984	1980	1980	1980	2104
	45	1268	1272	1272	1904	1896	1896	1900	1892	1884	1880	1876	1868	1872	1868	1876	1876	1880	1888	1888	1892	1892	1892	1884	1988
1	0	1392	1364	1396	1908	1920	1916	1916	1924	1932	1932	1932	1936	1928	1928	1924	1916	1912	1912	1908	1912	1920	1928	1932	2056
	15	1460	1484	1436	2164	2160	2164	2160	2156	2148	2152	2116	2052	2000	1968	1952	1960	1956	1952	1956	1956	1944	1940	1944	2080
	30	1400	1408	1436	2100	2100	2100	2096	2096	2096	2088	2076	2064	2044	2048	2056	2048	2048	2044	2036	2032	2036	2032	2028	2156
	45	1408	1404	1420	2108	2108	2108	2104	2104	2108	2112	2164	2244	2324	2352	2356	2356	2356	2364	2372	2372	2380	2380	2380	2496
2	0	1440	1424	1416	2168	2164	2160	2164	2160	2160	2144	2140	2136	2132	2132	2140	2144	2152	2148	2148	2148	2140	2140	2140	2256
	15	1344	1372	1360	2108	2116	2120	2124	2120	2124	2140	2144	2144	2148	2152	2152	2156	2152	2140	2128	2116	2112	2104	2104	2192
	30	1228	1216	1224	2100	2092	2096	2104	2104	2104	2104	2088	2084	2084	2080	2076	2072	2076	2092	2104	2108	2116	2128	2124	2248
	45	1444	1428	1392	2156	2152	2148	2136	2140	2124	2128	2144	2140	2116	2120	2124	2120	2108	2100	2092	2100	2092	2088	2088	2208
3	0	1356	1364	1396	2004	2016	2024	2028	2032	2052	2044	2044	2044	2064	2064	2060	2068	2080	2080	2080	2068	2072	2068	2064	2156
	15	1296	1312	1312	1920	1924	1916	1920	1920	1916	1920	1912	1924	1928	1928	1932	1932	1920	1924	1928	1936	1944	1956	1968	2072
	30	1152	1128	1156	1764	1756	1764	1756	1748	1748	1752	1752	1752	1752	1752	1752	1752	1764	1768	1764	1764	1756	1756	1760	1884
	45	1216	1232	1196	1744	1744	1736	1744	1752	1744	1740	1744	1740	1740	1736	1724	1716	1712	1712	1716	1724	1728	1724	1720	1824
4	0	1300	1284	1324	1776	1780	1776	1780	1776	1776	1776	1780	1780	1780	1776	1780	1780	1776	1772	1772	1768	1768	1772	1772	1896

VOLUME (VPHPL): 1050,
DURATION: 30,
AND LOCATION: J

		NODE1																							
		60	70	80	90	100	110	120	130	140	150	160	170	180	190	191	192	201	202	203	210	211	212	213	220
		VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH	VPH
		(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)	(adj)
HOUR	MINUTE																								
0	30	1464	1460	1436	1976	1976	1976	1968	1976	1980	1984	1984	1984	1984	1992	1988	1988	1984	1976	1984	1984	1980	1980	1980	2104
	45	1268	1272	1272	1904	1896	1896	1900	1892	1884	1880	1876	1868	1872	1868	1876	1876	1880	1888	1888	1892	1892	1892	1884	1988
1	0	1392	1364	1396	1908	1920	1916	1916	1924	1932	1932	1932	1936	1928	1928	1924	1916	1912	1912	1908	1912	1920	1928	1932	2056
	15	1460	1484	1400	1976	1912	1848	1764	1696	1620	1544	1468	1404	1344	1316	1316	1320	1324	1316	1320	1320	1316	1312	1312	1456
	30	1400	1404	1080	1448	1452	1444	1464	1452	1444	1452	1472	1456	1440	1440	1444	1444	1444	1452	1452	1448	1452	1456	1464	1612
	45	1408	1408	1812	2428	2480	2544	2552	2568	2596	2596	2568	2576	2596	2596	2568	2548	2528	2512	2508	2504	2496	2484	2476	2540
2	0	1432	1424	1412	2248	2240	2260	2316	2376	2428	2492	2508	2500	2496	2496	2500	2496	2492	2492	2480	2472	2468	2468	2464	2584
	15	1352	1372	1376	2104	2116	2116	2108	2104	2112	2112	2180	2260	2324	2356	2372	2388	2408	2424	2440	2452	2460	2468	2468	2580
	30	1228	1212	1212	2080	2084	2068	2076	2076	2068	2072	2072	2072	2072	2068	2076	2084	2084	2084	2084	2088	2088	2084	2096	2224
	45	1444	1432	1400	2176	2168	2172	2172	2168	2168	2156	2152	2128	2132	2136	2136	2136	2132	2128	2120	2112	2112	2112	2104	2212
3	0	1356	1368	1388	2072	2076	2080	2076	2076	2076	2088	2092	2116	2112	2112	2112	2116	2120	2124	2128	2132	2124	2128	2128	2216
	15	1296	1308	1312	1864	1856	1860	1864	1868	1864	1868	1864	1868	1872	1868	1868	1864	1856	1844	1844	1848	1856	1856	1856	1968
	30	1152	1128	1156	1816	1824	1824	1820	1820	1820	1820	1824	1820	1820	1824	1824	1828	1840	1848	1848	1848	1848	1852	1860	1984
	45	1216	1232	1204	1760	1756	1752	1756	1764	1776	1768	1768	1764	1752	1740	1732	1724	1724	1724	1724	1724	1728	1724	1712	1824
4	0	1296	1284	1316	1760	1764	1764	1760	1756	1744	1752	1752	1756	1768	1776	1780	1780	1772	1772	1776	1776	1776	1772	1768	1868

Appendix D

Examples QSIM

-Note: Values are the averages obtained by runnign QSIM in stochastic mode.

AADT/C=1

HOUR	VHT_U	VHT_R	VHT_I	VMT
1	0.97	0.00	0.00	58
2	0.63	0.00	0.00	38
3	0.52	0.00	0.00	31
4	0.52	0.00	0.00	31
5	0.88	0.00	0.00	53
6	2.67	0.00	0.00	160
7	7.48	0.00	0.00	448
8	11.07	0.00	0.01	664
9	8.16	0.00	0.01	489
10	5.93	0.00	0.01	355
11	5.62	0.00	0.01	337
12	5.87	0.00	0.01	352
13	6.07	0.00	0.01	364
14	6.18	0.00	0.01	371
15	6.72	0.00	0.00	403
16	7.47	0.00	0.00	448
17	7.95	0.00	0.00	477
18	7.82	0.00	0.00	470
19	6.08	0.00	0.00	365
20	4.48	0.00	0.01	269
21	3.53	0.00	0.00	211
22	3.20	0.00	0.00	192
23	2.60	0.00	0.00	156
24	1.82	0.00	0.00	109
25	1.32	0.00	0.00	79
26	0.76	0.00	0.00	46
27	0.58	0.00	0.00	35
28	0.50	0.00	0.00	30
29	0.66	0.00	0.00	40
30	1.55	0.00	0.00	93
31	4.00	0.00	0.00	240
32	6.65	0.00	0.00	399
33	5.88	0.00	0.00	353
34	5.13	0.00	0.00	308
35	5.33	0.00	0.00	320
36	5.87	0.00	0.00	352
37	6.20	0.00	0.00	372
38	6.34	0.00	0.00	380
39	7.14	0.00	0.00	428
40	9.18	0.00	0.00	551
41	11.01	0.00	0.01	661
42	11.12	0.00	0.04	667
43	7.41	0.00	0.04	443
44	5.12	0.00	0.01	307
45	4.08	0.00	0.00	245
46	3.73	0.00	0.00	224
47	2.98	0.00	0.00	179
48	2.25	0.00	0.00	135
49	1.92	0.00	0.00	115
50	1.29	0.00	0.00	77
51	0.95	0.00	0.00	57
52	0.61	0.00	0.00	37
53	0.56	0.00	0.00	34
54	0.91	0.00	0.00	55
55	1.79	0.00	0.00	107
56	2.58	0.00	0.00	155
57	3.30	0.00	0.00	198
58	4.18	0.00	0.00	250
59	5.04	0.00	0.00	302
60	5.74	0.00	0.00	344
61	6.29	0.00	0.00	377
62	6.28	0.00	0.00	377
63	6.30	0.00	0.00	378
64	6.39	0.00	0.00	383
65	6.39	0.00	0.00	384
66	6.13	0.00	0.00	367
67	5.54	0.00	0.01	332
68	4.59	0.00	0.01	275
69	3.77	0.00	0.01	226
70	3.35	0.00	0.00	201
71	2.91	0.00	0.00	175
72	2.21	0.00	0.00	133
TOTAL	318.09	0.00	0.27	19,077

AADT/C=2

HOUR	VHT_U	VHT_R	VHT_I	VMT
1	1.94	0.00	0.00	116
2	1.26	0.00	0.00	75
3	1.04	0.00	0.00	62
4	1.05	0.00	0.00	63
5	1.75	0.00	0.00	105
6	5.35	0.00	0.00	320
7	14.91	0.00	0.01	895
8	22.12	0.00	0.04	1,328
9	16.33	0.00	0.06	979
10	11.83	0.00	0.03	710
11	11.25	0.00	0.03	674
12	11.72	0.00	0.03	703
13	12.12	0.00	0.02	728
14	12.35	0.00	0.02	742
15	13.41	0.00	0.03	806
16	14.95	0.00	0.04	896
17	15.90	0.00	0.04	955
18	15.65	0.00	0.03	940
19	12.15	0.00	0.03	729
20	8.94	0.00	0.02	537
21	7.05	0.00	0.03	423
22	6.40	0.00	0.02	384
23	5.19	0.00	0.00	312
24	3.62	0.00	0.00	217
25	2.64	0.00	0.00	159
26	1.52	0.00	0.00	91
27	1.15	0.00	0.00	69
28	1.00	0.00	0.00	60
29	1.32	0.00	0.00	79
30	3.11	0.00	0.00	186
31	8.01	0.00	0.00	481
32	13.29	0.00	0.01	798
33	11.77	0.00	0.01	705
34	10.26	0.00	0.01	615
35	10.67	0.00	0.00	640
36	11.73	0.00	0.01	704
37	12.41	0.00	0.03	743
38	12.68	0.00	0.02	761
39	14.28	0.00	0.00	858
40	18.38	0.00	0.01	1,102
41	22.06	0.00	0.02	1,323
42	22.19	0.00	0.03	1,331
43	14.77	0.00	0.02	887
44	10.21	0.00	0.01	614
45	8.16	0.00	0.00	490
46	7.46	0.00	0.01	448
47	5.99	0.00	0.02	358
48	4.49	0.00	0.02	269
49	3.84	0.00	0.00	230
50	2.57	0.00	0.00	154
51	1.89	0.00	0.00	114
52	1.23	0.00	0.00	73
53	1.12	0.00	0.00	67
54	1.83	0.00	0.00	110
55	3.57	0.00	0.00	213
56	5.17	0.00	0.00	310
57	6.60	0.00	0.00	396
58	8.34	0.00	0.00	500
59	10.08	0.00	0.01	604
60	11.48	0.00	0.01	689
61	12.56	0.00	0.01	753
62	12.56	0.00	0.02	753
63	12.60	0.00	0.02	757
64	12.77	0.00	0.03	766
65	12.78	0.00	0.03	766
66	12.26	0.00	0.02	736
67	11.08	0.00	0.02	665
68	9.15	0.00	0.01	549
69	7.55	0.00	0.01	453
70	6.71	0.00	0.02	403
71	5.82	0.00	0.02	349
72	4.44	0.00	0.01	267
TOTAL	635.83	0.00	0.94	38,151

AADT/C=3

HOUR	VHT_U	VHT_R	VHT_I	VMT
1	2.91	0.00	0.00	175
2	1.89	0.00	0.00	113
3	1.57	0.00	0.00	94
4	1.57	0.00	0.00	94
5	2.63	0.00	0.00	158
6	8.00	0.00	0.00	481
7	22.40	0.00	0.02	1,344
8	33.23	0.00	0.10	1,991
9	24.46	0.00	0.20	1,468
10	17.76	0.00	0.17	1,065
11	16.84	0.00	0.13	1,012
12	17.55	0.00	0.12	1,054
13	18.22	0.00	0.06	1,092
14	18.55	0.00	0.03	1,113
15	20.13	0.00	0.05	1,208
16	22.42	0.00	0.07	1,345
17	23.87	0.00	0.07	1,432
18	23.53	0.00	0.05	1,409
19	18.24	0.00	0.05	1,095
20	13.42	0.00	0.06	806
21	10.56	0.00	0.04	634
22	9.58	0.00	0.04	575
23	7.80	0.00	0.03	468
24	5.46	0.00	0.01	327
25	3.95	0.00	0.00	237
26	2.28	0.00	0.00	137
27	1.73	0.00	0.00	104
28	1.50	0.00	0.00	90
29	1.99	0.00	0.00	119
30	4.66	0.00	0.00	280
31	12.01	0.00	0.00	721
32	19.94	0.00	0.03	1,197
33	17.61	0.00	0.05	1,058
34	15.38	0.00	0.04	924
35	15.99	0.00	0.02	960
36	17.60	0.00	0.02	1,056
37	18.61	0.00	0.02	1,116
38	19.02	0.00	0.02	1,141
39	21.42	0.00	0.05	1,285
40	27.57	0.00	0.09	1,654
41	33.04	0.00	0.11	1,983
42	33.33	0.00	0.07	1,999
43	22.15	0.00	0.03	1,330
44	15.30	0.00	0.03	919
45	12.23	0.00	0.04	735
46	11.25	0.00	0.04	674
47	8.98	0.00	0.03	538
48	6.74	0.00	0.03	404
49	5.75	0.00	0.00	346
50	3.86	0.00	0.00	231
51	2.84	0.00	0.00	170
52	1.84	0.00	0.00	110
53	1.67	0.00	0.00	101
54	2.73	0.00	0.00	165
55	5.36	0.00	0.00	320
56	7.75	0.00	0.00	463
57	9.91	0.00	0.01	591
58	12.50	0.00	0.02	751
59	15.12	0.00	0.02	906
60	17.20	0.00	0.02	1,033
61	18.82	0.00	0.05	1,131
62	18.80	0.00	0.04	1,129
63	18.93	0.00	0.02	1,135
64	19.22	0.00	0.03	1,150
65	19.18	0.00	0.04	1,151
66	18.35	0.00	0.06	1,102
67	16.57	0.00	0.06	996
68	13.76	0.00	0.02	824
69	11.32	0.00	0.02	678
70	10.04	0.00	0.02	603
71	8.71	0.00	0.01	523
72	6.67	0.00	0.00	401
TOTAL	953.77	0.00	2.47	57,224

AADT/C=4

HOUR	VHT_U	VHT_R	VHT_I	VMT
1	3.89	0.00	0.00	233
2	2.52	0.00	0.00	151
3	2.08	0.00	0.00	125
4	2.09	0.00	0.00	126
5	3.51	0.00	0.00	210
6	10.69	0.00	0.00	641
7	29.79	0.00	0.03	1,790
8	44.29	0.00	0.11	2,655
9	32.64	0.00	0.13	1,960
10	23.64	0.00	0.09	1,419
11	22.48	0.00	0.08	1,350
12	23.40	0.00	0.07	1,405
13	24.27	0.00	0.04	1,456
14	24.73	0.00	0.05	1,485
15	26.87	0.00	0.10	1,611
16	29.88	0.00	0.10	1,793
17	31.80	0.00	0.06	1,910
18	31.36	0.00	0.06	1,881
19	24.30	0.00	0.08	1,460
20	17.89	0.00	0.07	1,072
21	14.07	0.00	0.05	845
22	12.78	0.00	0.03	767
23	10.37	0.00	0.04	624
24	7.25	0.00	0.03	436
25	5.30	0.00	0.00	316
26	3.04	0.00	0.00	182
27	2.31	0.00	0.00	138
28	2.00	0.00	0.00	120
29	2.65	0.00	0.00	159
30	6.21	0.00	0.00	373
31	16.02	0.00	0.01	961
32	26.59	0.00	0.02	1,595
33	23.50	0.00	0.03	1,410
34	20.49	0.00	0.05	1,232
35	21.35	0.00	0.08	1,279
36	23.49	0.00	0.11	1,409
37	24.82	0.00	0.11	1,489
38	25.34	0.00	0.14	1,520
39	28.55	0.00	0.15	1,716
40	36.76	0.00	0.14	2,204
41	44.11	0.00	0.23	2,646
42	44.39	0.00	0.45	2,665
43	29.49	0.00	0.44	1,772
44	20.42	0.00	0.24	1,226
45	16.35	0.00	0.14	981
46	14.96	0.00	0.09	897
47	11.96	0.00	0.04	717
48	8.99	0.00	0.01	540
49	7.67	0.00	0.00	460
50	5.16	0.00	0.00	308
51	3.78	0.00	0.00	227
52	2.45	0.00	0.00	147
53	2.25	0.00	0.00	135
54	3.66	0.00	0.00	219
55	7.12	0.00	0.01	426
56	10.33	0.00	0.02	618
57	13.19	0.00	0.02	791
58	16.71	0.00	0.01	1,001
59	20.18	0.00	0.02	1,211
60	22.93	0.00	0.04	1,375
61	25.10	0.00	0.07	1,507
62	25.12	0.00	0.09	1,508
63	25.20	0.00	0.07	1,513
64	25.59	0.00	0.07	1,536
65	25.56	0.00	0.08	1,533
66	24.51	0.00	0.09	1,472
67	22.16	0.00	0.09	1,329
68	18.29	0.00	0.08	1,099
69	15.05	0.00	0.07	904
70	13.40	0.00	0.05	803
71	11.60	0.00	0.03	697
72	8.89	0.00	0.02	533
TOTAL	1,271.57	0.00	4.65	76,309

AADT/C=5

HOUR	VHT_U	VHT_R	VHT_I	VMT
1	4.85	0.00	0.00	291
2	3.15	0.00	0.00	189
3	2.60	0.00	0.00	156
4	2.63	0.00	0.00	157
5	4.38	0.00	0.00	263
6	13.36	0.00	0.00	801
7	37.29	0.00	0.08	2,237
8	55.37	0.00	0.60	3,320
9	40.79	0.00	0.79	2,448
10	29.60	0.00	0.40	1,776
11	28.08	0.00	0.20	1,687
12	29.30	0.00	0.14	1,759
13	30.35	0.00	0.14	1,821
14	30.95	0.00	0.14	1,855
15	33.50	0.00	0.19	2,013
16	37.36	0.00	0.25	2,241
17	39.80	0.00	0.24	2,388
18	39.13	0.00	0.25	2,348
19	30.43	0.00	0.18	1,824
20	22.36	0.00	0.07	1,342
21	17.61	0.00	0.06	1,055
22	15.98	0.00	0.08	959
23	12.99	0.00	0.10	780
24	9.04	0.00	0.12	544
25	6.57	0.00	0.00	395
26	3.81	0.00	0.00	228
27	2.88	0.00	0.00	173
28	2.50	0.00	0.00	150
29	3.32	0.00	0.00	199
30	7.77	0.00	0.00	466
31	20.04	0.00	0.02	1,202
32	33.26	0.00	0.08	1,993
33	29.39	0.00	0.09	1,764
34	25.65	0.00	0.03	1,541
35	26.65	0.00	0.02	1,600
36	29.37	0.00	0.05	1,762
37	31.02	0.00	0.06	1,861
38	31.72	0.00	0.08	1,901
39	35.73	0.00	0.17	2,144
40	45.95	0.00	0.40	2,759
41	55.20	0.00	0.92	3,307
42	55.56	0.00	1.58	3,329
43	36.96	0.00	1.27	2,218
44	25.59	0.00	0.49	1,535
45	20.43	0.00	0.22	1,226
46	18.73	0.00	0.09	1,122
47	14.95	0.00	0.03	896
48	11.23	0.00	0.02	674
49	9.58	0.00	0.00	575
50	6.42	0.00	0.00	386
51	4.73	0.00	0.00	284
52	3.06	0.00	0.00	184
53	2.80	0.00	0.00	168
54	4.58	0.00	0.00	274
55	8.86	0.00	0.00	531
56	12.93	0.00	0.02	773
57	16.52	0.00	0.05	987
58	20.85	0.00	0.06	1,252
59	25.12	0.00	0.08	1,509
60	28.66	0.00	0.13	1,720
61	31.46	0.00	0.20	1,886
62	31.34	0.00	0.26	1,881
63	31.48	0.00	0.23	1,892
64	31.94	0.00	0.18	1,917
65	31.99	0.00	0.15	1,918
66	30.66	0.00	0.15	1,838
67	27.70	0.00	0.17	1,660
68	22.96	0.00	0.16	1,374
69	18.84	0.00	0.13	1,131
70	16.74	0.00	0.10	1,006
71	14.52	0.00	0.09	872
72	11.11	0.00	0.08	666
TOTAL	1,590.02	0.00	11.96	95,383

AADT/C=6

HOUR	VHT_U	VHT_R	VHT_I	VMT
1	5.81	0.00	0.00	349
2	3.78	0.00	0.00	226
3	3.13	0.00	0.00	187
4	3.14	0.00	0.00	189
5	5.27	0.00	0.01	315
6	16.04	0.00	0.02	962
7	44.74	0.00	0.14	2,685
8	66.72	0.00	1.20	3,987
9	49.02	0.00	1.89	2,938
10	35.53	0.00	1.22	2,131
11	33.74	0.00	0.62	2,023
12	35.10	0.00	0.36	2,107
13	36.37	0.00	0.28	2,180
14	37.15	0.00	0.29	2,228
15	40.25	0.00	0.32	2,416
16	44.83	0.00	0.44	2,691
17	47.81	0.00	0.65	2,863
18	46.95	0.00	0.85	2,819
19	36.49	0.00	0.73	2,190
20	26.82	0.00	0.38	1,608
21	21.16	0.00	0.20	1,269
22	19.19	0.00	0.13	1,152
23	15.60	0.00	0.07	936
24	10.88	0.00	0.06	654
25	7.92	0.00	0.00	475
26	4.56	0.00	0.00	274
27	3.46	0.00	0.00	208
28	2.99	0.00	0.00	180
29	3.98	0.00	0.00	238
30	9.32	0.00	0.00	560
31	24.03	0.00	0.00	1,442
32	39.91	0.00	0.10	2,393
33	35.25	0.00	0.24	2,116
34	30.83	0.00	0.25	1,847
35	31.94	0.00	0.19	1,918
36	35.28	0.00	0.14	2,117
37	37.20	0.00	0.15	2,232
38	37.99	0.00	0.20	2,280
39	42.89	0.00	0.26	2,570
40	55.18	0.00	0.77	3,308
41	66.33	0.00	2.01	3,968
42	66.84	0.00	3.27	3,993
43	44.30	0.00	2.55	2,659
44	30.77	0.00	0.88	1,841
45	24.47	0.00	0.32	1,470
46	22.46	0.00	0.17	1,345
47	17.95	0.00	0.07	1,076
48	13.57	0.00	0.02	810
49	11.48	0.00	0.00	690
50	7.72	0.00	0.00	462
51	5.68	0.00	0.00	341
52	3.66	0.00	0.00	220
53	3.36	0.00	0.00	201
54	5.46	0.00	0.00	329
55	10.61	0.00	0.00	637
56	15.37	0.00	0.02	929
57	19.77	0.00	0.02	1,187
58	25.04	0.00	0.02	1,502
59	30.22	0.00	0.04	1,810
60	34.52	0.00	0.10	2,069
61	37.72	0.00	0.22	2,260
62	37.72	0.00	0.30	2,260
63	37.85	0.00	0.32	2,270
64	38.34	0.00	0.33	2,300
65	38.35	0.00	0.40	2,301
66	36.88	0.00	0.37	2,210
67	33.22	0.00	0.36	1,991
68	27.52	0.00	0.36	1,651
69	22.57	0.00	0.27	1,358
70	20.12	0.00	0.21	1,205
71	17.45	0.00	0.12	1,048
72	13.35	0.00	0.06	801
TOTAL	1,908.93	0.00	25.00	114,456

AADT/C=7

HOUR	VHT_U	VHT_R	VHT_I	VMT
1	6.79	0.00	0.00	407
2	4.39	0.00	0.00	264
3	3.64	0.00	0.00	219
4	3.66	0.00	0.00	220
5	6.14	0.00	0.00	368
6	18.69	0.00	0.01	1,122
7	52.23	0.00	0.28	3,130
8	78.71	0.08	2.98	4,643
9	57.17	0.08	4.37	3,429
10	41.41	0.00	2.30	2,486
11	39.35	0.00	1.00	2,359
12	41.01	0.00	0.70	2,459
13	42.51	0.00	0.68	2,546
14	43.25	0.00	0.75	2,594
15	46.97	0.00	0.75	2,818
16	52.27	0.00	0.96	3,135
17	55.72	0.00	1.40	3,340
18	54.83	0.00	1.53	3,286
19	42.59	0.00	1.07	2,555
20	31.31	0.00	0.46	1,879
21	24.66	0.00	0.17	1,478
22	22.39	0.00	0.06	1,342
23	18.24	0.00	0.04	1,093
24	12.67	0.00	0.05	762
25	9.21	0.00	0.00	554
26	5.32	0.00	0.00	319
27	4.03	0.00	0.01	243
28	3.51	0.00	0.01	210
29	4.64	0.00	0.00	279
30	10.87	0.00	0.01	652
31	27.99	0.00	0.04	1,680
32	46.52	0.00	0.25	2,791
33	41.13	0.00	0.43	2,468
34	35.92	0.00	0.39	2,156
35	37.24	0.00	0.35	2,237
36	41.09	0.00	0.33	2,465
37	43.38	0.00	0.39	2,604
38	44.41	0.00	0.55	2,663
39	50.06	0.00	0.70	2,999
40	64.51	0.00	1.54	3,860
41	78.41	0.21	4.22	4,633
42	79.29	0.66	7.93	4,661
43	51.80	0.45	6.86	3,104
44	35.85	0.00	2.52	2,149
45	28.56	0.00	0.74	1,717
46	26.14	0.00	0.43	1,572
47	20.92	0.00	0.41	1,255
48	15.76	0.00	0.41	943
49	13.42	0.00	0.00	805
50	8.99	0.00	0.00	540
51	6.62	0.00	0.01	398
52	4.29	0.00	0.01	257
53	3.93	0.00	0.01	235
54	6.39	0.00	0.01	384
55	12.36	0.00	0.01	745
56	17.90	0.00	0.01	1,080
57	23.03	0.00	0.03	1,381
58	29.09	0.00	0.08	1,752
59	35.22	0.00	0.16	2,112
60	40.13	0.00	0.34	2,410
61	43.99	0.00	0.56	2,638
62	43.96	0.00	0.69	2,636
63	44.06	0.00	0.73	2,648
64	44.76	0.00	0.83	2,683
65	44.81	0.00	0.95	2,683
66	42.91	0.00	0.96	2,576
67	38.83	0.00	0.72	2,320
68	32.13	0.00	0.38	1,925
69	26.41	0.00	0.25	1,585
70	23.49	0.00	0.26	1,411
71	20.33	0.00	0.25	1,220
72	15.55	0.00	0.18	935
TOTAL	2,229.75	1.47	55.51	133,507

AADT/C=8

HOUR	VHT_U	VHT_R	VHT_I	VMT
1	7.86	0.00	0.00	473
2	5.00	0.00	0.00	299
3	4.06	0.00	0.00	243
4	4.04	0.00	0.00	242
5	6.81	0.00	0.00	409
6	20.95	0.00	0.01	1,257
7	58.80	0.00	0.57	3,525
8	90.47	8.82	5.82	5,178
9	67.74	9.33	8.74	4,046
10	48.85	0.51	4.95	2,929
11	45.41	0.00	2.42	2,724
12	47.39	0.00	1.68	2,841
13	48.87	0.00	1.43	2,929
14	49.97	0.00	1.40	2,996
15	53.75	0.00	1.43	3,223
16	59.37	0.00	1.80	3,558
17	63.02	0.00	2.60	3,769
18	61.87	0.00	3.21	3,703
19	48.74	0.00	2.70	2,923
20	36.00	0.00	1.48	2,156
21	28.17	0.00	0.59	1,688
22	26.03	0.00	0.23	1,560
23	21.31	0.00	0.11	1,279
24	14.87	0.00	0.06	891
25	10.48	0.00	0.00	629
26	6.13	0.00	0.01	368
27	4.66	0.00	0.00	280
28	3.95	0.00	0.00	237
29	5.17	0.00	0.01	311
30	12.55	0.00	0.01	754
31	33.36	0.00	0.05	2,004
32	54.57	0.00	0.46	3,272
33	48.78	0.00	0.85	2,929
34	41.64	0.00	0.74	2,498
35	42.66	0.00	0.55	2,564
36	47.41	0.00	0.64	2,845
37	50.04	0.00	0.90	3,003
38	51.12	0.00	1.08	3,063
39	57.49	0.00	1.42	3,443
40	72.80	0.00	2.95	4,328
41	87.91	4.29	8.07	5,078
42	88.07	13.34	15.59	5,078
43	58.88	9.11	13.90	3,528
44	41.04	0.06	5.78	2,467
45	32.73	0.00	2.10	1,964
46	30.49	0.00	0.87	1,828
47	24.70	0.00	0.37	1,484
48	18.62	0.00	0.17	1,116
49	15.35	0.00	0.02	923
50	10.29	0.00	0.03	618
51	7.57	0.00	0.01	454
52	4.88	0.00	0.01	293
53	4.48	0.00	0.00	269
54	7.30	0.00	0.00	439
55	14.18	0.00	0.02	848
56	20.68	0.00	0.09	1,239
57	26.38	0.00	0.19	1,580
58	33.44	0.00	0.25	2,003
59	40.37	0.00	0.33	2,418
60	45.91	0.00	0.54	2,757
61	50.18	0.00	0.82	3,009
62	50.27	0.00	1.06	3,013
63	50.42	0.00	1.31	3,024
64	51.10	0.00	1.42	3,074
65	51.18	0.00	1.40	3,069
66	48.96	0.00	1.33	2,943
67	44.33	0.00	1.24	2,656
68	36.69	0.00	1.01	2,198
69	30.11	0.00	0.68	1,809
70	26.81	0.00	0.53	1,611
71	23.21	0.00	0.44	1,394
72	17.83	0.00	0.32	1,068
TOTAL	2,556.49	45.46	110.84	152,618

AADT/C=9

HOUR	VHT_U	VHT_R	VHT_I	VMT
1	8.99	0.00	0.00	539
2	5.57	0.00	0.00	334
3	4.45	0.00	0.00	267
4	4.34	0.00	0.00	261
5	7.44	0.00	0.00	447
6	23.05	0.00	0.02	1,380
7	65.31	0.00	1.15	3,897
8	103.12	54.69	11.77	5,671
9	79.88	75.17	19.64	4,696
10	56.61	20.61	12.59	3,395
11	51.54	0.13	5.24	3,098
12	53.83	0.00	2.77	3,227
13	55.27	0.00	2.19	3,313
14	56.72	0.00	2.37	3,402
15	60.49	0.00	2.75	3,623
16	66.39	0.00	3.22	3,965
17	70.05	0.00	4.39	4,180
18	68.72	0.00	5.56	4,102
19	54.93	0.00	4.43	3,292
20	40.74	0.00	2.07	2,443
21	31.57	0.00	0.76	1,900
22	29.60	0.00	0.27	1,779
23	24.58	0.00	0.19	1,477
24	17.07	0.00	0.14	1,025
25	11.74	0.00	0.01	701
26	6.99	0.00	0.01	418
27	5.31	0.00	0.01	319
28	4.35	0.00	0.00	261
29	5.66	0.00	0.00	341
30	14.29	0.00	0.02	856
31	39.06	0.00	0.17	2,344
32	63.09	0.00	1.01	3,773
33	56.95	0.00	1.81	3,416
34	47.51	0.00	1.60	2,848
35	48.25	0.00	1.10	2,890
36	53.83	0.00	1.14	3,231
37	56.73	0.00	1.59	3,402
38	57.93	0.00	2.05	3,472
39	65.11	0.00	2.89	3,894
40	81.39	0.53	6.60	4,782
41	97.75	27.31	17.99	5,475
42	96.96	80.85	31.02	5,433
43	66.24	60.98	27.32	3,951
44	46.41	6.92	12.67	2,790
45	36.95	0.01	4.31	2,214
46	34.95	0.00	1.49	2,093
47	28.67	0.00	0.60	1,724
48	21.59	0.00	0.22	1,294
49	17.26	0.00	0.01	1,035
50	11.57	0.00	0.01	695
51	8.52	0.00	0.01	512
52	5.49	0.00	0.01	330
53	5.03	0.00	0.02	302
54	8.16	0.00	0.02	491
55	16.00	0.00	0.01	959
56	23.13	0.00	0.03	1,393
57	29.71	0.00	0.12	1,783
58	37.57	0.00	0.27	2,253
59	45.31	0.00	0.45	2,716
60	51.85	0.00	0.74	3,098
61	56.69	0.00	1.31	3,394
62	56.54	0.00	1.90	3,390
63	56.76	0.00	2.09	3,402
64	57.78	0.00	2.21	3,452
65	57.76	0.00	2.48	3,452
66	55.26	0.00	2.42	3,307
67	49.70	0.00	1.97	2,989
68	41.18	0.00	1.27	2,472
69	33.94	0.00	0.63	2,035
70	30.27	0.00	0.35	1,815
71	26.10	0.00	0.22	1,567
72	20.10	0.00	0.15	1,202
TOTAL	2,889.64	327.20	215.88	171,679

AADT/C=10

HOUR	VHT_U	VHT_R	VHT_I	VMT
1	10.25	0.00	0.01	616
2	6.18	0.00	0.01	371
3	4.83	0.00	0.01	290
4	4.61	0.00	0.01	276
5	7.85	0.00	0.01	470
6	25.12	0.00	0.03	1,508
7	70.63	0.16	1.29	4,202
8	112.01	124.36	7.84	5,984
9	89.67	217.80	16.78	5,155
10	64.51	100.79	17.31	3,862
11	58.68	7.23	10.61	3,517
12	60.75	0.04	5.69	3,639
13	62.11	0.00	3.99	3,719
14	63.72	0.00	3.78	3,814
15	67.74	0.00	4.40	4,044
16	74.19	0.04	6.14	4,408
17	77.72	0.15	8.84	4,596
18	76.85	0.42	11.16	4,542
19	62.36	0.31	10.15	3,727
20	46.32	0.00	5.91	2,779
21	35.83	0.00	2.47	2,149
22	33.78	0.00	1.11	2,029
23	27.91	0.00	0.70	1,673
24	19.50	0.00	0.42	1,167
25	12.85	0.00	0.00	770
26	7.65	0.00	0.00	458
27	5.82	0.00	0.00	349
28	4.57	0.00	0.00	274
29	6.12	0.00	0.00	367
30	16.08	0.00	0.02	965
31	45.65	0.00	0.15	2,736
32	72.10	0.00	1.71	4,292
33	65.72	0.00	3.45	3,929
34	54.57	0.00	3.27	3,272
35	54.69	0.00	2.67	3,281
36	60.59	0.00	2.71	3,626
37	63.42	0.00	3.29	3,793
38	64.88	0.00	4.08	3,880
39	72.85	0.04	5.34	4,325
40	89.69	8.22	9.52	5,148
41	108.04	102.86	21.36	5,850
42	105.37	265.71	37.99	5,751
43	74.67	235.43	39.27	4,401
44	52.61	66.31	23.68	3,147
45	41.66	1.91	9.87	2,499
46	39.16	0.00	3.50	2,347
47	32.34	0.00	1.51	1,944
48	24.16	0.00	0.65	1,448
49	19.13	0.00	0.02	1,149
50	12.84	0.00	0.02	770
51	9.45	0.00	0.01	568
52	6.12	0.00	0.01	367
53	5.60	0.00	0.00	335
54	9.15	0.00	0.01	548
55	17.78	0.00	0.03	1,064
56	25.80	0.00	0.13	1,545
57	32.80	0.00	0.31	1,975
58	41.72	0.00	0.49	2,503
59	50.49	0.00	0.78	3,028
60	57.61	0.00	1.52	3,440
61	63.12	0.00	2.69	3,770
62	63.10	0.00	3.56	3,772
63	63.54	0.00	3.83	3,783
64	64.43	0.08	4.07	3,839
65	64.41	0.22	4.49	3,841
66	61.64	0.21	4.48	3,680
67	55.36	0.07	3.86	3,318
68	45.68	0.00	2.81	2,745
69	37.70	0.00	1.58	2,260
70	33.59	0.00	0.81	2,013
71	28.98	0.00	0.45	1,744
72	22.24	0.00	0.22	1,332
TOTAL	3,230.66	1,132.36	328.89	190,780

AADT/C=11

HOUR	VHT_U	VHT_R	VHT_I	VMT
1	11.58	0.00	0.01	695
2	6.77	0.00	0.01	406
3	5.18	0.00	0.01	311
4	4.82	0.00	0.01	289
5	8.15	0.00	0.01	490
6	27.17	0.00	0.03	1,630
7	75.78	0.53	1.75	4,476
8	118.68	191.19	13.12	6,236
9	101.14	412.37	31.52	5,602
10	73.06	291.16	37.41	4,349
11	66.29	76.45	26.61	3,959
12	68.19	7.57	15.95	4,064
13	69.24	0.71	11.80	4,128
14	71.11	0.15	9.99	4,230
15	75.47	0.17	10.11	4,467
16	82.91	0.93	13.33	4,852
17	86.25	3.69	18.76	5,011
18	86.20	7.96	23.95	4,993
19	70.29	5.83	21.79	4,178
20	52.08	0.79	12.44	3,128
21	40.19	0.00	5.61	2,404
22	38.03	0.00	2.76	2,280
23	31.41	0.00	1.52	1,882
24	21.92	0.00	0.82	1,314
25	13.88	0.00	0.01	833
26	8.31	0.00	0.02	497
27	6.25	0.00	0.01	376
28	4.74	0.00	0.00	284
29	6.53	0.00	0.00	392
30	17.98	0.00	0.02	1,078
31	52.54	0.00	0.48	3,148
32	82.55	1.11	3.92	4,838
33	75.16	1.36	7.30	4,455
34	62.05	0.25	6.49	3,712
35	61.47	0.00	4.87	3,680
36	67.52	0.00	4.91	4,027
37	70.18	0.00	6.19	4,185
38	72.21	0.00	7.43	4,293
39	81.31	1.15	9.98	4,758
40	98.05	32.47	17.83	5,478
41	117.06	232.92	35.25	6,173
42	112.73	548.44	55.87	6,016
43	83.88	575.63	64.76	4,851
44	58.76	264.31	51.11	3,520
45	46.32	36.11	25.09	2,777
46	43.55	0.60	8.68	2,609
47	36.11	0.01	3.40	2,173
48	26.75	0.00	1.53	1,605
49	21.07	0.00	0.03	1,266
50	14.14	0.00	0.05	848
51	10.41	0.00	0.04	625
52	6.71	0.00	0.02	403
53	6.16	0.00	0.01	369
54	10.03	0.00	0.01	601
55	19.57	0.00	0.02	1,172
56	28.37	0.00	0.14	1,692
57	36.29	0.00	0.32	2,179
58	46.00	0.00	0.67	2,754
59	55.50	0.13	1.30	3,325
60	63.48	0.30	2.66	3,791
61	69.90	0.85	4.31	4,140
62	69.78	1.03	5.68	4,140
63	70.11	1.01	6.51	4,158
64	71.11	2.00	7.31	4,215
65	71.52	3.47	8.67	4,223
66	68.44	4.02	8.54	4,045
67	61.24	2.15	6.57	3,656
68	50.49	0.26	4.17	3,025
69	41.45	0.00	2.11	2,490
70	37.02	0.00	1.04	2,216
71	31.96	0.00	0.60	1,919
72	24.40	0.00	0.30	1,468
TOTAL	3,582.95	2,709.10	635.54	209,844

AADT/C=12

HOUR	VHT_U	VHT_R	VHT_I	VMT
1	13.00	0.00	0.00	778
2	7.37	0.00	0.01	440
3	5.53	0.00	0.01	332
4	4.98	0.00	0.01	299
5	8.40	0.00	0.00	504
6	28.98	0.00	0.02	1,740
7	80.79	2.44	2.59	4,718
8	123.87	257.59	15.77	6,429
9	113.14	655.56	34.04	6,028
10	82.97	654.35	46.25	4,856
11	74.38	347.18	47.33	4,413
12	76.07	124.79	38.88	4,500
13	76.90	41.69	31.02	4,548
14	79.07	14.28	27.01	4,651
15	83.98	9.82	25.98	4,894
16	93.05	22.77	32.38	5,287
17	95.92	52.19	45.33	5,410
18	96.76	93.92	58.22	5,430
19	79.25	86.98	56.98	4,641
20	58.38	29.72	35.16	3,492
21	44.58	1.57	14.06	2,669
22	42.37	0.02	5.13	2,543
23	34.96	0.00	2.09	2,101
24	24.46	0.00	0.85	1,466
25	14.92	0.00	0.01	894
26	8.87	0.00	0.02	534
27	6.70	0.00	0.02	402
28	4.83	0.00	0.01	290
29	6.87	0.00	0.00	413
30	19.92	0.00	0.03	1,194
31	59.95	0.00	0.75	3,591
32	95.94	24.92	5.15	5,400
33	86.40	42.40	11.64	5,017
34	70.07	19.22	12.97	4,177
35	68.70	1.80	10.50	4,097
36	74.84	0.33	9.81	4,436
37	77.84	0.93	11.19	4,583
38	80.23	1.69	13.84	4,711
39	91.05	15.37	19.60	5,197
40	106.37	106.20	30.22	5,783
41	124.52	447.81	50.76	6,450
42	118.44	924.25	76.88	6,227
43	94.59	1,088.16	94.72	5,308
44	65.52	718.34	88.64	3,899
45	51.28	217.80	57.72	3,074
46	47.98	19.92	26.40	2,876
47	40.14	0.59	9.96	2,404
48	29.39	0.00	3.94	1,766
49	22.96	0.00	0.01	1,380
50	15.46	0.00	0.01	927
51	11.35	0.00	0.02	681
52	7.34	0.00	0.01	440
53	6.70	0.00	0.01	403
54	10.93	0.00	0.00	657
55	21.17	0.00	0.07	1,272
56	30.75	0.00	0.21	1,848
57	39.65	0.00	0.38	2,374
58	50.34	0.00	0.77	3,010
59	60.73	0.36	2.01	3,619
60	70.03	2.76	4.34	4,129
61	77.24	7.99	7.97	4,523
62	77.00	10.05	11.90	4,518
63	77.43	9.92	14.29	4,537
64	79.23	16.50	14.25	4,600
65	79.18	25.49	17.09	4,606
66	75.46	26.01	19.24	4,410
67	67.20	14.96	14.39	3,988
68	55.04	3.49	8.63	3,295
69	45.24	0.09	4.63	2,714
70	40.20	0.00	2.35	2,413
71	34.94	0.00	1.41	2,093
72	26.66	0.00	0.88	1,600
TOTAL	3,956.75	6,142.21	1,178.81	228,928

AADT/C=13

HOUR	VHT_U	VHT_R	VHT_I	VMT
1	17.66	0.00	0.01	1,060
2	12.11	0.00	0.01	726
3	10.31	0.00	0.02	617
4	9.76	0.00	0.02	586
5	13.20	0.00	0.03	791
6	33.62	0.00	0.09	2,016
7	86.23	9.04	3.90	4,972
8	130.02	353.18	19.63	6,669
9	119.66	909.29	44.71	6,268
10	88.78	1,017.49	62.39	5,110
11	79.45	714.55	64.77	4,668
12	81.18	410.55	60.30	4,759
13	82.00	231.35	56.27	4,799
14	84.25	134.03	55.20	4,907
15	89.88	97.75	57.91	5,150
16	99.42	124.16	70.30	5,541
17	102.72	203.34	88.83	5,659
18	103.49	309.50	106.88	5,678
19	84.83	308.71	110.00	4,895
20	63.03	150.24	78.60	3,755
21	49.03	26.22	36.42	2,948
22	47.03	1.11	13.54	2,820
23	39.53	0.01	5.73	2,372
24	29.07	0.00	2.19	1,741
25	19.65	0.00	0.01	1,179
26	13.61	0.00	0.01	819
27	11.48	0.00	0.01	686
28	9.63	0.00	0.01	577
29	11.64	0.00	0.01	697
30	24.55	0.00	0.05	1,471
31	64.40	0.00	0.88	3,851
32	102.47	52.26	8.83	5,652
33	92.33	100.80	23.22	5,271
34	74.79	60.45	25.29	4,437
35	73.43	13.45	17.76	4,359
36	79.87	3.29	15.32	4,694
37	82.92	4.45	17.54	4,842
38	85.76	9.34	21.45	4,966
39	97.20	45.86	29.48	5,447
40	112.75	206.41	53.73	6,028
41	130.79	691.92	82.58	6,693
42	125.04	1,349.80	103.77	6,474
43	100.69	1,655.65	126.30	5,555
44	70.34	1,298.33	129.52	4,156
45	55.78	585.03	100.06	3,340
46	52.45	131.04	56.46	3,139
47	44.60	14.28	22.32	2,670
48	34.04	0.52	7.72	2,040
49	27.63	0.00	0.04	1,660
50	20.18	0.00	0.04	1,213
51	16.04	0.00	0.02	962
52	12.07	0.00	0.02	725
53	11.49	0.00	0.03	690
54	15.70	0.00	0.03	943
55	25.93	0.00	0.05	1,556
56	35.49	0.04	0.24	2,130
57	44.15	0.15	0.58	2,640
58	54.98	0.58	0.91	3,277
59	65.46	2.17	2.63	3,883
60	75.07	10.23	5.91	4,388
61	82.70	24.74	12.07	4,774
62	82.47	34.04	18.34	4,775
63	83.06	39.34	20.03	4,790
64	84.80	53.05	21.48	4,862
65	84.89	73.84	25.09	4,858
66	81.12	79.16	27.50	4,670
67	72.15	51.16	24.69	4,249
68	59.80	15.52	16.24	3,570
69	49.78	1.21	7.94	2,985
70	44.83	0.00	3.78	2,688
71	39.38	0.00	2.00	2,363
72	31.37	0.00	1.05	1,880
TOTAL	4,327.00	11,608.64	1,970.82	248,082

AADT/C=14

HOUR	VHT_U	VHT_R	VHT_I	VMT
1	22.94	0.00	0.02	1,380
2	17.48	0.00	0.05	1,049
3	15.71	0.00	0.06	944
4	15.15	0.00	0.05	910
5	18.54	0.00	0.04	1,111
6	38.58	0.00	0.09	2,314
7	91.76	22.70	5.53	5,208
8	134.92	453.47	24.25	6,873
9	125.40	1,159.20	48.03	6,480
10	94.39	1,399.40	62.77	5,339
11	84.51	1,169.60	70.53	4,915
12	86.43	873.21	76.84	4,994
13	87.48	659.84	80.48	5,041
14	89.74	515.50	86.17	5,143
15	95.67	457.69	96.02	5,383
16	105.56	526.24	112.71	5,764
17	108.95	700.20	133.62	5,881
18	109.62	916.95	151.19	5,898
19	90.38	955.26	158.23	5,131
20	67.57	632.87	139.00	4,016
21	53.73	229.36	91.25	3,222
22	51.77	40.12	43.67	3,097
23	44.35	4.02	17.67	2,662
24	34.14	0.11	6.41	2,047
25	24.91	0.00	0.01	1,493
26	19.01	0.00	0.02	1,142
27	16.84	0.00	0.02	1,013
28	15.08	0.00	0.05	903
29	17.06	0.00	0.04	1,022
30	29.66	0.00	0.04	1,780
31	69.08	0.00	1.15	4,113
32	108.57	93.17	10.84	5,870
33	98.31	204.99	26.23	5,495
34	79.60	158.41	31.14	4,682
35	78.00	61.12	27.89	4,603
36	84.91	26.80	27.09	4,936
37	88.22	28.83	30.39	5,078
38	91.10	42.55	36.79	5,196
39	103.26	114.05	50.11	5,668
40	119.02	374.89	76.60	6,248
41	135.60	1,005.12	105.78	6,894
42	129.85	1,804.65	126.16	6,662
43	106.33	2,243.54	146.06	5,768
44	75.25	1,968.70	161.87	4,415
45	60.45	1,160.86	151.09	3,612
46	57.02	442.94	108.30	3,412
47	49.40	104.05	56.80	2,958
48	38.96	10.61	22.25	2,340
49	32.75	0.00	0.06	1,966
50	25.33	0.00	0.11	1,523
51	21.39	0.00	0.08	1,283
52	17.53	0.00	0.05	1,052
53	16.89	0.00	0.05	1,013
54	20.91	0.00	0.04	1,264
55	31.11	0.00	0.12	1,863
56	40.81	0.43	0.56	2,436
57	48.98	1.15	1.31	2,925
58	59.61	2.29	1.98	3,539
59	70.72	8.33	3.91	4,148
60	80.35	26.58	9.77	4,636
61	88.25	60.69	18.37	5,018
62	87.58	88.01	26.64	5,015
63	88.38	101.57	33.57	5,030
64	89.82	125.44	40.48	5,092
65	90.48	165.47	44.79	5,097
66	86.40	187.58	43.42	4,909
67	77.40	146.60	37.02	4,501
68	64.30	65.82	26.49	3,830
69	54.26	13.38	15.14	3,255
70	49.49	1.12	7.21	2,970
71	44.14	0.08	3.59	2,655
72	36.26	0.00	1.96	2,178
TOTAL	4,703.38	21,555.58	2,918.11	267,300

AADT/C=15

HOUR	VHT_U	VHT_R	VHT_I	VMT
1	28.77	0.00	0.02	1,727
2	23.53	0.00	0.03	1,415
3	21.85	0.00	0.03	1,310
4	21.37	0.00	0.04	1,279
5	24.55	0.00	0.07	1,473
6	43.92	0.00	0.21	2,631
7	97.33	46.25	4.78	5,420
8	138.53	559.20	19.54	7,026
9	129.64	1,381.23	41.56	6,647
10	99.86	1,738.67	61.19	5,549
11	89.57	1,618.04	72.83	5,130
12	91.74	1,406.70	80.20	5,217
13	92.57	1,246.94	90.32	5,255
14	95.16	1,137.67	105.18	5,361
15	101.03	1,125.80	120.02	5,586
16	111.26	1,285.69	131.93	5,957
17	114.10	1,584.28	145.84	6,064
18	114.70	1,922.62	165.15	6,089
19	95.78	2,043.85	183.39	5,355
20	72.55	1,657.02	184.29	4,270
21	58.61	939.85	157.81	3,502
22	56.53	361.85	113.03	3,385
23	49.42	95.12	65.56	2,969
24	39.51	12.48	28.41	2,372
25	30.68	0.00	0.05	1,839
26	25.03	0.00	0.11	1,497
27	22.96	0.00	0.11	1,375
28	21.22	0.00	0.07	1,271
29	23.03	0.00	0.06	1,385
30	35.39	0.00	0.12	2,118
31	73.71	0.28	1.81	4,369
32	113.78	139.79	13.54	6,057
33	103.85	333.27	32.11	5,698
34	84.24	310.29	40.92	4,909
35	83.04	178.77	41.15	4,840
36	90.29	120.62	42.33	5,157
37	93.46	123.61	50.07	5,298
38	96.60	152.85	62.68	5,417
39	108.76	280.58	78.47	5,870
40	123.67	650.77	101.21	6,420
41	139.20	1,405.74	123.16	7,040
42	133.96	2,322.05	140.25	6,831
43	111.81	2,890.80	153.92	5,969
44	80.34	2,744.03	166.01	4,654
45	65.06	1,961.29	176.02	3,879
46	61.65	1,068.92	165.34	3,687
47	54.37	423.80	123.51	3,251
48	44.30	98.36	66.65	2,657
49	38.20	0.00	0.08	2,291
50	31.12	0.00	0.14	1,868
51	27.29	0.00	0.09	1,639
52	23.45	0.00	0.10	1,409
53	22.93	0.00	0.11	1,374
54	26.80	0.00	0.10	1,605
55	36.54	0.00	0.28	2,194
56	46.24	1.62	2.51	2,741
57	54.43	5.02	4.01	3,221
58	64.72	9.26	3.71	3,819
59	75.55	22.38	7.08	4,395
60	85.73	61.31	14.65	4,873
61	93.72	130.21	21.34	5,241
62	93.44	194.21	27.08	5,241
63	93.83	237.73	36.50	5,259
64	95.30	290.89	47.29	5,311
65	95.87	365.01	53.89	5,319
66	91.47	407.92	58.33	5,138
67	82.11	347.86	59.71	4,729
68	69.24	200.10	50.27	4,088
69	59.36	68.08	34.33	3,544
70	54.63	12.41	19.79	3,264
71	49.38	1.50	9.88	2,962
72	41.71	0.07	5.05	2,498
TOTAL	5,085.34	37,724.70	3,807.39	286,500

AADT/C=16

HOUR	VHT_U	VHT_R	VHT_I	VMT
1	35.26	0.00	0.06	2,115
2	30.20	0.00	0.11	1,811
3	28.62	0.00	0.11	1,714
4	28.14	0.00	0.12	1,685
5	31.13	0.00	0.08	1,867
6	49.59	0.00	0.30	2,970
7	102.10	72.89	6.14	5,609
8	140.84	645.15	29.64	7,133
9	132.62	1,542.01	60.83	6,770
10	105.10	2,003.42	80.40	5,737
11	94.92	2,007.80	90.14	5,347
12	96.48	1,907.09	102.99	5,416
13	97.85	1,845.45	117.53	5,460
14	100.45	1,835.26	129.31	5,560
15	105.65	1,912.97	149.56	5,766
16	115.65	2,166.10	171.79	6,119
17	118.42	2,571.45	189.34	6,220
18	119.07	3,021.87	206.09	6,245
19	100.69	3,254.96	217.54	5,540
20	77.66	2,940.40	220.64	4,523
21	63.64	2,133.17	213.30	3,797
22	61.60	1,251.93	186.74	3,676
23	54.93	583.37	141.92	3,286
24	45.57	179.72	87.69	2,729
25	36.97	0.00	0.10	2,218
26	31.57	0.00	0.19	1,897
27	29.58	0.00	0.15	1,778
28	27.94	0.00	0.13	1,680
29	29.75	0.00	0.14	1,784
30	41.25	0.00	0.21	2,476
31	78.49	1.36	2.98	4,614
32	118.00	183.05	20.32	6,216
33	108.91	462.42	44.59	5,880
34	89.30	499.69	52.84	5,129
35	88.04	381.34	49.37	5,063
36	95.21	327.52	51.39	5,362
37	98.69	357.04	60.31	5,494
38	101.70	429.27	72.46	5,606
39	113.36	629.25	88.86	6,037
40	127.20	1,101.13	112.85	6,561
41	141.82	1,951.15	136.40	7,158
42	136.76	2,950.91	152.32	6,950
43	115.91	3,610.79	169.09	6,133
44	85.48	3,585.23	184.53	4,883
45	70.31	2,923.61	192.89	4,154
46	66.85	2,034.65	193.55	3,975
47	59.41	1,171.17	178.67	3,557
48	50.00	483.46	132.13	2,989
49	44.01	0.00	0.16	2,642
50	37.38	0.00	0.36	2,247
51	33.72	0.00	0.40	2,024
52	30.28	0.00	0.35	1,809
53	29.65	0.00	0.23	1,783
54	33.46	0.00	0.28	2,011
55	42.83	0.74	0.68	2,563
56	52.79	12.55	2.15	3,087
57	60.50	26.09	4.30	3,535
58	70.58	33.92	3.99	4,085
59	81.17	59.08	6.42	4,639
60	90.70	122.50	15.41	5,088
61	98.79	232.85	24.77	5,440
62	98.48	345.35	34.80	5,443
63	98.54	431.50	50.31	5,452
64	100.25	530.43	64.27	5,506
65	100.62	652.72	69.61	5,508
66	96.59	738.00	70.17	5,338
67	87.65	700.60	64.86	4,963
68	74.45	504.03	57.22	4,354
69	64.59	252.89	46.47	3,831
70	59.86	89.12	31.37	3,568
71	54.94	24.19	18.22	3,285
72	47.43	5.98	8.88	2,842
TOTAL	5,467.92	59,720.58	4,874.51	305,730

AADT/C=17

HOUR	VHT_U	VHT_R	VHT_I	VMT
1	42.31	0.00	0.14	2,530
2	37.56	0.00	0.36	2,252
3	35.92	0.00	0.38	2,160
4	35.59	0.00	0.31	2,133
5	38.36	0.00	0.35	2,304
6	55.55	0.00	0.93	3,322
7	106.71	107.69	5.88	5,782
8	142.49	747.17	19.53	7,195
9	135.05	1,711.90	39.58	6,868
10	109.30	2,256.79	61.36	5,895
11	99.75	2,366.04	78.19	5,534
12	101.69	2,386.28	86.32	5,599
13	102.57	2,439.90	97.14	5,639
14	104.70	2,525.36	118.02	5,726
15	110.34	2,703.60	140.34	5,930
16	119.16	3,055.57	162.45	6,255
17	122.20	3,553.47	180.01	6,354
18	122.26	4,092.63	198.16	6,374
19	105.18	4,416.35	220.84	5,719
20	82.83	4,212.54	237.23	4,769
21	69.04	3,489.16	246.39	4,093
22	67.24	2,572.48	244.53	3,992
23	60.71	1,666.31	228.49	3,627
24	51.79	844.07	187.44	3,103
25	43.86	0.00	0.18	2,627
26	38.85	0.00	0.35	2,329
27	36.92	0.00	0.42	2,219
28	35.40	0.00	0.46	2,121
29	37.14	0.00	0.40	2,227
30	47.84	0.00	0.63	2,871
31	83.48	6.32	2.98	4,854
32	121.60	236.90	18.25	6,346
33	113.18	604.66	41.64	6,032
34	94.34	714.01	55.47	5,340
35	92.84	636.85	63.36	5,271
36	100.57	627.77	68.94	5,555
37	103.66	721.77	74.90	5,675
38	106.08	860.47	92.08	5,776
39	117.14	1,140.33	114.49	6,179
40	130.34	1,710.13	130.94	6,669
41	143.05	2,630.27	149.41	7,218
42	138.57	3,671.33	175.57	7,034
43	119.32	4,398.99	199.19	6,269
44	90.65	4,488.28	217.16	5,108
45	75.50	3,967.72	230.23	4,418
46	72.20	3,185.20	241.50	4,262
47	65.37	2,303.62	243.36	3,878
48	56.07	1,371.52	213.79	3,342
49	50.44	0.00	0.40	3,024
50	44.10	0.00	0.85	2,649
51	40.87	0.00	0.85	2,447
52	37.52	0.00	0.60	2,251
53	37.05	0.00	0.45	2,225
54	40.31	0.00	0.76	2,427
55	50.01	3.57	2.93	2,953
56	59.53	33.80	6.11	3,446
57	66.72	66.85	9.29	3,854
58	76.13	83.76	9.69	4,375
59	86.38	126.91	12.38	4,882
60	95.77	229.09	17.69	5,294
61	103.20	390.49	26.88	5,627
62	102.92	555.89	43.88	5,625
63	103.19	705.72	52.36	5,624
64	104.79	872.35	55.37	5,684
65	104.81	1,051.10	66.26	5,683
66	101.42	1,187.89	78.77	5,536
67	92.74	1,189.66	86.58	5,182
68	79.77	984.07	89.03	4,614
69	70.57	645.79	80.48	4,134
70	65.92	344.31	60.90	3,888
71	60.81	154.27	40.71	3,613
72	53.92	55.33	25.70	3,201
TOTAL	5,851.18	87,104.28	5,658.99	325,015

AADT/C=18

HOUR	VHT_U	VHT_R	VHT_I	VMT
1	49.75	0.00	0.28	2,983
2	45.54	0.00	0.56	2,732
3	44.00	0.00	0.62	2,649
4	43.72	0.00	0.63	2,622
5	46.23	0.00	0.67	2,772
6	61.97	0.00	1.53	3,699
7	110.22	130.99	16.79	5,931
8	142.99	801.96	41.27	7,217
9	136.17	1,791.72	61.70	6,915
10	113.29	2,402.72	78.75	6,031
11	104.25	2,613.29	96.36	5,706
12	106.16	2,737.90	111.63	5,767
13	106.72	2,891.88	125.72	5,796
14	109.25	3,084.23	139.69	5,882
15	114.06	3,367.71	152.24	6,063
16	122.37	3,809.11	168.53	6,367
17	124.63	4,378.69	186.86	6,454
18	124.76	4,979.18	207.94	6,467
19	109.28	5,388.03	229.86	5,881
20	88.44	5,315.02	248.81	5,014
21	75.11	4,754.13	265.97	4,408
22	73.24	3,976.07	274.18	4,304
23	67.42	3,114.85	261.30	3,971
24	58.85	2,132.13	232.81	3,495
25	51.22	0.00	0.46	3,072
26	46.67	0.00	1.00	2,794
27	44.99	0.00	1.12	2,700
28	43.62	0.00	1.13	2,615
29	45.11	0.00	1.18	2,703
30	54.99	0.00	1.71	3,294
31	88.88	14.68	7.09	5,089
32	124.35	290.31	20.76	6,442
33	116.60	733.06	41.15	6,155
34	99.26	919.54	61.88	5,528
35	97.85	919.88	75.48	5,466
36	104.93	982.97	87.37	5,725
37	107.81	1,149.11	100.75	5,830
38	110.21	1,370.43	118.18	5,927
39	120.06	1,731.52	141.82	6,290
40	131.65	2,359.04	164.92	6,735
41	143.49	3,308.94	184.38	7,233
42	139.11	4,366.36	210.76	7,066
43	122.09	5,139.86	233.47	6,371
44	95.49	5,332.83	250.56	5,314
45	81.48	4,967.11	268.72	4,704
46	78.26	4,358.58	280.29	4,555
47	71.56	3,606.63	285.52	4,192
48	63.05	2,669.66	275.29	3,719
49	57.45	0.24	0.61	3,427
50	51.68	0.24	1.31	3,097
51	48.55	0.00	1.30	2,907
52	45.27	0.00	1.09	2,721
53	45.22	0.00	0.98	2,705
54	48.62	1.49	1.18	2,895
55	57.78	20.53	2.68	3,364
56	67.28	87.20	8.38	3,816
57	73.23	149.77	16.86	4,175
58	82.04	177.30	24.94	4,651
59	91.68	240.69	32.77	5,109
60	100.59	382.18	42.86	5,504
61	107.19	597.58	56.43	5,785
62	107.07	831.69	67.64	5,783
63	107.26	1,050.89	75.11	5,786
64	108.63	1,280.47	87.36	5,846
65	108.95	1,528.21	101.61	5,851
66	105.32	1,731.74	116.96	5,707
67	97.93	1,796.98	131.11	5,395
68	85.72	1,639.52	136.57	4,873
69	76.29	1,272.40	140.03	4,432
70	71.78	852.88	139.88	4,203
71	67.72	511.24	121.60	3,961
72	61.12	268.72	91.02	3,587
TOTAL	6,235.55	116,312.08	7,119.95	344,227

Appendix E

Methodology

Methodology

The QSIM Model

The QSIM model was developed previously by the Research Team for several FHWA research projects (References 1, 2, and 3). These studies were concerned with estimating the cumulative effects of recurring congestion on vehicle speeds over the course of an entire day. Because most analytical methods consider only the effects of peak-hour congestion (such as methods that link speeds to the V/C ratio), a new measurement of daily congestion was used: the Average Annual Daily Traffic-to-Capacity (AADT/C) ratio, where capacity is the two-way capacity. For reference, the AADT values that result from various AADT/C ratios for typical situations are provided in Table E.1.

Table E.1 AADT/C Levels and Corresponding AADT Values

	Freeways (10% Trucks)		4-Lane Signalized Arterials (8% trucks)[3]
	4-Lanes[1]	6-Lanes[2]	
AADT/C	AADT[4]	AADT[4]	AADT[4]
9	72,000	113,000	30,000
10	80,000	126,000	33,000
11	88,000	138,000	37,000
12	96,000	151,000	40,000
13	104,000	163,000	43,000
14	112,000	176,000	47,000
15	120,000	188,000	50,000

[1] Ideal Capacity = 2,200 pcphpl.

[2] Ideal Capacity = 2,300 pcphpl.

[3] Ideal Capacity = 900 pcphpl (based on a saturation flow rate of 1,800 pcphpl and 50 percent green time).

[4] Rounded to nearest 1,000.

For these studies, the QSIM model was developed to study the effects of queuing on link-specific speeds. QSIM is a stochastic macroscopic traffic simulation model. Its stochastic feature is the ability to set test volumes randomly from a distribution and to simulate the effect of traffic variability by looping over a very high number of replications (usually more than 1,000). It then analyzes, with the help of macroscopic traffic flow relationships, the effects of temporal variations in traffic and queuing on an hour-by-hour basis for weekdays and for weekends/holidays. Weekday travel is analyzed separately in each direction the "home-to-work" peak direction, for which the peak occurs in the morning, and the "work-to-home" direction, for which the peak occurs in the afternoon. Both freeways and signalized arterials are considered by QSIM. The basic steps undertaken by the QSIM model are discussed below.

Set Test Section Capacity

The procedure starts by defining a test section for QSIM to analyze. The capacity of the section is determined using *HCM* procedures. The following basic capacity values were used:

- Freeways 2,300 pcphpl, based on the 1994 *HCM* for 6+ lane facilities; and

- Signalized Arterials 950 pcphpl, based on the *HCM's* saturation flow rate of 1,900 pcphpl and a 50 percent green time.

The test section length is also set at this time; this is a key factor in QSIM as the speed and delay of vehicles are measured over the length of the section. For this study, segment length was fixed at 1.5 miles (7,920 feet) for freeways. For signalized arterials, the length of the segment is equal to the signal spacing. Setting a variable segment length for arterials is believed to capture the effect of queuing more realistically than a fixed one. Thus, high-signal densities imply a shorter segment length, therefore, a higher percentage of the link will be consumed by queuing.

Temporal Distributions and Peak Spreading

Once the AADT/C level is set, AADT is determined by multiplying AADT/C by the (two-way) capacity. Average Weekday Daily Traffic (AWDT) and Average Weekend/ Holiday Daily Traffic (AWEDT) are determined by applying factors to AADT: 1.0757 for AWDT and 0.8393 for AWEDT (Reference 2). From these daily volumes, temporal distributions are used to determine "target" volumes by hour. Separate distributions exist for freeways and non-freeways; three AADT/C ratios (AADT/C less than or equal to seven, AADT/C between seven and 11, and AADT/C greater than 11); and peak direction (morning and afternoon). Direct application of these distributions would lead to problems for AADT/C ratios on the boundary values. For example, the high-AADT/C range's distribution is flatter than the middle range; this could possibly lead to predicting congestion in an hour for the middle range while not predicting congestion in the same hour for the high range. Therefore, a smoothing procedure was used to address this issue. This procedure accounted for problems at the boundary values and further spread out traffic throughout the day as AADT/C ratios increased above 13. This additional peak-spreading feature was deemed necessary since the data for developing the distributions (713 urban ATRs [Reference 2]) did not have a large number of sites where AADT/C was greater than 13. It should be pointed out that this procedure is not based on observed data but has been instituted as a purely mechanical procedure to account for two conditions: 1) counterintuitive results at the AADT/C boundaries of the original temporal distributions; and 2) excessive queuing that would result at very high-AADT/C ratios if the temporal distributions were unaltered. This second condition is really the phenomenon of peak spreading.

Stochastic Variation in Traffic Volumes

In order to account for day-to-day variability in traffic flows, QSIM stochastically determines what the test volume in a given hour should be from the "target" hourly volume (determined above) and information on hourly variability, where the "target" volumes are the mean of normal distribution and the variance is defined as:

$$\text{Variance} = (\text{Coeff. of Variation} * \text{Mean})^2. \quad (1)$$

Random sampling is then used to select the test volume from this distribution.

Uncongested Speed Functions

If the test volume is less than the section's capacity, newly developed uncongested speed functions are applied. The uncongested speed functions were determined by running FRESIM and NETSIM in a series of experiments to gauge the effects of various highway and traffic conditions (Reference 1). The results were then analyzed with multiple and nonlinear regression analysis to develop equations that predict delay. (Speed was calculated as a function of delay, as described below.) The relationships used were as follows:

Freeways

$$\text{Delay} = 4.46\ V/C - 1.55\ (V/C)^2 - 0.05\ S_{ff}\ V/C + 0.044\ S_{ff}\ (V/C)^2 \quad (2)$$

Where: Delay is due to congestion and measured in vehicle-hours per 1,000 vehicle-miles;

V/C is the volume to capacity ratio (maximum = 1.0); and

S_{ff} is free-flow speed in miles per hour.

This function exhibits a small but noticeable decrease in speeds as V/C increases up to 1.0. To be more consistent with the speed/flow relationships in the *HCM*, it was decided to use the modified BPR curve suggested in Reference 4. This form is:

$$\text{Delay} = (1 + 0.2\ (V/C)^{10}) / S_{ff} \quad (3)$$

Signalized Arterials

$$d_{sig} = (27.0 + 33.0\ (V/C)^{1.23})\ (1 - e^{-.29n}) \quad (4)$$

Where: d_{sig} is delay in vehicle-hours per 1,000 vehicle-miles; and

n is the number of signals per mile, assuming an "intermediate" signal progression case.

In both of these formulations, delay is the additional travel time beyond that which would result if all vehicles could traverse the section at the free-flow speed. Delay includes not only the time spent sitting at traffic control devices, but also the time lost while decelerating to a stop and then accelerating back to the free-flow speed. The second term of the equation varies between zero and one and is essentially an adjustment factor for the delay due to the V/C ratio; for high values of signals per mile the term is close to one.

Perform Queuing Analysis

Determine Percent of Link Under Queuing. If test volume exceeds capacity, a queue is assumed to form. For simplicity, the program assumes that the bottleneck point from which the queue builds is at the downstream end of the segment. The program accumulates total travel time on the segment. If the length of the queue exceeds the length of the segment, total delay due to the bottleneck will naturally exceed total delay on the segment itself. (This additional delay can be estimated by increasing segment length.) For freeways, once volumes exceed capacity, vehicles are assumed to move through the bottleneck point at a flow rate less than capacity. Therefore, two basic freeway capacity values are used: 2,300 pcphpl (the new *HCM* capacity for six or more lanes) for unsaturated conditions and 2,000 pcphpl for oversaturated conditions (Reference 5).

Queues are estimated for the beginning and ending of each hour. If the demand volume plus any leftover queue is greater than the capacity of the section, the queue at the end of the hour is calculated by:

$$Q2 = Q1 + V - C \tag{5}$$

Where: Q1 = queue at the beginning of the hour (vehicles);
Q2 = queue at the end of the hour (vehicles);
V = demand (test) volume for the hour (vehicles); and
C = bottleneck capacity of the section (vehicles).

Calculate Queue Speed. For both freeways and signalized arterials, if the V/C ratio is greater than 1.0, queuing is assumed to take place. Queuing will also affect traffic if there is a standing queue at the end of the preceding hour. If travel in the hour under consideration is affected by queuing, the program analyzes the growth (or decline) in queue length over the hour. Vehicle-hours of travel are estimated separately for those portions of the segment that are affected by queuing and those that are not. The approach developed by Dowling and Skabardonis to combine speeds for queued and unqueued conditions was modified for use here (Reference 6). Their formulation is:

$$\begin{aligned}\text{Link Speed} = {} & [\text{Queue Speed} * (\text{Queue Length/Link Length})] + \\ & [\text{Nonqueue Speed} * (1 \quad \text{Queue Length/Link Length})]\end{aligned} \tag{6}$$

In the current formulation, the speed on the segment is based on estimating total vehicle-hours of travel (VHT) and vehicle-miles of travel (VMT) first, then computing speeds as VMT/VHT; this avoids the computational problems of the Dowling and Skabardonis approach. VMT and VHT are tracked separately for queued and unqueued portions of the test segment:

VMT = {(UQL * DVOL) + (AQL * CAP)}/5280 (7)

Where: UQL = length of the segment that is not queued, in feet;

DVOL = demand volume for this hour (determined stochastically from the temporal distributions), in vehicles;

AQL = average queue length during the hour, in feet; and

CAP = the bottleneck capacity, in vehicles.

The first term counts the number of vehicles that are entering the segment at the back of the queue. When the entire segment is consumed by a queue, this term becomes zero. The second term counts the number of vehicles in the queue that are processed through the bottleneck. Queue length is found by multiplying the number of queued vehicles by the calculated queue spacing (Equation 9).

VHT = (UQL * DVOL * UQDEL) + (AQL/QSPACE) (8)

Where: UQDEL = unqueued delay, in hours per vehicle-foot, calculated using the uncongested delay function;

QSPACE = spacing of vehicles in the queue, in feet per vehicle; and

= Queue Speed/CAP.

The first term is the number of vehicle-hours experienced by vehicles on the unqueued portion of the segment. The second term calculates the number of vehicles that (on average) are in the queue during the hour. Note that QSPACE depends on the assumed queue speed, which for freeways was determined empirically from freeway data to be 15.5 mph. For arterials, queue speed was determined analytically as capacity (vehicles per hour) times vehicle spacing (feet per vehicle) and is roughly eight to nine mph. The second term is equivalent to estimating queued VHT (QVHT) as a function of queued VMT (QVMT) and queue speed:

QVHT = QVMT/Queue Speed (9)

Letting: QVMT = AQL * CAP (the second term in Equation 6), and

Queue Speed = CAP * QSPACE;

Produces: QVHT = (AQL * CAP)/(CAP * QSPACE); and (10)

= AQL/QSPACE.

Note that in the methodology, the traditional speed/flow/density relationships are used. There is some evidence that in the congested (unstable) traffic flow regime these relationships do not apply. Additional microscopic simulation carried out by the Research Team indicates that the *number of vehicle merging operations over a given space* significantly influences speed, flow, and density (Appendix A). Vehicle merges are in turn a function of the type of bottleneck and traffic demand. The assumed freeway queue speed of 15.5 mph is felt to be representative of an on-ramp bottlenecks, therefore, the current research applies to this situation only. (However, on-ramps are the most common form of bottlenecks in most areas.)

QSIM Modifications for Freeway Incidents

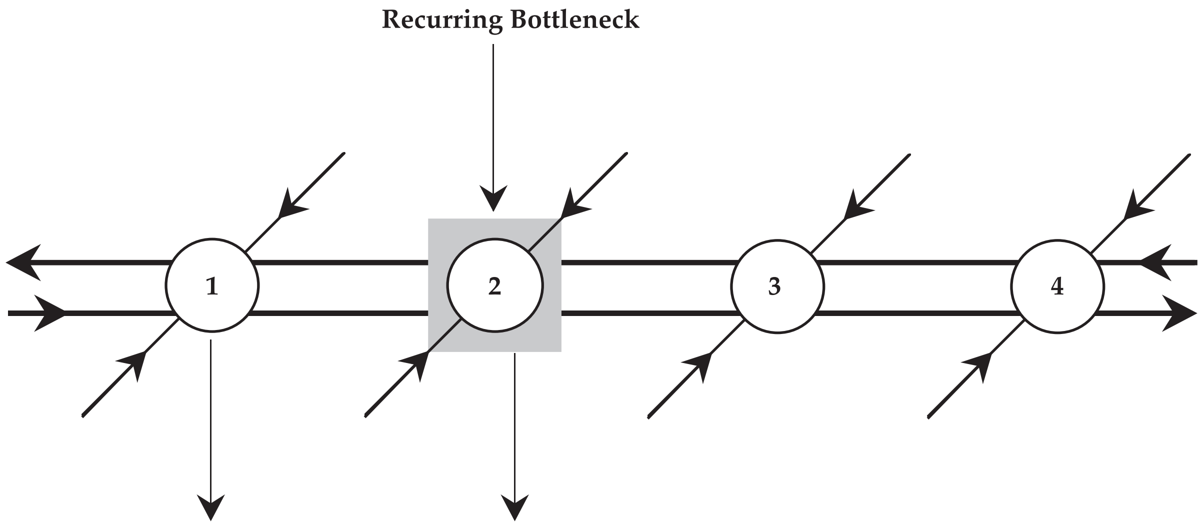
Because QSIM is stochastic, it was felt to be an ideal platform for studying incidents, since incident occurrence can be thought of as a stochastic (i.e., random process). The modifications to QSIM to include incidents are outlined below.

- **Monitor traffic flow for five-minute intervals**. Because most incidents are less than an hour in duration, shorter time periods are necessary to capture their effect. The Research Team selected five-minutes as the most efficient intervals. Once QSIM has selected its hourly test volume, the volume is divided by 12 and traffic flow is monitored for each five-minute interval. Note that this assumes an equal distribution of traffic within an hour. Future versions of QSIM may incorporate something like the *HCM's* peak-hour factor, but within the larger context of queuing, we feel that this would have a small   if not negligible   effect on the results.

- **Track total vehicle-hours rather than link delays/speeds**. The goal of this project is different from the previous ones where QSIM was used in that we are now interested in the **total** impact of incidents rather than predicting link-specific delays. The original version of QSIM tracked total queues but only tabulated delay statistics for the test section (e.g., 1.5 miles for freeways). Therefore, the modified QSIM now tracks total vehicle-hours of travel (VHT) in the queue as opposed to just the queue's effects on the test segment. In addition, the VHT for unqueued conditions is also calculated using the delay functions discussed above. This is done even if a queue exists. Therefore, the concept used here is the "vertical stacking" of queues, adopted here for ease of tracking. This approach does not require that queue length in distance terms be tracked, just total number of vehicles.

- **Adapt QSIM for modeling a corridor rather than sample segments.** The original version of QSIM was established to model HPMS sample segments on an individual basis. For sketch planning, analyzing a corridor (a consecutive sequence of segments) is more appropriate. The basic approach is outlined in Figure E.1. It is predicated on first identifying "true" recurring bottlenecks; a "true" recurring bottleneck is one that is the primary generator of queues in the corridor. In this approach, VHT for each segment in the corridor has two sources of VHT: VHT under uncongested conditions and VHT for incident conditions. In addition, recurring bottlenecks have a third component: VHT for recurring delay. Capturing both uncongested delay and queuing-related delay on a segment is not double counting since including uncongested delay partially accounts for the delay underestimation assuming "vertical stacking." (Queues actually build faster than indicated the simple assumption of vertical stacking.) As mentioned above, the total VHT due to queues (either due to recurring or nonrecurring sources) is tracked by QSIM, not just delay on the segment itself. (The model allows the queue to run off of the segment.) Thus, what the model estimates is the total systemwide delay due to conditions on individual segments.

Figure E.1 Adapting the QSIM Approach for a Corridor



Total VHT = $VHT_u + VHT_i$ Total VHT = $VHT_u + VHT_i + VHT_r$

Where: VHT_u = VHT under uncongested conditions
VHT_i = VHT under incident conditions
VHT_r = VHT under recurring bottleneck

Note: Total VHT at Nodes 3 and 4 computed as for Node 1.

- **Imbed field-collected incident distributions**. A previous FHWA study collected incident-related data from several urban areas (Reference 7). These data were the basis for stochastically assigning incident characteristics.

The incident procedure now in QSIM is presented in Figure E.2. The "data input" boxes in that figure are keyed with numbers which are explored below.

Incident Rates

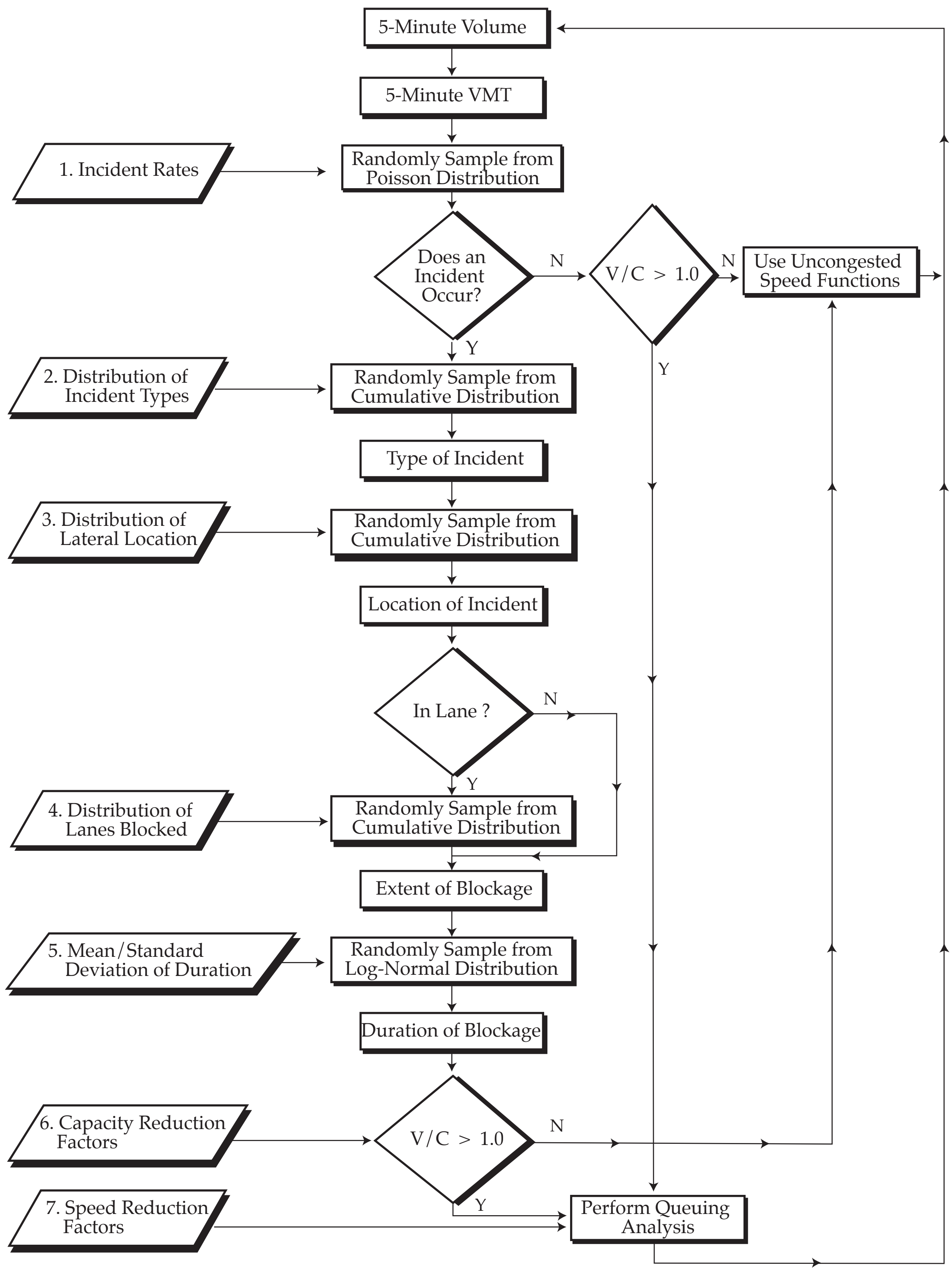
The first step in the sequential process of assigning incident characteristics is to determine whether an incident occurs. The *Freeway Incident Detection Issues* project (Reference 7) developed basic incident rates by AADT/C range, incident type, and peak/off-peak time periods (Table E.2). The Research Team feels that breaking the data down by these parameters reduces the sample sizes to a such a degree that the mean rates are unreliable. Therefore, we have chosen to collapse the rates by AADT/C category, time period, and incident type. (Incident type will be determined in the next step.) When this is done, the basic rate for freeways becomes 9.336 incidents per million vehicle-miles of travel (MVMT), or the average of peak and off-peak rates In Table E.2.

Table E.2 Basic Freeway Incident Rates

	AADT/C<=7	7<AADT/C<=10	AADT/C>10	Average	Excluding Accidents	Distribution (Percent)
Peak						
Abandoned	1.830	1.911	2.679	2.140		17.1
Accident	0.549	0.463	2.347	1.120		8.9
Debris	0.127	0.199	0.538	0.288		2.3
Mechanical/Elec	1.553	1.828	5.837	3.073		24.5
Stalled	1.392	1.579	3.936	2.302		18.4
Tire	1.125	1.392	3.907	2.141		17.1
Other	0.773	0.330	3.295	1.466		11.7
Total	**7.349**	**7.702**	**22.539**	**12.530**	**11.410**	**100.0**
Off-Peak						
Abandoned	1.830	1.224	2.330	1.795		29.2
Accident	0.549	0.281	0.552	0.461		7.5
Debris	0.127	0.131	0.188	0.149		2.4
Mechanical/Elec	1.553	0.893	1.315	1.254		20.4
Stalled	1.392	0.801	0.833	1.009		16.4
Tire	1.125	0.849	0.912	0.962		15.7
Other	0.773	0.248	0.516	0.512		8.3
Total	**7.349**	**4.427**	**6.646**	**6.141**	**5.680**	**100.0**

Source: Reference 7.

Figure E.2 Details of Incident Modeling Within QSIM



To account for safety effects more explicitly, the accident rate portion of total incident rate was developed separately. Previous studies have noted that accident potential increases with congestion. One study developed accident rates for V/C ranges (Reference 8):

V/C Ratio	Accident Rate per MVMT
0-0.70	1.344
0.71-0.90	1.531
0.91-1.00	1.884
GT 1.00	2.038

An equation was fit to these data by taking the midpoint of the V/C range and adding a point at V/C = 0.01 equal to 1.0 accidents per MVMT; this point was selected based on the data in Table E.2. The resulting equation is:

Accidents per MVMT = 1.066 + (0.946 V/C^3) {R^2 = 0.994} (11)

Thus, while the other components of incident rates stay constant, accident rate increases with V/C. This leads to a higher total incident rate for high-V/C ratios. The incident rate for any given time period is calculated by removing the original accident rate from Table E.2 (0.791 per MVMT, the average of 1.120 and 0.461) from the total (9.336 per MVMT) and then adding back in the computed accident rate based on V/C. V/C is calculated based on the revised capacity of the section assuming bottleneck flow rates (see below) but is capped at 1.1 to avoid excessively high values for accident rate. Though not perfect, this partially accounts for the phenomenon of secondary accidents; if a queue has formed then V/C increases because capacity decreases. Clearly, there are other factors at work in secondary accidents (rubbernecking, and the maneuvering of emergency vehicles) but the research on the subject is sketchy.

The total incident rate is used to determine if an incident occurs in a given a time period. Assuming that incidents occur randomly, i.e., they follow a Poisson distribution, the probability that an incident occurs on a particular highway section is then computed as:

$$F(x) = \frac{n^x e^{-n}}{x!} \qquad (12)$$

Where: n = average number of incidents during the time period;

= (incident rate) x (VMT for the section during the time period); and

x = number of incidents.

The Poisson distribution is then randomly sampled to determine the number of incidents on a particular section for the given time period. It is possible, though highly unlikely, that the sampling procedure will indicate that more than one incident will occur during the time period. For simplicity, it is assumed that only one incident can occur within a five-minute time period. It is also possible for a second incident to occur while the first one is still in place. If this is the case, then the second incident is "stored" until the first one ends; simultaneous incidents were not modeled.

Distribution of Incident Types

Because accident rates vary as a function of V/C, the distribution of incident types is affected. Therefore, the incident type distribution is adjusted every time period to account for varying accident rates. The probability of the remaining incident types is based on the average of the peak and off-peak rates from Table E.2 and are:

Incident Type	Incident Rate per MVT
Abandoned	1.968
Accident	(varies with V/C)
Debris	0.219
Mechanical	2.164
Stalled	1.656
Tire	1.552
Other	0.989

Distribution of Lateral Location

The lateral location of incidents is determined from the distribution given in Table E.3.

Table E.3 Lateral Location Distribution

Incident Type	On-Shoulder (Percent)	In-Lane (Percent)
Abandoned	97.9	2.1
Accident	60.6	39.4
Debris	26.5	73.5
Mechanical/Elec	90.0	10.0
Stalled Vehicle	93.7	6.3
Flat Tire	97.1	2.9
Other	95.1	4.9

Distribution of Lanes Blocked

If an incident is assigned to be "in-lane," then the data in Table E.4 is used to determine how many lanes are affected by the incident. These percentages can be adjusted to account for the number of lanes being modeled in QSIM. For example, if two-lanes (one direction) are being modeled, then 15.8% + 2.7% + 0.7% = 19.2% of accidents affect both lanes.

Table E.4 Number of Lanes Affected for In-Lane Incidents (Percent)

Incident Type	1-Lane	2-Lanes	3-Lanes	4+ Lanes
Abandoned	100.0	0.0	0.0	0.0
Accident	80.8	15.8	2.7	0.7
Debris	96.7	3.3	0.0	0.0
Mechanical/Elec	97.8	2.2	0.0	0.0
Stalled Vehicle	97.9	2.1	0.0	0.0
Flat Tire	96.9	3.3	0.0	0.0
Other	94.3	5.7	0.0	0.0

Determination of Incident Duration

Reference 7 also presents data on incident durations. These data have been aggregated into Table E.5. The statistics in Table E.5 are assumed to come from a log-normal distribution.

Table E.5 Incident Durations (Minutes)

	Incident Location			
	Shoulder		In-Lane	
Incident Type	Mean	Std. Dev.	Mean	Std. Dev.
Accidents	39.7	33.4	47.1	40.2
Mechanical/Electrical	41.4	30.6	38.7	30.5
Tires/Stalled Vehicles/Other	38.2	36.1	34.7	26.6
Abandoned/Debris	31.3	39.5	29.6	34.0

Capacity Reduction Factors

This step is the crux of the original research undertaken for this project. QSIM requires estimates of the capacity loss due to incidents as well as the speed of vehicles while they are in queues (if link speed estimation is of interest). An extensive series of experiments using the FRESIM traffic simulation model was undertaken to examine the effect of lane-blockage incidents. A complete discussion of the FRESIM experiments and their implications for traffic analysis is presented in Appendix A.

One of the issues with regard to incidents is the location of the incident relative to a recurring bottleneck. The original version of QSIM assumes that a recurring bottleneck (e.g., an on-ramp) exists at the downstream end of the test segment and the V/C ratio of the segment is the total volume and capacity of the bottleneck. Thus, in the case of the on- ramp the volume is the sum of the mainline volume plus the ramp volume. In the field, if an incident occurs upstream of the ramp area, it affects a traffic volume lower than the bottleneck volume. Tests showed that upstream incidents did indeed have less impact than incidents in the ramp (merge) area. However, relative location of the incident was not included in QSIM for two reasons:

- First, consider the case where an upstream incident causes a queue to form and the original V/C of the bottleneck was between 0.7 and 1.0. When the upstream incident clears, a wave of stored vehicles is released. This wave of vehicles, moving at flow rates approaching capacity, causes the traffic flow in the previously uncongested ramp area to break down, even under relatively low on-ramp volumes. This effect was observed in the FRESIM experiments.

- Second, queues from downstream incidents could affect traffic flow in the subject ramp area.

As a way to compensate for these two factors, it was assumed that all incidents in QSIM occur in the vicinity of the recurring bottleneck. The FRESIM tests indicate that traffic flow through a series of recurring and non-recurring bottlenecks is complex and depends greatly on local conditions. The relative incident location assumption keeps the modeling as simple as possible and allows the results of the modeling process to be more generalized.

A summary of the traffic parameters for lane-blockage incidents used by QSIM is presented in Table E.6. Note that speeds and densities are presented because they were easily obtained from the FRESIM results. Future applications of QSIM for link speed estimation may use these, but for the current project, only capacities are required.

Table E.6 Freeway Lane-Blockage Incident Traffic Parameters from FREESIM Experiments

Original Number of Lanes	Number of Lanes Blocked	Capacity (pcphpl)[a]	Speed (mph)	Density (pcplm)
2	1	1,850	10.0	160
	2	1[b]	3.0	210
	1	1,995	11.5	120
3	2	1,850	4.0	150
	3	1[b]	3.0	210
	1	2,000	15.0	120
4	2	1,900	10.0	160
	3	1,850	4.0	175
	4	1[b]	3.0	210

[a] Per lane capacity of remaining lanes.

[b] Capacity is actually zero when all lanes are blocked but was set to one to avoid internal division problems.

The foregoing discussion applies only to lane blockage accidents. Based on the Research Team's previous experience with FRESIM, we believe that is does a reasonable job simulating *longitudinal* aspects of traffic flow (e.g., merge situations). However, it does not adequately address *lateral* concerns (e.g., narrow lane widths). This is because the car-following logic that is at the heart of FRESIM does not assume any lateral influences on vehicle behavior. Since shoulder incidents occur outside of FRESIM's modeling framework, it can not be relied upon to estimate the effect of these incidents. The FRESIM does have a "rubbernecking factor" to account for incidents outside of traffic lanes. This factor is used to reduce desired vehicle headways by a certain percent, with 10 percent being the suggested value. However, tests showed that by applying the 10 percent rubbernecking factor, there was only a small difference in speed and no difference in capacity. This conflicts with the findings of the *Freeway Incident Detection Issues* report (Reference 7) which found that shoulder incidents affect roadway capacity. **Therefore, the following values were used for capacity reductions for shoulder incidents:**[1]

- Accidents and Debris   reduce capacity by 20 percent.
- All Other Incident Types   reduce capacity by 15 percent for two-lane freeway sections and by 10 percent for three-lane freeway sections.

Number of Replicates

For recurring congestion, it was found that the results were stable after about 1,000 replicates (i.e., passes of the model through the stochastic process; these can be thought of as "days of simulation"). Because the assignment of incident characteristics is a sequential process resulting in a substantial range of possible outcomes, many more replicates are needed: 15,000 was the number selected.[2]

QSIM Modifications for Signalized Arterial Incidents

Reference 7 was the only available information on incident characteristics and was restricted to freeways. Because the original QSIM also simulates signalized arterials, the Research Team applied the freeway incident distributions to arterials, with the following modifications:

- The accident rate component of total incident rate for arterials uses the procedure developed for the HPMS Analytical Process and HERS models (Reference 12). Separate equations exist for median and two-way left turn lane median (TWLTL) designs; QSIM averages the results of these equations:

[1] Based on data in Table XXVIII in Reference 7.

[2] As discussed later, the number of replicates for studying the effects of incident duration was increased to 60,000 to ensure stability when sampling from the log-normal distribution of incident durations.

$$\text{Median accidents/mi.} = 0.000322 * (\text{AADT}^{1.1749}) * (\text{Signals/mi.}^{0.2515}) \quad (13)$$

$$\text{TWLTL accidents/mi.} = 0.000463 * (\text{AADT}^{1.1498}) * (\text{Signals/mi.}^{0.4011}) \quad (14)$$

Here, accidents per mile are on an annual basis. Accident rate is then:

$$\text{Accidents per MVMT} = (\text{Accidents/mi.} * 1000000)/(\text{AADT} * 365 * 1.0) \quad (15)$$

Where: 1.0 is the assumed section length in miles.

- Only lane blockage incidents were assumed to have an effect on traffic flow. The main reason for this was the lack of credible data or a procedure for estimating arterial capacity loss for shoulder incidents. Also, arterial shoulder incidents tend to be minor and speeds are more restricted than for freeways.
- In theory, the distance of the lane blockage from the signal (bottleneck) should have a substantial impact on traffic flow. Arterial midblock volumes are almost always well below midblock capacities due to the "metering" effect of upstream signals. However, if the blockage occurs within close proximity of a signal, capacity is greatly reduced, i.e., the "processing rate" of the signal is greatly affected. To deal with this problem, longitudinal location of the incident was determined stochastically. If the incident is an accident, then it is assumed that 11 percent of the accidents occur within 50 feet of the signal. This percentage is based on Tennessee data on suburban arterials. Although this number might seem low, the data (10,000 accidents) showed that a large share of accidents occurred at non-signalized intersections along the sections. If the accident does not occur within 50 feet of the signal or the incident is not an accident, then it is assigned a distance from the signal assuming a uniform distribution along the remaining section length. Here, section length is based on the signal density to account for interaction among signals.
- An adjustment factor to the section capacity is computed based on longitudinal location (i.e., distance from the signal). The factor is based on the NETSIM experiments (Appendix B) that noted the maximum flow rates downstream of incidents that blocked one of two lanes. The function that was fit to these data is:

$$\text{Incident flow} = 810.44 + (7.2702 * \text{Distance}) \quad (0.0138078 * \text{Distance}^2),$$
$$\text{for Distance} <= 300 \text{ feet or } 1{,}750 \text{ for Distance} > 300 \text{ feet} \quad (16)$$

The adjustment to capacity is then:

$$\text{Capacity} = (\text{Original capacity}) * (\text{Incident flow}/1900) \quad (17)$$

For one lane blocked of 2. If both lanes are blocked, then capacity = 1.

Note the incident flow is compared to 1,900 vph; this was the value for through movement capacity in the NETSIM experiments. The procedure results in a 57 percent drop in capacity when the incident occurs at the signal (distance from the signal is zero) and an eight percent drop when distance is greater than or equal to 300 feet. This procedure assumes that a queue does not form at midblock locations. In other words, midblock volumes are assumed to be low enough so that the remaining 1,750 vph in capacity can handle them. This may not be the case for all arterials. Also, the queue is not assumed to spillback to upstream signals. Both of these factors are subjects for further exploration in the future.