PREAMBLE

This report was prepared as a partial requirement of CE601 Interchange Traffic Simulation at Portland State University (PSU). This is the second report prepared for this course and details the simulation of a diamond interchange and adjacent arterial intersections in Wilsonville, Oregon, USA; the first report involved the simulation of a single isolated intersection in Vancouver, Washington, USA.

1. INTRODUCTION

This study reports on the computerized microscopic simulation of a small suburban network centered on the diamond interchange of Interstate 5 and Wilsonville Road in northern Oregon. The results of the simulation are compared to traffic observations and to the results of procedures described in the Transportation Research Board's Highway Capacity Manual 2000.

The following section contains a description of VISSIM, the traffic simulation software used for this report. Section 3 describes the analysis network and the type of data that were collected on-site and the data that were acquired during multiple runs of the simulation software. Section 4 presents some key findings, such as travel times and lane group delays, resulting from this study.

Section 5 presents comments on the report's findings. Section 6 outlines topics for future research in the area of microscopic simulation of small networks. Appendix A outlines a procedure for determining the number of simulation runs required to achieve statistically reasonable predictions of measures of effectiveness of an intersection or system. Appendix B summarizes some of the recent literature related to microscopic simulation of traffic at interchanges and closely spaced intersections. Finally, Appendix C contains Highway Capacity Software (HCS) results.

2. SOFTWARE DESCRIPTION

The software used in the simulations described in both CE 601 reports is the VISSIM traffic simulation model. VISSIM *[1,2]* is an urban traffic and public transit operations software package produced by PTV Planung Transport Verkehr AG of Karlsruhe, Germany. The North American distributor for VISSIM is Innovative Transportation Concepts Inc. (ITC) of Corvallis, Oregon, USA. VISSIM is an acronym for the German words "Verkehr in Städten – Simulation" which loosely translates to English as "traffic in towns – simulation". VISSIM is a computerized stochastic microscopic, time step, and behavior based simulation model. The current (December 2001) version of VISSIM is 3.60, although version 3.50 was used for the study described herein.

VISSIM is capable of modeling the movements of automobiles, trucks, light and heavy rail trains, bicycles, and pedestrians on a detailed network of streets, railroads, and sidewalks *[2]*. The VISSIM software package uses two distinct computer programs, the first is a traffic flow model that includes lane change and car following logic, the second is a traffic signal control emulator capable of reproducing both fixed time and actuated traffic signals *[1]*. The VISSIM software uses driver behavior models developed for urban behavior and freeway behavior by R. Wiedemann *[3]*.

Wiedemann's traffic flow models are discrete, stochastic, time step based microscopic models. Central to both models is Wiedemann's car following logic, a graphic depiction of this logic is shown in Figure 1. A faster moving vehicle will decelerate as it approaches a slower vehicle. The premise is that the faster vehicle seeks a safe headway (AX) at which to follow the slower vehicle. The computer model begins to adjust the faster vehicle's speed when a perception threshold distance (SDX or SDV) is reached. At headway distances less than SDX/SDV, the faster vehicle will decelerate as the driver attempts to create a minimum safe headway (AX). Indeed, the driver may decelerate to the point that he is traveling slower than the lead vehicle (OPDV) and will accelerate to establish the desired headway. A series of oscillations will be modeled by VISSIM as the safe headway is approached. VISSIM models imperfect throttle control on all vehicles,

which creates a condition of constantly changing velocities and headways.   The software user can change many of the parameters of the car following model which allows for the creation of a customized driver behavior model *[3]*.

When traffic is modeled on multi-lane streets, VISSIM employs a rule based lane change model.   A following vehicle will desire a lane change if either the lead vehicle is traveling slower than the following vehicle's desired speed or if the following vehicle is approaching a required turn. The lane change will be modeled only if the movement can be made safely *[3]*.

Accurate microscopic simulation of traffic and traffic control within VISSIM requires that a detailed network be created. VISSIM employs a "link" based network system, where each link is coded with attributes such as number of lanes, lane width, and gradient. All network inputs are via a graphical user interface which allows the user to build the network by inserting a series of links and connectors. Although "freehand" drafting of the network is possible with VISSIM, network modeling is more efficient when an air photograph or line drawing is used as a background or underlay as shown in Figure 2.   Network links are joined by connectors as shown in Figure 3, thereby eliminating the need for "nodes" that are used in many other traffic network software packages.

Traffic volumes are assigned to all links entering the network as shown in Figure 4. VISSIM loads the assigned traffic onto the network in a random manner using the Poisson distribution *[1]*. The user is able to specify the composition of the traffic stream (i.e. proportion of cars, trucks, heavy trucks etc.) as well as define distribution functions for desired speeds, weight, power, and acceleration/deceleration characteristics.

Intersection turning movements and other route based decisions are modeled in VISSIM by assigning proportions of each link's vehicular flow rate to each possible route as shown in Figure 5. The flow of vehicles though an intersection is governed by sign

and/or signal control as shown in Figure 6. The red and green bars at the link ends on Figure 6 represent the current status of signal control on each lane approach. As the movement of each vehicle is simulated by the software, an animation of all vehicles' movements can be shown on the computer screen (see Figure 6). The blue objects represent automobiles and the black objects represent heavy trucks. On-screen evaluation of the animation allows the user to observe the traffic operations and make notes of such things as inefficient signal timings and offsets, queue spill-back, and weaving problems. A wide variety of data including route travel time, delay, queue length, and link volumes can be collected during each simulation run and stored in data files for off-line analysis.

3. WILSONVILLE ROAD / INTERSTATE 5 INTERCHANGE ANALYSIS

3.1 Project Location

The model network for this project is the area surrounding the intersection of Interstate 5 and Wilsonville Road located in the City of Wilsonville, Oregon as shown in Figure 7. The network includes the diamond interchange of Interstate 5 and Wilsonville Road as well as the Wilsonville Road intersections with the Oregon Electric Railroad, Boones Ferry Road, Parkway Avenue and Town Center Loop West.

3.2 Simulation Model Application

The geometry of the network was coded using a series of links and connectors as described in Section 2 of this report. The four signalized intersections in the network are all actuated and although VISSIM is capable of handling actuated signal control, actuation was deemed to be beyond the scope of this report. These four intersections were modeled as pre-timed by using observed PM peak period average cycle times observed on the site on December 13, 2001. It should be noted that in almost all cases, during the PM peak period, signal operation approached that of pre-timed signals with little variance in the observed phase lengths.

Ten (10) one hour simulation runs were completed. As an example of the measures of effectiveness that could be computed, route-specific travel times and delay at selected movements of the I-5 Ramp intersections with Wilsonville Road were collected during each of these simulation runs. Appendix A presents a procedure for determining the required number of simulation runs based on statistical parameters that may be obtained after a small number of initial runs. The stochastic nature of the VISSIM program necessitates that an adequate number of runs be executed and that results of one or a few runs should never be used in decision making.

4. RESULTS

4.1 Cycle Time Optimization

The four study intersections are currently actuated, in order to model these intersections as fixed-timed an average cycle time was determined by observing several cycles at each intersection.   It was found that all four intersections operated on cycle length of approximately 90 seconds. To determine if this was an optimum cycle time, a battery of VISSIM runs were performed at cycle lengths of 60, 75, 90, and 115 seconds. Figure 8 shows the simulated interchange delay at these four trial cycle times. Interchange delay was computed by weighting the delay of each of the ramp intersection movements by their average proportion of total vehicles served. From this analysis, a 90 second cycle time appears to be a reasonable choice. This 90 second cycle length was used for all subsequent analyses.

4.2 Travel Time Comparison

Travel time data were collected during ten VISSIM simulation runs on three routes as shown in Figure 9. A small data set comprised of 5 actual network trips for each route was acquired at the site on December 13, 2001.   The VISSIM simulation results appear to be good predictors of travel time for routes 1 and 3. The discrepancy in the simulated versus actual travel times on Route 2 may be a result of the fact that the intersections were simulated with fixed time coordinated signals while the actuated signals at times did not appear to be coordinated to provide progressive flow. The nature of the actuation logic may lead to a lack of coordination among the series of signals traversed in Route 2.

4.3 Average Vehicle Delay Comparison

Average vehicle delay data were collected during the ten VISSIM simulation runs for selected approaches of the two Interstate 5 ramp intersections with Wilsonville Road. For each simulated intersection movement a comparison delay was computed using procedures outlined in the Transportation Research Board's Highway Capacity Manual (HCM). Chapter 26 (Interchange Ramp Terminals) of the HCM2000 directs the user to evaluate delays at diamond interchanges using procedures from Chapter 16 (Signalized

Intersections) *[4]*. The HCM2000 Chapter 16 procedures form the basis for the "Signals" module of the HCS2000-Highway Capacity Software (HCS). Comparisons of lane group delays predicted by HCS and VISSIM are shown in Figure 10. Appendix C contains HCS output.

The HCM lane group incremental delay computation includes an Upstream Filtering or Metering Adjustment Factor (I) to account for the impact of metered arrivals from the upstream intersection. The HCM methodology directs that a factor of I=1.0 be used for isolated intersections where the arrival pattern would follow a random distribution. For the closely spaced intersections such as those in the study network, the HCM methodology directs that the I factor be computed using the following equation:

$$I = 1.0 - 0.91X_u^{2.68}$$

Where X_u is approximated as the volume to capacity (v/c) ratio of the upstream through movement. While it appears logical that the delay of a lane group will be lower when the arrival rates are non-uniform and the signals are coordinated to take advantage of this type of arrival pattern, the HCM delay calculation methodology contains many empirical factors which makes the comparison of a single factor such as the Upstream Filtering or Metering Adjustment Factor to a fundamental principle of traffic flow very difficult.

Incremental delay is defined in the HCM2000 as *"...delay due to non-uniform arrivals and temporary cycle failures ... as well as delay caused by sustained periods of oversaturation..."*. After viewing ten hours of VISSIM simulated flow, there were very few instances of oversaturation or cycle failures observed

Comparisons of HCS and VISSIM average vehicle delay at all eight movements reveal relatively small differences. While this in an interesting observation, it does not in itself prove the usefulness of either method. The HCS methodology for delay calculation is simply a "model" of traffic flow that could be described as deterministic and macroscopic.

4.4 Traffic Demand

The hourly traffic volumes used in sections 4.1-4.3 were based on PM peak hour vehicle volume data acquired by DKS Associates in May, 1999. This data came in the form of intersection turning movement counts for the six intersections in the network. To study how the VISSIM simulation program responds to changes in traffic demand, the network was loaded with different levels of traffic (Low, Medium, High, and Very High). These traffic levels correspond to 0.5, 0.75, 1.0 and 1.25 times the May, 1999 PM Peak hour volumes respectively.

Figure 11 shows the VISSIM simulated interchange delay at these four traffic levels. Interchange delay was again computed by weighting the delay of each of the ramp intersection movements by that movement's average proportion of total vehicles served. Average delays increased with increasing traffic, which is consistent with expectations. Of particular interest was the observation of the animation during the "Very High" traffic load. The animation showed that there were several instances when the queues of both eastbound and westbound Wilsonville Road traffic spilled back to limit movement at the adjacent ramp intersection. Any methodology that aims to accurately predict interchange delays at times heavy traffic flow must recognize the impact of queue spill-back.

5. CONCLUSIONS

This report examined the use of a computerized microscopic stochastic traffic simulation tool (VISSIM) as means of evaluating a small urban traffic network including a diamond Interstate Highway interchange. From the analysis of results, the following conclusions were drawn.

Simulated interchange delay results from the VISSIM model appear to be consistent with delays predicted by HCM2000 methodologies.   Model to model comparisons in themselves are not entirely meaningful, however, it appears that the microscopic simulation and the animation that is inherent in the simulation may provide a good tool to evaluate the movement of traffic at diamond interchanges.

The importance of modeling nearby intersections that influence the actual diamond interchange intersections was clearly observed. The VISSIM model generates traffic according to a random distribution, therefore it is vital that the metering effects of nearby intersections be included in the analysis of an interchange.

The stochastic nature of the VISSIM simulation model will result in new results each time the model is seeded with a new random seed. It is vital, therefore, that a statistically sound method be followed in determining the required number of model runs. Appendix A presents a procedure for determining the required number of model runs.

6. FUTURE RESEARCH

The following areas appear to starting points for future research on traffic flow at diamond interchange and other closely spaced intersections.

- A more statistically rigorous comparison of modeled results to field data.

- A detailed analysis of the internal logic (car-following, gap acceptance, etc.) of the VISSIM to other models and a to field data related to this logic.

- Analyses incorporating actuation logic at signalized intersections.

- Extension of the analysis to include ramp metering.

- Extension of the analysis to include freeway weaving sections near the study interchange.

REFERENCES

1.   PTV Planung Transport Verkehr AG, *VISSIM 3.50 User Manual*, Karlsruhe, Germany, 2000.

2.   Bloomberg, L., and Dale, J. *A Comparison of the VISSIM and CORSIM Traffic Simulation Models.* Institute of Transportation Engineers Annual Meeting, August 2000.

3.   PTV Planung Transport Verkehr AG, *VISSIM Traffic Flow Simulation - Technical Description*, Karlsruhe, Germany, 2000.

4.   Transportation Research Board. *Highway Capacity Manual*. Washington, D.C., 2000.

5.   Hogg, R.V., and Tanis, E.A., *Probability and Statistical Inference 4th Edition*. Macmillan Publishing Company, New York, 1993.

6.   Moen, B., Fitts, J., Carter, D., and Ouyang, Y., *A Comparison of the VISSIM Model to Other Widely Used Traffic Simulation and Analysis Programs*. ITE 2000 Annual Meeting CD-ROM, Institute of Transportation Engineers, Nashville, Tennessee, 2000.

7.   Lee, S., and Messer, C.J., *Assessment of Three Traffic Simulation Models for Diamond Interchange Analysis*. A Paper in CD-ROM of the 81st Annual Meeting of TRB, National Research Council, Washington, D.C., 2002

8.   Wang, Y., and Prevedouros, P.D., *Comparison of INTEGRATION, TSIS/CORSIM, and WATSim in Replicating Volumes and Speeds on Three Small Networks.* Transportation Research Record 1644, TRB, National Research Council, Washington, D.C., 1998, pp. 880-92.

LIST OF FIGURES

Legend:

AX: Minimum desired distance between the fronts of two successive vehicles in a standing queue.

BX: Upper range of desired distance between the fronts of two successive vehicles in a standing queue.

SDV: Action point where a driver consciously observes that he is approaching a slower car in front. SDV increases with increasing speed differences.

CLDV   Closing delta velocity, a factor applied to model additional deceleration by the usage of brakes.

OPDV: Action point where the following driver notices that he is slower than the leading vehicle and starts to accelerate again.

SDX: Perception threshold to model the maximum following distance. Approximately 150m.

Figure 1 Graphical Depiction of Wiedemann's Car Following Model *[3]*
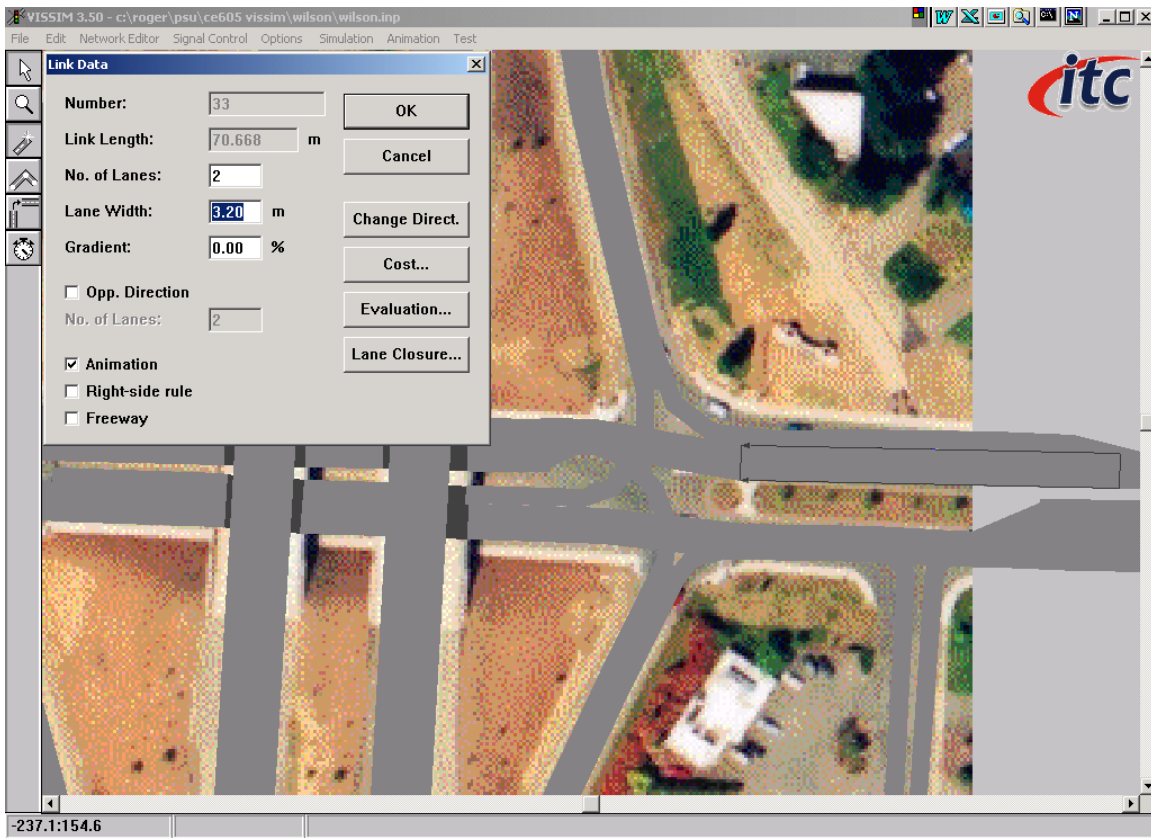
Figure 2 VISSIM Screen Shot (link data)
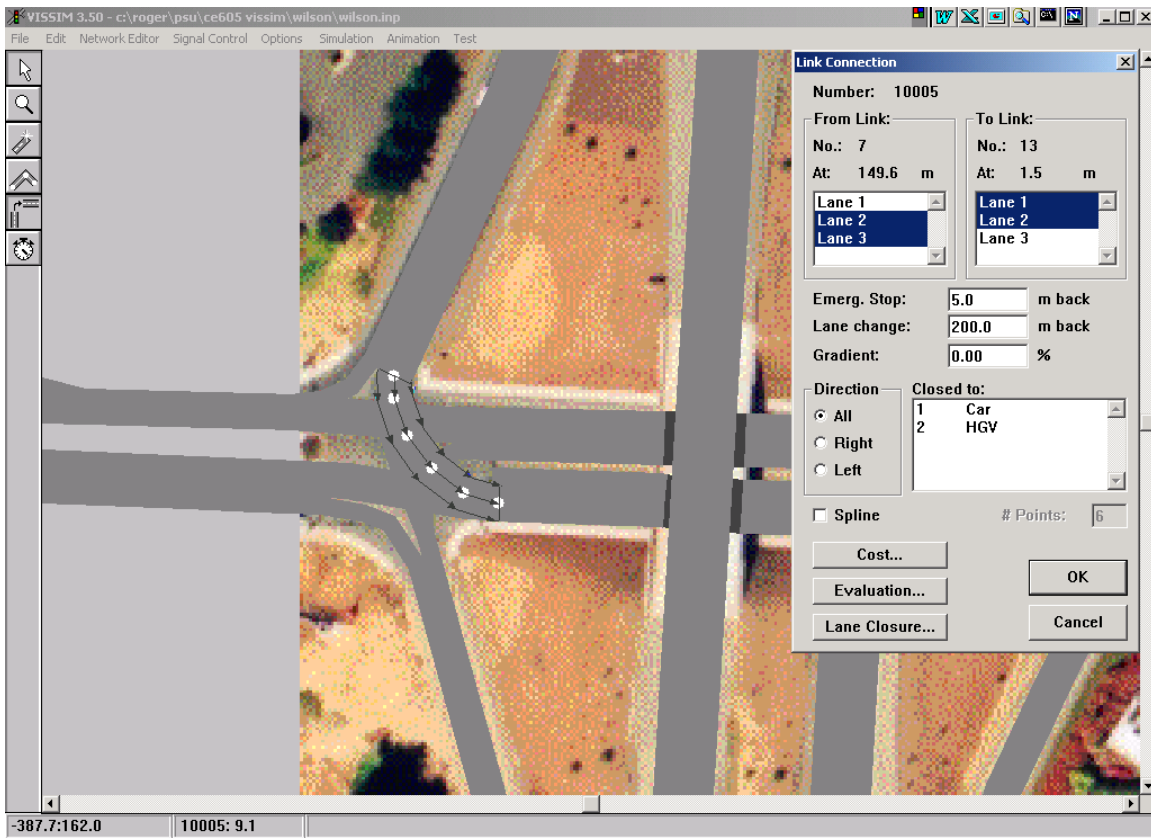
Figure 3 VISSIM Screen Shot (link connection data)
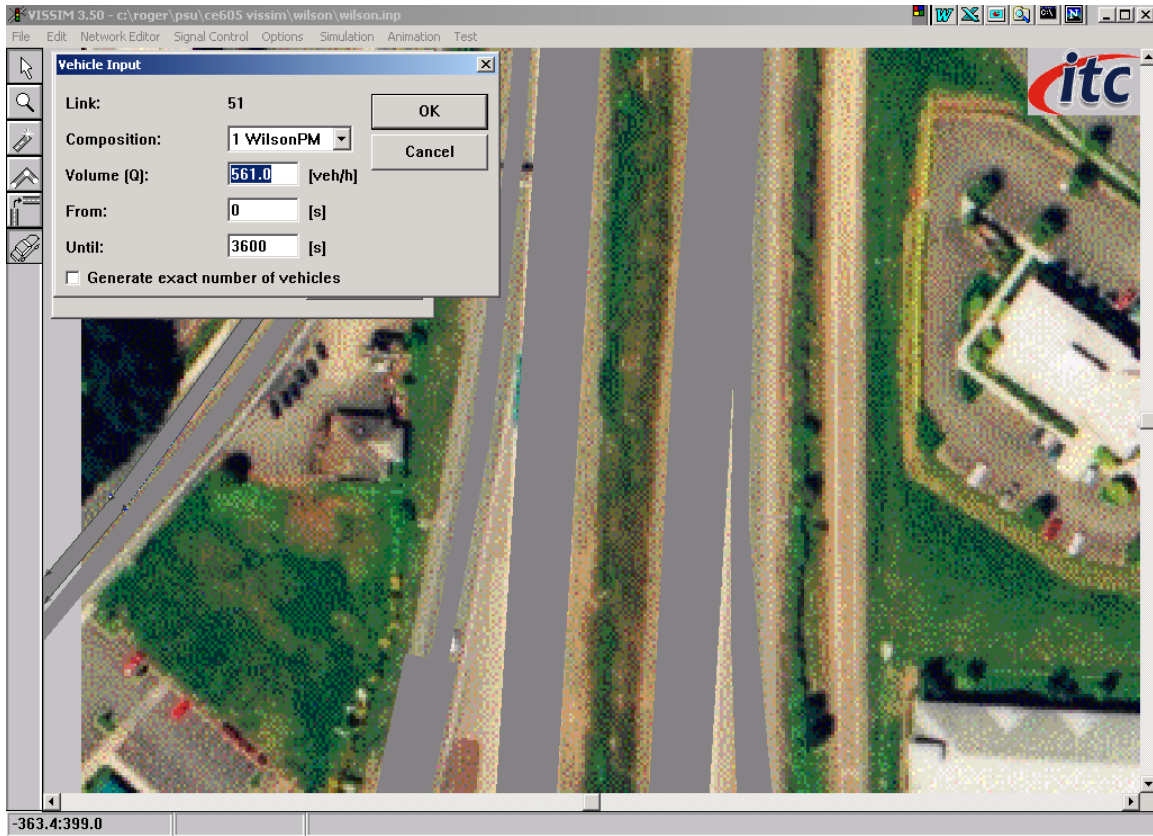
Figure 4 VISSIM Screen Shot (vehicle input)
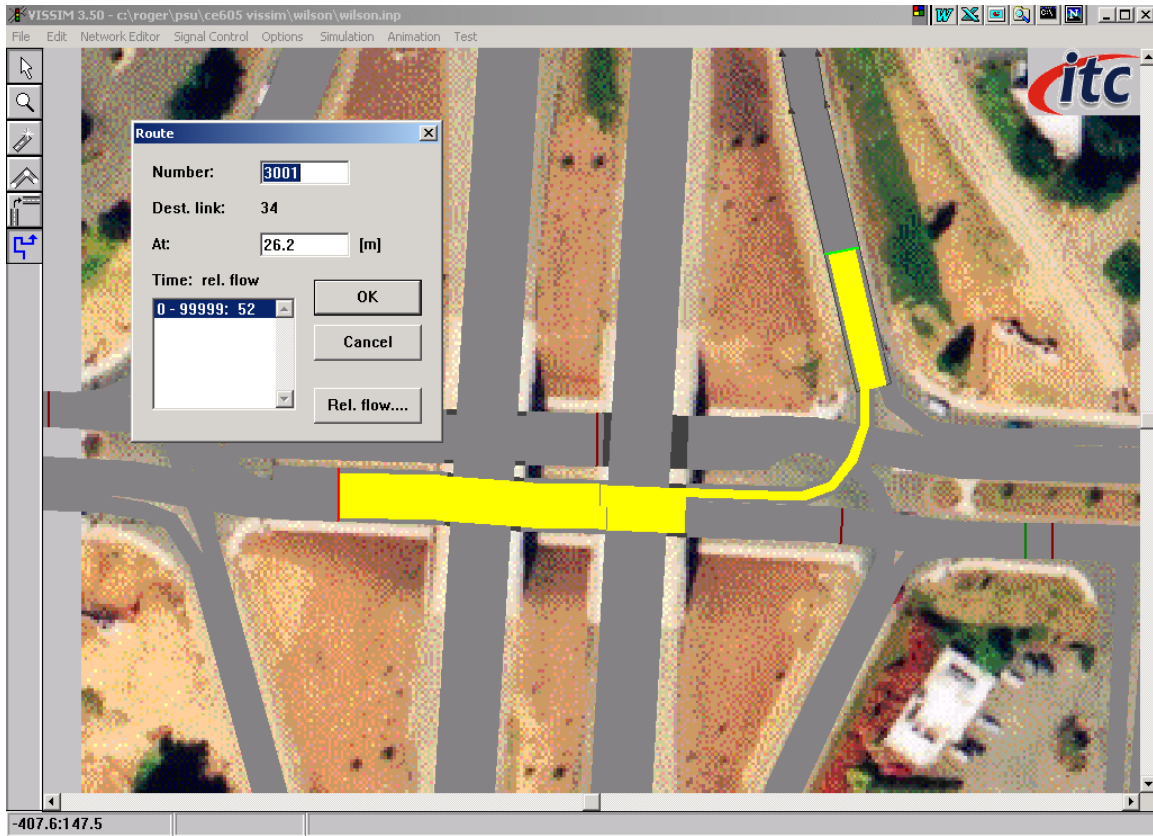
Figure 5 VISSIM Screen Shot (route data)
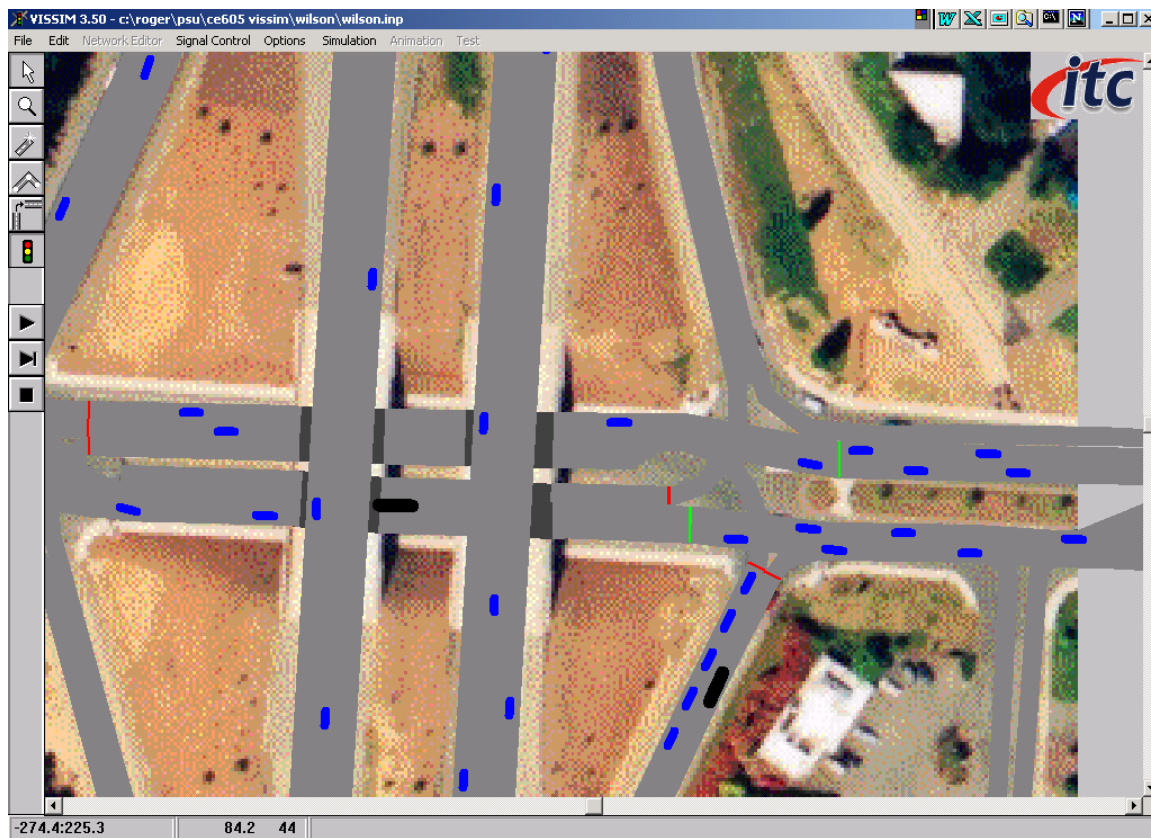
Figure 6 VISSIM Screen Shot (animation)
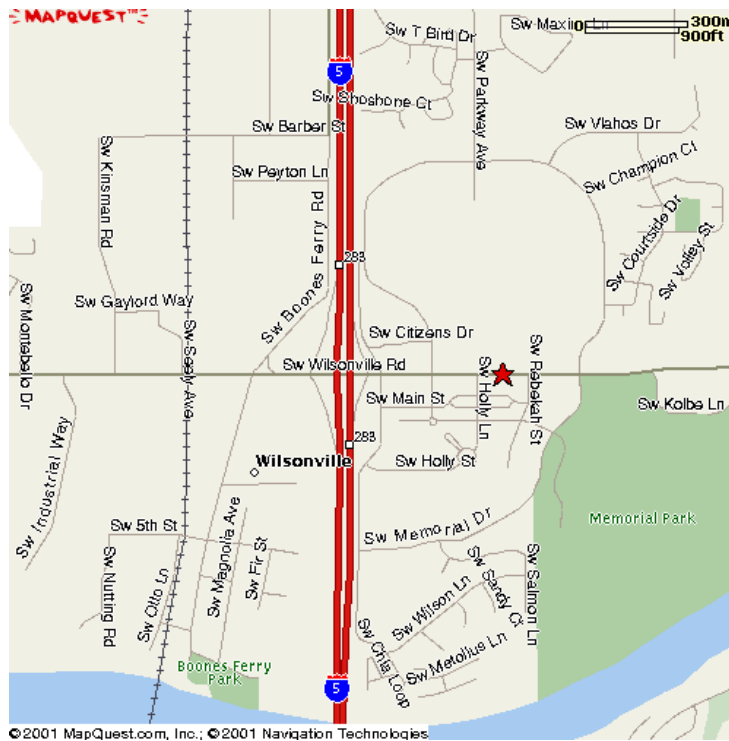
Figure 7 Wilsonville, Oregon Location Map
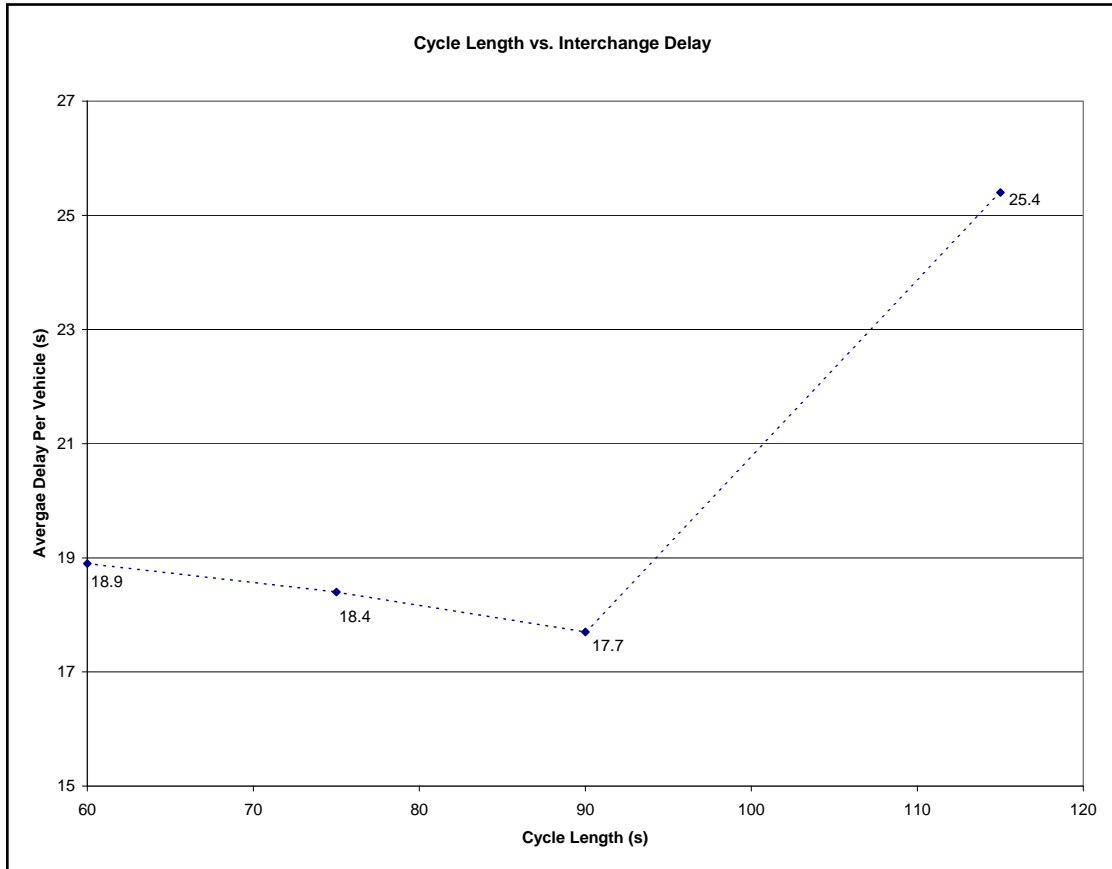
Figure 8 Cycle Length vs. Interchange Delay
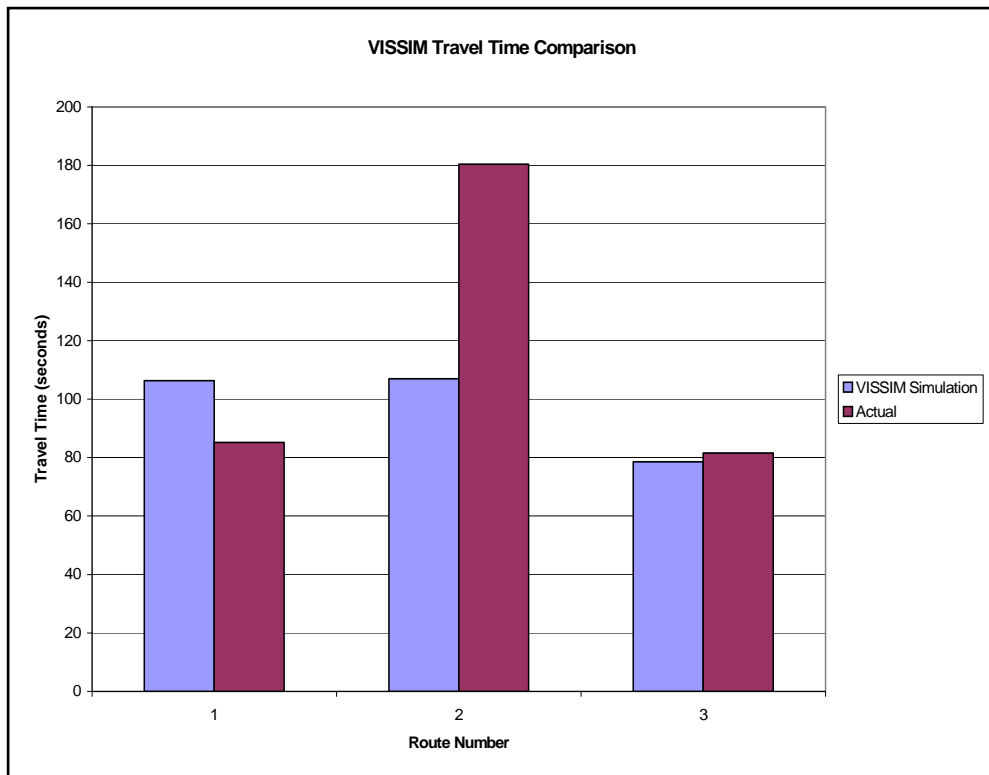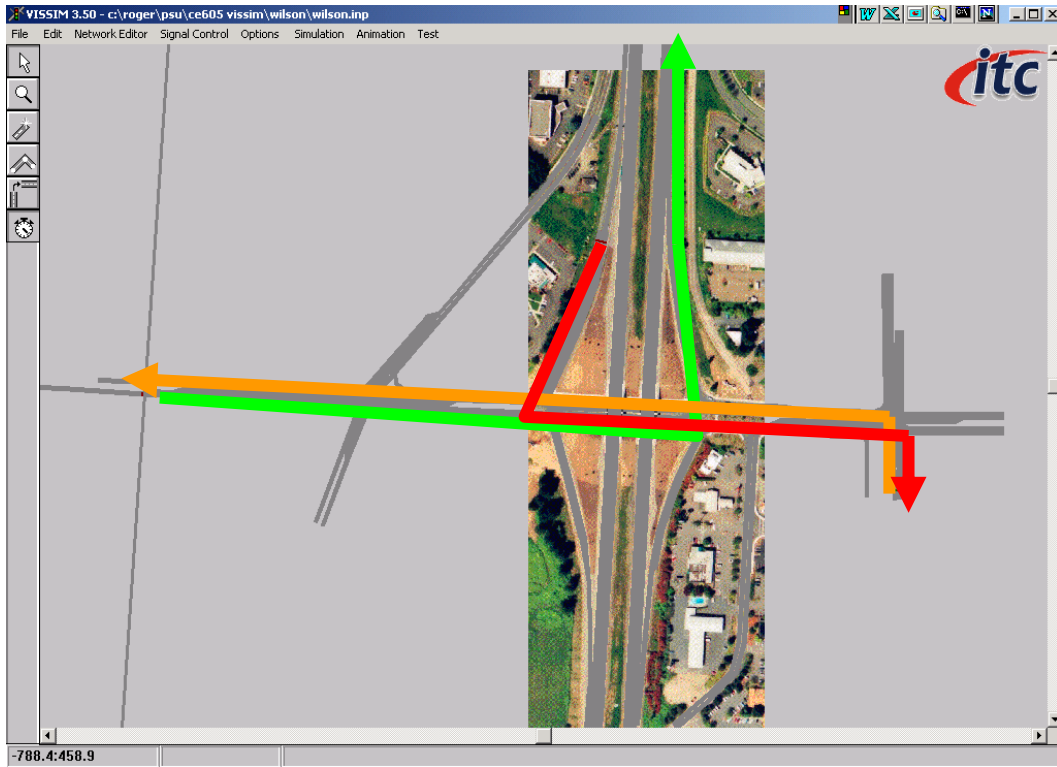
Figure 9 Route Specific Travel Times Route 1-Green, Route 2-Gold, Route 3-Red
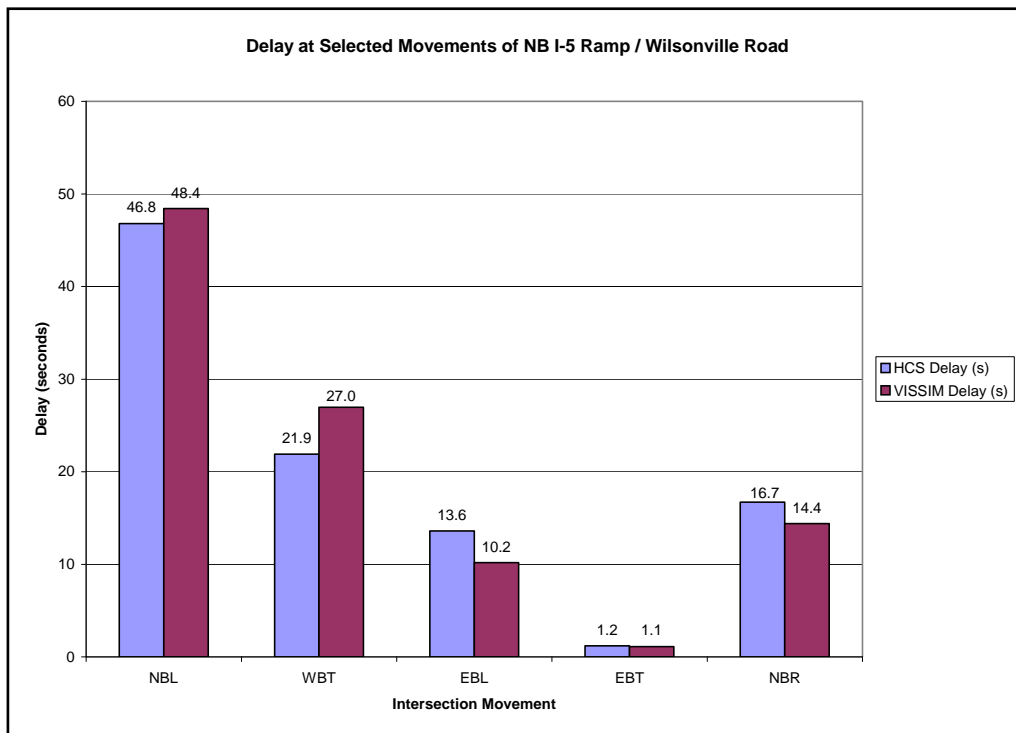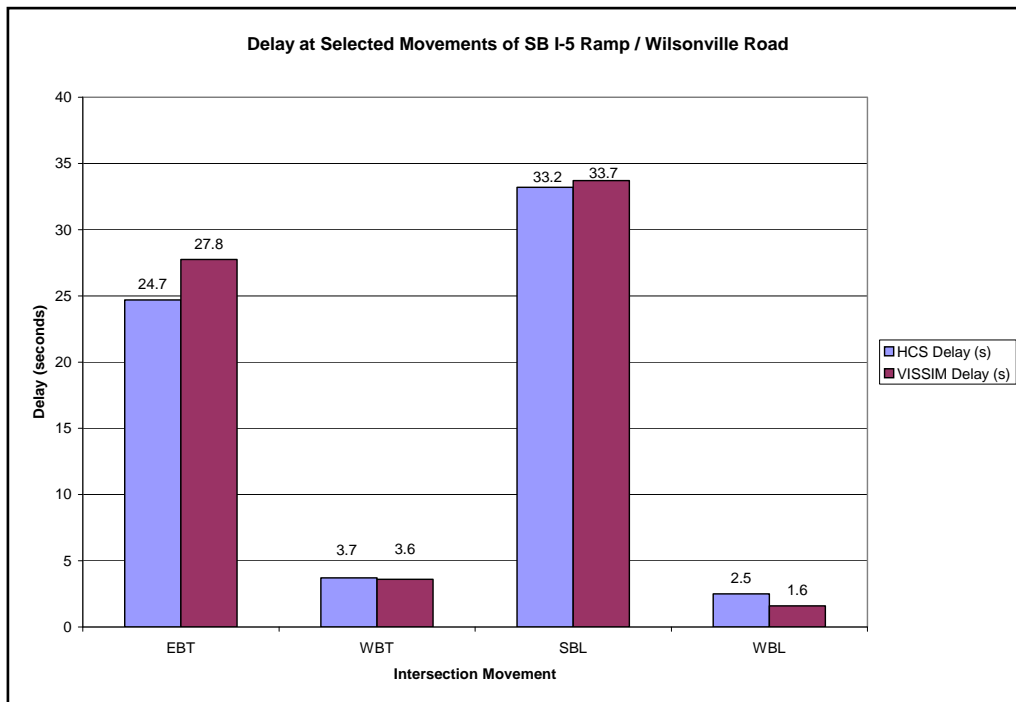
Figure 10 Delay at Selected Movements of I-5 Ramps and Wilsonville Road
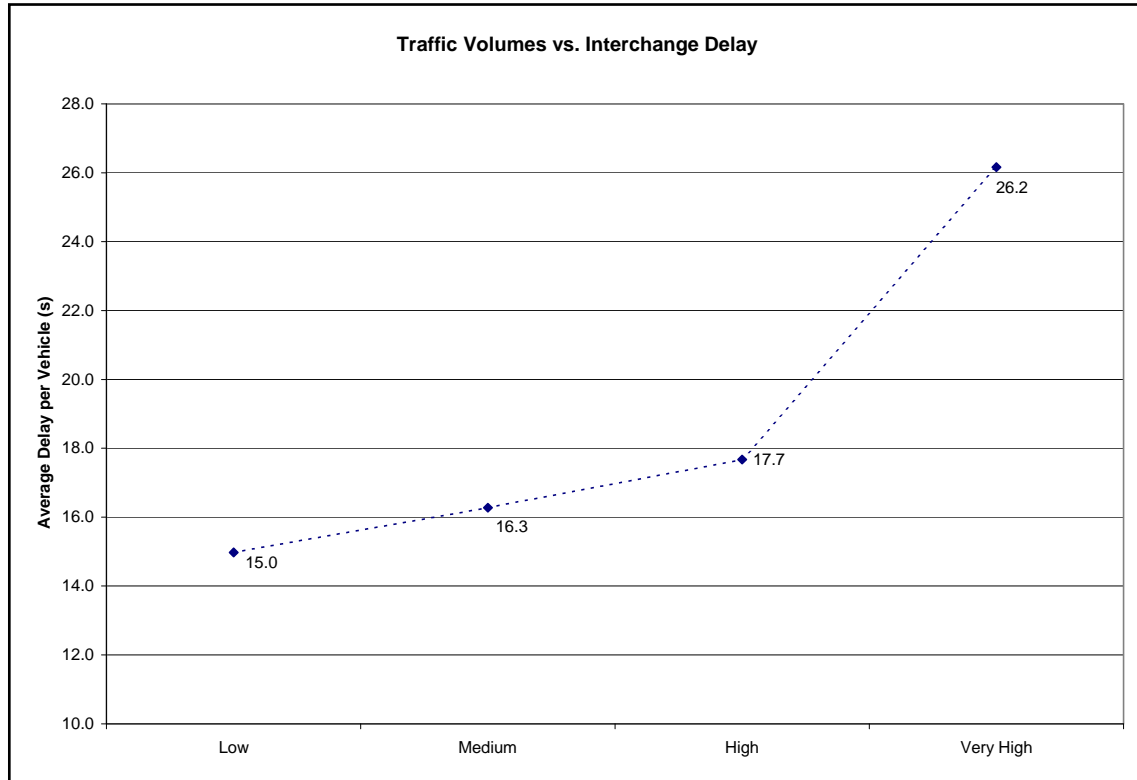
Figure 11 Traffic Volume vs. Interchange Delay

APPENDIX A REQUIRED NUMBER OF SIMULATION RUNS

Due to the stochastic nature of the VISSIM program, each model run with identical operation conditions but with different random seed numbers will produce different results. It is prudent, therefor to execute a small number of simulation runs (say 10) and with the statistical estimators of this trial, compute according to commonly accepted statistical principles, the number of simulation runs required to meet a stated objective (i.e 80%, 90%, 95% etc. level of confidence).

Based on the theories of probability and statistics, the following equation *[5]* can be used to compute the required number of simulation runs.

$$n_r \geq \frac{s^2 z^2_{\alpha/2}}{\varepsilon^2}$$

Where:

s^2 is the variance (generally based on a relatively small number of initial simulation runs)

$z_{\alpha/2}$ is the threshold value for a $100(1-\alpha)$ percent confidence interval

n_r is number of runs required

ε is the maximum error of the estimate

Example:

The following delay data for the NB left movement at the NB I-5 Ramp Intersection with Wilsonville Road was determined from 10 runs of VISSIM

Each value represents seconds of delay.

45.2
41.9
42.2
41.9
59.9
46.8
62.1
58
46.9
39.2

Mean of this data=48.4s

s^2 of this data = 70.525s^2

s=8.398s

α=0.10 (corresponds with 90% confidence)

$\alpha/2$=0.05 (corresponds with 90% confidence)

Z=1.645 (from statistical table *[5]*)

ε =1.5 seconds (based on reasonable error of delay estimate *[7]*)

$$n_r \geq \frac{s^2 z^2{}_{\alpha/2}}{\varepsilon^2} = \frac{(70.525)1.645^2}{1.5^2} \approx 85 \; runs$$

APPENDIX B LITERATURE REVIEW

Several recent papers discuss the use of VISSIM and other computerized microscopic traffic models as tools for the analysis of interchanges and closely spaced intersections in urban networks.

Moen et. al *[6]* compared VISSIM to two other popular simulation packages, CORSIM, and TRANSYT-7F. Although their study did not include a diamond interchange, the modeling of an area of downtown Dallas, Texas described in the paper included closely spaced intersections with queue spillback and heavy traffic volumes. Overall, they found that CORSIM and VISSIM are suitable for predicting measures of effectiveness of various type of intersections for planning and operational decisions. The authors discuss a salient fact inherent in the attempt to compare simulated traffic delay measures with field data - they explain that the "total delay" computed by the simulation software includes all forms of delay, including delay caused by traffic flow factors and geometric delay. This type of "total delay" data is very difficult to collect on real street networks. The dilemma of "how can I validate my model" is important as simulation becomes more popular and the demand for calibration or validation of microscopic simulation data becomes more widespread.

Lee and Messer *[7]* assessed three computer traffic simulation models, two microscopic (CORSIM and SimTraffic) and one macroscopic (Synchro), for diamond interchange analysis. Although VISSIM was not tested, comments pertaining to microscopic simulation would be of value. The researchers recommend that either of the microscopic models can be used for high-quality analysis of actuated diamond interchanges including those with queue spill-back. The researchers echo others in their call for a large number of simulation runs to produce acceptable estimates of measures of effectiveness.

Bloomberg and Dale *[2]* compare two microscopic computer traffic simulation models, CORSIM and VISSIM, on both a simple intersection and a congested urban network,

both in Seattle, Washington. They conclude that both models are useful for planning and operations level analyses. They make some comparisons of the microscopic simulation results to results of HCM2000 Methodology and conclude that areas with queue spill-back may not be suited for the HCM's macroscopic modeling techniques. The authors state that large numbers of simulation runs are required for the proper use of the model output and they encourage future research into comparisons of simulated results to field data.

Wang and Prevedouros *[8]* compare two microscopic computer traffic simulation models, CORSIM and WARSim, on three small urban networks, including a diamond interchange in Honolulu, Hawaii. The study networks had the advantage of being equipped with video surveillance equipment and freeway loop detectors. The authors found that ability to calibrate such measures as density and speed with "real" traffic data aided in their confidence in the results of the simulation. The authors caution that "default" parameter imbedded in simulation software may not always produce "reasonable" results.

APPENDIX C HIGHWAY CAPACITY SOFTWARE (HCS) RESULTS

```
HCS2000: Signalized Intersections Release 4.1b

Analyst: Lindgren                       Inter.: I5 Northramps @Wilsonville
Agency:  Portland State University      Area Type: All other areas
Date:   12/18/2001                      Jurisd:
Period: 17:00-18:00                     Year:   1999
Project ID:
E/W St: Wilsonville Road                N/S St: SB Ramps of I5

_____SIGNALIZED INTERSECTION SUMMARY_____
          | Eastbound     | Westbound    | Northbound    | Southbound    |
          | L    T    R   | L    T    R  | L    T    R   | L    T    R   |
          |_____|_____|_____|_____|
No. Lanes | 1    2    0   | 0    2    0  | 1    0    1   | 0    0    0   |
LGConfig  | L    T        |      T       | L         R   |               |
Volume    |455  412       |     433      |346        336 |               |
Lane Width|3.6  3.6       |     3.6      |3.6        3.6 |               |
RTOR Vol  |               |              |           302 |               |
_____
Duration   0.25      Area Type: All other areas
_____Signal Operations_____
Phase Combination 1    2    3    4 |          5    6    7    8
EB   Left         P                | NB  Left   P
     Thru         P    P            |     Thru
     Right                          |     Right  P
     Peds                           |     Peds
WB   Left                           | SB  Left
     Thru              P            |     Thru
     Right                          |     Right
     Peds                           |     Peds
NB   Right                          | EB  Right
SB   Right                          | WB  Right
Green             28.0 32.0                   18.0
Yellow            3.0  3.0                     3.0
All Red           1.0  1.0                     1.0
                                        Cycle Length: 90.0    secs
_____Intersection Performance Summary_____
Appr/   Lane     Adj Sat    Ratios      Lane Group    Approach
Lane    Group   Flow Rate _____   _____   _____
Grp    Capacity    (s)    v/c   g/C    Delay LOS     Delay LOS
_____
Eastbound
L       562      1805    0.81  0.31    13.6   B
T       2567     3610    0.16  0.71     1.2   A      7.7   A

Westbound

T       1284     3610    0.34  0.36    21.9   C     21.9   C

Northbound
L       361      1805    0.96  0.20    46.8   D
                                                    44.1   D
R       389      1843    0.09  0.21    16.4   B
Southbound



        Intersection Delay = 19.6  (sec/veh)   Intersection LOS = B
_____

             HCS2000: Signalized Intersections Release 4.1b

Roger Lindgren
Oregon University System



Phone:                            Fax:
E-Mail:
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_____OPERATIONAL ANALYSIS_____

Analyst:                Lindgren
Intersection:           I5 Northramps @Wilsonville
Agency/Co.:             Portland State University
Area Type:              All other areas
Date Performed:         12/18/2001
Jurisdiction:
Analysis Time Period:   17:00-18:00
Analysis Year:          1999
Project ID:
                   East/West Street            North/South Street
              Wilsonville Road              SB Ramps of I5

_____VOLUME DATA_____

             |   Eastbound    |   Westbound    |   Northbound   |  Southbound   |
             | L    T    R    | L    T    R    | L    T    R    | L    T    R   |
             |_____|_____|_____|_____|
Volume       |455  412        |     433        |346       336   |               |
% Heavy Veh  |0    0          |     0          |0         0     |               |
PHF          |1.00 1.00       |     1.00       |1.00      1.00  |               |
PK 15 Vol    |114  103        |     109        |87        84    |               |
Hi Ln Vol    |                |                |                |               |
% Grade      |     0          |     0          |     0          |               |
Ideal Sat    |1900 1900       |     1900       |1900      1900  |               |
ParkExist    |                |                |                |               |
NumPark      |                |                |                |               |
No. Lanes    |  1    2    0   | 0    2    0    |  1    0    1   | 0    0    0   |
LGConfig     | L    T         |      T         | L         R    |               |
Lane Width   |3.6  3.6        |     3.6        |3.6       3.6   |               |
RTOR Vol     |                |                |          302   |               |
Adj Flow     |455  412        |     433        |346       34    |               |
%InSharedLn  |                |                |                |               |
Prop LTs     |     0.000      |     0.000      |                |               |
Prop RTs     |                | 0.000          |          1.000 |               |
Peds  Bikes  |                | 0              | 0              | 0             |
Buses        |0    0          |     0          |0         0     |               |
%InProtPhase |                |                |                |               |
Duration     0.25      Area Type: All other areas

_____OPERATING PARAMETERS_____

             |   Eastbound    |   Westbound    |   Northbound   |  Southbound   |
             | L    T    R    | L    T    R    | L    T    R    | L    T    R   |
             |_____|_____|_____|_____|
Init Unmet   |0.0  0.0        |     0.0        |0.0       0.0   |               |
Arriv. Type  |96   93         |     10         |30        55    |               |
Unit Ext.    |3.0  3.0        |     3.0        |2.0       3.0   |               |
I Factor     |     1.000      |     1.000      |     0.250      |               |
Lost Time    |2.0  2.0        |     2.0        |2.0       1.0   |               |
Ext of g     |2.0  2.0        |     2.0        |2.0       2.0   |               |
Ped Min g    |                |     3.2        |     3.2        |     3.2       |

_____PHASE DATA_____

Phase Combination 1     2    3    4 |              5    6    7    8

EB   Left          P                | NB  Left    P
     Thru          P    P           |     Thru
     Right                          |     Right   P
     Peds                           |     Peds

WB   Left                           | SB  Left
     Thru               P           |     Thru
     Right                          |     Right
     Peds                           |     Peds

NB   Right                          | EB  Right
```

```
                                      |
SB  Right                             |  WB  Right
                                      |
                                      |
Green               28.0  32.0                    18.0
Yellow               3.0   3.0                     3.0
All Red              1.0   1.0                     1.0


                                              Cycle Length: 90.0    secs
```

_____VOLUME ADJUSTMENT AND SATURATION FLOW WORKSHEET_____

Volume Adjustment

	Eastbound			Westbound			Northbound			Southbound		
	L	T	R	L	T	R	L	T	R	L	T	R
Volume, V	455	412			433		346		336			
PHF	1.00	1.00			1.00		1.00		1.00			
Adj flow	455	412			433		346		34			
No. Lanes	1	2	0	0	2	0	1	0	1	0	0	0
Lane group	L	T			T		L		R			
Adj flow	455	412			433		346		34			
Prop LTs		0.000			0.000							
Prop RTs					0.000				1.000			

Saturation Flow Rate (see Exhibit 16-7 to determine the adjustment factors)_____

```
           Eastbound            Westbound           Northbound          Southbound
LG     L      T                     T              L            R
So   1900   1900                  1900           1900         1900
Lanes 1     2       0       0      2       0      1       0    1       0      0      0
fW   1.000  1.000                 1.000          1.000        1.000
fHV  1.000  1.000                 1.000          1.000        1.000
fG   1.000  1.000                 1.000          1.000        1.000
fP   1.000  1.000                 1.000          1.000        1.000
fBB  1.000  1.000                 1.000          1.000        1.000
fA   1.00   1.00                  1.00           1.00         1.00
fLU  1.00   0.95                  0.95           1.00         1.00
fRT         1.000                 1.000                       0.970*
fLT  0.950  1.000                 1.000          0.950
Sec.
fLpb 1.000  1.000                 1.000          1.000
fRpb        1.000                 1.000                       1.000
S    1805   3610                  3610           1805         1843
Sec.
```

_____CAPACITY AND LOS WORKSHEET_____

Capacity Analysis and Lane Group Capacity

Appr/ Mvmt	Lane Group	Adj Flow Rate (v)	Adj Sat Flow Rate (s)	Flow Ratio (v/s)	Green Ratio (g/C)	Lane Group Capacity (c)	v/c Ratio
Eastbound							
Prot							
Perm							
Left	L	455	1805	# 0.25	0.31	562	0.81
Prot							
Perm							
Thru	T	412	3610	0.11	0.71	2567	0.16
Right							
Westbound							
Prot							
Perm							
Left							
Prot							
Perm							
Thru	T	433	3610	# 0.12	0.36	1284	0.34
Right							
Northbound							
Prot							
Perm							
Left	L	346	1805	# 0.19	0.20	361	0.96

```
   Prot
   Perm
   Thru
   Right  R         34          1843      0.02    0.21    389     0.09
Southbound
   Prot
   Perm
   Left
   Prot
   Perm
   Thru
   Right
```
_____
Sum of flow ratios for critical lane groups, Yc =   Sum (v/s)   = 0.56
Total lost time per cycle, L = 12.00 sec
Critical flow rate to capacity ratio,   Xc = (Yc)(C)/(C-L) = 0.65

Control Delay and LOS Determination_____

Appr/	Ratios		Unf Del	Prog Adj	Lane Grp	Incremental Factor Del		Res Del	Lane Group		Approach	
Lane												
Grp	v/c	g/C	d1	Fact	Cap	k	d2	d3	Delay	LOS	Delay	LOS
_____
Eastbound
| L | 0.81 | 0.31 | 28.5 | 0.058 | 562 | 0.50 | 12.0 | 0.0 | 13.6 | B | | |
| T | 0.16 | 0.71 | 4.2 | 0.242 | 2567 | 0.50 | 0.1 | 0.0 | 1.2 | A | 7.7 | A |

Westbound

| T | 0.34 | 0.36 | 21.2 | 1.000 | 1284 | 0.50 | 0.7 | 0.0 | 21.9 | C | 21.9 | C |

Northbound
L	0.96	0.20	35.6	0.875	361	0.50	15.7	0.0	46.8	D		
											44.1	D
R	0.09	0.21	28.5	0.570	389	0.50	0.1	0.0	16.4	B		
Southbound

_____
      Intersection Delay = 19.6 (sec/veh)   Intersection LOS = B

_____SUPPLEMENTAL PERMITTED LT WORKSHEET_____
                        for exclusive lefts
Input
                                                    EB   WB   NB   SB
Cycle length, C   90.0   sec
Total actual green time for LT lane group, G (s)
Effective permitted green time for LT lane group, g(s)
Opposing effective green time, go (s)
Number of lanes in LT lane group, N
Number of lanes in opposing approach, No
Adjusted LT flow rate, VLT (veh/h)
Proportion of LT in LT lane group, PLT
Proportion of LT in opposing flow, PLTo
Adjusted opposing flow rate, Vo (veh/h)
Lost time for LT lane group, tL
Computation
LT volume per cycle, LTC=VLTC/3600
Opposing lane util. factor, fLUo   0.95 0.95
Opposing flow, Volc=VoC/[3600(No)fLUo] (veh/ln/cyc)
gf=G[exp(- a * (LTC ** b))]-tl, gf<=g
Opposing platoon ratio, Rpo (refer Exhibit 16-11)
Opposing Queue Ratio, qro=Max[1-Rpo(go/C),0]
gq, (see Exhibit C16-4,5,6,7,8)
gu=g-gq if gq>=gf, or = g-gf if gq<gf
n=Max(gq-gf)/2,0)
PTHo=1-PLTo
```

```
PL*=PLT[1+(N-1)g/(gf+gu/EL1+4.24)]
EL1 (refer to Exhibit C16-3)
EL2=Max((1-Ptho**n)/Plto, 1.0)
fmin=2(1+PL)/g  or  fmin=2(1+Pl)/g
gdiff=max(gq-gf,0)
fm=[gf/g]+[gu/g]/[1+PL(EL1-1)], (min=fmin;max=1.00)
flt=fm=[gf/g]+[gu/g]/[1+PL(EL1-1)]+[gdiff/g]/[1+PL(EL2-1)],(fmin<=fm<=1.00)
or flt=[fm+0.91(N-1)]/N**
Left-turn adjustment, fLT
```

For special case of single-lane approach opposed by multilane approach,
see text.
* If Pl>=1 for shared left-turn lanes with N>1, then assume de-facto
  left-turn lane and redo calculations.
** For permitted left-turns with multiple exclusive left-turn lanes, flt=fm.
For special case of multilane approach opposed by single-lane approach
or when gf>gq, see text.

```
_____SUPPLEMENTAL PERMITTED LT WORKSHEET_____
                       for shared lefts
Input
                                                EB    WB    NB    SB
Cycle length, C                         90.0    sec
Total actual green time for LT lane group, G (s)
Effective permitted green time for LT lane group, g(s)
Opposing effective green time, go (s)
Number of lanes in LT lane group, N
Number of lanes in opposing approach, No
Adjusted LT flow rate, VLT (veh/h)
Proportion of LT in LT lane group, PLT        0.000 0.000
Proportion of LT in opposing flow, PLTo
Adjusted opposing flow rate, Vo (veh/h)
Lost time for LT lane group, tL
Computation
LT volume per cycle, LTC=VLTC/3600
Opposing lane util. factor, fLUo              0.95  0.95
Opposing flow, Volc=VoC/[3600(No)fLUo] (veh/ln/cyc)
gf=G[exp(- a * (LTC ** b))]-tl, gf<=g
Opposing platoon ratio, Rpo (refer Exhibit 16-11)
Opposing Queue Ratio, qro=Max[1-Rpo(go/C),0]
gq, (see Exhibit C16-4,5,6,7,8)
gu=g-gq if gq>=gf, or = g-gf if gq<gf
n=Max(gq-gf)/2,0)
PTHo=1-PLTo
PL*=PLT[1+(N-1)g/(gf+gu/EL1+4.24)]
EL1 (refer to Exhibit C16-3)
EL2=Max((1-Ptho**n)/Plto, 1.0)
fmin=2(1+PL)/g  or  fmin=2(1+Pl)/g
gdiff=max(gq-gf,0)
fm=[gf/g]+[gu/g]/[1+PL(EL1-1)], (min=fmin;max=1.00)
flt=fm=[gf/g]+[gu/g]/[1+PL(EL1-1)]+[gdiff/g]/[1+PL(EL2-1)],(fmin<=fm<=1.00)
or flt=[fm+0.91(N-1)]/N**
Left-turn adjustment, fLT
```

For special case of single-lane approach opposed by multilane approach,
see text.
* If Pl>=1 for shared left-turn lanes with N>1, then assume de-facto
  left-turn lane and redo calculations.
** For permitted left-turns with multiple exclusive left-turn lanes, flt=fm.
For special case of multilane approach opposed by single-lane approach
or when gf>gq, see text.

```
_____SUPPLEMENTAL PEDESTRIAN-BICYCLE EFFECTS WORKSHEET_____
Permitted Left Turns
                                                EB    WB    NB    SB
Effective pedestrian green time, gp (s)
Conflicting pedestrian volume, Vped (p/h)
Pedestrian flow rate, Vpedg (p/h)
OCCpedg
```

```
Opposing queue clearing green, gq (s)
Eff. ped. green consumed by opp. veh. queue, gq/gp
OCCpedu
Opposing flow rate, Vo (veh/h)
OCCr
Number of cross-street receiving lanes, Nrec
Number of turning lanes, Nturn
ApbT
Proportion of left turns, PLT
Proportion of left turns using protected phase, PLTA
Left-turn adjustment, fLpb
Permitted Right Turns
Effective pedestrian green time, gp (s)
Conflicting pedestrian volume, Vped (p/h)
Conflicting bicycle volume, Vbic (bicycles/h)
Vpedg
OCCpedg
Effective green, g (s)
Vbicg
OCCbicg
OCCr
Number of cross-street receiving lanes, Nrec
Number of turning lanes, Nturn
ApbT
Proportion right-turns, PRT
Proportion right-turns using protected phase, PRTA
Right turn adjustment, fRpb
```

_____SUPPLEMENTAL UNIFORM DELAY WORKSHEET_____

```
                                              EBLT   WBLT   NBLT   SBLT
Cycle length, C                       90.0   sec
Adj. LT vol from Vol Adjustment Worksheet, v
v/c ratio from Capacity Worksheet, X
Protected phase effective green interval, g (s)
Opposing queue effective green interval, gq
Unopposed green interval, gu
Red time r=(C-g-gq-gu)
Arrival rate, qa=v/(3600(max[X,1.0]))
Protected ph. departure rate, Sp=s/3600
Permitted ph. departure rate, Ss=s(gq+gu)/(gu*3600)
XPerm
XProt
Case
Queue at beginning of green arrow, Qa
Queue at beginning of unsaturated green, Qu
Residual queue, Qr
Uniform Delay, d1
```

_____DELAY/LOS WORKSHEET WITH INITIAL QUEUE_____

Appr/ Lane Group	Initial Unmet Demand Q veh	Dur. Unmet Demand t hrs.	Uniform Delay Unadj. ds	Uniform Delay Adj. d1 sec	Initial Queue Param. u	Final Unmet Demand Q veh	Initial Queue Delay d3 sec	Lane Group Delay d sec

Eastbound

Westbound

Northbound

Southbound

```
_____
      Intersection Delay  19.6   sec/veh     Intersection LOS   B

_____BACK OF QUEUE WORKSHEET_____
          Eastbound        Westbound       Northbound        Southbound
LaneGroup  |L    T     |         T     |L         R     |           |
Init Queue |0.0  0.0   |         0.0   |0.0       0.0   |           |
Flow Rate  |455  206   |         216   |346       34    |           |
So         |1900 1900  |         1900  |1900      1900  |           |
No.Lanes   |1    2    0 |0   2    0 |1    0    1 |0   0   0  |
SL         |1805 1805  |         1805  |1805      1843  |           |
LnCapacity |562  1283  |         642   |361       389   |           |
Flow Ratio |0.25 0.11  |         0.12  |0.19      0.02  |           |
v/c Ratio  |0.81 0.16  |         0.34  |0.96      0.09  |           |
Grn Ratio  |0.31 0.71  |         0.36  |0.20      0.21  |           |
I Factor   |     1.000 |         1.000 |      0.250     |           |
AT or PVG  |96   93    |         10    |30        55    |           |
Pltn Ratio |3.05 1.31  |         0.28  |1.50      2.61  |           |
PF2        |0.20 0.25  |         1.00  |0.99      0.59  |           |
Q1         |2.0  0.4   |         4.0   |8.5       0.4   |           |
kB         |0.8  1.4   |         0.8   |0.1       0.1   |           |
Q2         |2.7  0.3   |         0.4   |1.7       0.0   |           |
Q Average  |4.7  0.7   |         4.4   |10.2      0.4   |           |
Q Spacing  |7.6  7.6   |         7.6   |7.6       99.0  |           |
Q Storage  |0    0     |         0     |0         0     |           |
Q S Ratio  |          |               |               |           |
70th Percentile Output:
fB%        |1.2  1.3   |         1.2   |1.2       1.3   |           |
BOQ        |5.9  0.9   |         5.4   |12.4      0.5   |           |
QSRatio    |          |               |               |           |
85th Percentile Output:
fB%        |1.5  1.7   |         1.5   |1.4       1.7   |           |
BOQ        |7.2  1.1   |         6.7   |14.7      0.7   |           |
QSRatio    |          |               |               |           |
90th Percentile Output:
fB%        |1.7  1.9   |         1.7   |1.6       2.0   |           |
BOQ        |8.0  1.3   |         7.5   |16.0      0.8   |           |
QSRatio    |          |               |               |           |
95th Percentile Output:
fB%        |2.0  2.5   |         2.0   |1.7       2.5   |           |
BOQ        |9.4  1.7   |         8.8   |17.6      1.0   |           |
QSRatio    |          |               |               |           |
98th Percentile Output:
fB%        |2.3  3.0   |         2.3   |1.9       3.1   |           |
BOQ        |10.8 2.1   |         10.2  |19.3      1.3   |           |
QSRatio    |          |               |               |           |
_____

_____ERROR MESSAGES_____

     No errors to report.
```

```
hCS2000: Signalized Intersections Release 4.1b


Analyst: Lindgren                      Inter.: I5 Southramps @ Wilsonville R
Agency:  Portland State University     Area Type: All other areas
Date:   12/18/2001                     Jurisd:
Period: 17:00-18:00                    Year:   1999
Project ID:
E/W St: Wilsonville Road               N/S St: Interstate 5

_____SIGNALIZED INTERSECTION SUMMARY_____
              | Eastbound     |  Westbound     |  Northbound   |  Southbound     |
              | L    T    R   |  L    T    R   |  L    T    R  |  L    T    R    |
              |_____|_____|_____|_____|
No. Lanes     | 0    2    0   |  1    2    0   |  0    0    0  |  2    0    1    |
LGConfig      |      T        |  L    T        |              |  L         R    |
Volume        |     765       | 504  590       |              | 534       437   |
Lane Width    |     3.6       | 3.6  3.6       |              | 3.6       3.6   |
RTOR Vol      |               |                |              |           350   |
_____
Duration   0.25      Area Type: All other areas
_____Signal Operations_____
Phase Combination 1     2     3     4 |            5     6     7     8
EB   Left                             | NB   Left
     Thru             P                |      Thru
     Right            P                |      Right
     Peds                              |      Peds
WB   Left       P                      | SB   Left       P
     Thru       P     P                |      Thru
     Right                             |      Right      P
     Peds                              |      Peds
NB   Right                             | EB   Right
SB   Right                             | WB   Right
Green           32.0  31.0  0.0                   18.0
Yellow          3.0   0.0                         3.0
All Red         1.0   1.0                         1.0
                                        Cycle Length: 90.0    secs
_____Intersection Performance Summary_____
Appr/   Lane         Adj Sat    Ratios        Lane Group    Approach
Lane    Group        Flow Rate  _____    _____    _____
Grp     Capacity      (s)    v/c    g/C    Delay LOS    Delay LOS
_____
Eastbound

T        1243        3610    0.62   0.34    24.7   C     24.7   C

Westbound
L        642         1805    0.79   0.36    2.5    A
T        2687        3610    0.22   0.74    3.6    A     3.1    A

Northbound



Southbound
L        700         3502    0.76   0.20    33.2   C
                                                          32.6   C
R        323         1615    0.27   0.20    28.7   C
        Intersection Delay = 17.1  (sec/veh)    Intersection LOS = B
_____

               HCS2000: Signalized Intersections Release 4.1b

Roger Lindgren
Oregon University System



Phone:                               Fax:
E-Mail:
```

```
_____OPERATIONAL ANALYSIS_____

Analyst:                Lindgren
Intersection:           I5 Southramps @ Wilsonville R
Agency/Co.:             Portland State University
Area Type:              All other areas
Date Performed:         12/18/2001
Jurisdiction:
Analysis Time Period:   17:00-18:00
Analysis Year:          1999
Project ID:
                     East/West Street          North/South Street
                  Wilsonville Road             Interstate 5

_____VOLUME DATA_____

              |   Eastbound   |   Westbound   |   Northbound  |   Southbound  |
              | L    T    R   | L    T    R   | L    T    R   | L    T    R   |
              |_____|_____|_____|_____|
Volume        |     765       |504  590       |               |534       437  |
% Heavy Veh   |      0        | 0    0        |               | 0         0   |
PHF           |     1.00      |1.00 1.00      |               |1.00      1.00 |
PK 15 Vol     |     192       |126  148       |               |134       110  |
Hi Ln Vol     |               |               |               |               |
% Grade       |      0        |      0        |               |     0         |
Ideal Sat     |     1900      |1900 1900      |               |1900      1900 |
ParkExist     |               |               |               |               |
NumPark       |               |               |               |               |
No. Lanes     | 0    2    0   | 1    2    0   | 0    0    0   | 2    0    1   |
LGConfig      |      T        | L    T        |               | L         R   |
Lane Width    |     3.6       |3.6  3.6       |               |3.6       3.6  |
RTOR Vol      |               |               |               |          350  |
Adj Flow      |     765       |504  590       |               |534        87  |
%InSharedLn   |               |               |               |               |
Prop LTs      |     0.000     |     0.000     |               |               |
Prop RTs      |               |     0.000     |               |          1.000|
Peds  Bikes   | 0             |               | 0             | 0             |
Buses         | 0             | 0    0        |               | 0         0   |
%InProtPhase  |               |               |               |               |
Duration   0.25     Area Type: All other areas

_____OPERATING PARAMETERS_____

              |   Eastbound   |   Westbound   |   Northbound  |   Southbound  |
              | L    T    R   | L    T    R   | L    T    R   | L    T    R   |
              |_____|_____|_____|_____|
Init Unmet    |     0.0       |0.0  0.0       |               |0.0       0.0  |
Arriv. Type   |      40       |100  3         |               | 40        30  |
Unit Ext.     |     3.0       |3.0  3.0       |               |3.0       3.0  |
I Factor      |    1.000      |     0.250     |               |    1.000      |
Lost Time     |     2.0       |2.0  2.0       |               |2.0       2.0  |
Ext of g      |     2.0       |2.0  2.0       |               |2.0       2.0  |
Ped Min g     |     3.2       |               |      3.2      |    3.2        |

_____PHASE DATA_____

Phase Combination 1     2     3     4 |              5     6     7     8

EB  Left                              | NB  Left
    Thru              P               |     Thru
    Right             P               |     Right
    Peds                              |     Peds

WB  Left           P                  | SB  Left    P
    Thru           P     P            |     Thru
    Right                             |     Right    P
    Peds                              |     Peds

NB  Right                             | EB  Right
```

```
                                    |
SB  Right                           |  WB  Right
                                    |
                                    |
Green              32.0  31.0  0.0            18.0
Yellow             3.0   0.0                  3.0
All Red            1.0   1.0                  1.0


                                        Cycle Length: 90.0    secs
```

_____VOLUME ADJUSTMENT AND SATURATION FLOW WORKSHEET_____

Volume Adjustment

	Eastbound			Westbound			Northbound			Southbound		
	L	T	R	L	T	R	L	T	R	L	T	R
Volume, V		765		504	590					534		437
PHF		1.00		1.00	1.00					1.00		1.00
Adj flow		765		504	590					534		87
No. Lanes	0	2	0	1	2	0	0	0	0	2	0	1
Lane group		T		L	T					L		R
Adj flow		765		504	590					534		87
Prop LTs		0.000			0.000							
Prop RTs					0.000							1.000

Saturation Flow Rate (see Exhibit 16-7 to determine the adjustment factors)_____

```
        Eastbound          Westbound          Northbound          Southbound
LG          T           L      T                                   L        R
So        1900        1900   1900                                 1900     1900
Lanes 0    2     0      1      2     0       0      0      0        2     0   1
fW        1.000       1.000  1.000                                1.000    1.000
fHV       1.000       1.000  1.000                                1.000    1.000
fG        1.000       1.000  1.000                                1.000    1.000
fP        1.000       1.000  1.000                                1.000    1.000
fBB       1.000       1.000  1.000                                1.000    1.000
fA        1.00        1.00   1.00                                 1.00     1.00
fLU       0.95        1.00   0.95                                 0.97     1.00
fRT       1.000              1.000                                         0.850
fLT       1.000       0.950  1.000                                0.950
Sec.
fLpb      1.000       1.000  1.000                                1.000
fRpb      1.000              1.000                                         1.000
S         3610        1805   3610                                 3502     1615
Sec.
```

_____CAPACITY AND LOS WORKSHEET_____

Capacity Analysis and Lane Group Capacity

		Adj	Adj Sat	Flow	Green	--Lane Group--	
Appr/	Lane	Flow Rate	Flow Rate	Ratio	Ratio	Capacity	v/c
Mvmt	Group	(v)	(s)	(v/s)	(g/C)	(c)	Ratio
Eastbound							
Prot							
Perm							
Left							
Prot							
Perm							
Thru	T	765	3610	# 0.21	0.34	1243	0.62
Right							
Westbound							
Prot							
Perm							
Left	L	504	1805	# 0.28	0.36	642	0.79
Prot							
Perm							
Thru	T	590	3610	0.16	0.74	2687	0.22
Right							
Northbound							
Prot							
Perm							
Left							

```
   Prot
   Perm
   Thru
   Right
Southbound
   Prot
   Perm
   Left   L           534         3502     # 0.15    0.20    700     0.76
   Prot
   Perm
   Thru
   Right  R            87         1615       0.05    0.20    323     0.27
```
_____
Sum of flow ratios for critical lane groups, Yc =   Sum (v/s)   = 0.64
Total lost time per cycle, L = 9.00   sec
Critical flow rate to capacity ratio,   Xc = (Yc)(C)/(C-L) = 0.72

Control Delay and LOS Determination_____
```
Appr/   Ratios   Unf  Prog Lane   Incremental  Res   Lane Group    Approach
Lane _____  Del  Adj  Grp    Factor Del   Del   _____  _____
Grp   v/c  g/C   d1   Fact Cap    k      d2     d3     Delay LOS   Delay LOS
```
_____
Eastbound

```
T    0.62 0.34  24.5 0.915 1243  0.50   2.3    0.0   24.7  C    24.7  C
```

Westbound
```
L    0.79 0.36  25.9 0.000 642   0.50   2.5    0.0   2.5   A
T    0.22 0.74  3.5  1.000 2687  0.50   0.0    0.0   3.6   A    3.1   A
```

Northbound

Southbound
```
L    0.76 0.20  34.0 0.750 700   0.50   7.7    0.0   33.2  C
                                                            32.6  C
R    0.27 0.20  30.4 0.875 323   0.50   2.0    0.0   28.7  C
```
_____
        Intersection Delay = 17.1 (sec/veh)   Intersection LOS = B
Errors exist. See bottom of text report.

_____SUPPLEMENTAL PERMITTED LT WORKSHEET_____
                          for exclusive lefts
Input
                                                  EB   WB   NB   SB
Cycle length, C   90.0   sec
Total actual green time for LT lane group, G (s)
Effective permitted green time for LT lane group, g(s)
Opposing effective green time, go (s)
Number of lanes in LT lane group, N
Number of lanes in opposing approach, No
Adjusted LT flow rate, VLT (veh/h)
Proportion of LT in LT lane group, PLT
Proportion of LT in opposing flow, PLTo
Adjusted opposing flow rate, Vo (veh/h)
Lost time for LT lane group, tL
Computation
LT volume per cycle, LTC=VLTC/3600
Opposing lane util. factor, fLUo   0.95 0.95
Opposing flow, Volc=VoC/[3600(No)fLUo] (veh/ln/cyc)
gf=G[exp(- a * (LTC ** b))]-tl, gf<=g
Opposing platoon ratio, Rpo (refer Exhibit 16-11)
Opposing Queue Ratio, qro=Max[1-Rpo(go/C),0]
gq, (see Exhibit C16-4,5,6,7,8)
gu=g-gq if gq>=gf, or = g-gf if gq<gf
n=Max(gq-gf)/2,0)
PTHo=1-PLTo

```
PL*=PLT[1+(N-1)g/(gf+gu/EL1+4.24)]
EL1 (refer to Exhibit C16-3)
EL2=Max((1-Ptho**n)/Plto, 1.0)
fmin=2(1+PL)/g  or  fmin=2(1+Pl)/g
gdiff=max(gq-gf,0)
fm=[gf/g]+[gu/g]/[1+PL(EL1-1)], (min=fmin;max=1.00)
flt=fm=[gf/g]+[gu/g]/[1+PL(EL1-1)]+[gdiff/g]/[1+PL(EL2-1)],(fmin<=fm<=1.00)
or flt=[fm+0.91(N-1)]/N**
Left-turn adjustment, fLT
```

For special case of single-lane approach opposed by multilane approach,
see text.
* If Pl>=1 for shared left-turn lanes with N>1, then assume de-facto
  left-turn lane and redo calculations.
** For permitted left-turns with multiple exclusive left-turn lanes, flt=fm.
For special case of multilane approach opposed by single-lane approach
or when gf>gq, see text.

_____SUPPLEMENTAL PERMITTED LT WORKSHEET_____
                        for shared lefts
Input

		EB	WB	NB	SB
Cycle length, C	90.0 sec				
Total actual green time for LT lane group, G (s)					
Effective permitted green time for LT lane group, g(s)					
Opposing effective green time, go (s)					
Number of lanes in LT lane group, N					
Number of lanes in opposing approach, No					
Adjusted LT flow rate, VLT (veh/h)					
Proportion of LT in LT lane group, PLT		0.000	0.000		
Proportion of LT in opposing flow, PLTo					
Adjusted opposing flow rate, Vo (veh/h)					
Lost time for LT lane group, tL					
Computation					
LT volume per cycle, LTC=VLTC/3600					
Opposing lane util. factor, fLUo		0.95	0.95		
Opposing flow, Volc=VoC/[3600(No)fLUo] (veh/ln/cyc)					
gf=G[exp(- a * (LTC ** b))]-tl, gf<=g					
Opposing platoon ratio, Rpo (refer Exhibit 16-11)					
Opposing Queue Ratio, qro=Max[1-Rpo(go/C),0]					
gq, (see Exhibit C16-4,5,6,7,8)					
gu=g-gq if gq>=gf, or = g-gf if gq<gf					
n=Max(gq-gf)/2,0)					
PTHo=1-PLTo					

```
PL*=PLT[1+(N-1)g/(gf+gu/EL1+4.24)]
EL1 (refer to Exhibit C16-3)
EL2=Max((1-Ptho**n)/Plto, 1.0)
fmin=2(1+PL)/g  or  fmin=2(1+Pl)/g
gdiff=max(gq-gf,0)
fm=[gf/g]+[gu/g]/[1+PL(EL1-1)], (min=fmin;max=1.00)
flt=fm=[gf/g]+[gu/g]/[1+PL(EL1-1)]+[gdiff/g]/[1+PL(EL2-1)],(fmin<=fm<=1.00)
or flt=[fm+0.91(N-1)]/N**
Left-turn adjustment, fLT
```

For special case of single-lane approach opposed by multilane approach,
see text.
* If Pl>=1 for shared left-turn lanes with N>1, then assume de-facto
  left-turn lane and redo calculations.
** For permitted left-turns with multiple exclusive left-turn lanes, flt=fm.
For special case of multilane approach opposed by single-lane approach
or when gf>gq, see text.

_____SUPPLEMENTAL PEDESTRIAN-BICYCLE EFFECTS WORKSHEET_____
Permitted Left Turns

	EB	WB	NB	SB
Effective pedestrian green time, gp (s)				
Conflicting pedestrian volume, Vped (p/h)				
Pedestrian flow rate, Vpedg (p/h)				
OCCpedg				

```
Opposing queue clearing green, gq (s)
Eff. ped. green consumed by opp. veh. queue, gq/gp
OCCpedu
Opposing flow rate, Vo (veh/h)
OCCr
Number of cross-street receiving lanes, Nrec
Number of turning lanes, Nturn
ApbT
Proportion of left turns, PLT
Proportion of left turns using protected phase, PLTA
Left-turn adjustment, fLpb
Permitted Right Turns
Effective pedestrian green time, gp (s)
Conflicting pedestrian volume, Vped (p/h)
Conflicting bicycle volume, Vbic (bicycles/h)
Vpedg
OCCpedg
Effective green, g (s)
Vbicg
OCCbicg
OCCr
Number of cross-street receiving lanes, Nrec
Number of turning lanes, Nturn
ApbT
Proportion right-turns, PRT
Proportion right-turns using protected phase, PRTA
Right turn adjustment, fRpb
```

_____SUPPLEMENTAL UNIFORM DELAY WORKSHEET_____

```
                                           EBLT   WBLT   NBLT   SBLT
Cycle length, C                        90.0   sec
Adj. LT vol from Vol Adjustment Worksheet, v
v/c ratio from Capacity Worksheet, X
Protected phase effective green interval, g (s)
Opposing queue effective green interval, gq
Unopposed green interval, gu
Red time r=(C-g-gq-gu)
Arrival rate, qa=v/(3600(max[X,1.0]))
Protected ph. departure rate, Sp=s/3600
Permitted ph. departure rate, Ss=s(gq+gu)/(gu*3600)
XPerm
XProt
Case
Queue at beginning of green arrow, Qa
Queue at beginning of unsaturated green, Qu
Residual queue, Qr
Uniform Delay, d1
```

_____DELAY/LOS WORKSHEET WITH INITIAL QUEUE_____

```
        Initial Dur.     Uniform Delay   Initial Final   Initial Lane
Appr/   Unmet   Unmet    _____  Queue   Unmet   Queue   Group
Lane    Demand  Demand   Unadj.  Adj.    Param.  Demand  Delay   Delay
Group   Q veh   t hrs.   ds      d1 sec  u       Q veh   d3 sec  d sec
_____
Eastbound




Westbound




Northbound
```

Southbound

```
_____
      Intersection Delay  17.1   sec/veh    Intersection LOS  B
_____BACK OF QUEUE WORKSHEET_____
          Eastbound        Westbound      Northbound      Southbound
LaneGroup  |     T       |L    T       |             |L          R    |
Init Queue |    0.0      |0.0  0.0     |             |0.0        0.0   |
Flow Rate  |    382      |504  295     |             |267        87    |
So         |    1900     |1900 1900    |             |1900       1900  |
No.Lanes   |0   2    0   |1    2    0  |0    0    0  |2     0    1     |
SL         |    1805     |1805 1805    |             |1751       1615  |
LnCapacity |    621      |642  1343    |             |350        323   |
Flow Ratio |    0.21     |0.28 0.16    |             |0.15       0.05  |
v/c Ratio  |    0.62     |0.79 0.22    |             |0.76       0.27  |
Grn Ratio  |    0.34     |0.36 0.74    |             |0.20       0.20  |
I Factor   |    1.000    |     0.250   |             |      1.000      |
AT or PVG  |    40       |100  3       |             |40         30    |
Pltn Ratio |    1.16     |2.67 1.00    |             |2.00       1.50  |
PF2        |    0.96     |0.00 1.00    |             |0.91       0.90  |
Q1         |    7.6      |0.0  2.3     |             |5.8        1.7   |
kB         |    0.8      |0.2  0.4     |             |0.5        0.5   |
Q2         |    1.3      |0.7  0.1     |             |1.5        0.2   |
Q Average  |    8.9      |0.7  2.4     |             |7.3        1.8   |
Q Spacing  |    7.6      |7.6  7.6     |             |7.6        7.6   |
Q Storage  |    0        |0    0       |             |0          0     |
Q S Ratio  |            |            |             |                |
70th Percentile Output:
fB%        |    1.2      |1.3  1.3     |             |1.2        1.3   |
BOQ        |    10.8     |0.9  3.0     |             |8.9        2.3   |
QSRatio    |            |            |             |                |
85th Percentile Output:
fB%        |    1.5      |1.7  1.6     |             |1.5        1.6   |
BOQ        |    12.8     |1.2  3.7     |             |10.7       3.0   |
QSRatio    |            |            |             |                |
90th Percentile Output:
fB%        |    1.6      |1.9  1.8     |             |1.6        1.8   |
BOQ        |    14.0     |1.4  4.3     |             |11.8       3.4   |
QSRatio    |            |            |             |                |
95th Percentile Output:
fB%        |    1.8      |2.5  2.2     |             |1.8        2.3   |
BOQ        |    15.7     |1.8  5.2     |             |13.4       4.2   |
QSRatio    |            |            |             |                |
98th Percentile Output:
fB%        |    2.0      |3.0  2.6     |             |2.0        2.7   |
BOQ        |    17.3     |2.2  6.2     |             |15.0       5.1   |
QSRatio    |            |            |             |                |
_____

_____ERROR MESSAGES_____
```