Microscopic Simulation of Traffic at a Suburban Interchange

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Abstract Recent advances in computer hardware and software technology have led to the increased use of traffic simulation models. Depending on the required objective of the simulation, models range from microscopic models, which detail the movement of individual vehicles, to macroscopic models that use gross traffic descriptors such as flow. Because of the fine level of detail required in a microscopic model, applications tend towards traffic operations over a relatively small geographical area. Macroscopic models are generally applied over a much larger, system-wide, geographical area and are more useful for transportation planning rather than traffic engineering.

INTRODUCTION

Two popular computerized microscopic traffic simulation programs (Paramics and VISSIM) were used to analyze a freeway diamond interchange. The study area is the intersection of Interstate 5 and Wilsonville Road, located on southern edge of the Portland, Oregon metropolitan area. The study area includes four closely spaced signalized roadway intersections and a heavy rail line crossing.

The driver behavior and vehicle maneuvering models employed by each program are discussed. The procedural steps required to implement each simulation model are presented along with performance evaluation data. Travel times and delays predicted by the models are compared to those predicted by the 2000 Highway Capacity Manual and also to data collected by a probe vehicle. The importance of model verification, validation and calibration are emphasized. The stochastic nature of the models is examined and a statistical procedure to determine the required number of simulation runs is presented.

BACKGOUND

Computer processing advances have led to the increased use of traffic simulation models. Depending on the simulation objectives, models range from macroscopic models that use traffic descriptors such as flow, density and speed to microscopic models, which detail the movement of individual vehicles. (1) Macroscopic models are generally applied over large geographical areas and are more useful for transportation planning and corridor operations analysis rather than detailed traffic engineering in areas with complicated geometry and tight right-of-way restrictions. Because of the level of detail required in a microscopic model, applications tend towards traffic operations over relatively small geographical areas.

The Transportation Research Board's Highway Capacity Manual (HCM) presents methodologies recommended for use in planning and operational analysis of an individual transportation network element such as a signalized intersection or a mainline section of a freeway. (1) The HCM equations and worksheets are based on limited statistical models that can be considered to be macroscopic. In part because the HCM models do not consider the behavior of individual vehicles, and due to the deterministic nature of HCM models, there is a growing recognition that stochastic microscopic simulation models can be very useful in operational analyses on small to mid-sized transportation networks. One strength of modern simulation models is that they are based on the random movements of each vehicle. This discrete modeling provides the opportunity to view the animated vehicles on a graphical representation of the network. In addition, microscopic traffic simulation models do not need to explicitly model such behavior as queuing, vehicle platoons, or shock waves. These situations occur in the simulation for the same reason they occur on the actual road networks, that is because they are natural consequences of the interaction of drivers, vehicles, road geometry and traffic control mechanisms. (2)

The objective of this paper is to investigate two popular microscopic traffic simulation models, Paramics and VISSIM. The modeled area consists of the area surrounding the diamond interchange of Interstate 5 (I-5) and Wilsonville Road, located in the city of Wilsonville, Oregon. Figure 1 shows the location of the study area. This interchange is characterized by high traffic volumes (80,000 ADT on I-5) and heavy peak hour traffic to/from the City of Wilsonville. The study described herein details the key features of each software package and evaluates their effectiveness in modeling a diamond interchange and several adjacent intersections.

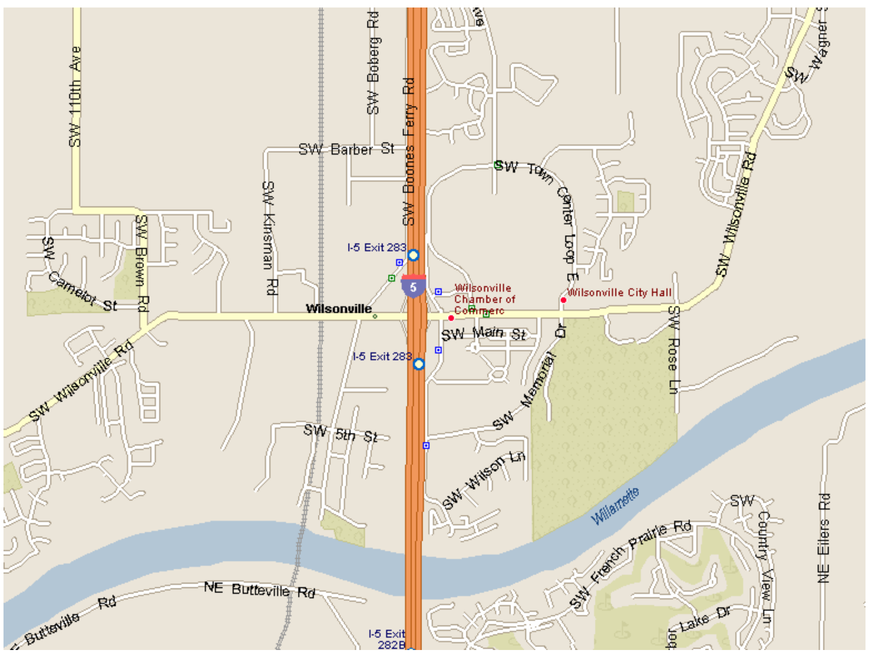


Figure 1 Site Map

The next section of this report contains a description of the two microscopic traffic software packages, Paramics and VISSIM. This is followed by a description of the analysis network and the data collection phase of the project. Next we discuss the model implementation stage, from network coding to model calibration. Finally, the report ends with a review of the major findings and a suggested list of items requiring further research.

SOFTWARE DESCRIPTION

Paramics is a software suite used to model the movement and behavior of individual vehicles on road networks. Paramics is a product of Quadstone Limited of Scotland, UK. There are four modules within the suite; Modeller, Processor, Analyser, and Programmer. A typical transportation engineering package consists of three of these modules – Modeller, Processor, and Analyser. (2)

- Paramics Modeller provides network building tools as well as traffic simulation and statistical output.
- Paramics Processor provides the same functionality as Modeller but it sets up and runs without visualization. The output is created in the form of batch files. It helps to increase the simulation speed for a large network.
- Paramics Analyser reads output from each simulation run by Modeller and provides the visualization of select results.

Paramics Version 3, Build 7 was used for this project. Paramics is capable of modeling the movements of different types of vehicles. Vehicle type can be defined by physical characteristics – length, height, width, weight, maximum speed, etc. It is also possible to model public transportation vehicles like buses, light rail trains, and heavy rail trains. The version used for this project had no support for modeling pedestrian and bicycle movements realistically on the network, however, the interaction of pedestrians with the road users can be modeled via signal-controlled intersections.

Microscopic traffic simulation models depend on the accuracy of the coding of network features. Unlike macroscopic planning level software, an effective Paramics model requires a very detailed network to be created. Network coding in Paramics uses a "node" and “link” based network system, where each link is coded as a connector between two nodes. Network creation is accomplished within a graphical user interface that allows the user to build the network on top of a template road geometry file - aerial photos or CAD drawing, for example. Details on each link specify the characteristics of roadway such as number of lanes, lane width, types of roadway, design and speeds. Figure 2 shows a typical Paramics screen shot.

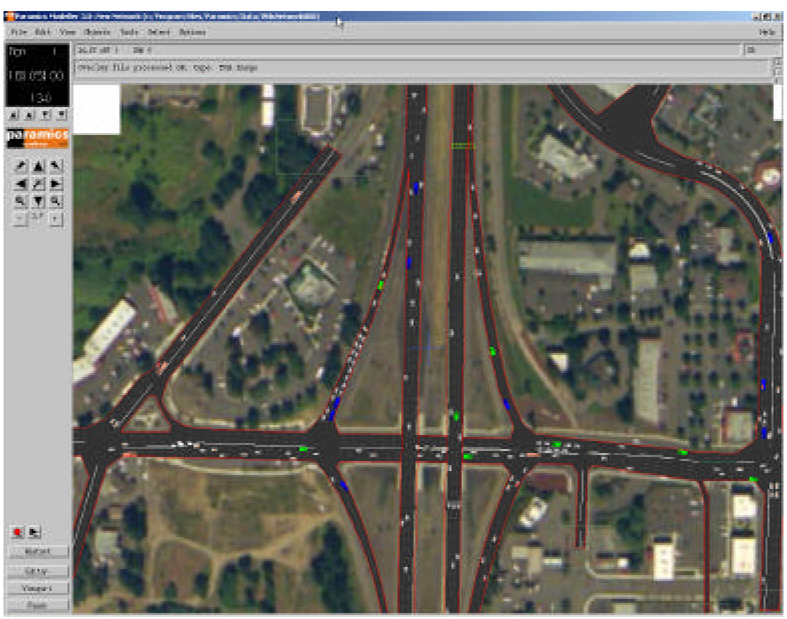


Figure 2 Paramics Screen Shot

Paramics software uses three traffic flow models; car following, gap acceptance and lane changing models, to control the movement of individual vehicles in the network. Paramics randomly distributes values of two key driver characteristics; aggression and awareness, to the driver of each vehicle. Furthermore, the Paramics driver behavior model is fully interactive with the network geometry, which allows for changes in vehicle speed and position depending on:

- position of stop and curb lines,
- intersection signal times,
- intersection coding with both fixed time and actuated,
- location of bus stops,
- location of pedestrian crossings,
- lane control and access restrictions,
- areas where on-street parking affect the performance of vehicles.

Travel demand in Paramics is defined by an origin-destination matrix. Trips are released from and arrive at areas called zones. Traffic assignment in Paramics applies to all vehicle types except fixed route vehicles, such as buses and trains. The travel cost for each vehicle to reach its destination is calculated at each time step. The comparison is made between alternative routes and the least cost route will be taken as the best route. The assignment model predicts the route according to the origin-destination pair. Three main assignment techniques used in Paramics are:

- All-or-nothing assignment method – assumes that all drivers traveling with same knowledge base for route choice and there is no congestion effect. Link costs do not depend on the flow levels.
- Stochastic assignment method – emphasizes the variability in drivers' perceptions of costs and the composite measure that they try to minimize (distance, travel time, generalized cost).
- Dynamic feedback assignment – assumes that the drivers who are familiar with the road network will reroute if information on the present traffic condition is provided back to them.

VISSIM is an urban traffic and public transit operations software package produced by PTV Planung Transport Verkehr AG of Karlsruhe, Germany. (3,4) 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. VISSIM 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. (4) 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. (3) The VISSIM software uses driver behavior models developed by R. Wiedemann in 1974 (urban behavior) and 1999 (freeway behavior). (5)

Wiedemann's traffic flow models are discrete, stochastic, time step based microscopic models. Central to both models is Wiedemann's car following model. A faster moving vehicle will decelerate as is approaches a slower vehicle. The premise is that the faster vehicle seeks a safe headway at which to follow the slower vehicle. The computer model begins to adjust the faster vehicle's speed when a perception threshold distance is reached. At headway distances less than this threshold, the faster vehicle will decelerate as the driver attempts to create a minimum safe headway. The driver may decelerate to the point that he is traveling slower than the lead vehicle 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. (5)

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. (5)

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 that allows the user to build the network by inserting a series of links and connectors. Figure 3 shows a typical VISSIM screen shot. 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. Network links are joined by connectors as shown in thereby eliminating the need for "nodes" that are used in many other traffic network software packages.

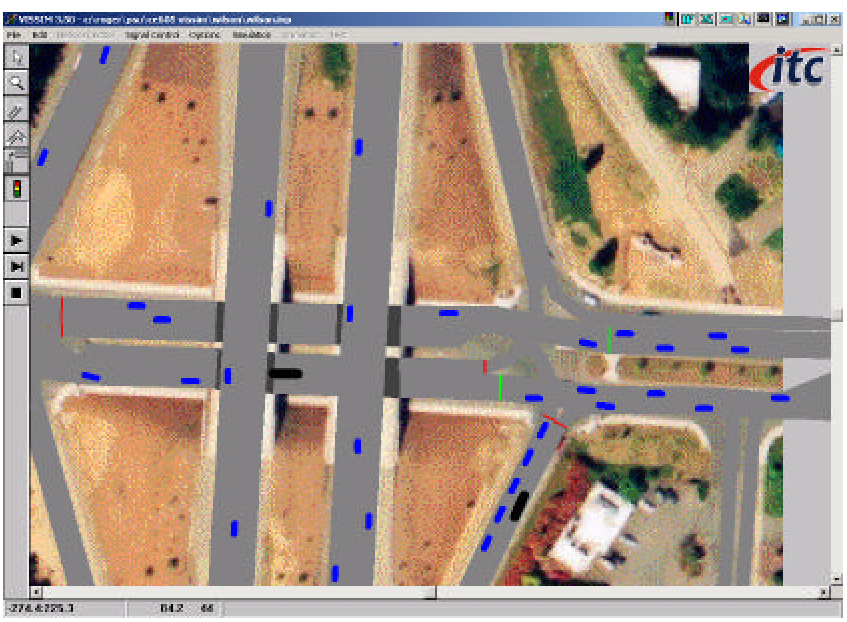


Figure 3 VISSIM Screen Shot

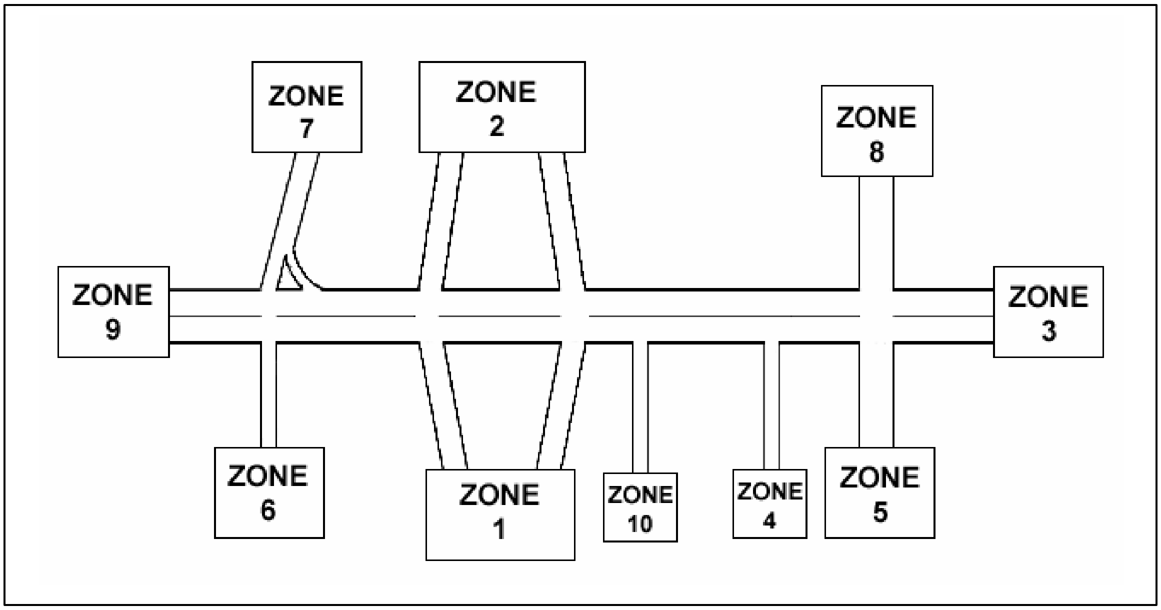
Traffic volumes are assigned to all links entering the network. VISSIM loads the assigned traffic onto the network in a random manner using the Poisson distribution. (3) The user is able to specify the composition of the traffic stream (i.e. proportion of cars, trucks, heavy trucks etc.) as well as define 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. The flow of vehicles though an intersection is governed by sign and/or signal control. As the movement of each vehicle is simulated by the software, an animation of all vehicles' movements can be shown on the computer screen. 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.

SITE AND DATA DESCRIPTION

In the case of both Paramics and VISSIM, the networks are coded using a graphical user interface. At this stage there are minor differences in the functionality of the software. Paramics uses nodes and links that make the network skeleton creation step slightly more time consuming than VISSIM's link based methodology. However, VISSIM requires the added step of creating connections at link intersections for each possible turning movement. Ultimately, the time required for initial network coding is approximately the same for both modeling packages.

Traffic demand can be coded in VISSIM using either intersection turning movements or by an origin destination matrix. In the case of this small study network, and since intersection counts were available, the turning movement count method was employed. In Paramics, the traffic demand is defined solely by an origin-destination matrix. The network considered for the present study was coded with ten zones located on each end of the intersections including both northbound and southbound I-5. The origin destination matrix for Paramics was established using the maximum likelihood method. In order to obtain the destination volumes, the ratios of the turning movements on each intersection along the direction of traffic movement of the origin-destination pair were applied to its origin volume. The last outcome on each origin-destination pair represents the final through movement volume or the destination volume. Thirty iterations were conducted in order to balance the final matrix with the real number of trips obtained from that turning movement counts. The balanced OD matrix for Paramics modeling is shown in Table 1.



Unbalanced Origin-Destination Matrix

FROM \ TO	1	2	3	4	5	6	7	8	9	10		Total	Final Target	Delta	*From TMC*
1	0	3000	166	9	12	24	31	121	131	27		**3523**	3682	159	*3682*
2	3000	0	126	7	9	57	72	91	308	21		**3691**	3971	280	*3971*
3	237	143	0	0	51	22	27	38	118	0		**636**	636	0	*636*
4	0	0	0	0	0	0	0	0	0	0		**0**	0	0	*0*
5	41	69	29	0	0	6	8	46	34	0		**234**	234	0	*234*
6	74	53	24	1	2	0	23	17	41	4		**239**	239	0	*239*
7	207	149	67	4	5	33	0	48	38	11		**561**	561	0	*561*
8	155	259	37	0	63	24	30	0	128	0		**696**	696	0	*696*
9	279	201	90	5	6	33	30	65	0	15		**725**	725	0	*725*
10	0	0	58	3	4	0	0	42	0	0		**108**	39	-69	*39*
												10412	**10783**	**371**	***10783***
Total	**3994**	**3873**	**597**	**30**	**152**	**200**	**221**	**469**	**798**	**78**	**10412**				
Final Target	4095	3817	764	53	164	195	214	591	766	124	**10783**				
Delta	101	-56	167	23	12	-5	-7	122	-32	46	**371**				
From TMC	*4062*	*3786*	*758*	*53*	*163*	*193*	*212*	*586*	*760*	*123*	***10696***				

Balanced zonal attractions

Total zonal attractions (from TMC) need to be balanced with total productions

Table 1 Origin-Destination Matrix

Model Verification Each microscopic model must be verified. Verification involves checking to ensure that the coded network represents actual conditions. For each model, a series of simulation runs were conducted to determine if the model was functioning as intended. Both VISSIM and Paramics allow for on-line viewing of the simulation runs. In addition, they both allow for extensive data collection that can be reviewed off-line. These verification runs revealed network coding errors such as lack of right turns on red, excessive speeds around corners, and lack of connection between links. Several iterations of verification allowed for the correction of all coding errors. The on-line viewing of the simulations greatly enhanced the verification process since the modeler could easily identify coding errors; for instance, the absence of right turns on red was immediately obvious when viewing on-line simulations.

Model Validation Validation is the process of determining if the driver behavior models inherent in each software package are producing results that matched with observed driver behavior. In this study, model validation was accomplished with an empirical comparison of the results of several simulation runs to behavior observed during several site visits and also with a comparison to generally expected driver behavior. Again, the on-line viewing of the simulation runs greatly enhanced the modeler's ability to identify unexpected driver behavior.

One example of a model validation process is as follows; early validation runs in VISSIM resulted in a large number of lane change attempts in the short section between interchange ramp terminals. In contrast to the model, traffic observed at the site appeared to be pre-positioned for interchange movements and far fewer lane changes were observed in this critical area. Changes in the location of key routing decision points resolved these inconsistencies.

The validation process employed on this project was subjective and limited in scope. The need for a more thorough validation process was identified as an area for further research, particularly on the interaction of ramp terminal traffic with freeway traffic.

Model Calibration Calibration involves a comparison of the simulation results to data collected by direct observation of real traffic. Model calibration is a critical step to consider when employing micro-simulation. Measures of effectiveness collected during multiple simulation runs on a verified and validated network must be compared to actual traffic data.

Due to the stochastic nature of the simulation models, a relatively large number of runs must be conducted. Each model run with identical operation conditions but with different random seed numbers will produce different results. It is prudent, therefore to execute a number of simulation runs (say 15) and with the statistical estimators from this trial, compute according to commonly accepted statistical principles, the number of simulation runs required to meet a stated objective.

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

$$n_r \geq \frac{s^2 z^2{}_{a/2}}{e^2}$$

s^2 = variance (based on trial runs)
$z_{\alpha/2}$ = threshold value for a 100(1-α) percent confidence interval
n_r = number of runs required
e = maximum error of the estimate

Example The following interchange delay data I-5 Interchange with Wilsonville Road was determined from 15 simulation runs:

Mean delay = 31.44 s
s^2 of this data = 6.00 s^2
s = 2.45 s
α = 0.05 (corresponds with 95% confidence)
$\alpha/2$ = 0.025 (corresponds with 95% confidence)
Z = 1.96 from statistical table (6)
e =1.0 s (based on reasonable error of delay estimate)

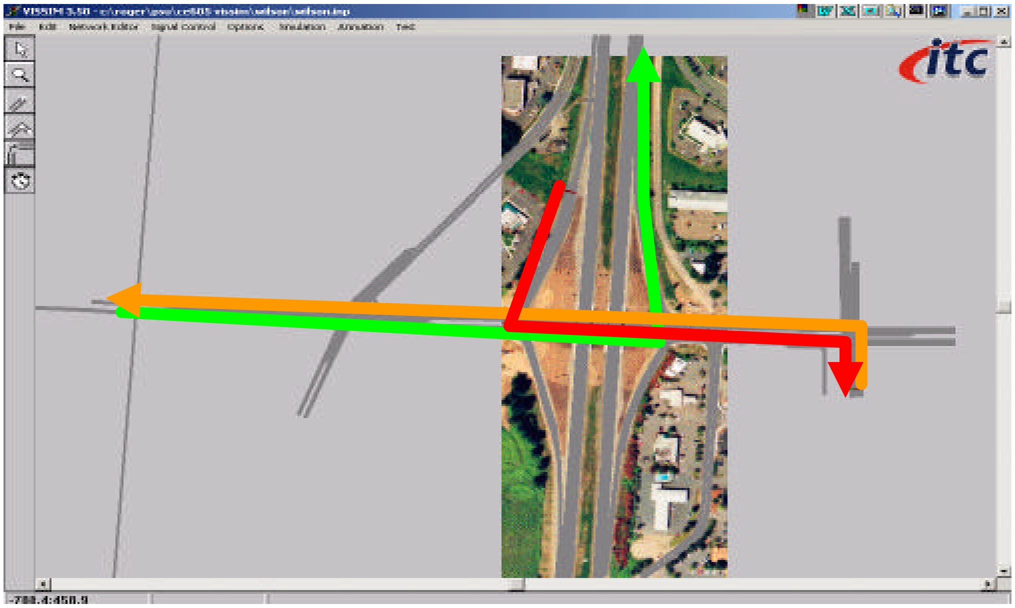
$$n_r \geq \frac{s^2 z^2{}_{\alpha/2}}{e^2} = \frac{(6.00)1.96^2}{1.0^2} \approx 23\, runs$$

As shown, for this study it was determined that 23 simulation runs were required in order to establish an estimate for interchange delay with a 1.0 second maximum allowable error and a 95% level of confidence.

ANALYSIS

Turning Movement Counts The calibration of the two models, Paramics and VISSIM, varied somewhat depending on the characteristics of the models. In Paramics, for example, traffic demand was input using an origin-destination matrix, therefore a logical calibration step would be to compare modeled turning movement counts to actual counts. Turning movement counts from the six study intersections (four signalized and two stop-controlled) were collected during fifteen two-hour Paramics simulation runs. Paramics Analyser was used to generate data files showing these turning counts. A comparison between the observed on-site turning movement data and Paramics results was made on both directional split proportion and vehicle counts. The results show relatively small differences on directional split proportion as compared to actual turning movement counts obtained in the field. Such a comparison for VISSIM was not possible since the observed turning movements counts were directly input to the model.

Travel Time Data were collected during ten VISSIM and Paramics simulation runs on three routes as shown in Figure 4. A small data set comprised of five probe vehicle trips for each route was acquired at the site on December 13, 2001. The discrepancy in the simulated versus actual travel times on Routes 2 and 3 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 Routes 2 and 3.



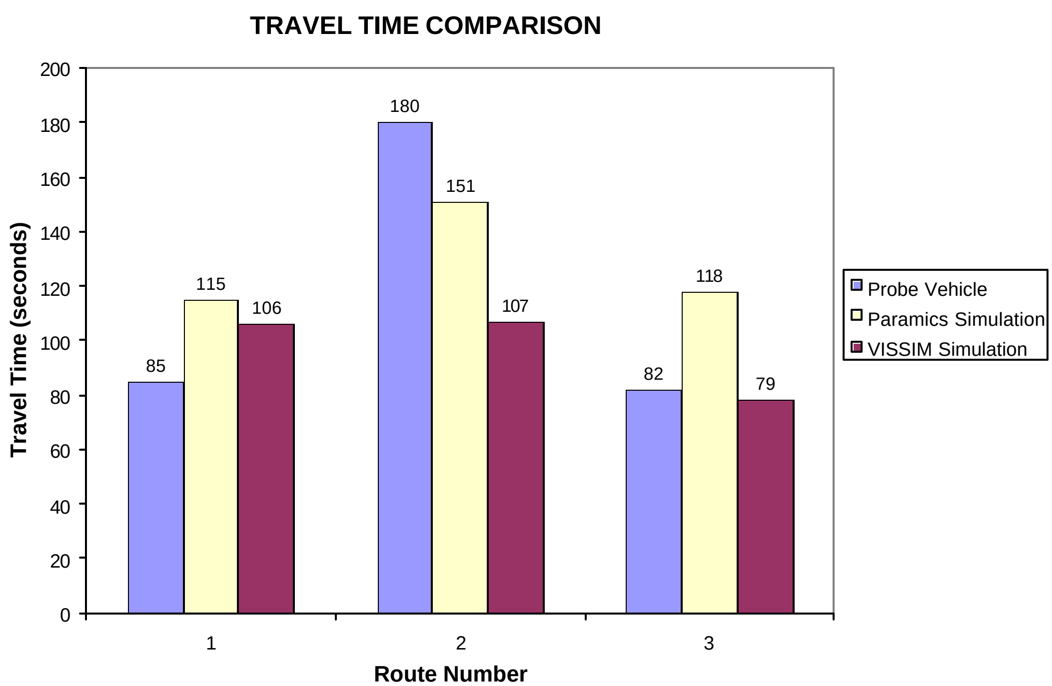


Figure 4 Travel Time Comparison

Average Vehicle Delay Delay data were collected during ten VISSIM and Paramics simulation runs for selected approaches of the NB I-5 ramp intersection with Wilsonville Road. Additionally, for each simulated intersection movement, a delay was computed using procedures outlined in the Transportation Research Board's Highway Capacity Manual (HCM). Lane group delays predicted by HCM, VISSIM, and Paramics are shown in Figure 5. Comparisons of average vehicle delay at all movements reveal relatively small differences. While this in an interesting observation, it does not in itself prove the usefulness of either method. The HCM methodology for delay calculation is simply a "model" of traffic flow that could be described as deterministic and macroscopic.

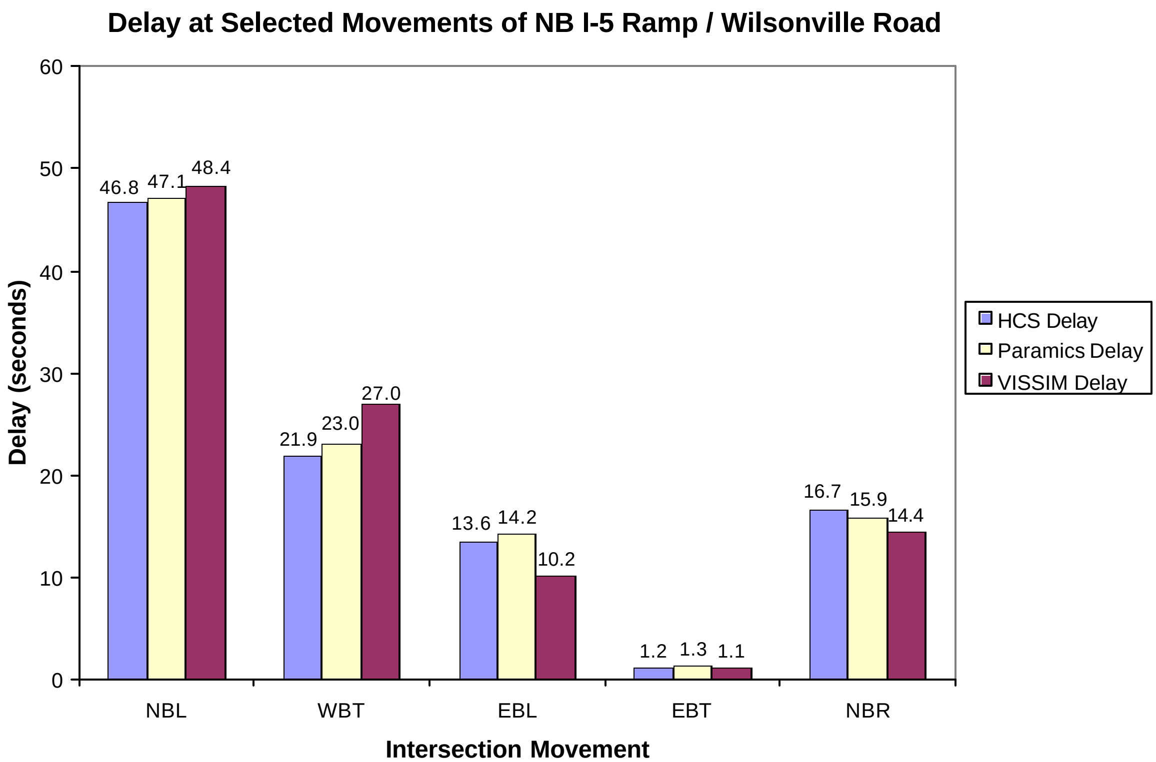


Figure 5 Intersection Movement Delay

Traffic Demand Variations The hourly traffic volumes used in both models 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 network 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 6 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.

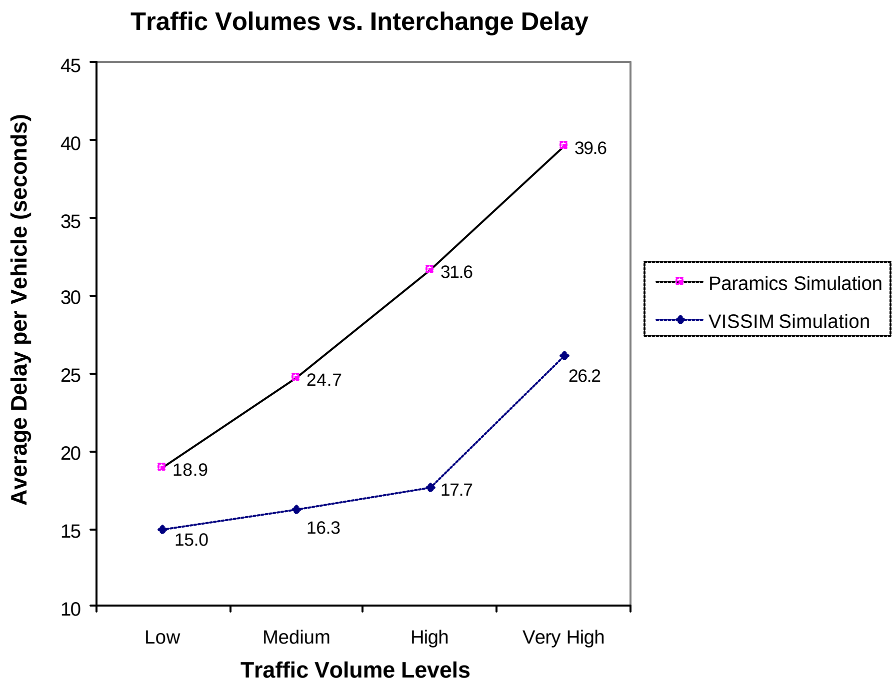


Figure 6 Interchange Delay

Modeling Geometric Changes One of the strengths of simulation models is the ability to experiment with new situations that do not exist today. The traffic demand variation analysis discussed in the previous section is one example of such future situations; another example is modeling of changes in network geometry such as the addition of a new lane, turn bay, or other physical change to the network.

In the traffic demand variation, it was observed that at "Very High" traffic levels (1.25 times the 1999 levels) there was a significant delay for the I-5 Northbound ramp left turning movement to Wilsonville Road westbound. For example, with a single left turn lane, the modeled average vehicle delay was 74.9 seconds. When a second left turn lane was added, the modeled delay of this same movement was reduced to 34.4 seconds. In the case of both software packages, Paramics and VISSIM, once the initial network is coded and validated, it is a simple process to make changes and to study the impact of the changes, both visually on-line and by an off-line analysis of the collected data.

CONCLUSIONS

This paper examined the use of two computerized microscopic stochastic traffic simulation tools (Paramics and 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 Paramics and VISSIM models 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 Paramics and VISSIM models generate 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 ramp terminals studied had non random arrival patterns and only by modeling adjacent intersections were these non random arrivals properly simulated.

The stochastic nature of the Paramics and VISSIM simulation models 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. Due to the stochastic nature of real traffic, all studies of real traffic for validation and calibration must also include a large number of observations.

Future Research The following areas appear to be starting points for future research on traffic flow at diamond interchanges and other closely spaced intersections:

- A more statistically rigorous comparison of modeled results to field data resulting in improved validation and calibration.
- A detailed analysis of the internal logic (car-following, gap acceptance, etc.) of the Paramics and VISSIM models and comparison 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.
- Evaluation of freeway traffic near closely spaced interchanges.

Also, it would be helpful to continue to explore ways that microscopic simulation tools such as Paramics and VISSIM can be used to simulate larger multimodal freeway/arterial corridors.

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