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C-01-83: Operational Analysis Technical Guidance & Support

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Task 1 - LITERATURE REVIEW
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16. Abstract

In recent years computer simulation has become one of the most widely used and powerful tools in providing synthetic versions of highway traffic. Traffic simulation allows us to understand the current network characteristics, and predict the likely impact of the desired system under various demands and network conditions, where physical experimentation is difficult or often impossible. In this context, computer simulation is a very helpful offline tool for testing the proposed system components prior to implementation. It is clearly a cheaper and quicker way to analyze the effectiveness and the potential benefits of any proposed systems. With the advent of computer technology traffic simulation has developed from a research tool of limited group of experts to a widely used technology in the research, planning, demonstration and development of traffic systems. Today, many available software packages can simulate network traffic flow under short and long-term variations in travel demand, under various random events such as road closures, incidents, route diversions, and can also collect detailed results on vehicle delays, link travel time, stop time, etc. The common traffic simulation software packages are either based on microscopic or macroscopic simulation models. These use either stochastic or deterministic approach. With the increasing use of roundabouts in traffic system, many simulation software packages have been developed that are dedicated exclusively for roundabout design and analysis. The commonly used software packages in the market have been discussed here with context to their use in designing roundabouts, along with the commercial software packages for roundabouts only

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In recent years computer simulation has become one of the most widely used and powerful tools in providing synthetic versions of highway traffic. Traffic simulation allows us to understand the current network characteristics, and predict the likely impact of the desired system under various demands and network conditions, where physical experimentation is difficult or often impossible. In this context, computer simulation is a very helpful offline tool for testing the proposed system components prior to implementation. It is clearly a cheaper and quicker way to analyze the effectiveness and the potential benefits of any proposed systems.

With the advent of computer technology traffic simulation has developed from a research tool of limited group of experts to a widely used technology in the research, planning, demonstration and development of traffic systems. Today, many available software packages can simulate network traffic flow under short and long-term variations in travel demand, under various random events such as road closures, incidents, route diversions, and can also collect detailed results on vehicle delays, link travel time, stop time, etc.

The common traffic simulation software packages are either based on microscopic or macroscopic simulation models. These use either stochastic or deterministic approach. With the increasing use of roundabouts in traffic system, many simulation software packages have been developed that are dedicated exclusively for roundabout design and analysis.

The commonly used software packages in the market have been discussed here with context to their use in designing roundabouts, along with the commercial software packages for roundabouts only.

Table 1 Software packages in traffic simulation

Common Software Packages	
PARAMICS	AIMSUN2
VISSIM	NEMIS
CORSIM	TRANSIMS
INTEGRATION	TRANSYT
SIMTRAFFIC	WATSIM
SATURN	HUTSIM
DRACULA	CARSIM
GETRAM	MITSIM

1. Common Traffic Simulation Softwares

One of the most important analytical tools of traffic engineering is computer simulation. If a traffic system is simulated on a computer by means of a simulation model, it is possible to predict the effect of traffic control and TSM (Traffic Systems Management) strategies on the system's operational performance. Thus the history of traffic simulation has seen many software packages coming up. The commercial and well-established software packages are discussed in this section. (Refer to Table 1.1)

1.1. PARAMICS- PARAllel MICroscopic Simulation

PARAMICS is an advanced suite of software tools for microscopic traffic simulation developed by Quadstone Limited. It used to model the movement and behavior of individual vehicles on urban and highway road networks. It allows users to customize many features of the underlying simulation model through Application Programming Interfaces (API).

Accurate geometry of network and smooth coding of links in PARAMICS are important for simulation results because driver's behavior relies on characteristics of drivers and vehicles, the interactions between vehicles, and network geometry as well. It has the ability to obtain detailed state variable information on each vehicle on time scales with better than second-by-second accuracy. The basic input data for the simulation are a road network and time dependant traffic demand (OD-matrix). Paramics determines the shortest path for each vehicle and reconsiders this path at each intersection. The actual traffic situation, knowledge of local routes and the presence of route advice (VMSs or onboard route navigation systems) all influence the final route.

Paramics is controlled via a graphical user interface, which visualizes the network and simulated traffic in two or three dimensions. The results of the simulation are presented in a lively and comprehensible way for customers and other interested people. A significant disadvantage of the Paramics model is the use and reliance on origin-destination matrices to derive traffic volumes.

1.2. VISSIM- VISual SIMulation

VISSIM was developed at the University of Karlsruhe, Germany, with commercial distribution beginning in 1993 by PTV Transworld AG. It is a microscopic, time-step, and behavior-based simulation model developed to analyze the full range of functionally classified roadways and public transportation operations.

It includes modules ranging from demand forecasting to detailed intersection control analysis and simulation. VISSIM can analyze traffic and transit operations under a variety of policy constraints, making it a useful evaluation tool. It features quality animation capabilities.

It uses the Wiedemann car following model, which represents the psychological processes of the driver to obtain a desired following distance and relative speed to the lead vehicle. Dynamic ramp metering and signal control can be evaluated, and external interface through application program interface (API) is possible. The model features an intuitive, easy-to-learn graphic user interface (GUI), with all geometry and traffic control features available for editing via a simple graphical menu. It also has a dynamic assignment routine, which can be used to determine the user-equilibrium (UE) driver route choice based on observed travel times through the network, such as routine congestion, bridge closure, or delay at signalized intersections.

VISSIM should be considered for urban environments that contain transit or pedestrians (or both). It has detailed representation of passenger boarding and alighting at bus stops, and available algorithms to emulate the Transit Signal Priority (TSP) operation in the leading traffic signal controllers.

1.3 TRAF- it consists of an integrated set of simulation models that represents the traffic environment. Its component models are:

- . **NETSIM,** a microscopic stochastic simulation model of urban traffic
- . **FRESIM,** a microscopic stochastic simulation model of freeway traffic
- . **NETFLO,** a macroscopic simulation of urban traffic
- . **FREFLO,** a macroscopic simulation of freeway traffic

The naming system for these models is based on a combination of prefixes and suffixes.

NET- surface street network

FRE- freeway network

SIM- microscopic simulation

FLO- macroscopic simulation

The combination of NETSIM and FRESIM is named CORSIM, for corridor-microscopic simulation.

The combination of NETFLO and FREFLO is named CORFLO, for corridor-macroscopic simulation.

1.4. CORSIM- CORridor SIMulation

CORSIM is a combination of two microscopic models, NETSIM and FRESIM. Within the earlier integrated traffic simulation system (TRAF), the freeway/urban street system, simulated with the combination of NETSIM and FRESIM, were composite rather than integrated networks. A Windows version of TSIS (Traffic Software Integrated System) was developed to provide an integrated, user-friendly, graphical user interface and environment for executing. CORSIM simulates traffic and traffic control systems using commonly accepted vehicle and driver behavior models. It is a comprehensive microscopic traffic simulation, applicable to surface, streets, freeways, and integrated networks with a complete selection of control devices (i.e., stop/yield sign, traffic signals, and ramp metering).

CORSIM's specific advantages can be listed as follows:

- Its ability to model complicated geometry conditions
- Its ability to simulate different traffic conditions
- Its ability to simulate different traffic control management and operation
- Its ability to account for the interactions between different components of networks
- Its ability to interface with external control logic and programs
- Its ability to model time varying traffic and control conditions

1.5. INTEGRATION

INTEGRATION is a simulation model developed primarily for research use that has recently been distributed on a commercial basis. Integration does not have an API or access to vehicle state variables on a time step-by-time step basis. Integration appears to be weaker at explicit simulation of detailed vehicle-to-vehicle interactions than other simulation models, given that it originated from a hybrid "mesoscopic" macro/micro modeling base. Integration does not appear to explicitly model movements in the intersection box. Integration has been modified to output TTC distributions and predicts crash rate statistics using previously developed nonlinear regression models (based on link mean speed).

It can simulate U-turns, but it also is least able to model complex signal operations. Integration, on the other hand, models only the aggregate speed-volume interactions of traffic and not the details of a vehicle's lane-changing and car-following behavior; thus, it is commonly classified as a mesoscopic integrated simulation model. Integration is a routing-oriented model for mixed networks; vehicles' trip origins, destinations and departure times are specified external to the model.

1.6. SIMTRAFFIC- TRAFFIC SIMulation

SIMTRAFFIC developed by Trafficware, is an easy-to-use traffic simulation tool that is designed for use by field traffic engineers primarily as an adjunct to the SYNCHRO signal-timing optimization software. It has a link-node structure; and have simple and quick data entry GUI. A significant disadvantage of SIMTRAFFIC is the lack of API functions or supporting detailed output of vehicle-state variable information and automated statistical analysis capabilities of other codes. On the other hand, SIMTRAFFIC has the most resolute state variable standard update intervals of all models surveyed (0.1 s) and claims many improvements over the CORSIM models for representing real-world traffic conditions, although the validity of those improvements is not known.

SIMTRAFFIC is used to create input files for CORSIM. It can be used for traffic signal optimization studies, traffic impact studies, and corridor studies. It does not have transit capabilities and is not a multi modal tool, can be used only for pedestrians. The output cannot be visualized in 3-dimensional format.

1.7. SATURN- Simulation and Assignment of Traffic to Urban Road Networks

SATURN is a suite flexible network analysis programs developed at the Institute for Transport Studies, University of Leeds and distributed by WS Atkins of Epsom since 1981.

Its approach is as a combines traffic simulation and assignment model for the analysis of road-investment schemes ranging from traffic management schemes over relatively localized networks through to major infrastructure improvements. It performs various functions:

- As a traffic assignment model
- As a simulation model of individual junctions
- As a network editor, database and analysis system
- As a matrix manipulation package for the production of matrices
- As a trip matrix demand model covering the basic elements of trip distribution, modal split etc.

SATURN possesses powerful graphical display capabilities for network, junction and matrix-based data. The other options available allows for on-screen cordoning, select link reassignments, GIS-style background displays, animated queues, data editing and tree building.

Its matrix manipulation program offers a full range of interactive matrix operations as required by standard transport planning applications, e.g. matrix building, editing, factoring, furnessing, transposing etc. It also provides easy transfer between SATURN and other transport and spreadsheet packages.

1.8. DRACULA- Dynamic Route Assignment Combining User Learning and microsimulation

DRACULA is a dynamic network microsimulation model developed at University of Leeds since 1993. It is a new approach to modeling road traffic networks, in which the emphasis is on the “micro-simulation” of individual trip makers’ choices and individual vehicles’ movements.

It represents directly driver choices as they evolve from day to day combined with a detailed within-day traffic simulation model of the space-time trajectories of individual vehicles according to car-following, lane-changing rules and intersection regulations. It therefore provides strong interaction between demand and supply.

The current release version is named DRACULA-MARS (Microscopic Analysis of Road Systems)

1.9. GETRAM-Generic Environment for TRaffic Analysis and Modeling

GETRAM is a simulation environment comprising a traffic network graphical editor (TEDI), a microscopic traffic simulator (AIMSUN2), a network database, a module for storing results and an Application Programming Interface to aid interfacing to assignment models and other simulation models.

1.10. AIMSUN2- Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks

AIMSUN2 is a software tool, which is able to reproduce the real traffic conditions of any traffic network on a computer. It is mainly used for testing new traffic control systems and management policies or for the evaluation of the different options for implementing a new infrastructure before building it. The behavior of every single vehicle in the network is continuously modeled throughout the simulation period, using several driver behavior models (car following, lane changing, gap acceptance).

The main features of this simulation model are:

- Can deal with different traffic networks and different types of traffic control may be modeled

- Two different types of simulation are involved: one based on input traffic flows and turning proportions where vehicles are distributed stochastically around the network and one based on O-D matrices and route selection models where vehicles are assigned to specific routes from the start of their journey to their destination.
- Provides a picture of the network and an animated representation of the vehicles in it. Through the interface, the user may access any information in the model and define traffic incidents before or during the simulation run.
- Environmental measurements, such as fuel consumption and pollution emissions, are also provided.
- A standard interface to External Adaptive Traffic Control Systems, such as SCOOT or C-Regular, is available.
- AIMSUN2 is programmed in C and C++ using X-Windows

1.11. NEMIS

NEMIS is a scientific software package, used principally for research and development work and for the technical assessment of traffic control strategies. It was designed as a specific solution to the problem of on-street testing. It is capable of modeling urban networks and vehicle behavior in considerable detail, and is well structured to meet a variety of application needs. Its usefulness has been demonstrated for the following tasks:

- Analysis of the effects of regulation and network modification on traffic mobility
- Evaluation of different traffic light control strategies
- Testing of traffic assignment techniques
- Simulation and evaluation of route guidance strategies and variable message systems
- Evaluating the effects of improved public transport facilities on inner city traffic flow
- Testing the effectiveness of parking management systems

- Examination of strategies aimed at reducing fuel consumption/exhaust emission.

1.12. TRANSIMS- TRansportation Analysis and SIMulation System

TRANSIMS is an integrated system of travel forecasting models designed to give transportation planners accurate, complete information on traffic impacts, congestion, and pollution. It was developed to meet the Clean Air Act, the Intermodal Surface Transportation Efficiency Act, Transportation Equity Act for the 21st Century, and other regulations. It consists of coordinated models and databases that create a virtual metropolitan region that fully represent the region’s transportation infrastructure, its inhabitants, and their activities. It then simulates the movement of individuals across the transportation network on a second-by-second basis mimicking the traveling and driving behavior of real people in the region.

TRANSIMS starts with data about people's activities and the trips they take to carry out those activities, and then builds a model of household and activity demand. The model forecasts how changes in transportation policy or infrastructure might affect those activities and trips. It tries to capture every important interaction between travel subsystems, such as an individual's activity plans and congestion on the transportation system. TRANSIMS tracks individual travelers and so can evaluate transportation alternatives and reliability to determine who might benefit and who might be adversely affected by transportation changes.

1.13. TRANSYT

TRANSYT is a complete traffic signal timing optimization software package for traffic networks, arterial streets, or single intersections having complex or simple conditions. Its strength lies in its ability to simulate traffic conditions in a level of detail beyond other optimization programs.

TRANSYT is also one of the most comprehensive signal timing tools available. It is comprehensive because it has broader capabilities than other signal timing programs. To name just a few, these capabilities include:

- Detailed simulation of existing conditions
- Optimization of cycle length, phasing sequence, splits and offsets
- Detailed analysis of traffic-actuated control
- Optimization based on a wide variety of objective functions
- Hill-climb and genetic algorithm optimization
- Explicit simulation of platoon dispersion, queue spillback and spillover
- Multi-cycle and multi-period simulation
- Full flexibility in modeling unusual lane configurations and timing plans
- Full flexibility in modeling English and metric units, right-hand and left-hand driving

TRANSYT has evolved into a benchmark within the transportation profession. It has facilitated greater understanding of signal timing optimization, while continuing to improve traffic operations as a result of its designs being widely implemented in the field.

1.14. WATSIM- Wide Area Traffic SIMulation

WATSIM is an enhancement of the NETSIM model by one of the original developers of NETSIM. As such, WATSIM inherits many of the limitations of the CORSIM model, including fixed 1-s time steps. WATSIM has many additional features over CORSIM, including light-rail modeling. WATSIM lacks many of the features of general-distribution tools for supporting this type of surrogate safety research, such as configurable output files, post-processing tools, and APIs.

1.15. HUTSIM

HUTSIM is currently being modified by Helsinki University to evaluate the use of a nanoscopic driver behavior model to produce delays in driver reaction time that lead to surrogate safety measures. They have tentatively selected TTC as their primary surrogate measure. Some of the details of driver behavior modeling in the HUTSIM simulation were unavailable given the scope of this project. The demo software available indicates a less sophisticated visualization and model-building GUI than other tools, although the software contains an add-on analyzer module for post-processing output data into graphs/charts. It appears that all modifications to HUTSIM are being made internally since no API is available. Sight-distance limitation modeling is a significant advantage of the HUTSIM simulation model.

1.16. CARSIM- CAR-following SIMulation

(Benekohol, R. K. and Treiterer, J., 1988. “CARSIM: Car following model for simulation of traffic in normal and stop-and-go conditions”)

CARSIM is features to simulate not only normal traffic flow but also stop-and-go conditions on freeways, has been developed. The features of CARSIM are:

- Marginally safe spacing are provided for all vehicles
- Start-up delays of vehicles are taken into account
- Reaction times of drivers are randomly generated
- Shorter reaction times are assigned at higher densities
- Dual behavior of traffic in congested and non-congested conditions is considered in developing the car-following logic of this model

The validation of CARSIM has been performed at microscopic and macroscopic levels.

1.17. MITSIM- MIcroscopic Traffic SIMulator

The role of MITSIM is to represent the "world". The traffic and network elements are represented in detail in order to capture the sensitivity of traffic flows to the control and routing strategies. The main elements of MITSIM are:

- *Network Components:* The road network along with the traffic controls and surveillance devices are represented at the microscopic level. The road network consists of nodes, links, segments (links are divided into segments with uniform geometric characteristics), and lanes.

- *Travel Demand and Route Choice:* The traffic simulator accepts as input time-dependent origin to destination trip tables. These OD tables represent either expected conditions or are defined as part of a scenario for evaluation. A probabilistic route choice model is used to capture drivers' route choice decisions.
- *Driving Behavior:* The origin/destination flows are translated into individual vehicles wishing to enter the network at a specific time. Behavior parameters (such as desired speed, aggressiveness, etc.) and vehicle characteristics are assigned to each vehicle/driver combination. MITSIM moves vehicles according to car-following and lane-changing models. The car-following model captures the response of a driver to conditions ahead as a function of relative speed, headway and other traffic measures. The lane-changing model distinguishes between mandatory and discretionary lane changes. Merging, drivers' responses to traffic signals, speed limits, incidents, and tollbooths are also captured. Rigorous econometric methods have been developed for the calibration of the various parameters and driving behavior models.

In the next section, we present a comparison of several simulation packages as applied to the estimation of signalized intersection delays. Similar comparisons can be made using other simulation packages. However, the fact that calibrated intersection models developed using SimTraffic, CORSIM, Paramics and HCS were already available to us. Thus, we decided to use them to illustrate the type of comparative study that can be conducted in order to demonstrate, the differences among some of the best known microscopic traffic simulation packages,

Illustrative Example for the Comparison of Well Known Microscopic Simulation Packages

In this section we have three main goals:

1. Describe variables needed to use and calibrate Paramics, CORSIM, and SImTraffic.
2. Describe various concepts of delays for arterials as adopted by these models.
3. Present numerical examples.

Description of Calibration Parameters of Various Simulation Packages

In recent years computer simulation has become one of the most widely used and powerful tools for studying the current network characteristics, and predicting the likely impacts of the desired system under various traffic demand and network conditions. In fact, computer simulation is proved to be a very helpful analysis and design tool for testing the proposed system components prior to implementation.

Simulation models for traffic operations provide a set of independent variables that describe driver behavior and traffic control operation. A standard traffic operation analysis package such as HCS does not provide these variables. Furthermore, simulation packages provide a range of adjustment parameters for traffic control devices and traffic flow characteristics. However, to reveal the actual condition in simulation packages higher level of efforts and expertise are required. Since each simulation model has its own default parameter values it is necessary to know these values and how it influences the simulation results. Following sections describe different parameters available for the calibration of CORSIM, SimTraffic, PARAMICS and VISSIM simulation packages.

CORSIM Simulation Parameters

CORSIM is a combination of two microscopic models, NETSIM and FRESIM. [1] Within the earlier integrated traffic simulation system (TRAF), the freeway/urban street system, simulated with the combination of NETSIM and FRESIM, were composite rather than integrated networks. A Windows version of TSIS (Traffic Software Integrated System) was developed to provide an integrated, user-friendly, graphical user interface and environment for executing. CORSIM simulates traffic and traffic control systems using commonly accepted vehicle and driver behavior models. It is a comprehensive microscopic traffic simulation, applicable to surface, streets, freeways, and integrated networks with a complete selection of control devices (i.e., stop/yield sign, traffic signals, and ramp metering).

Specific advantages of CORSIM can be listed as follows:

- Its ability to model complicated geometry conditions
- Its ability to simulate different traffic conditions
- Its ability to simulate different traffic control management and operation
- Its ability to account for the interactions between different components of
- networks
- Its ability to interface with external control logic and programs
- Its ability to model time varying traffic and control conditions

Traffic Assignment

In CORSIM, traffic assignment is based on the link costs calculated based on the Davidson's functions. By the assignment of demand using the Frank-Wolfe shortest algorithm, the volume-to-capacity ratios are calculated.

CORSIM comprises several input parameters that can be considered for calibration. These parameters can be used to calibrate the model and hence to match local real-world conditions. These parameters take account of vehicle performance parameters and driver behavior parameters. The driver behavior parameters include start-up lost time, distribution of free flow speed by driver type, mean duration of parking maneuvers, lane change parameters, maximum left and right turning speeds, probability of joining spillback, probability of left turn jumpers and lagers, gap acceptance at stop signs, gap acceptance for left and right turns, pedestrian delay and driver familiarity with path. Vehicle performance parameters include speed and acceleration characteristics, fleet distribution and passenger occupancy.

Driver behavior parameters influence traffic flow, speeds and queue significantly. Table 1 and 2 shows these parameters with default values and calibration range. Some parameters are link specific and others are network wide. Link specific parameters are those parameters that can be changed for every link. Network wide parameters are those parameters those will influence whole network. Each parameter has a default value and can be changed within some range.

Link specific parameters:

Link specific parameters include mean start-up delay and mean discharge headway. Table 2 shows default values and calibration ranges for each of these parameters.

Table 2 Link Specific Parameters (CORSIM)

Parameters	Default value	Calibration range
Mean start-up Delay (NETSIM)	2.0 seconds	0.5-9.9 sec
Mean Start-up Delay (FRESIM)	1.0 second	0.5-6.0 sec
Mean Discharge Headway	1.8 seconds (2000 vphpl)	1.4-2.4 sec

Mean start-up delay is the time taken by first vehicle in the queue to react phase change from red to green. Mean discharge headway is the time taken by vehicle to react its leader vehicle while discharging from a standing queue. This value can be altered for driver type 1 to driver type 10. Free flow speed is also link specific parameter to calibrate the model.

Network wide Parameters:

Network wide parameters for arterial include driver's familiarity with network, acceptable gap in oncoming traffic for right-turn-on-red or right-turn at stop sign, acceptable gap in oncoming traffic for permissive left turners and discharge headways. Network wide parameters for freeways include car-following sensitivity factor and time to complete a lane change. Table 3 shows default values and calibration ranges for each of these parameters.

Table 1 Network Parameters (CORSIM)

Parameters	Default value	Calibration range
Driver's familiarity with network	10% - drivers that know one turn movement in advance 90%-drivers that know two turn movement in advance	Sum of these two values must equal 100
Acceptable gap in oncoming traffic for right-turn-on-red or right-turn at stop sign	"10 sec for driver type 1" to "3.6 sec for driver type 10"	3.6 to 10 sec for driver types from 1 to 10
Acceptable gap in oncoming traffic for permissive left-turners	"7.8 sec for driver type 1" to "2.7 sec for driver type 10"	2.7 to 7.8 sec for driver types from 1 to 10
Time to complete a lane change	3.0 sec	2.0-5.0 sec
Car-following sensitivity factor	"0.6 sec for driver type 1" to "1.5 sec for driver type 10"	0.6 to 1.5 sec for driver types from 1 to 10

SimTraffic simulation parameters

SimTraffic developed by Trafficware, is an easy-to-use traffic simulation tool that is designed for use by field traffic engineers primarily as an adjunct to the Synchro signal-timing optimization software. It has a link-node structure; and have simple and quick data entry GUI. A significant disadvantage of SimTraffic is the lack of API functions or supporting detailed output of vehicle-state variable information and automated statistical analysis capabilities of other codes. On the other hand, SimTraffic has the most resolute state variable standard update intervals of all models surveyed (0.1 s) and claims many improvements over the CORSIM models for representing real-world traffic conditions, although the validity of those improvements is not known. SimTraffic is used to create input files for CORSIM. It can be used for traffic signal optimization studies, traffic impact studies, and corridor studies. It does not have transit capabilities and is not a multi modal tool, can be used only for pedestrians. The output cannot be visualized in 3-dimensional format. The following paragraph summarizes some of the important parameters of SimTraffic based on the information given in the user's manual.

"SimTraffic provides vehicle and driver parameters to regulate vehicle and driver characteristics respectively to calibrate the model. Vehicle characteristics include vehicle occurrence, maximum acceleration and vehicle length. Driver characteristics include yellow deceleration, green react time, headway, gap acceptance factor, positioning distance, positioning advantage and mandatory lane change start factor. Driver parameters influence the flow, delay and queue significantly. These parameters vary for driver type 1 to driver type 10. Driver type 1 is considered the most conservative and driver type 10 is considered the most aggressive.

Yellow Deceleration- This value defines the maximum deceleration rate for each driver type when a driver faces a yellow light. This value varies from 12 ft/sec^2 for driver type 1 to 7 ft/sec^2 for driver type 10. If using this deceleration value a vehicle cannot stop it will pass the intersection on red.

Green React Time- Green react time is the time a driver takes to react when it face the green. This value varies from 0.8 sec for driver type 1 to 0.2 sec for driver type 10.

Headway- Headway is the time distance between two vehicles which drivers try to maintain. Headways at 0 mph, 20 mph and 50 mph can be specified for driver type 1 to driver type 10. Default values range from 2.2 sec to 1.0 sec at speed of 50mph, 1.8 sec to 0.8 sec at speed of 20mph and 0.65 to 0.35 at speed of 0 mph for driver type 1 to driver type 10.

Gap Acceptance Factor- this value defines the gap between vehicles at unsignalized intersection, for right turns on red and for permitted left turns. The default value varies form 1.15 to 0.85 for different driver types. Lower value indicates more aggressive drivers.

Positioning Distance- At positioning distance, specified, a driver will predict the lane changes. To make the future turn drivers change the lanes at some distance. This distance depends on the driver's aggressiveness and familiarity. Drivers will change the lane earlier for high positioning distance. Drivers with low positioning distance will change the lane later. Default values vary from 1500 ft to 100 ft for driver type 1 to driver type 10.

Positioning advantage- Positioning advantage is the number of vehicles specified for each driver type. To make a future turn driver changes a lane. If the number of vehicles ahead in target lane is greater by "positioning advantage" vehicles than those in current lane, a driver will postpone a lane change.

Mandatory lane change start factor- this factor decides starting point of lane changes in the link. If the value is lower, lane change will take place upstream and is associated with conservative driver. If the value is higher, lane change will take place downstream and is associated with aggressive drivers."(19)

Paramics Simulation Calibration Parameters

PARAMICS is an advanced suite of software tools for microscopic traffic simulation. It used to model the movement and behavior of individual vehicles on urban and highway road networks. It allows users to customize many features of the underlying simulation model through Application Programming Interfaces (API). [3]

Paramics offers a wide range of functionality to suit every user's needs. The software is able to perform all the functions with the availability of it sub modules. These modules are:

Paramics Modeller, Estimator, Processor, Analyser, Programmer, Monitor, Designer, Viewer.

These modules are designed to work together seamlessly, improving usability, integration and productivity. Accurate geometry of network and smooth coding of links in PARAMICS are important for simulation results because driver's behavior relies on characteristics of drivers and vehicles, the interactions between vehicles, and network geometry as well. It has the ability to obtain detailed state variable information at each time step defined by the analyst. The basic input data for the simulation are a road network and time dependant traffic demand (OD-matrix). Paramics determines the shortest path for each vehicle and reconsiders this path at each intersection. The actual traffic situation, knowledge of local routes and the presence of route advice (VMSs or onboard route navigation systems) all influence the final route.

Traffic Assignment

Routing trees are constructed in Paramics based on the cost of the each link enroute the O-D pair. The assignment can be based on many factors such as: Link Restrictions, Familiarity of the driver, global weights assigned to parameters of the cost function, cost factors of the links and link types, dynamic assignment, cost perturbation, etc. Each vehicle type can be assigned a different assignment procedure, which can be based on the trip-type.

The only disadvantage of traffic assignment in Paramics is that it is based on the cost of each link, which is affected with the presence of short links.

When the results obtained from simulation do not match with the observed values it is necessary to make some changes with selected model input parameters. Calibration parameters for Paramics model include network geometry, signposting, time steps per seconds, speed memory, mean target headway and mean reaction time.

Network geometry: the first step in calibrating the network is to verify the physical characteristics of the modeled network geometry. If the kerb position at intersection is not correct, vehicles may take the turn with lower speed or in unrealistic way to make it safe. "The position of stop line affects the rate at which vehicles can travel across a junction from one link to the next." In Paramics, there is an entry point and exit point for each lane of a link. If the exit point (stop line) of a link is not aligned properly and in line with entry point of the next link the vehicle slows down to enter the next link at a safe speed. When the flow is high this slow down is more exclusive.

Signposting: the concept of signposting make driver aware of junction, restrictions and road narrowing ahead. This parameter provides two numbers (F,S). The first number (F) stands for the distance of the signpost from end of the link. The second number (S) stands for the distance from the signpost, towards the flow, over which a vehicle can react to make a lane change. The driver with lowest awareness value will react to the signpost at (F-S) distance from the junction. Other drivers will react to the signpost between (F) and (F-S) distance from the junction.

Time steps per seconds: time steps per second determine the number of calculations per second. For example, if the time step per second is 2 the calculation is done every 0.5 seconds of simulation. The default value is 2. Calculation of vehicle speed and acceleration has some randomization associated with them. Different simulation results can be obtained by changing the time steps per second. "High density flow requires more time steps per second to operate in a free manner."

Mean target headway and Mean reaction time: mean target headway and mean reaction time can change performance of the model significantly. Default value of mean headway and mean reaction time is 1.0 sec.

VISSIM- VISual SIMulation

VISSIM was developed at the University of Karlsruhe, Germany, with commercial distribution beginning in 1993 by PTV Transworld AG. (21) It is a microscopic, time-step, and behavior-based simulation model developed to analyze the full range of functionally classified roadways and public transportation operations. It includes modules ranging from demand forecasting to detailed intersection control analysis and simulation. VISSIM can analyze traffic and transit operations under a variety of policy constraints, making it a useful evaluation tool. It features quality animation capabilities.

VISSIM should be considered for urban environments that contain transit or pedestrians (or both). It has detailed representation of passenger boarding and alighting at bus stops, and available algorithms to emulate the Transit Signal Priority (TSP) operation in the leading traffic signal controllers.

Traffic Assignment

Features of the VISSIM traffic assignment model are as follows:

- Selecting between different types of traffic demand modeling: either static routing based on turning movement data/intersection counts or free route choice using dynamic assignment based on alternative routes.
- Transparent dynamic assignment module offering a variety of parameters using trip purpose related and time-dependent origin-destination matrices. True multi-class networks, i.e. route choice can be determined for each vehicle type, thus allowing pedestrian precincts, bus lanes, HOV lanes, driving restrictions for trucks etc. to be modeled.

VISSIM, unlike most other microscopic simulation softwares, does not use the link and node for network building. So, route assignment is relatively easier in VISSIM.

Various Definitions of Vehicular Delays

The term “vehicle delay” can be defined in different ways in transportation planning. They are as follows:

1. Stop delay

2. Time-in-queue delay
3. Link Delay (usually used in micro simulation models)
4. Control delay

Stopped delay is the time that a vehicle has to spend stopped due to red signal. Time-in-queue for a vehicle is the time from joining a queue to passing a stop line. Vehicle link delay is the time difference between the actual and free-flow link travel time for a driver unit on particular link. Typically, each micro simulation model provides link delay.

Control delay in CORSIM

Control delay can be defined as the delay incurred by vehicles at intersection approach due to traffic control at an intersection. It includes the time lost due to acceleration and deceleration of a vehicle in addition to the stopped time of a vehicle due to a traffic control device. Following sections explain the definition and estimation of delay as stated by different models. Control delay is the primary measure of performance in HCM. In HCM, performance of a signalized intersection is expressed based on Level of Service (LOS). Six categories (A-F) of LOS are defined based on control delay in HCM. Delay per vehicle for each category is defined in Table 4.1 of HCM 1997.

Delay calculation in various Computer Simulation Packages

Many computer simulation packages are available to analyze transportation networks. Each simulation package provides vehicle delay based on some algorithms and assumptions. Here, delay estimated by CORSIM, SimTraffic and Paramics are discussed. CORSIM provides both link delay and control delay. SimTraffic gives stopped delay and link delay. The control delay given by Synchro is similar to the control delay given by HCS [(5)]. Whereas Paramics provides only link delay in the Paramics Modeller module.

CORSIM: control delay includes initial deceleration delay, queue move-up time, stopped delay and final acceleration delay. The following figure (Figure 1) illustrates the components of control delay.

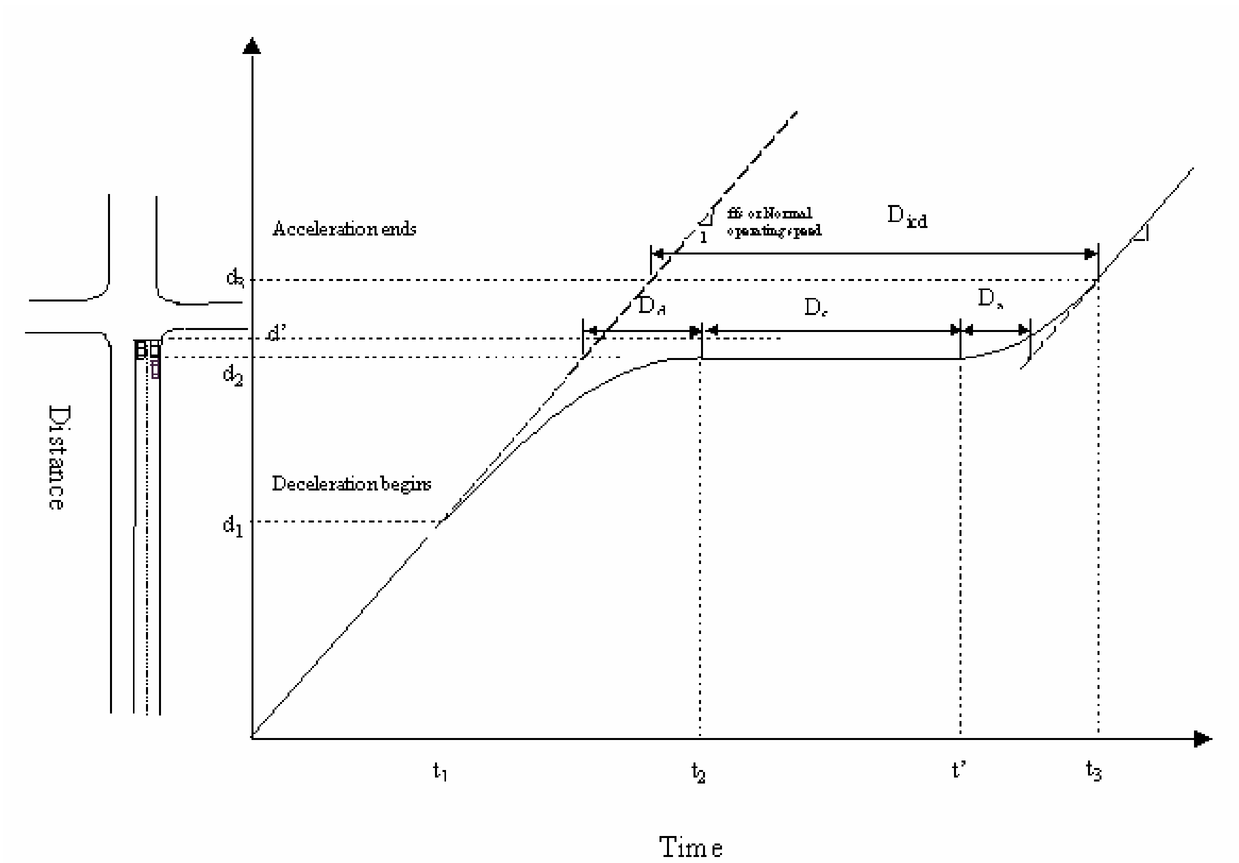

Figure 1. Control Delay Definition in CORSIM (From TSIS 5.0 Help Menu)

$$D_{icd} = D_{dec} + D_{st} + D_{acc} \qquad (1)$$

Where

D_{icd}:Intersection control delay (sec/veh)

D_{dec}: Delay incurred while a vehicle is decelerating while approaching the stop bar or the end of the queue (sec/veh)

D_{st}: Stopped delay (sec/veh)

D_{acc}: Delay incurred while a vehicle is accelerating to gain its full operating speed after the signal indication turns green (sec/veh)

The intersection control delay D_{icd} can be calculated as follows:

Link Delay in CORSIM, SimTraffic and PARAMICS

$$D_{icd} = (t_3 - t_1) - \frac{d_3 - d_1}{V}$$

(2)

Where V is the normal operating speed of the vehicle before the vehicle slows down and responses to intersection control. When traffic volume is light, the free flow speed (ffs) of the vehicle on the link can replace V in equation (2). However, at high demand, V can be considerably smaller than ffs. In other word, while the vehicle is delayed by intersection control, it is also delayed by high volume. The total delay from time t_1 to t_3 is calculated in equation (3).

$$D_{total} = D_{icd} + \left(\frac{d_3 - d_1}{V} - \frac{d_3 - d_1}{ffs} \right) \tag{3}$$

Control delay fully comprises any slow down caused by intersection signal control. Stopped delay (D_s) considers the delay caused when a vehicle stops in the queue waiting for a green signal indication or waiting for its leader to move forward. It does not consider the delay caused when the vehicle is slowing down and approaching the stop bar or the end of the queue (D_d), nor it considers delay caused while a vehicle is in a process of regaining its normal operating speed (D_a). Consideration of delay caused due to acceleration (D_a) is stopped when a vehicle passes the stop bar of the intersection even though it may still be in the process of regaining its full operating speed. The portion of D_a that is ignored may represent a significant part of D_a if the vehicle is among those first vehicles behind the stop bar.

Vehicle link delay is the time difference between the actual and free-flow link travel time for a driver unit on particular link. The average link delay is obtained by dividing the total delay time, experienced by vehicle that have already traversed the link, by the number of vehicle that have discharged from the link.

CORSIM link delay (veh-min): “the difference between the total travel time and the moving time represents the time that vehicles are delayed if they can not travel at free flow speed.”

SimTraffic link delay: “ Total Delay is equal to the travel time minus the time it would take the vehicle with no other vehicles or traffic control devices. Delay per vehicle is calculated by dividing the total delay by the number of vehicles.”

Paramics link delay: “ delay represents the increase in link travel time due to congestion. Delay is calculated as:

Simulated travel time – calculated free flow time

The calculated free flow time depends on both the link’s speed and the vehicle’s maximum speed. Basically it is the time the vehicle would take to traverse the link when there is no other traffic on link.”

Comparison of Control and Link Delays on Arterials Calculated by CORSIM, SimTraffic and PARAMICS

Comparison of control delay calculated by CORSIM and HCS.

To evaluate the consistency of delay estimates obtained from various models, delay evaluations were carried out for the intersection shown in Figure 2. CORSIM, SimTraffic and PARAMICS are used to compare the link delay estimates. CORSIM and HCS are used to compare control delay estimates.

Figure 6.4 shows a single intersection with pretimed traffic signal. East-west road is a major road in that flow remains high as compared to north-south flow. At intersection only through movement is allowed for east bound and west bound flow. For each model, delay evaluations are carried out for v/c ratio varying between 0.1 and 1.5 at the interval of 0.1. This range provides the evaluation to be carried out for under saturated and over saturated traffic conditions. Simulations were performed for 15 min control period. The reason for selecting 15 min period is that HCM model requires 15 min analysis period. Intersection was created in Synchro and PARAMICS. Using Synchro network, CORSIM and SimTraffic analysis was carried out. For each model analysis was carried out using default parameters.

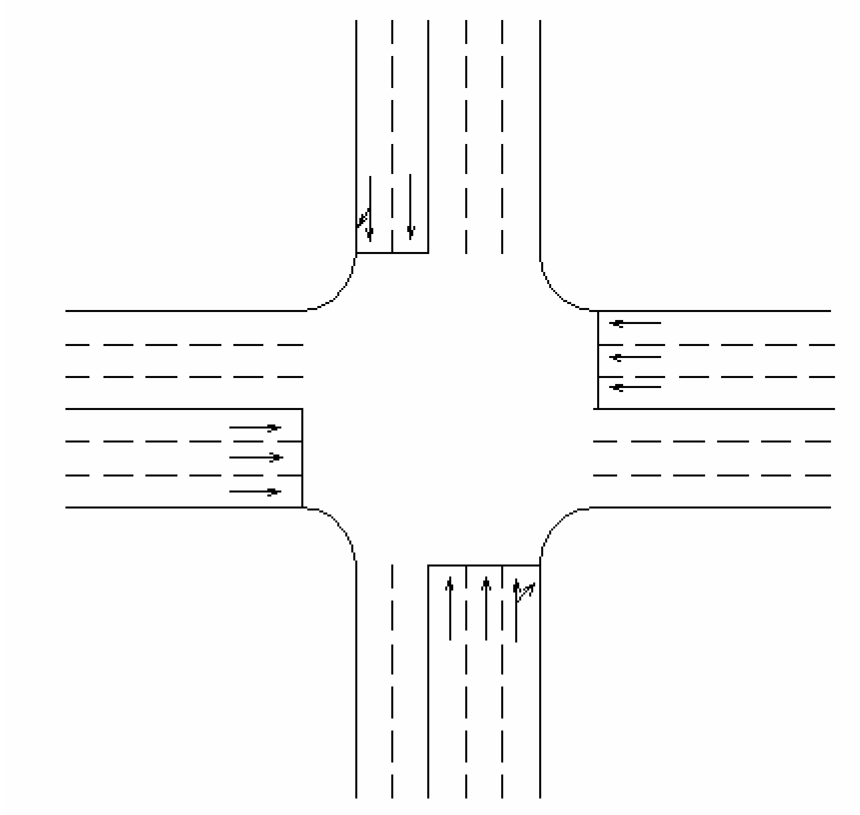

Figure 2. Delay Evaluation Scenario (Route 10 and US 202)

Simulation and signal parameters used for the study are as follows:

Simulation Time	15 min
Saturation flow	1900 veh/hr
Free flow speed	50mph on E-W road, 30mph on N-S road
Link length	EB= 3750 ft WB=3750 ft NB = 2500ft SB= 2500ft

Signal Plan;

Cycle length	130 sec
Green time	E-W= 91 sec
	N-S= 29 sec
Y+AR	5 sec

Figure 3 to Figure 6 illustrates the result of delay estimations that were carried out for the intersection shown in Figure 2.

Comparison of Link Delays Calculated by CORSIM, SimTraffic and PARAMICS

Figure 3 and Figure 4 illustrate the link delays for different approaches of an intersection modeled in CORSIM, SimTraffic and PARAMICS. Delay estimation is carried out for different v/c ratio ranging form 0.5 to 1.5. Figure 3 illustrates the link delay for both under and over saturated condition. Whereas, Figure 4 illustrate the link delay comparison between different models for under saturated condition. Figure 3 shows that for low v/c ratio all simulation models give comparable results. Results for higher v/c ratio show a huge difference between delay estimates from all three-simulation models. Particularly, SimTraffic gives very high values of link delay for v/c ratio greater than 1.2. Figure 4 illustrates that SimTraffic and CORSIM produce closer results as compared to PARAMICS. Figure 3 and Figure 4 show that there is no trend between delay estimates obtained from CORSIM, SimTraffic and PARAMICS for different approaches. However, results show same behavior between eastbound and westbound delay estimates and likewise between northbound and southbound delay estimates. It is observed that PARAMICS gives lowest delay estimates. Whereas, SimTraffic produces highest delay estimates.

Figure 5 and Figure 6 show the control delay for different approaches of an intersection modeled in CORSIM and HCS. Figure 5 illustrates the control delay for both under and over saturated condition. Whereas, Figure 5 illustrates the control delay comparison between different models for under saturated condition. Figure 5 shows that for low v/c ratios HCS and CORSIM give comparable results. For v/c ratios greater than 0.9 the difference is big between delay estimates of HCS and CORSIM. Figure 6 shows that for v/c ratios below 0.9 results obtained from HCS and CORSIM are comparable. Incremental delay term d_2 used in HCM equation is very sensitive to v/c ratio. For v/c ratio above 1.0 this term is very high and hence it increases the control delay by large amount.

Above results show that for the same geometry, flow and signal timing data each simulation software gives different estimation of delay. This is due to the fact that each software considers different vehicle arrivals. These results show the sensitivity of delay estimates to vehicle arrivals. To understand the sensitivity of delay estimates to vehicle arrivals more explicitly control delay was estimated for one approach on second and third intersection of an arterial for different demand levels. For this test, intersections on route 18 are considered. Five intersections are considered in route 18. Following section describes this test and results obtained from it.

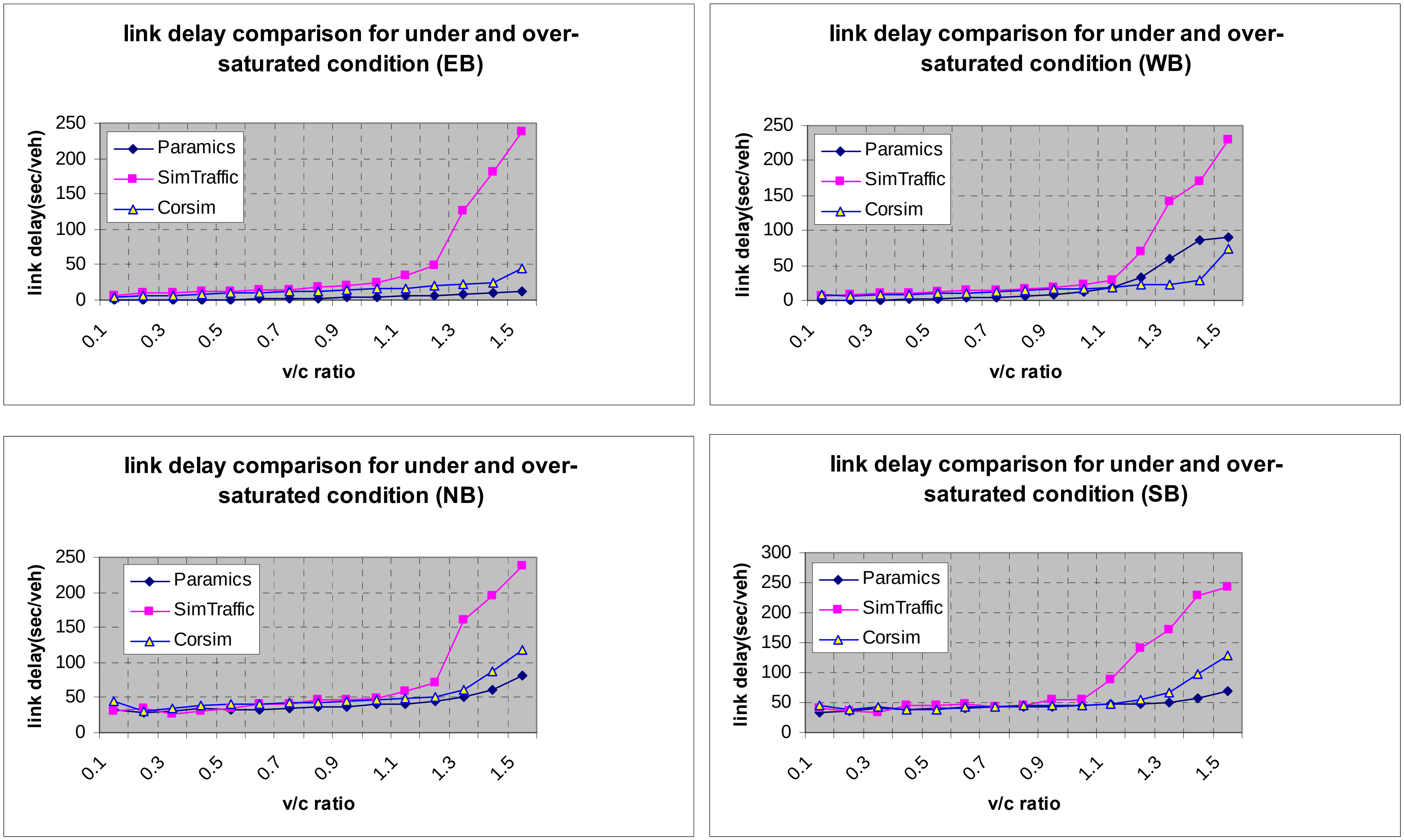

Figure 3. Link Delay Comparison for Under and Over-Saturated Condition

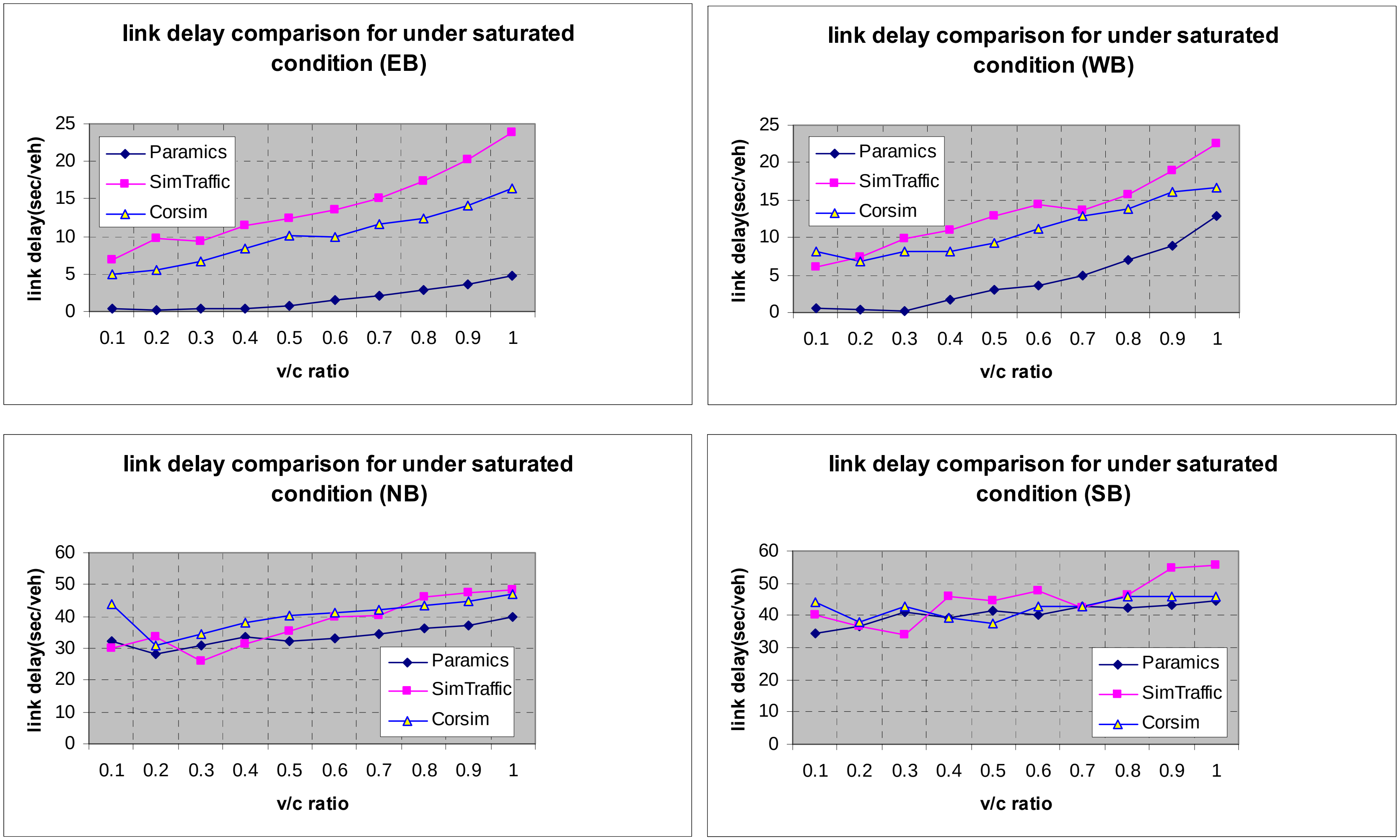

Figure 4. Link Delay Comparisons For Under Saturated Condition

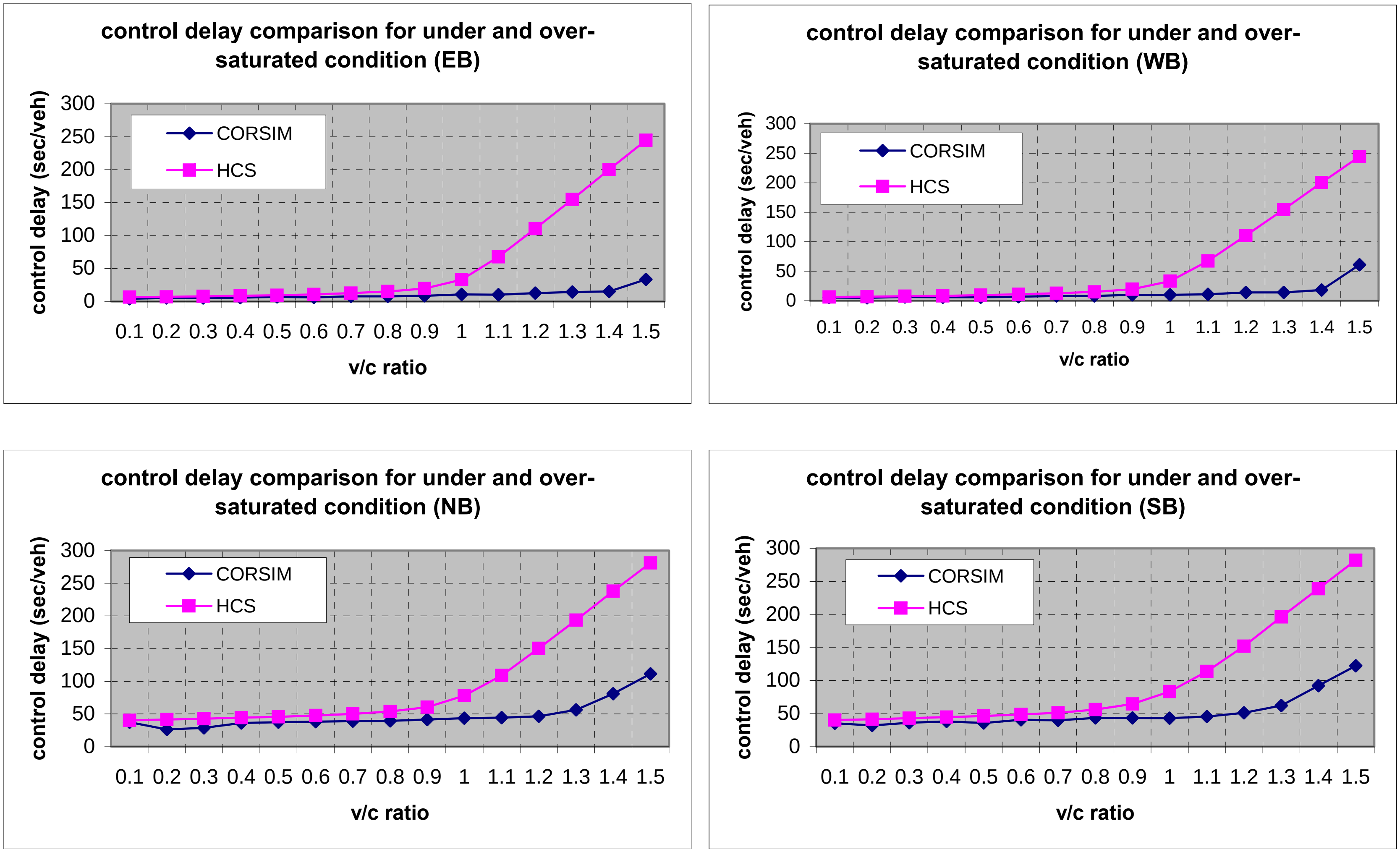

Figure 5. Control Delay Comparison For Under and Over-Saturated Condition

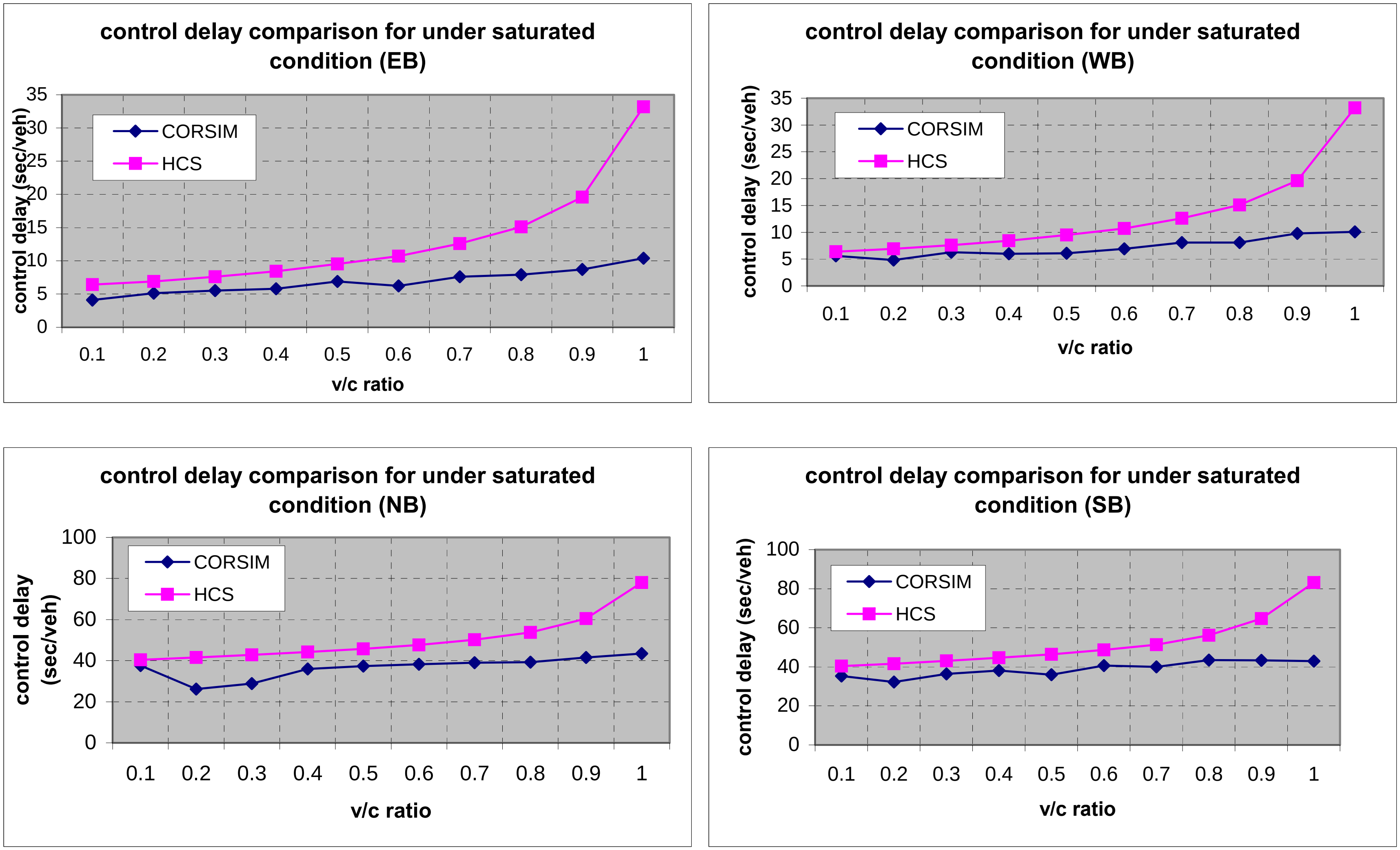

Figure 6. Control Delay Comparisons for Under Saturated Condition

Conclusions

Each simulation software package provides a delay estimation that is a very important MOE in determining the level of service at signalized intersections. However, the above simple examples show that even for the same traffic flow and network conditions, each simulation software produces different delay estimations. Different experiments are carried out to recognize the basis for this discrepancy.

- At low volume-to-capacity (v/c) ratio, all the software packages gave consistent results for link delay estimates. But at higher v/c ratio, Paramics gave relatively lower link delays than CORSIM and SimTraffic.
- For control delay estimates, HCS gave a relatively lower estimates that CORSIM at higher v/c ratios. The reason for this is the sensitivity of the incremental term in the HCM equation for control delay, to v/c ratio.
- The comparison of the speed data with the GPS observations and Paramics simulation showed that the speeds simulated in Paramics are consistent with observed speeds.

Further analysis is needed to better explain these differences.

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