NDOT Research Report

Report No: RDT02-032

COMPARATIVE EVALUATION OF SIMULATION SOFTWARE FOR TRAFFIC OPERATIONS

December 2002

Prepared by Research Division
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TECHNICAL REPORT DOCUMENTATION PAGE

Report No. **RDT 03-032**	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle **Comparative Evaluation of Simulation Software for Traffic Operations**	5. Report Date **November 24, 2002** 6. Performing Organization Code	
7. Author(s) **Mohamed S Kaseko**	8. Performing Organization Report No.	
9. Performing Organization Name and Address **Transportation Research Center** **Howard R Hughes College of Engineering** **University of Nevada Las Vegas** **4505 Maryland Parkway, Box 454007** **Las Vegas, NV 89154-4007**	10. Work Unit No. **11. Contract or Grant No.** **P049-01-803**	
12. Sponsoring Agency Name and Address **Nevada Department of Transportation** **1263 South Stewart Street** **Carson City, Nevada 89712**	13. Type or Report and **Period Covered** **January 1, 2001 - June 30, 2002** 14. Sponsoring Agency Code **NDOT**	
15. Supplementary Notes		

16. Abstract

The objective of this research project was to perform a comparative evaluation of several traffic simulation software with the purpose of identifying their suitability for use on NDOT-sponsored projects. The evaluation was done for traffic conditions on freeway segments, freeway ramps and interchanges, and coordinated intersections on a surface street. The software that were evaluated included VISSIM, TSIS/CORSIM, and SYNHRO/SIMTRAFFIC. They were evaluated based on their ability to model different traffic operational conditions, and provide suitable measures of effectiveness.

TSIS/CORSIM is the most developed and probably the most popular software. It can simulate most traffic situations, including special cases such as HOV lane operations, incident conditions, ramp metering, and transit operations. The output data has all the major MOEs in disaggregate and aggregate format, both link specific and network wide, such as vehicle-miles, vehicle hours of travel. VISSIM, on the other hand, is a fairly new software program with very frequent upgrades. It is potentially very powerful; allowing the user a lot more flexibility in network coding, input data and simulation of special situations such as roundabouts, interaction with light-rail systems, and intersection and midblock pedestrian crossing situations. However, it requires more effort in network building and setting-up of simulation situations. It also output several data that requires added effort to compile and post-process in order to provide aggregate and network-wide estimates.

Of the three software evaluated, SIMTRAFFIC is the user-friendliest, in terms of the ease of coding a network and running the program. The software typically works with the macroscopic model SYNCHRO and this pair of software can be used to quickly evaluate different optimal traffic and network situations.

17. Key Words **Traffic simulation, VISSIM, TSIS/CORSIM, SIMTRAFFIC,**		18. Distribution Statement **Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161**	
19. Security Classification is report) **Unclassified**	20. Security Classif. (of this page) **Unclassified**	21. No. Of Pages 57	22. Price

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Introduction and Study Objective

The Nevada Department of Transportation (NDOT) frequently requests developers and local public transportation agencies, such as the cities, counties and the Regional Transportation Commission (RTC) involved in large regional projects to perform analysis and simulation of traffic conditions on roadway and freeway sections and networks. These analyses typically involve the use of computer software to simulate traffic conditions on roadway sections and networks with complex signal systems. The analyses are not only important in prediction of network performance, but are also key inputs into funding decisions for construction, operation, and maintenance of the projects. Several computer software programs exist that are capable of doing such traffic analyses and simulations. Software, such as SYNCHRO/SIMTRAFFIC, TSIS/CORSIM, ITRAF, VISSIM, and INTEGRATION, to name a few, all claim to make accurate estimates of network, arterial and intersections levels-of-service, vehicle delays, queue lengths and other performance measures. However, as shown by various researchers (see next section), each of these programs have their strengths and weaknesses. Their performance, in terms of reproducing observed field conditions, depend on the traffic conditions at hand and how well the models are calibrated.

The main objective of this research project was to perform a comparative evaluation of several transportation analysis and simulation software with the purpose of identifying software programs that are suitable for use on NDOT-sponsored projects. The software will be evaluated on their ability to accurately reflect field traffic conditions. The evaluation will be done for traffic conditions on freeway segments, freeway ramps and interchanges, and coordinated arterials. The software will be evaluated based on their ability to closely reproduce observed field traffic speeds, density, queue lengths and vehicle delays.

The software programs VISSIM, TSIS/CORSIM, and SYNHRO/SIMTRAFFIC were identified for detail evaluation for this project. VISSIM and TSIS/CORSIM were evaluated for both freeway and arterial sections, while SYNCHRO/SIMTRAFFIC was evaluated for the arterial segment only. The following is a brief overview of the software programs.

CORSIM/TSIS

CORSIM is part of the Traffic Software Integrated System (TSIS) Version 5.0 (Windows based) and it contains NETSIM and FRESIM programs. NETSIM is a microscopic network simulation model for arterial streets while FRESIM is a microscopic freeway simulation model. NETSIM can simulate most operational conditions experienced in an urban street network environment. FRESIM can simulate complex freeway geometric features, such as lane add/drops, inclusion of auxiliary lanes, and variation in slopes, superelevation, and radius of curvature. The model can handle freeway operational features such as lane changing, on-ramp metering, and representation of a variety of traffic behaviors in freeway facilities. CORSIM microscopically simulates traffic and traffic controls systems on integrated networks of freeway and surface streets, using commonly accepted vehicle and driver behavior models. CORSIM has the ability to model parking, bus stops and random traffic interruptions. CORSIM reports system performance in terms of total delay, stop delay, total stops, stops/vehicle, travel distance and time, fuel consumption, emissions and maximum queue length.

VISSIM

VISSIM (Version 3.60) is part of PTV Vision integrated software for transportation planning and traffic engineering tasks. VISSIM is a microscopic simulation software for modeling traffic flow on arterial streets as well as freeways. The software can be used to simulate and analyze various design alternatives, such as roundabouts, unsignalized and signalized intersections, and grade separated interchanges. The tool can be used to analyze toll plaza facilities, conduct traffic impacts studies, and to test the operability of ramp metering and interchange design. The output include 1) measures of effectiveness such as traffic volume, mean speed, travel times, delay, queue length, number of stops, time-space-diagrams, 2) vehicle emissions, and 3) signal control data such as minimum, maximum and average green time per signal group/phase, waiting time after detector calls and display of dynamic signal timing plans.

SYNCHRO/SIMTRAFFIC

SYNCHRO and SIMTRAFFIC are a pair of windows-based programs and are used widely by agencies and consultants for arterial signal timing design and evaluation. SYNCHRO performs signal-timing optimization for networks and individual intersections based on minimizing delays and stops. It has the capability to optimize splits, cycle lengths, phase sequences and offsets. The latest version (5.0) can model interchanges and complex signal phasing. The key features of the software are capacity analysis, signal coordination, actuated signal control, and time-space diagrams. The software reports system performance using total delay, stop delay, total stops, stops/vehicle, travel distance and time, level of service (LOS), maximum queue length, queue penalty, dilemma vehicles, fuel consumption, and emissions as the measures of effectiveness (MOE). SYNCHRO can also be used to generate input files for SIMTRAFFIC, CORSIM, HCS, TRANSYT 7F, and PASSER.

SIMTRAFFIC is microscopic simulation model, similar to the NETSIM module of TSIS/CORSIM. It is designed to be used to simulate and evaluate performance of an arterial network based on input traffic and signal timing. It outputs the similar measures of effectiveness as SYNCHRO.
The study was divided into the following main tasks.

Task 1: Literature Review

Although for this project only the three software programs listed above were selected for detailed evaluation, several other traffic simulation software programs were reviewed for this project. These are some of most widely used software programs for simulation of traffic and transportation networks, and they include SYNCHRO/SIMTRAFFIC, TSIS/CORSIM, ITRAF, INTEGRATION, VISSIM, WATSim, TRANSYT-7F, PASSER and MITSIMLab. A brief review of these programs is presented below. MITSIMLab, a simulation and modeling software developed at the Massachusetts Institute of Technology (Jha, Cuneo and Ben-Akiva, 1999) is currently not distributed commercially and no user documentation is available for the same. Hence, it was not considered in the evaluation process.

CORSIM/TSIS

CORSIM is part of the Traffic Software Integrated System (TSIS) Version 5 (Windows based) and contains both NETSIM (NETwork SIMulation) and FRESIM (FREeway SIMulation) programs. NETSIM is a microscopic simulation model for arterial networks while FRESIM is a microscopic simulation model for freeway systems. NETSIM can simulate most operational conditions experienced in an urban street network environment. It provides a high level of detail and may be the most widely used traffic simulation model. The NETSIM model uses an interval scanning simulation approach to move vehicles to each section according to car-following logic and in response to traffic control and other conditions.
The FRESIM model is derived from the INTRAS model developed in the late 1970's. Being a microscopic model, it models each vehicle and driver in a discrete manner. The model can simulate complex freeway geometrics such as lane add/drops, inclusion of auxiliary lanes, and variation in slopes, superelevation, and radius of curvature. The model can handle freeway operational features such as lane changing, on-ramp metering, and representation of a variety of traffic behaviors in freeway facilities.
Thus, CORSIM microscopically simulates traffic and traffic controls systems on integrated networks of freeway and surface streets using commonly accepted vehicle and driver behavior models. The software is capable of simultaneously simulating traffic operations on surface streets as well as on freeways in an integrated fashion. The overall goal is to mimic both the small scale and large-scale dynamics of traffic. The user has control over a large number of simulation parameters that include traffic, driver, vehicle and geometric characteristics. Examples of such parameters include including the road grade, percentage of trucks, driver aggressiveness, free flow speed, vehicle acceleration rates, queue discharge headway etc.
CORSIM provides several output measures of effectiveness, such as average vehicle delays, link speeds and travel times, queue lengths and number of stops. It also outputs aggregate measures such as vehicle-miles and vehicle-hours of travel. Vehicle emissions can also be output. The outputs are by link as well as system-wide measures.

The capacity is an implied output of the program and is generally determined by increasing demand and observing the maximum flow rate. Thus, capacity can be influenced by changing input parameters, but cannot be directly specified. The speed-flow curve is not directly specified but could be controlled using the input parameters. CORSIM is similar to SIMTRAFFIC with some limitations and enhancements. A few of the limitations include longer running time and capacity to analyze fewer intersections. The advantages include the ability to model parking, bus stops and random interruptions. CORSIM reports system performance in terms of total delay, stop delay, total stops, stops/vehicle, travel distance and time, fuel consumption, emissions and maximum queue length.

SYNCHRO/SIMTRAFFIC

SYNCHRO is a windows-based program developed by TRAFFICWARE and is used widely by agencies and consultants. SYNCHRO uses a mouse and menu driven input method, allowing the user to “click and drag” to create links (nodes are created implicitly). It also allows the use of a “background” Drawing Exchange Format (DXF) file to use as a template for tracing the street network. Not only does this method make for easy network coding, but it also produces a graphical representation of the network that can be used in the reports and presentations. This graphical input method is very intuitive and user-friendly.

SYNCHRO offers the user a choice between two types of signal delay calculations: (1) the 1997 HCM formulation (which it calls Webster’s delay) and (2) percentile delay. Like TRANSYT-7F, SYNCHRO also integrates the area under the arrival-departure curve to calculate uniform delay, using a 0.1-second time slice resolution. SYNCHRO’s percentile delay option allows the user an alternative way to estimate intersection control delay. The percentile method allows actuated conditions and coordination to be modeled in more detail. However, this method of delay calculations is not recognized by public agencies for traffic impact studies. Thus, this method may be of most use for just evaluating the relative differences to be realized from various actuated and coordinated conditions, not for reporting to public agencies.

SYNCHRO performs signal-timing optimization for networks and individual intersections based on minimizing delays and stops. It has the capability to optimize splits, cycle lengths, phase sequences and offsets. Like TRANSYT-7F, SYNCHRO uses a “performance index” for its optimization objective function. SYNCHRO can also perform a search for the best cycle length (within the user-specified range) and determine appropriate phase lengths and coordination offsets for this cycle length, and also evaluates different lead/lag phase orderings. SYNCHRO can also perform separate optimizations on different sub-groupings of intersections within the overall network. The sub-groupings can be user-specified or program-determined based on user –specified coordination factor thresholds.

SYNCHRO also employs its own green time calculator for actuated conditions. It estimates green times for each of the five different percentile volume loadings according to the Poisson distribution. SYNCHRO uses formulas which are based on the inputs from the actuated controller settings input stage, to predict phase gapping and skipping probabilities for each of the five volume scenarios, and adjusts the average green times accordingly. The delay is calculated for each volume scenario and then averaged across all five volume loadings to determine the overall signal delay under actuated conditions.

The overall input data requirements for SYNCHRO are similar to those for TRANSYT-7F. However, the tool does not go to the level of detail as TRANSYT-7F in simulating traffic flow such as platoon dispersion and upstream to downstream origin-destination patterns. It instead relies more on analytical relationships for estimating these effects.

The key factors of the program include capacity analysis, coordination, actuated signal lengths, and indicate queue spill back. The 50^{th} percentile queue length is the maximum queue length for a cycle with average arrivals. The 95^{th} percentile queue length is adjusted using a Poisson distribution. The latest version (4.0) can model interchanges and complex signal phasing. The key features of the software are capacity analysis, signal coordination, actuated signal control, and time-space diagrams. The software reports system performance using total delay, stop delay, total stops, stops/vehicle, travel distance and time, level of service (LOS), maximum queue length, queue penalty, dilemma vehicles, fuel consumption, and emissions as the measures of effectiveness (MOE). SYNCHRO can also be used to generate input files for SIMTRAFFIC, CORSIM, HCS 3, TRANSYT 7F, and PASSER.

SIMTRAFFIC is used for microscopic simulation and animation of signalized intersections and freeway systems. The key features of the software include the following.

1. The ability to model networks of signalized and unsignalized intersections,
2. Check and fine-tune traffic signal operations,
3. Analyze closely spaced intersections with blocking and lane change problems,
4. Simulate the affects of signals on nearby unsignalized intersections and driveways, and,
5. Analyze the operation of intersections under heavy congestion.

SIMTRAFFIC is easier to use when compared to CORSIM. SIMTRAFFIC uses many of the same driver and vehicle performance characteristics as CORSIM so that simulation results are comparable. In some cases SIMTRAFFIC goes beyond CORSIM by eliminating some of CORSIM's arbitrary limits.

ITRAF

ITRAF 3.0 is a 32-bit application that runs under Windows 95/98 and Windows NT. It supports the input data requirements for FRESIM freeway networks in addition to handling two new types of files for the NETSIM model: template files and script files. Script files can be created manually or optionally from Geographic Information Systems (GIS) software, thus simplifying the task of producing the NETSIM files.

INTEGRATION

INTEGRATION, a mesoscopic routing-oriented simulation model of integrated freeway and surface networks, was developed in the late 1980s. The software is used to model the aggregate speed-volume interactions of traffic but not the details of vehicles lane-changing and car-following behavior. Hence, it is called a mesoscopic model. The model is routing-based and thus needs data pertaining to vehicle’s trip origin, destination and departure time. The actual trip path and the arrival times at each link along the path are derived within the simulation based on the modeled interactions with other vehicles. INTEGRATION has the graphical capability to view vehicles as they move through the network but does not have the interface to view and edit network data.

PTV Vision and VISSIM

PTV Vision is an integrated software solution for all transportation planning and traffic engineering tasks. It can be used for planning studies of larger than regional dimensions in addition to urban traffic studies and innovative traffic management. PTV Vision includes various components. They include:

1) travel demand forecasting based on activity chains (VISEM),
2) planning, network assignment and evaluation (VISUM),
3) microscopic simulation of traffic flow and modeling of traffic-responsive signal control (VISSIM),
4) mesoscopic traffic flow simulation for dynamic route guidance (DYNEMO),
5) design tool for traffic signal control (CROSSIG), and
6) flow chart editor for traffic responsive signal control logic (VisVAP).

VISSIM is a decision support tool for modeling transit and traffic flow in urban areas as well as interurban motorways/ freeways. The traffic flow model in VISSIM is a discrete, stochastic, time step based microscopic model, with driver-vehicle-units as single entities. The model contains a psycho-physical car following model for longitudinal vehicle movement and a rule-based algorithm for lateral movements. The software can be used for capacity analysis and testing of transit priority schemes. Various design alternatives available in VISSIM include roundabouts, unsignalized and signalized intersections, and grade separated interchanges. The output include 1) measures of effectiveness such as volume, mean speed, travel times, delay, queue length, number of stops, time-space-diagrams, 2) vehicle emissions, and 3) signal control data such as minimum, maximum and average green time per signal group/phase, waiting time after detector calls and display of dynamic signal timing plans. The tool can be used to design, test and evaluate various scenarios. In addition, it can be used to analyze toll plaza facilities, conduct traffic impacts studies, and, to test the operability of ramp metering and interchange design.

WATSim

Wide Area Traffic Simulation Model (WATSim) is a time-scanning simulation model developed by KLD Associates. The software is a significant extension of TRAF-NETSIM and provides an integrated simulation of freeways and surface streets at microscopic detail. Each vehicle in the traffic stream is represented as a distinct entity and is "moved" each second accounting for the current traffic conditions. Vehicle trajectories are computed according to car-following logic, which responds to the performance of neighboring vehicles, traffic control devices, and other conditions influencing driver behavior. These responses reflect both the performance capabilities of the individual vehicle and the relative "aggressiveness" of the simulated motorist.

Each vehicle is assigned a driver with specific behavioral characteristics to perform driver decisions including lane selection and lane changing. Each vehicle also is identified by category (car, car-pool, bus, truck). For example, car-pools and buses may be restricted to specific lanes. An individual vehicle is further characterized by type of car, bus, etc. reflecting specific operational and performance characteristics. The end user can specify up to 16 different types of vehicles.

The output of the model includes measures of effectiveness such as speed, volume, delay, spillback, queues, fuel consumption and pollutant emissions. Traffic performance measures are available for each network link, each intersection, groups of links and the entire network over user-specified time intervals. Measures of effectiveness for a toll plaza can be provided on a per-lane basis while measures of transit operations are available by route and station. The software has the ability to display animated simulated traffic operations and has the feature to interact with a statistical analysis package.

TRANSYT-7F

TRANSYT-7F is a macroscopic, deterministic optimization and simulation model that can be used to analyze a street network. The software considers platoons of vehicles instead of individual vehicles. TRANSYT-7F simulates traffic flow in small time increments, so its representation of traffic is more detailed than other macroscopic models that assume uniform distributions within traffic platoons. The cycle length, phasing data, approach volumes and turning movements, link lengths, saturation flow rates and approach speeds are required inputs for the analysis. The software can be used to evaluate existing timings and optimize proposed conditions to minimize stops, delay, fuel consumption, and cost. The performance measures include delays, average queues, stops, fuel consumption, and time-space diagrams.

PASSER

PASSER helps traffic engineers and planners develop timing strategies that optimize the flow of traffic on a single arterial or through the entire network. The objective is to maximize the progression band, which is the time interval between the passage of the first vehicle and the passage of the last vehicle that can travel without being stopped – i.e., those which encounter consecutive green traffic lights - on a section of a signalized roadway. Roadway networks have numerous alternate signal timing strategies that can tremendously affect delays, fuel consumption and emissions. PASSER is designed to choose the best signal timings given certain traffic data. There are three PASSER programs that work with three different traffic signal scenarios: PASSER II for single signalized roadways, PASSER III for diamond interchanges, and PASSER IV for single or multiple roadways and diamond interchanges. PASSER can analyze numerous variables that affect progression. The most valuable aspect of all PASSER programs is the optimization feature, which can analyze all signalization scenarios and determine the best option. For example, traffic engineers might evaluate signal-phasing sequences and determine the optimal one.

Summary on Research on Traffic Simulation Software

Research efforts on testing and validating various transportation software programs have been ongoing over the past few years. Most of these efforts are case specific. For example, Khasnabis ET. Al. (1996) presents the application of a simulation model to assess the possible consequences of preemption of a single isolated intersection or a series of intersections along a bus route using NETSIM software. From the volume levels studied in the project, it was determined that savings in delay along the bus route resulting from preemption exceeded the increases in delay along the cross street.
Daigle ET. Al. (1998) used CORSIM to evaluate the I-40 Cross-town Expressway in Oklahoma City. The authors considered a 3-mile section, which bypasses downtown and connects two major freeway systems. The study section encompasses 6 ramp locations. The objective is to analyze traffic operation on two of the preferred freeway design alternatives. Analysis based on CORSIM results helped the authorities identify problem areas at freeway-ramp locations and future problem locations at nearby intersections. Observations showed that CORSIM is sensitive to geometric distances such as ramp spacing and acceleration/deceleration taper distances.
Wang and Prevedouros (1998) compared INTEGRATION, CORSIM and WATSim in replicating volumes and speeds on three small networks. The case studies considered include the following scenarios.

1. Congested on-ramp merge section and the effect of platooned ramp traffic
2. Freeway divergence situation
3. A network consisting of
   a). a freeway weaving section containing off-ramp and onramp, and
   b). a signalized intersection at which off-ramp terminates.

Two 15-minute time periods were used to simulate the 15-minute period traffic flow in the network - first for the initialization and 2nd for drawing the simulation results. The surface street part was simulated using NETSIM and the freeway part was simulated using FRESIM. Simulation results were obtained after initialization was completed and the network reached equilibrium. The FRESIM module used the default car-following and lane-changing parameters.
In the first case, the simulated volumes on mainline segments were considerably smaller than the actual volumes. The intersection signal and the onramp platoon effect on the simulated result were also examined. All freeway parameters remained unchanged, but the intersection was treated as a single node. The resultant throughputs from this run decreased, and the simulated speeds on both the mainline segments and on the onramp were lower than those from the integrated network.
In the second case, vehicles which cannot complete lane-changing maneuvers to the off-ramp pass through the divergence node to the downstream mainline and produced missed vehicle statistics output file. In the third case, the four phases and the pre-timed signal timing plan was easily simulated by CORSIM without any lane alignment problem between upstream and downstream links. However, NETSIM could not simulate the U-turn vehicles, which discharge during the same signal phase as the left-turning vehicles. The U-turn vehicles were modeled as left turning vehicles. For the weaving restriction, a lane

barrier was defined in FRESIM to prevent lane-changing maneuvers between affected lanes in a pair. The restriction affects both lanes separated by the barrier. However, vehicles are allowed to cross the barrier from the right lane to the left on the weaving section.

Prevedouros and Wang (1999) conducted the simulation of traffic conditions on a large freeway/arterial network using three different software programs (CORSIM, INTEGRATION and WATSim). The study includes the evaluation of the ability of each model to replicate observed field traffic conditions and performance measures. The authors used the default car-following parameter settings corresponding to freeway capacities as high as 3,000 vehicles per hour per lane (vphpl) to replicate the real traffic conditions. The authors observed that NETSIM component had no problems with default model parameters for the surface street sub-network. However, low freeway volumes and a large number of destination-reassigned and missed vehicles were produced by FRESIM. Thus, the study shows that car-following and lane-changing parameters have significant effect on FRESIM results.

WATSim employs a similar logic (as CORSIM) in simulating surface street networks. The results produced by CORSIM and WATSim were close for the Vineyard Boulevard arterial and other street links. However, the difference in freeway simulation is apparent. CORSIM evokes FRESIM, which usually produces lower simulated speeds on freeway onramp merge segments. Thus CORSIM parameters needed radical modifications to duplicate observed volumes, which is not a desired feature. However, CORSIM has the most realistic lane-changing maneuvers. Overall, the models were able to produce results that were reasonably close to field observations. However, all the software required extensive modifications to the various default input parameters (i.e., extensive parameter calibration effort required).

The literature documents few efforts that are based on studying the performance of several software considering one, or a few, parameters such as delay, queue lengths, etc. Mystkowski and Khan (1999) compared queue length estimates provided by the various software programs (SIGNAL94, SYNCHRO3, TRANSYT-7F, PASSER II-90 and CORSIM). The authors made the following assumptions.

1. Arrival rate is uniform
2. Departure distribution is uniform and is the saturation flow rate or the arrival rate depending on the presence of a queue.
3. There is no initial queue at the start of the green.

Field data was collected at three locations in the Denver metropolitan area. An isolated intersection was selected as one location. The second and the third locations selected consisted of closely spaced intersections. Data was collected using videotape at each location. At the 2nd and the 3rd locations, which consisted of the successive intersections, the video cameras were synchronized so that the same vehicles were observed as they passed through each intersection. The total intersections traffic volumes were grouped into 15-minute time periods. At the first site, five 15-minutes time periods (60 cycles) of data were collected. At the second and the third sites, three 15-minute time periods (36 cycles) and seven 15-minute time periods (63 cycles) of data were collected.

Observations show that for a high volume/capacity (v/c) ratio, CORSIM and TRANYST-7F both produce reasonable results that are within two vehicles of the field measurements. The variation is less than or equal to 8 percent. The results of the SIGNAL94 and SYNCHRO 3 (95%) are reasonable, differing from field measurements by one to three vehicles. In case of a medium v/c ratio, CORSIM yielded the most reasonable results (within one to two vehicles of the field measurements). SYNCHRO 3 (50%) and SYNCHRO 3 (95%) over-estimated by four or more vehicles for at least one considered intersection. Under low v/c conditions, the results are reasonable in few cases for all programs. The study concludes that there is a significant variation in the performance of the programs depending on ratio. The programs either overestimate or underestimate depending on various traffic conditions.

Rillet ET. Al. (2000) compared TRANSIMS and CORSIM simulation models. A section of the I-10 in Houston, TX was chosen as the test bed. The section is approximately 23 km long and consists of fourteen on-ramps and thirteen off-ramps. Even though the corridor consists of the frontage roads and the HOV facility, the focus was on the non-HOV section only. Traffic volumes were collected in May and June of 1996. In addition, this data was supplemented with direct counts taken on five separate days in July and August of 1996. A database was developed based on readings that occurred on a Wednesday/ Thursday and these counts were adjusted so as to ensure consistency across the network. These volumes were used as the baseline data for the analysis.

Both TRANSIMS and CORSIM generated roughly equivalent results with respect to replicating the baseline volumes. It was significantly easier to calibrate the TRANSIMS model because of the lower number of the calibration parameters available. The calibration of the CORSIM was made easier because of the wide range of literature available. The validation analyses showed that TRANSIMS is particularly sensitive to the random deceleration parameter. In general, the calibrated TRANSIMS model tended to underestimate the observed travel times whereas CORSIM overestimated the observed travel times. However, the travel times serve only as a rough guide to the accuracy of the simulation. More importantly it was found that the variability in TRANSIMS link travel times was significantly lower than what was observed on the actual highway system. It was hypothesized that this might affect certain measures of effectiveness (MOE) that are derived from the model such as vehicle emissions.

Hall ET. Al. (2000) observed that CORSIM produced reasonable results throughout, although there were clear differences between its prediction and the results obtained from FREQ. The estimated speed differences were relatively low in few data sets whereas in others the differences were relatively large. There were no program crashes or unexpected errors and was remarkably stable during the experimental time. The results obtained were similar to those from FREQ and FREEVAL (Freeway Evaluation – the HCM based spreadsheet model). However, CORSIM is close to FREQ in terms of replicating the field data and would have performed better with a slightly larger capacity adjustment value than that determined by FREEVAL.

Bloomberg and Dale (2000) compared CORSIM and VISSIM by simulating traffic on a part of the State Route (SR) 519. The section is 2-way, 4-lane (with left turning bays), at-grade roadway that ends at 4^{th} Avenue. The section considered is near to the CBD area. The alternative analysis was conducted for the Washington State Department of Transportation (WSDOT) in 1999. The input data required for the two models were quite similar. It includes lane geometry, traffic volumes, percent trucks, free-flow speeds, traffic control devices and signal control. 6 design alternatives were considered. 10 model runs were conducted for each design alternative. A total of 180 runs were made with each model. CORSIM yielded unrealistic results occasionally under congested traffic conditions. In few cases vehicles got stuck for periods of time thus necessitating the need to make changes to CORSIM input parameters. A sensitivity analysis was done for each set of alternatives by varying demand assumptions.

Elefteriadou, ET. Al. (2000) worked on identifying traffic modeling situations that cannot be modeled with the Highway Capacity Manual Software (HCS) and provision of guidelines for selection of appropriate software for such cases. The study suggests use of software depending on the traffic problem being modeled. The recommendations are based on modeling capabilities of the software, but not the accuracy of estimated outputs.

Prassas (2000) compared results obtained simulating using NETSIM to HCS. The study evaluates the need for appropriate calibration of variables. The findings include the effect of the default parameters in NETSIM on output traffic performance values. The study used HCS results as "ground truth".

Washburn ET. Al. (2001) compared by estimating intersection delay using TRANSYT-7F, SYNCHRO, and HCS. A central east-west arterial (NE 45^{th} Street) connecting the University of Washington with I-5 was chosen as the study section. The study section spans a distance of 823-m (2700 feet). The network includes two signalized intersections. These signals were present on heavily traveled connected streets. The study section consists of two travel lanes in each direction, with left-turn bays and center two-way left turn lane. Overall the network contains 10 signalized intersections. Most of the signals were placed about 85 m (280 feet) apart. The data collected include signal timings, traffic volumes, lane channelization bus stops and bus volumes, travel time and general queuing conditions.

The Washburn study suggests that differences in delay estimates between the three programs were mainly due to the different ways the programs accounted for the effects of signal coordination and traffic filtering at the upstream intersections. HCS computes a “progression” adjustment factor to be applied to the uniform delay component of the delay computation, and uses an “I”-factor in the random delay component to account for the filtering effects. On the other hand, TRANSYT-7F and SYNCHRO account for these effects implicitly by the way they compute the uniform delay components, which is by integration of queued vehicles at regular time intervals over the total simulation time. The study also notes that differences in permitted left-turn movements and right-turns-on-red (RTOR) can also occur due to different permitted movement models and/or the different assumptions about the values of some of the parameters used in those models. The authors further acknowledge that each program has strengths and weaknesses, and neither is ideal for every situation. They recommend that application of each program should carefully consider the characteristics of the study section and project objectives. The authors suggest that for intersections with random vehicle arrivals, pretimed signals and protected movements, the software should produce same results no matter which one is used. Specifically, they recommend that HCS be used for situations involving analysis of truly isolated intersections and/or if a public agency specifically requires HCS reports for traffic studies. However, the authors do not make any specific recommendations on when or under what circumstances one should use TRANSYT-7F or SYNCHRO.

Zhang ET. Al. (2001) simulated and analyzed a signalized intersection with multiple demand levels. Three different scenarios were considered for analysis. They are:

Scenario 1: All movements are under-saturated

Scenario 2: Some movements are under-saturated and some movements are over- saturated.

Scenario 3: All movements are over-saturated.

The data collected include hourly volumes at the intersection considered for all the three scenarios. The difference between control delay, queue delay and stopped delay were analyzed. The queue delay in CORSIM was always higher than the stopped delay. However, the difference between the queue delay and the stopped delay in CORSIM is relatively small. The control delay was thought of as a better parameter that accurately accounts for the slow down caused by the intersection control. Observations show that CORSIM’s intersection control delay calculation procedure is valid and match with those of HCM procedure in most cases. As demand level increases to congested conditions, HCM and CORSIM seem to generate slightly different average control delay. The sensitivity with respect to congestion versus uncongested conditions, and use of different PHF values was also studied.

Fellendorf and Vortisch (2001) present the possibilities of validating the microscopic traffic simulation model VISSIM, both on a microscopic and a macroscopic level. The VISSIM car-following model was originally designed to model driver behavior on German freeways. There is no general speed limit on the German freeways but speed limits on the highly congested freeways are limited to 120 km/h. As a result, the maximum flow on a single lane is about 1800 vehicles/hour. The distribution of the total volume to the single lanes is examined to validate the lane-changing behavior. One of the most important input parameters for lane usage is the distribution of the desired speeds. If the distribution is narrow, vehicles tend to use the lanes more uniformly.

Both microscopic calibration and macroscopic validation results show that simulation tools based on the psycho-physical car following models can reproduce traffic flow very realistically under different real conditions. Therefore, it is possible but also necessary to adapt the model to the local traffic situation; at least national regulations and driving styles must be taken into account.

In summary, different software can produce different results for the same traffic scenario that is being evaluated. A software program may be good for estimating some of the parameters, but usually not all of the parameters. Therefore, different traffic scenarios may require different software. There is a need to accurately calibrate parameters to achieve reasonable results based on unique local conditions. None of the research papers reviewed include any discussion on the sample sizes, design of evaluation criteria, defining procedures for statistical analysis of data, hypothesis testing and comparative analysis of the results.

Analysis and Evaluation of the Selected Software

For this project, three software were evaluated. VISSIM and TSIS/CORSIM (referred to simply as “CORSIM” in the rest of the document) were evaluated for simulation of both freeway segments and arterial street networks, while SYNCHRO/ SIMTRAFFIC (referred to simply as “SIMTRAFFIC” in the rest of the document) was evaluated for simulation of an arterial only.

For freeway simulation, the following aspects were evaluated:

- Simulation of operation of freeway segments
  - Including examination of the features for input data
- Incorporation of
  - HOV lanes
  - Incidents
  - Construction zones
  - Rerouting of traffic
  - Vehicle detection
  - Evaluation of LOS measures
- Simulation of on-ramps, including
  - Ramp metering, with/without HOV bypass
  - Vehicle detection for ramp metering
  - Strategies for input flow
  - Evaluation of LOS measures

Lane changing and traffic merging and diverging behavior were also examined. Measures of effectiveness (MOEs) evaluated included link speeds, flow and densities. While the CORSIM output reports also include link and network-wide vehicle-miles and vehicle-hours of travel, VISSIM outputs only the link flows, speeds and densities. However, the user can export the VISSIM output into a spreadsheet and post-process them to produce desired vehicle-miles and vehicle-hours of travel measures. Both software can also output vehicle emissions measures, broken down into individual types of emissions, such as CO, CO_{2-} and HC Emissions.

For arterial simulation, the software was evaluated based on simulation of an arterial street with four signalized intersections. Issues addressed in the evaluation include:

- Input of approach flows and turning movements, and vehicle mix
- Intersection geometry
- Signal phasing and timing
- Detector locations and modes

- Stop and yield conditions
- Transit operations
- Transit Preemption
- Actuated control
- Mid block Traffic Characteristics
- Output MOE evaluated
  - Approach delays, queues and number of stops
  - Level of service (based on average vehicle delays)
  - Time space diagrams
  - Vehicle emissions

Ability to simulate roundabout operation was also examined.
Since some of the evaluation involved comparing simulation data with field data, the following section summarizes the procedure used to obtain the data.

Task 2: Design of Data Collection Effort

The data collection task involved the following sub-tasks.

(1) Selection of study locations
Two study locations were selected for the study. For freeway analysis, a section of the US-95 freeway between the I-15 interchange (The Spaghetti Bowl) and the Lake Mead Interchange was selected. For arterial analysis, a section of Martin Luther King Boulevard between Washington and Carey was selected.

(2) Determination of field data to be collected
The data needed for the study included (a) geometry of the roadways, such as the length and alignment of road segments, number and width of lanes, grades, shoulders, etc., (b) traffic data such as traffic volumes on freeway links and ramps, traffic mix in terms of the proportion of heavy vehicles, turning movements for the arterial intersections, and (c) traffic performance data such as link travel times, intersection delays and queues.

(3) Collection of Field Data
Freeway data was made available from an earlier NDOT-sponsored project that involved calibration of the CORSIM model for the section of the freeway. For the arterial street segment, a GPS based data collection procedure that included collection of link travel time data, and estimation of approach queues and intersection delays in the arterial direction. This data was collected using three vehicles that made several runs during the AM and PM peak periods on the arterial section. The vehicles were equipped with GPS units, which enabled the collection of data on link speeds, queue lengths and approach delays at each subject intersection.

Task 3: Data Collection

Data for the freeway section of the US-95 freeway between the I-15 interchange (The Spaghetti Bowl) and the Lake Mead Interchange was supplied by NDOT. The data included roadway geometry for the freeway section, including the lengths and number of lanes for each segment, the roadway alignment and location of ramps. Link travel time data, from test car runs, was also provided. This data was collected for an earlier NDOT-sponsored project involving the calibration of the CORSIM software.

For the arterial data, the geometric features for the Martin Luther King Blvd arterial was extracted from Clark County aerial maps. They included link distances, approach lanes and intersection configurations. Turning movement data for the AM and PM peak periods was provided by NDOT**.** Additional data for link speeds, approach queues and delays in the arterial direction were collected using a GPS-based procedure. Three test-cars equipped with GPS units made several runs in both directions on the arterial. The GPS units provided time and location data for each run, which was then used to extract link travel times, estimates of delays and queue lengths for through traffic**.**

Task 4: Testing of the Software Programs

4.1 Freeway Simulation (CORSIM vs. VISSIM)

The procedure for implementation of simulation included coding of the network, input of traffic data and calibration parameters, running of the software and interpretation of the results. To evaluate the performance of the software, several scenarios were tested including normal freeway operation, analysis of the effect of some key calibration parameters, ramp metering with/without HOV bypass, provision of HOV lanes, and incident simulation. For each scenario, the objectives of the task were to:

1. Identify the procedures for implementing the simulation for each software;
2. To compare and evaluate the results

Detailed descriptions of each of the cases are described in the next section.

The following are the basic steps in building a network to simulate freeway operations:

1. Obtain network geometry data.
2. Obtain traffic and signal data.
3. Build the network model (for FRESIM: using TRAFED, ITRAF or a Text Editor).
4. Input, modify the various calibration parameters as listed below
5. Run the simulation.
6. View the animation to verify the inputs and confirm vehicle movement and signal operations (Use TRAFVU for the FRESIM model).
7. Evaluate the relevant output MOEs

Table 1 summarizes the key calibration parameters and features for the software.

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Output Measures of Effectiveness (MOEs)

TSIS/CORSIM produces a single output file with summary MOE data. The output includes the MOEs such as speeds, delays, travel time, density, etc., by lane and by link. The data can also be output by simulation time intervals. Apart from the output file, certain detailed link outputs MOEs can be viewed online (on the screen) during the simulation. However, this on-screen output can neither be saved nor printed.

VISSIM produces several user-selected files for different MOEs. The VISSIM output MOE are typically given data by link and time interval and the user has to post-process the data to obtain summarized network data and/or cumulative data for the entire simulation period. VISSIM generates separate output files for each individual output. The output data, including vehicle speeds, delays, travel times, queue lengths, bus waiting times, etc., and is typically in detailed lane by lane and/or link by link basis and by time interval. Also data by individual vehicles types and data at special collection points can be output if desired by the user. Because of this level of detail, these output files tend to be many and very large. One disadvantage of VISSIM is that it does not produce summarized network output MOEs such as vehicle-miles of travel, vehicle-hours, etc. To obtain these summary measures post processing of the output by the user is necessary. The output files generated by VISSIM are text files that can easily be exported to a spreadsheet for post-processing. The various emission parameters that VISSIM produces include Benzene Emissions, CO Emissions, CO_{2-} Emissions, HC Emissions, Non-Methane Hydrocarbons (NMHC) Emissions, Non-Methane Organic Gas (NMOG) Emissions, NO_{x-} Emissions, Particulate Emissions, SO_2 Emissions, Soot Emissions, and Evaporations Emissions etc. Some of the detail data and graphs can also be viewed online during the simulation.

The advantage of having the output in such detail is that the user can be able to tailor the output to match their specific needs for their study. However, the downside of this is that for an inexperienced user or one who wants a quick analysis, such raw detailed output may pose problems and lengthen the time and complexity required to complete the study.

Table 2 summarizes the main output measures of effectiveness (MOE).

The evaluation of freeway simulation was divided into four subtasks:

1. Simulation of "normal" freeway operations
2. Simulation of freeway operations with ramp metering
3. Simulation of freeway operations with HOV lanes
4. Simulation of incidents on freeway sections

The following sub-sections provide details of the simulation scenarios evaluated. The results and evaluation of these simulations are summarized and discussed in **Section 5** of the report.

4.1.1 Simulation of normal freeway operations

For normal freeway operations, the following scenarios were simulated for each software:

Case 1: Using default calibration parameter values. For CORSIM, a calibrated model for US95 was supplied by NDOT, and was used as the base case for this study.

Case 2: Varying some key calibration parameters in order to evaluate the effects of the parameters on the key MOEs.

For CORSIM, Case 2 involved varying the following two key parameters:

(a) Driver aggressiveness for lane change, i.e., the more aggressive a driver is, the smaller the acceptable gap for lane change.

(b) Lane change gap acceptance parameters, and

These two parameters were thought to affect the number and opportunities for lane changing, and would therefore have an impact of traffic speeds and densities, and hence the freeway level of service.

For VISSIM, Case 2 involved varying the distribution for the maximum vehicle accelerations. VISSIM does not have similar gap acceptance parameters.

4.1.2 Simulation for ramp metering

Both VISSIM and CORSIM can simulate ramp metering. However, while CORSIM has pre-defined procedures for simulation of ramp metering, there are no such provisions in VISSIM. In CORSIM, using Record Type 37, specifications for ramp meters can be input to include the type of control, i.e. pretimed, demand/capacity, etc., how many cars per green and vehicle headways. If the ramp has an HOV lane, CORSIM automatically assumes that the HOV lane will bypass the ramp-meter.

In VISSIM, a ramp meter is coded as a regular signalized intersection. The major drawback for this is that other ramp metering strategies such as demand/capacity metering are more difficult to implement. They will need a more complex coding of the signal and detector configuration. Also, the number of cars per green cannot be directly controlled. However, based on known vehicle headways, the green duration can be set to allow only one vehicle per green. In case of multi-lane onramp with HOV lanes, VISSIM can easily simulate HOV bypass for the ramp metering.

To evaluate performance of the software programs, ramp-metering cases were simulated for the Summarily and Rainbow eastbound on-ramps. The Summarily onramp was selected for the case study because, under the base case simulation, traffic immediately downstream of the ramp is congested and traveling at rather low speeds because of the heavy merging traffic from the onramp. Hence, installing a ramp-meter should limit and control the merging traffic and hence result in an improvement in the level-of-service immediately downstream of the ramp. The Rainbow on-ramp was used to illustrate the simulation and effect of an HOV bypass on a ramp-meter.

The following three cases are presented:

Case 1: No ramp metering (Base case)

Case 2: Ramp metering at the EB Summarily and Rainbow onramp

Case 3: Modifying the Rainbow ramp-meter into one with an HOV bypass.

4.1.3 Simulation of HOV lanes

As with ramp metering, the CORSIM software has special provisions to simulate the operation of freeway sections with exclusive HOV lanes. This allows for, among other things, specification of entry and exit locations for the HOV lane and the rate of HOV lane violation, that is, the proportion of vehicles in the HOV lanes that are not HOV vehicles. If a ramp meter is placed on a ramp with an HOV lane, the software automatically assumes that the HOV lane bypasses the signal.

In VISSIM, there are no special provisions to simulate HOV operation. However, using the “lane closure” feature HOV operation can be simulated. This feature allows the restricting the use of any lane or set of lanes on a link to specific class or classes of vehicles only. One of the problems that was observed with this feature is that the class of vehicles designated for the restricted lane are allowed to enter and exit the HOV lane at any location, depending on other traffic conditions, such as lane changing opportunities. This means that the simulation cannot designate specific entry and exit segments or locations for the HOV lane. Also, unlike CORSIM, HOV violators cannot be coded into the simulation. To do this, one may have to create a separate vehicle type or class of "HOV violators", and make it one of the vehicle types "allowed" to use the HOV lane.

For evaluation of HOV simulation, a typical HOV analysis was studied. The study involved an analysis of an additional lane to be added on eastbound US95 between the "Rainbow Curve" and the "Spaghetti Bowl." The following cases for HOV operations for US95 eastbound were evaluated.

Case 1: No HOV lane (Base case)

Case 2: Addition use of a through lane:

Case 2a: For use by all traffic

Case 2b: For use as a restricted HOV lane.

The resulting measures of effectiveness, which include freeway link speeds with or without HOV lanes, are summarized and evaluated in Section 5.1.4.

4.1.4 Simulation of incidents and work zone lane closures

In CORSIM incidents can be specified easily using record type 29. The incident parameters that can be coded include the location of the incident, its effect on each lane, i.e., lane blockage or rubber necking with its corresponding capacity reduction, duration of the incident and length of roadway affected. Also the location of the advance warning sign can be specified. Work zone lane closures can be specified as incidents of longer duration and occupying longer segment lengths that may involve more than one link.

In VISSIM, once again, there are no special provisions for simulating incidents. However, for this study, incidents resulting in lane blockage were simulated at desired locations by creating a bus transit stop at the appropriate location at the center of the candidate lane(s). To create an incident, a bus is simulated to arrive at the location, at the desired time and stop at the location for the duration of time corresponding to the desired duration of the incident. One of the challenges of this method of creating incidents is to ensure that the "bus" arrives at the right time at the appropriate stop. This can be quite difficult, especially if the incident occurs during heavy traffic periods and/or the bus has to change lanes to get to the desired bus stop. Also if the incident requires two or more lane blockages, coordinating a number of busses to stop at the side-by-side bus stops can also be a big challenge. Another difficulty is with regard to specifying the appropriate length of the segment that would be affected by the incident. One possibility is to define a special "transit vehicle" whose length will correspond to the desired length of the affected roadway segment. However, an advantage of simulating incidents in VISSIM as compared to CORSIM is that, using VISSIM's ability to place vehicle detectors on any lane at any desired location(s), one can get more detailed location, time and lane-specific MOE for evaluation of the impact of incidents. For example, several detectors can be placed by lane upstream of the incident location that would enable observation of the temporal and spatial development of the effect of the incident, such build-up of upstream queues and propagation of the shock wave.

With respect to work zone simulation, such situations can be simulated in VISSIM by using the lane closure feature, which can prevent all vehicles from entering a specific link.

4.2 Arterial Simulation (VISSIM, CORSIM, and SYNCHRO/SIMTRAFFIC)

For arterial simulation, three software were evaluated, namely, VISSIM, CORSIM, and SYNCHRO/SIMTRAFFIC. The arterial segment simulated was Martin Luther King Blvd between Washington and Carey, which has four signalized intersections. As with freeway simulation, this task was broken down into the following steps:

- Network coding

- Input of traffic simulation data
- Running of the simulation with default calibration parameters
- Interpretation of the output results
- Comparative evaluation of the software

Tables 3 and 4 summarize the key comparative features of the simulation software evaluated. Of the three, CORSIM is the more refined software. All the desired features outlined earlier, including special provisions such as actuated control, transit preemption, exclusive bus lanes are predefined and can all be easily coded and simulated. All the standard output MOEs are available in the output file, both disaggregate (by link and/or time interval) and aggregate in terms of the total simulation time and measures such as vehicle-miles and vehicle-hours of travel

While VISSIM also offers the ability to implement all the desired features as in CORSIM, it is a less user friendly in a few key areas of network coding and input data. For example, while in CORSIM and SIMTRAFFIC all intersection approach movement yield priority schemes are predefined, in VISSIM, these priority schemes have to be set by the user. Examples of such movements include right yielding to pedestrians, right-turns-on-red yielding to conflicting movements, left turns yielding to opposing through for permitted left-turning phases, etc. However, some of the key advantages of VISSIM over the other two software include its ability to model and simulate pedestrian traffic at intersections and mid-block crossings, signalized or unsignalised. In VISSIM, one can also model and simulate the interaction of road traffic and light-rail systems.

For SIMTRAFFIC, one of its main advantages over the other software is the relatively more friendly data input and network coding user interface. Typically, input data for SIMTRAFFIC is done through its companion software SYNCHRO. There are two main advantages of using the pair of SYNCHRO and SIMTRAFFIC:

(1) SYNCHRO has a very user-friendly graphical window-based interface, which makes it much easier to build the network and input data.

(2) Since SYNCHRO is a macroscopic-based traffic optimization program, it can be used to generate several scenarios that can quickly be evaluated by SIMTARFFIC, without the extra effort required to transferring input data between programs if one was using a different program.

To evaluate these three programs further for arterial analysis, traffic simulations of the Martin Luther King Blvd were conducted for each software and the results evaluated and compared. As with the freeway simulation, two cases were evaluated, the first case with default parameter values, and the second case by varying a key calibration parameter values and observing its effect on intersection and arterial measures of effectiveness. The simulation results are discussed in Section 5.2.

Task 5 Comparative Analysis of Results

5.1 Freeway Simulation Cases

5.1.1 Basic Freeway operations

For both CORSIM and VISSIM, it is preferred to enter the complete OD table for the input traffic, as opposed to simply entering the turning proportions at the offramp locations. There are two main advantages of using the OD table. First, with the OD table, the simulation assumes that drivers know their complete path at the start of their trips, hence do make appropriate lane changing decisions early enough to avoid congestion at the offramp. Secondly, since an assignment algorithm is used to assign suitable paths for each OD pair, an evaluation can be made of the effects of incidents or of closing certain lanes or freeway sections. One can then observe how traffic is diverted around the problem area.

Table 5 summarizes the output MOE for simulation of freeway operations using VISSIM and TSIS/CORSIM. The simulation results are compared to link speeds that were measured in the field (supplied by NDOT). In CORSIM, the simulation produces higher speeds than field observations. It is observed that there are serious bottlenecks on 2-lane onramp that merge onto one lane just before merging onto the freeway, such as at the Summerlin Eastbound on-ramp. In such cases, traffic on the outside lane of the on-ramp, especially truck traffic, tends to have difficulties merging onto the inside lane before merging into the freeway. This results in long queues on the ramp and therefore limiting the flow of traffic onto the freeway. This in turn leads to lower traffic flow and higher speeds than observed traffic on the freeway downstream of the ramp.

With VISSIM, the simulation produces severe bottlenecks at diverging (offramp) areas due a lot of lane changing as traffic approaches the offramps. It appears that exiting vehicles make late lane changing decisions, resulting in congestion immediately upstream of the offramps due to the vehicles waiting for suitable gaps to complete the lane changing maneuvers. This results in lower average vehicle speeds than field observations. One potential solution is by restricting the duration of time that vehicles can wait for a lane change. VISSIM allows a duration of time to be set for which if the vehicle waits for a lane change longer than the preset duration, it is taken out of the network, thus allowing other vehicles to proceed. The default duration is 60 seconds. In the following section (sensitivity analysis), two cases for different values of this preset duration are simulated and their results compared.

However, while the CORSIM simulation was based on a calibrated model, the VISSIM simulation was essentially based on default parameters, with minor adjustments. As such, the VISSIM and CORSIM results in Table 5 cannot be directly compared. The importance of these comparative results is in identification of the capabilities and issues involved in using and calibrating the software for traffic simulation.

Other software characteristics worth noting:

- In CORSIM, the vehicles missing their turn may be forced to proceed to the next exit. In VISSIM, vehicles failing to switch lanes may be "forced" to disappear from the network after a pre-set duration. The default duration is 60 seconds. In theory, this value should be set high enough such that no vehicles are lost from the network. However, setting high durations tends to create more congestion since it appears that it is more difficult than would be expected for vehicles to change lanes when traffic is congested. Therefore care has to be exercised in determining the appropriate duration.
- CORSIM produces MOE in more readily usable form, from link specific measures to aggregate network measures such as vehicle-miles and vehicle-hours of travel.
- In VISSIM, the output is typically in very raw format, including link speeds, density and flow. To obtain aggregate measures such as network-wide vehicle-miles or vehicle-hours of travel, the use has to post-process the VISSIM output file.

5.1.2 Sensitivity Analysis for Selected Calibration variables

In CORSIM, two calibration parameters were selected for sensitivity analysis, namely:

(a) Lane change gap acceptance parameter (Record Type 81, entry 14).

(b) Driver aggressiveness for lane change (Record Type 70, entry 3), i.e., the more aggressive a driver is, the smaller the acceptable gap for lane change, and hence the higher the potential for lane changing.

These parameters do influence the lane changing behavior of drivers and have potential to influence traffic characteristics.

Hence varying these parameter values is likely to have on vehicle speeds and densities, especially in the vicinity of merging and weaving areas. These parameter values were varied above and below their default values.

Table 6 is a summary of the output of the CORSIM simulation by varying the lane change gap acceptance parameter. Examination of the results shows that the impact of the changes in these values is not very significant. A similar observation is made with regard to changes in the driver aggressiveness parameter (**Table 7**). It was anticipated that the impact of these parameters would be more significant in merging and weaving sections of the freeway, where there are a lot more lane changing activities. However, this was found not to be the case.

For VISSIM, **Table 8** presents a summary of the results for two different values of the duration for maximum waiting time for lane changing, namely 60 seconds (the default value) and 1 second. The 1-second duration is supposed to improve traffic flow, since vehicles are removed promptly if they fail to change lanes within 1 second. However, this means that the number of vehicles processed will be less that the desired input traffic due to the "lost" traffic. As can be observed in **Table 8**, traffic speeds and density have improved significantly under the 1-second maximum waiting time.

5.1.3 Ramp Metering

Tables 9 and **10** summarize the MOEs for the ramp-metering cases for CORSIM and VISSIM, respectively. Only the pre-timed signal was simulated. As expected, the density of traffic on the freeway segments immediate upstream and downstream of the on-ramps is significantly reduced and speeds increased, while traffic on the onramps upstream of the ramp-meter is more congested with slower speeds and higher densities.

5.1.4 HOV Operation

Tables 11 and 12 provide a summary of the case studies for HOV operation. The results show expected trends in MOEs for the different cases with/without HOV lanes, such as improved level of service (higher speeds, lower densities) with the additional HOV lane. Notice that adding a lane for general use by all traffic results in better level of service than restricting the additional lane for HOV operation only.

Comparing the CORSIM and VISSIM results, while the CORSIM results across different links are more consistent, the results for VISSIM are much less consistent, with very significant variation between some link flows and level-of-service. It is suspected that the inconsistencies in VISSIM may be due to the fact that in VISSIM, HOV traffic can enter/exit at any point on an HOV lane, as noted earlier in section 4.1.3. Hence, traffic speeds and densities on different sections of the HOV lane(s) will depend not only on the traffic volumes, but also on the traffic exit/entry activities within the section. In practice, HOV traffic is typically restricted to entering and exiting the HOV lanes only at designated locations or sections. Therefore, the VISSIM simulation with respect to HOV operations does not reflect actual field conditions. As such, unless one can devise a way of restricting the entry/exit locations of traffic into/out of HOV lanes, it is not recommended to use VISSIM for analysis of HOV operation. However, in a scenario where there are direct HOV on-ramps and off-ramps, VISSIM may be used.

5.2 Arterial Simulation

5.2.1 Arterial Simulation with Default Values

The following are the general observations with regard to arterial simulations with the software.

(1) Lane changing has a significant impact on the MOE in VISSIM. It appears that for congested links, vehicles often do not change lanes far enough in advance of their turning location. As a result, these lane-changing vehicles often cause severe congestion by impeding the through traffic. This results in higher observed link travel times, vehicle delays and proportion of stops for links with higher traffic flows, especially the upstream links. This was what was observed for this study on the northbound link of Washington – Owens, which has higher average delays and link travel time for VISSIM compared to both CORSIM and SIMTRAFFIC.

(2) Coding of intersection in VISSIM is more complex than the other programs. The user has to define all the right-of-way priorities, such as right-turning traffic yielding to pedestrians, left-turns yielding to opposing through for permitted movements, etc. Thus the network development process is more involving than with CORSIM and SIMTRAFFIC, for which all the intersection priority rules are pre-defined for intersections.

(3) In VISSIM, it is difficult to prevent “gridlock” when a saturated downstream intersection has queues extending into the upstream intersection. An attempt to prevent vehicles from entering an intersection when preceding vehicles are still within the intersection resulted in creating an effect of a stop control intersection, further worsening the situation. There is no such problem with CORSIM and SIMTRAFFIC, since the predefined traffic priority rules prevent vehicles from entering the intersection if there is no possibility of going through it.

Table 13 summarizes the measures of effectiveness resulting from simulation of the arterial network with default parameter values for the three software, namely, CORSIM, VISSIM, and SIMTRAFFIC. The simulation was done for the PM peak hour, with the peak direction of flow being northbound. The measures of effectiveness evaluated include.

- Link travel time
- Average link delay per vehicle (seconds)
- Average stopped delay per vehicle (seconds)
- Proportion of stopped vehicles (%)
- Average link speed (mph)
- Average queue length
- Maximum queue length

The table also contains some MOEs obtained from field data that was collected using the GPS units. However, due to the fact that the field MOEs were not collected at the same time the turning movement data was collected, the validity of comparing this data with the simulation MOEs is questionable. Hence, no emphasis was placed on comparing the simulated MOEs and field MOEs.

Vehicle delays (stopped delay; and approach delay)

The average vehicle delays obtained for CORSIM and SIMTRAFFIC were comparable to each other. As expected, higher delays were observed for northbound direction, which was the direction of peak direction travel and hence higher traffic flows. The vehicle delays obtained by VISSIM appear to be higher than those of both CORSIM and SIMTRAFFIC for the upstream links in both directions, namely Washington – Owens for the NB links, and Carey – Lake Mead, for the SB links, lower delays for the downstream links. This could be partly due the impact of the vehicle lane changing problems, as discussed above.

Proportion of stops

The proportion of stops obtained in the VISSIM simulations have a higher range of fluctuation than for the other two software. The proportion of stops in VISSIM varies from low of 43% to over 300% (i.e., vehicles stopping more than three times over a link), which appears to be high, compared to what was observed (not measured) in the field. VISSIM appears to come with reasonable estimates CORSIM produced proportion of stops that are generally lower and all less than 100%, between 42% and 99%. It appears VISSIM overestimates the proportion of stops

Queue lengths

Relative to CORSIM and SIMTRAFFIC, the queue lengths obtained in VISSIM, vary significantly between the different links. The average queue lengths fluctuate from a low of 0.9 vehicles to a high of 81.9, while with the other software, the queue lengths vary from 10 to 79 vehicles for SIMTRAFFIC and 2.5 to 24 vehicles for CORSRM.

5.2.2 Sensitivity Analysis with Acceleration Parameters

The most critical MOEs for arterial analysis are vehicle delays, queue lengths and number of stops. All these three MOEs can significantly be affected by the acceleration characteristics of the drivers/vehicles. Hence, to evaluate the impact of the acceleration parameters on the MOEs, the maximum acceleration rates were varied around the default values. Two extreme cases were evaluated, namely, 50% greater acceleration than the default values and 50% less maximum acceleration rates than the default.

For isolated intersections, increasing the acceleration rates would tend to reduce the average approach delay. However, on an arterial street with coordinated intersections, the effect is not obvious, as demonstrated by the results of this study (Tables 14 to 16). The results show that the changes in the acceleration rates did not affect any of the MOEs consistently, either positively or negatively. The situation was the same for all the software. Further analysis also indicates, as expected, that most of the impact of the changes in acceleration rates are in the direction of heavy traffic, i.e., the northbound links, and were a result of decreased acceleration rates. For the southbound links, changes in acceleration rates have minimal impact of the MOEs mainly because of the lower traffic volumes.

CONCLUDING REMARKS

The objective of this study was to compare and contrast the three software, CORSIM, VISSIM and SIMTRAFFIC for traffic simulation. All the three software programs have the ability to perform traffic simulations for the various operational conditions outlined in the objective. Each software has its strengths and weaknesses, as discussed in the report. The following is a summary of the unique features and shortcomings for each software.

TSIS/CORSIM

The most complete and well developed software. Most of the traffic operations situations, such as HOV lane operations, incident situations, ramp metering, are pre-defined and can easily be coded and incorporated into the simulation. The output data has all the major MOEs in desegregate and aggregate format, both link specific and network wide, such as vehicle-miles, vehicle hours of travel. The program produces one output file with all the desired MOEs results. One of the shortcomings of CORSIM is its inability to model roundabouts.

VISSIM

This is a fairly new software program, which is still frequently upgraded. It is potentially very powerful, allowing the user a lot more flexibility in network coding, input data and output data. Some of this flexibility include ability to easily code curved roadway alignments, roundabouts, and other special situations such as interaction with light-rail systems, intersection and midblock pedestrian crossing situations. None of these can be easily be simulated in CORSIM and SIMTRAFFIC. However, VISSIM required more effort in coding the network and inputting the simulation parameters. Also, VISSIM outputs several files with different output measures; typically at very desegregate level, such as average vehicle delays by link and time interval, individual vehicle paths, etc. Such disaggregate data can be very useful in detail traffic flow studies, transit vehicle operations, or analysis of effects of incident situations. Aggregate or global MOEs such as system-wide vehicle-miles or vehicle-hours of travel are not provided. The user has to post-process the desegregate output data and compute the desired aggregate MOEs.

SIMTRAFFIC

Of the three software, this is the most user-friendly in terms of the ease of coding a network and running the program. The software typically works with the macroscopic model SYNCHRO and this pair of software can be used to quickly evaluate different optimal traffic and network situations. However, among the major drawbacks, SIMTRAFFIC cannot simulate bus transit vehicles and neither can it simulate roundabouts.

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Table 1: Key Features and Parameters

	CORSIM (FRESIM)	VISSIM
Driver Types and Behavior	Ten driver types; Reflected by the discrete distribution of freeflow speed, car-following sensitivity factor; lane change gap acceptance parameters; and parameters that affect the number of discretionary lane changes	Reflected by continuos distribution of driver parameters such as desired speed and other car-following and lane changing parameters
Network Parameters	Link data: length and grade; number of lanes and lane configuration; link curvature; bus stops; vehicle detectors; free flow speed;	Link data: length and grade; number of lanes and lane configuration; bus stops, vehicle detectors; free flow speed; Curved links can be drawn directly
Vehicle Types	Seven vehicle types[1], including passenger cars, trucks and buses	Car, light truck, heavy truck, bus, articulated bus, Tram
Vehicle Characteristics	Distribution of acceleration and deceleration rates by speed and vehicle type; fleet distribution and passenger occupancy;	Distribution for maximum acceleration rates by speed and vehicle type
Traffic Operations	Input traffic volumes and vehicle mix; turning movements at off ramps; OD patterns; Bus operations	Input traffic volumes and vehicle mix; turning movements at off ramps; OD patterns; Bus operations
HOV Operation	Predefined; Can select appropriate HOV lane entry and exit locations	Can be coded as "lane closures" with restricted vehicle types. HOV vehicles can enter/exit at any location
Ramp Metering	Pre-defined; Can model all types of ramp metering, such as pretimed, demand/capacity, etc. One signal for all lanes (except HOV lane, automatic bypass)	Coded as regular signal. Only pretimed or actuated can be coded. Signal can be coded lane by lane. HOV bypass ok.
Incident Simulation	Predefined; Can select location, start time, duration, number of lanes, and nature of incident (i.e., lane blockage or rubber-necking)	Can simulate by creating a transit stop at incident location; Often difficult to coordinate start time and incident on multiple lanes.
Lane closure / work zones	Coded using the HOV feature	Coded using the lane closure feature
Dynamic Assignment	Given an OD matrix, selects appropriate routing for each OD pair	Given an OD matrix, selects appropriate routing for each OD pair

[1]- Two passenger car types: Low performance (14 feet long); High performance (16 feet long);
- Four truck types: Single unit (35ft) Semi-trailer with medium load (53ft), Semi-trailer with full load (53ft), and Double-bottom trailer (64ft); and
- Conventional bus (40ft).

Table 2: Output Measures of Effectiveness (MOEs)

Traffic MOE	CORSIM	VISSIM
Link statistics	Flow (veh/hr/lane) Density (veh/lane-mile) Speed (mph) Travel time (seconds/veh), and Delay (seconds/veh) Vehicle-miles Vehicle-minutes	Flow (veh/hr/lane) Density (veh/lane-mile) Speed (mph) Vehicle-miles Vehicle-minutes
Link statistics by lane	Flow (veh/hr) Travel time and delay (sec/veh) Speed (mph)	Flow (veh/hr) Speed (mph) Density (vpm)
Other link statistics	Fuel consumption: - total gallons, and - mpg, by vehicle type Vehicle emissions: - HC, CO and NO - in grams/mile by vehicle type - cumulative	Fuel consumption: - total gallons, and - by vehicle type Vehicle emissions: - HC, CO, CO2,

Table 3: Input Parameters and Characteristics for Arterial Simulation

Input Category	**VISSIM**	**CORSIM / NETSIM**	**SYNCHRO / SIMTRAFFIC**
Link Flows	• Link specific volumes (vph) entered at the starting of external links.	• Link flows (vph) entered at entry nodes.	• Intersection approach flows (vph) with turning movements are entered.
Traffic Mix (Vehicle types)	• Six: Car, HGV, Bus, Tram, Bike and Pedestrian.	• Four: Car, Heavy Vehicle (Truck), Car pool and Bus.	• Six: Car, Bus, Truck, Semi-truck, Truck DB and Carpool.
Turning Movements	• Turning Movements based on routing decisions. • Defined after defining the link volumes.	• Turning movements expressed as the percentage / number of vehicles of link flow. • Defined after defining entry volumes.	• Entered at the time of entering link flows only.
Intersection Geometry	• Advantage: Easy to construct overpass or underpass. • Disadvantage: Each and every link is to be connected to the corresponding link.	• Advantage in constructing straight links. Difficult in constructing curved links. Intersection designing is easy when compared to VISSIM.	• Intersection geometry is easy to develop. Lengths of left turning pocket lengths can be specified. • Direct input of the number of lanes by turning movement.
Signal Timing & Phasing	• Signal groups are to be defined. • Signal group data consists of cycle length, number of cycles, green, amber, and red times, etc. • Signal heads are to be placed at intersections that correspond to the signal groups.	• Description of the signals consists of type of the signal, and durations of different signal intervals.	• Direct input of type of signal, green time, amber time, pedestrian details, etc. • Easier to establish signals when compared to VISSIM and CORSIM.
Actuated Control	• Can be simulated.	• Can be simulated.	• Can be simulated
Detector Locations	• Can be placed manually. • Detailed description can be given such as detector location length, detector lane, type of vehicle to be detected etc.	• Can be placed manually • Detailed description is provided. But cannot differentiate the type of the vehicle present like VISSIM.	• Cannot be placed manually. • Number of detectors depends on detection zone length.

Table 3 (cont…): Input Parameters and Characteristics for Arterial Simulation

Input Category	**VISSIM**	**CORSIM / NETSIM**	**SYNCHRO / SIMTRAFFIC**
Stop and Yield Conditions	• Need to provide detailed descriptions of traffic movement priorities. Same is true at signalized intersections	• Easily coded	• Easily coded.
Roundabouts	• Can be coded. • Need to provide detailed descriptions of traffic movement priorities	• Very difficult to design.	• Can be done, with limited modeling following HCS 2000 procedures. Only MOE is the range of v/c ratios. But in transferring from SYNCHRO to SIMTRAFFIC, roundabouts are transferred as unsignalized intersections.
Transit Operations	• Route has to be specified, including starting and ending points and locations of bus stops • Also the dwelling time of the buses at the stops is to be specified.	• Data for defining the bus route is almost the same as VISSIM.	• Cannot be simulated
Transit Preemption	• Can be done using detectors for transit traffic only.	• Works only when bus traffic is allowed on an exclusive lane.	• Cannot be simulated.
Mid-block characteristics	• Cannot be changed.	• Can be changed.	• Can be changed.
Sinks / Sources	• Cannot be done. • Similar effect is produced by manually adding a lane for additional traffic.	• Can be done.	• Can be done.

Table 4: Output Measures of Effectiveness (MOEs) for Arterial Simulation

Output MOE	**VISSIM**	**CORSIM / NETSIM**	**SYNCHRO / SIMTRAFFIC**
Approach Delays	• Generates average total delay per vehicle (in seconds), average stopped time per vehicle (in seconds), vehicle throughput, average total delay per person (in seconds) and the total person throughput.	• Delays are expressed as vehicle minutes, minutes/mile and seconds per vehicle. • Provides data about queue delay and stopped delay.	• Advantage is software produces approach delays lane group-wise.
Approach Queues and Number of Stops	• Produces average queue length in feet or meters, maximum queue length and number of vehicle stops within the queue	• Queue lengths are represented in number of vehicles. Produces queue lengths on lane by lanes also.	• Produces 50th percentile and 95th percentile of queue lengths (in feet). It also gives the queue lengths on lane basis as CORSIM
Level of Service	• Can be deduced from average vehicle delays	• Can be deduced from average vehicle delays.	• Directly output by software.
Time Space Diagram	• Available.	• Not available.	• Available.
Emissions	• VISSIM produces benzene, CO, CO_2, HC, NO_x, SO_2 and particulate emission details. These details can be collected from the vehicle record file.	• CORSIM produces emission details and emission rate details for CO, HC and NO_x.	• Emissions are represented in kg for the full simulation period. It gives the details of CO, NO_x and VOC details

Table 5: Output MOE with Default Calibration Parameter Values[1]

Eastbound Links		Field Data		TSIS/CORSIM			VISSIM		
		No.of Lanes	Speed (mph)	Volume (vphpl)	Density (vpmpl)	Speed (mph)	Volume (vphpl)	Density (vpmpl)	Speed (mph)
Summerlin onramp	Rainbow onramp	4	29	1,892	51.6	36.8	1,017	114.4	9.5
Rainbow onramp	Jones offramp	4	29	1,747	39.1	44.7	1,047	101.5	14.7
Jones offramp	Jones onramp	3	36	2,181	47.4	46.0	1,283	61.1	25.0
Jones onramp	Decatur offramp	4	43	1,867	39.5	47.5	1,141	89.1	14.1
Decatur offramp	Decatur onramp	3	47	2,198	41.7	52.8	1,325	65.5	20.5
Decatur onramp	Valley view offramp	4	52	1,814	33.9	53.5	1,149	66.6	20.4
Valley view offramp	Valley view onramp	3	53	2,199	39.8	55.2	1,395	35.3	39.7
Valley view onramp	Rancho offramp	4	53	1,711	31.1	55.0	1,112	24.0	47.1
Rancho offramp	Rancho onramp	3	40	1,911	34.3	55.8	1,242	25.7	48.3
Rancho onramp	I-15 S.B. offramp	4	53	1,602	31.1	51.7	1,119	20.4	54.9

Westbound Links		Field Data		TSIS/CORSIM			VISSIM		
		No.of Lanes	Speed (mph)	Volume (vphpl)	Density (vplm)	Speed (mph)	Volume (vphpl)	Density (vplm)	Speed (mph)
Rancho offramp	Rancho onramp	3	59	1,208	21.2	57.1	1,260	25.4	49.7
Rancho onramp	Valley view offramp	4	55	1,033	18.0	57.4	1,026	44.1	23.8
Valley view offramp	Valley view onramp	3	57	1,162	20.3	57.3	1,224	24.9	49.2
Valley view onramp	Decatur offramp	4	55	989	17.3	57.3	993	31.6	31.9
Decatur offramp	Decatur onramp	3	56	1,091	19.0	57.4	1,184	24.5	48.4
Decatur onramp	Jones offramp	4	58	941	16.4	57.4	953	28.6	33.5
Jones offramp	Jones onramp	3	54	1,102	19.2	57.3	1,181	24.0	49.2
Jones onramp	Summerlin offramp	4	52	954	16.9	56.5	989	29.5	33.6

[1]Note that the CORSIM simulation was based on a calibrated model, while the VISSIM simulation was essentially based on default parameters, with minor adjustments. As such, the results in this table cannot be directly compared. The importance of these comparative results is in identification of the capabilities and issues involved in using and calibrating the software for traffic simulation.

Table 6: Effect of Changes in Gap Acceptance Parameter Values on Output MOE for CORSIM

		50% Decrease in Gap Size			Base Case			50% Increase in Gap size		
Eastbound Links		Volume (vphpl)	Density (vpmpl)	Speed (mph)	Volume (vphpl)	Density (vpmpl)	Speed (mph)	Volume (vphpl)	Density (vpmpl)	Speed (mph)
Summerlin onramp	Rainbow onramp	1,896	54.5	34.9	1,892	51.6	36.8	1,907	54.9	35.0
Rainbow onramp	Jones offramp	1,750	39.0	44.9	1,747	39.1	44.7	1,763	39.4	44.7
Jones offramp	Jones onramp	2,171	47.4	45.8	2,181	47.4	46.0	2,179	47.5	45.9
Jones onramp	Decatur offramp	1,862	39.4	47.4	1,867	39.5	47.5	1,868	39.6	47.3
Decatur offramp	Decatur onramp	2,208	42.4	52.2	2,198	41.7	52.8	2,208	42.2	52.3
Decatur onramp	Valley view offramp	1,817	34.4	52.9	1,814	33.9	53.5	1,821	34.7	52.5
Valley view offramp	Valley view onramp	2,211	40.1	55.0	2,199	39.8	55.2	2,208	40.1	55.0
Valley view onramp	Rancho offramp	1,723	31.1	55.4	1,711	31.1	55.0	1,720	31.0	55.5
Rancho offramp	Rancho onramp	1,901	34.0	56.0	1,911	34.3	55.8	1,927	34.6	55.7
Rancho onramp	I-15 S.B. offramp	1,600	30.9	51.9	1,602	31.1	51.7	1,617	32.1	50.7
Westbound Links										
Rancho offramp	Rancho onramp	1,234	21.8	56.7	1,208	21.2	57.1	1,232	21.7	57.0
Rancho onramp	Valley view offramp	1,055	18.5	57.2	1,033	18.0	57.4	1,053	18.4	57.3
Valley view offramp	Valley view onramp	1,183	20.7	57.2	1,162	20.3	57.3	1,188	20.7	57.2
Valley view onramp	Decatur offramp	1,010	17.7	57.2	989	17.3	57.3	1,014	17.7	57.3
Decatur offramp	Decatur onramp	1,114	19.4	57.4	1,091	19.0	57.4	1,127	19.6	57.4
Decatur onramp	Jones offramp	958	16.7	57.4	941	16.4	57.4	966	16.9	57.3
Jones offramp	Jones onramp	1,123	19.6	57.2	1,102	19.2	57.3	1,121	19.6	57.2
Jones onramp	Summerlin offramp	968	17.2	56.2	954	16.9	56.5	968	17.2	56.4

Table 7: Effect of Changes in Driver Aggressiveness Parameter Values on Output MOE for CORSIM

		Less Aggressive			Base Case			More Aggressive		
Eastbound Links		Volume (vphpl)	Density (vpmpl)	Speed (mph)	Volume (vphpl)	Density (vpmpl)	Speed (mph)	Volume (vphpl)	Density (vpmpl)	Speed (mph)
Summerlin onramp	Rainbow onramp	1,892	51.6	36.8	1,915	53.8	35.8	1,916	55.4	34.8
Rainbow onramp	Jones offramp	1,747	39.1	44.7	1,763	39.1	45.1	1,764	39.8	44.4
Jones offramp	Jones onramp	2,181	47.4	46.0	2,182	47.4	46.1	2,189	47.8	45.8
Jones onramp	Decatur offramp	1,867	39.5	47.5	1,868	39.3	47.7	1,875	39.5	47.6
Decatur offramp	Decatur onramp	2,198	41.7	52.8	2,206	41.7	53.0	2,221	42.5	52.4
Decatur onramp	Valley view offramp	1,814	33.9	53.5	1,817	34.0	53.5	1,826	34.2	53.3
Valley view offramp	Valley view onramp	2,199	39.8	55.2	2,190	39.8	55.0	2,185	39.6	55.1
Valley view onramp	Rancho offramp	1,711	31.1	55.0	1,704	30.8	55.3	1,705	30.7	55.5
Rancho offramp	Rancho onramp	1,911	34.3	55.8	1,902	34.1	55.9	1,900	34.1	55.9
Rancho onramp	I-15 S.B. offramp	1,602	31.1	51.7	1,597	31.5	50.9	1,595	30.4	52.5
Westbound Links										
Rancho offramp	Rancho onramp	1,208	21.2	57.1	1,210	21.2	57.2	1,206	21.1	57.2
Rancho onramp	Valley view offramp	1,033	18.0	57.4	1,035	18.1	57.3	1,030	18.0	57.3
Valley view offramp	Valley view onramp	1,162	20.3	57.3	1,164	20.3	57.2	1,165	20.4	57.2
Valley view onramp	Decatur offramp	989	17.3	57.3	994	17.3	57.3	996	17.4	57.3
Decatur offramp	Decatur onramp	1,091	19.0	57.4	1,105	19.2	57.4	1,116	19.4	57.4
Decatur onramp	Jones offramp	941	16.4	57.4	950	16.6	57.3	958	16.7	57.3
Jones offramp	Jones onramp	1,102	19.2	57.3	1,110	19.4	57.2	1,108	19.3	57.3
Jones onramp	Summerlin offramp	954	16.9	56.5	963	17.1	56.3	960	17.0	56.4

Table 8: VISSIM: Effect of Changing the Maximum Lane Change Waiting Time

		Base Case: Max Lane Change Waiting time = 60 sec			Maximum Lane Change Waiting time = 1 sec		
Eastbound Links		Volume (vphpl)	Density (vpmpl)	Speed (mph)	Volume (vphpl)	Density (vpmpl)	Speed (mph)
Summerlin onramp	Rainbow onramp	1,017	114.4	9.5	1,066	89.9	15.2
Rainbow onramp	Jones offramp	1,047	101.5	14.7	1,082	78.3	21.5
Jones offramp	Jones onramp	1,283	61.1	25.0	1,281	44.5	34.1
Jones onramp	Decatur offramp	1,141	89.1	14.1	1,119	74.7	18.5
Decatur offramp	Decatur onramp	1,325	65.5	20.5	1,307	31.7	44.5
Decatur onramp	Valley view offramp	1,149	66.6	20.4	1,122	52.2	28.2
Valley view offramp	Valley view onramp	1,395	35.3	39.7	1,326	36.6	40.2
Valley view onramp	Rancho offramp	1,112	24.0	47.1	1,061	24.3	48.8
Rancho offramp	Rancho onramp	1,242	25.7	48.3	1,155	26.0	48.9
Rancho onramp	I-15 S.B. offramp	1,119	20.4	54.9	1,055	20.6	55.0
Westbound Links							
Rancho offramp	Rancho onramp	1,260	25.4	49.7	1,287	25.9	49.4
Rancho onramp	Valley view offramp	1,026	44.1	23.8	1,042	27.8	37.4
Valley view offramp	Valley view onramp	1,224	24.9	49.2	1,203	25.5	48.8
Valley view onramp	Decatur offramp	993	31.6	31.9	1,001	29.3	34.4
Decatur offramp	Decatur onramp	1,184	24.5	48.4	1,207	24.6	47.8
Decatur onramp	Jones offramp	953	28.6	33.5	933	20.5	46.1
Jones offramp	Jones onramp	1,181	24.0	49.2	1,124	22.2	51.3
Jones onramp	Summerlin offramp	989	29.5	33.6	972	24.4	39.4

Table 9: Ramp metering results (CORSIM)

	Base Case (no ramp-metering)			With ramp-metering at both ramps			Ramp metering with HOV bypass at Rainbow onramp		
	Flow (vphpl)	Density (vpmpl)	Speed (mph)	Flow (vphpl)	Density (vpmpl)	Speed (mph)	Flow (vphpl)	Density (vpmpl)	Speed (mph)
Freeway Segments:									
SB Rainbow off - EB Summerlin On	1,817	47.2	39.6	1,834	46.4	40.4	1,860	47.4	40.2
EB Summerlin on - EB Rainbow On	1,886	51.9	36.6	1,741	41.9	41.8	1,758	42.6	41.6
EB Rainbow on - EB Jones off	1,741	39.7	43.9	1,630	35.6	45.9	1,643	35.8	46.0
Ramps:									
EB Summerlin Onramp	1,108	185.5	6.0	872	202.1	4.3	877	204.2	4.3
EB Rainbow Onramp	643	18.1	35.6	624	41.5	14.9	623	58.0	10.7
Mixed traffic lane							715	84.3	8.5
HOV lane							501	16.3	30.8

Table 10: Ramp metering results (VISSIM)

	Base Case (no ramp-metering)			Ramp-metering with no HOV bypass			Ramp metering with HOV bypass at Rainbow onramp		
	Flow (vphpl)	Density (vpmpl)	Speed (mph)	Flow (vphpl)	Density (vpmpl)	Speed (mph)	Flow (vphpl)	Density (vpmpl)	Speed (mph)
Freeway Segments:									
SB Rainbow off - EB Summerlin On	2,013	86.4	16.1	1,098	30.4	41.2	1,093	32.2	40.3
EB Summerlin on - EB Rainbow On	1,017	114.4	9.5	1,082	42.2	36.4	1,066	45.9	35.8
EB Rainbow on - EB Jones off	1,047	101.5	14.7	1,043	60.5	26.4	1,034	65.3	24.7
Ramps:									
EB Summerlin Onramp	451	183.2	2.5	573	163.6	3.6	561	165.3	3.5
EB Rainbow Onramp	453	9.7	46.6	417	122.8	5.1	418	57.0	7.3
Mixed traffic lane							681	111.0	6.1
HOV lane							155	3.6	43.7

Table 11: Freeway operation with an HOV lane - CORSIM Results

		Base Case			Add lane (for all traffic)			Add lane for HOV only		
Eastbound Links		Volume (vphpl)	Density (vpmpl)	Speed (mph)	Volume (vphpl)	Density (vpmpl)	Speed (mph)	Volume (vphpl)	Density (vpmpl)	Speed (mph)
Summerlin onramp	Rainbow onramp	1,892	51.6	36.8	1,463	36.2	41.1	1,468	38.1	39.2
Rainbow onramp	Jones offramp	1,747	39.1	44.7	1,430	30.7	46.6	1,437	31.1	46.2
Jones offramp	Jones onramp	2,181	47.4	46.0	1,673	35.4	47.3	1,670	35.5	47.0
Jones onramp	Decatur offramp	1,867	39.5	47.5	1,524	31.2	49.0	1,519	30.9	49.2
Decatur offramp	Decatur onramp	2,198	41.7	52.8	1,685	30.6	55.1	1,669	30.9	54.0
Decatur onramp	Valley view offramp	1,814	33.9	53.5	1,476	26.5	55.7	1,466	26.7	54.8
Valley view offramp	Valley view onramp	2,199	39.8	55.2	1,671	29.4	56.8	1,653	29.5	55.9
Valley view onramp	Rancho offramp	1,711	31.1	55.0	1,390	24.4	56.9	1,372	24.5	56.1
Rancho offramp	Rancho onramp	1,911	34.3	55.8	1,445	25.4	57.1	1,422	25.3	56.3
Rancho onramp	I-15 S.B. offramp	1,602	31.1	51.7	1,433	31.6	45.8	1,413	28.4	50.3

Table 12: Freeway operation with an HOV lane - VISSIM Results

		Base Case			Add lane (for all traffic)			Add lane for HOV only		
Eastbound Links		Volume (vphpl)	Density (vpmpl)	Speed (mph)	Volume (vphpl)	Density (vpmpl)	Speed (mph)	Volume (vphpl)	Density (vpmpl)	Speed (mph)
Summerlin onramp	Rainbow onramp	1,017	114.4	9.5	952	26.9	37.2	893	43.6	25.7
Rainbow onramp	Jones offramp	1,047	101.5	14.7	1,010	22.1	46.3	916	60.2	22.0
Jones offramp	Jones onramp	1,283	61.1	25.0	1,170	25.5	46.1	1,015	78.6	21.1
Jones onramp	Decatur offramp	1,141	89.1	14.1	1,114	30.1	38.2	932	107.7	9.2
Decatur offramp	Decatur onramp	1,325	65.5	20.5	1,241	28.6	43.5	1,000	21.9	45.9
Decatur onramp	Valley view offramp	1,149	66.6	20.4	1,117	45.1	26.8	928	26.1	35.8
Valley view offramp	Valley view onramp	1,395	35.3	39.7	1,269	31.3	40.5	1,061	23.4	45.5
Valley view onramp	Rancho offramp	1,112	24.0	47.1	1,065	25.7	41.8	903	18.8	48.2
Rancho offramp	Rancho onramp	1,242	25.7	48.3	1,123	23.8	47.1	944	18.7	50.6
Rancho onramp	I-15 SB. offramp	1,119	20.4	54.9	1,042	18.8	55.5	907	15.9	57.1

Table 13 Comparative MOE for Arterial Simulation

NORTHBOUND MLK	SIM-TRAFFIC	VISSIM	CORSIM	Field Data
Washington - Owens/Vegas				
Travel time		351.5	108.7	173.0
Delay / Veh (s)	57.8	88.0	66.8	
St Del/Veh (s)	37.6	50.4	39.7	104.8
Stop/Veh	1.04	**	0.86	
Avg Speed (mph)	17	5.3	17.3	
Link Flow (through vph)	1,206	1,236	1,229	
Average Queue length	21.5	94.2	10.5	25.2
Max. Queue length	34.8	102.2	38.0	
Owens/Vegas - Lake Mead				
Travel time		299.3	152.9	60.0
Delay / Veh (s)	241.4	80.5	113	
Stop Del/Veh (s)	186.5	62.1	72.8	10.9
Stop/Veh	3.93	2.83	0.99	
Avg Speed (mph)	6.0	5.8	11.7	
Vehicles Entered	1,304	1,376	1,431	
Average Queue length	79.0	81.9	24.0	4.1
Max. Queue length	128.5	124.4	49.5	
Lake Mead - Carey				
Travel time		58.9	71.6	49.0
Queue Delay / Veh (s)	29.4	12.5	31.2	
Stop Del/Veh (s)	16.7	6.3	17.0	2.5
Stop/Veh	0.46	0.51	0.42	
Avg Speed (mph)	24	29.2	25.3	
Vehicles Entered	1,259	1,220	1,206	
Average Queue length	12.8	0.9	4.5	2.7
Max. Queue length	20.8	5.2	22.5	

SOUTHBOUND MLK	SIM-TRAFFIC	VISSIM	CORSIM	Field Data
Carey - Lake Mead				
Travel time		90.6	75.3	89
Delay / Veh (s)	40.6	47.0	34.9	
St Del/Veh (s)	26.4	35.9	22.2	27
Stop/Veh	0.80	1.18	0.65	
Avg Speed (mph)	21	19.9	24.1	
Vehicles Entered	568	558	619	
Average Queue length	16.4	2.6	2.5	6.1
Max. Queue length	38.6	14.4	13.0	
Lake Mead - Owens/Vegas				
Travel time		59.6	87.5	91
Delay / Veh (s)	40.9	17.7	47.5	
St Del/Veh (s)	28	12.6	31.5	32
Stop/Veh	0.91	0.43	0.89	
Avg Speed (mph)	21.0	28.3	20.5	
Vehicles Entered	670	679	636	
Average Queue length	10.0	1.2	4.0	6.8
Max. Queue length	15.2	10.0	15.0	
Owens/Vegas - Washington				
Travel time		72.4	100.4	91
Delay / Veh (s)	57.7	31.8	58.4	
St Del/Veh (s)	42.2	22.6	42.8	28
Stop/Veh	0.85	1.07	0.80	
Avg Speed (mph)	19.0	24.3	18.8	
Vehicles Entered	625	544	664	
Average Queue length	12.5	2.5	6.0	8.3
Max. Queue length	17.7	12.3	21.5	

Table 14: Changes in MOE for Changes in Vehicle Maximum Accelerations and Decelerations for CORSIM Arterial Simulation (Northbound MLK)

NORTHBOUND	Base Case	50% Increase in Max Accelerations		50% Reduction in Max. Acceleration	
		New Value	%change	New Value	%change
Washington - Owens/Vegas					
Vehicle trips	1,229	1,240	0.9%	1,176	-4.3%
Total Travel time	108.7	94.4	-13.2%	102.4	-5.8%
Delay / Veh (s)	42.1	32.1	-23.7%	34.0	-19.1%
St Del/Veh (s)	39.7	30.6	-23.0%	32.4	-18.3%
Moving time	66.6	62.3	-6.5%	68.4	2.6%
Avg Speed (mph)	17.3	20.0	15.6%	18.4	6.4%
Moving Speed	28.3	30.3	7.0%	27.6	-2.6%
Stop/Veh	0.86	0.78	-9.3%	0.78	-9.3%
Average Queue length	10.5	8.0	-23.8%	7.5	-28.6%
Maximum Queue length	38.0	28.5	-25.0%	28.5	-25.0%
Owens/Vegas - Lake Mead					
Vehicle trips	1,431	1,411	-1.4%	1,353	-5.5%
Total Travel time	152.9	168.0	9.9%	225.9	47.7%
Delay / Veh (s)	78.2	91.4	16.8%	130.0	66.2%
St Del/Veh (s)	72.8	85.1	16.8%	118.6	62.9%
Moving time	74.7	76.6	2.6%	95.9	28.4%
Avg Speed (mph)	11.7	10.7	-8.5%	7.9	-32.5%
Moving Speed	24.1	23.5	-2.5%	18.8	-22.1%
Stop/Veh	0.99	0.99	0.0%	0.99	0.0%
Average Queue length	24.0	28.5	18.8%	40.5	68.8%
Maximum Queue length	49.5	59.0	19.2%	77.0	55.6%
Lake Mead - Carey					
Vehicle trips	1,206	1,182	-2.0%	1,143	-5.2%
Total Travel time	71.6	67.8	-5.3%	76.6	7.0%
Delay / Veh (s)	17.8	15.6	-12.4%	18.5	3.7%
St Del/Veh (s)	17.0	15.0	-12.0%	17.5	2.7%
Moving time	53.8	52.2	-2.9%	58.1	8.1%
Avg Speed (mph)	25.3	26.7	5.5%	23.7	-6.3%
Moving Speed	33.8	34.8	3.0%	31.3	-7.5%
Stop/Veh	0.42	0.39	-7.1%	0.38	-9.5%
Average Queue length	4.5	4.0	-11.1%	4.0	-11.1%
Maximum Queue length	22.5	21.5	-4.4%	18.0	-20.0%

Table 14(b): Changes in MOE for Changes in Vehicle Maximum Accelerations and Decelerations for CORSIM Arterial Simulation (Southbound MLK)

SOUTHBOUND	Base Case	50% Increase in Max Accelerations		50% Reduction in Max. Acceleration	
		New Value	%change	New Value	%change
Carey - Lake Mead					
Vehicle trips	619	618	-0.2%	619	0.0%
Total Travel time	75.3	73.7	-2.1%	80.4	6.8%
Delay / Veh (s)	22.7	22.7	-0.1%	23.3	2.3%
St Del/Veh (s)	22.2	22.3	0.3%	22.7	2.0%
Moving time	52.6	51.0	-3.0%	57.1	8.7%
Avg Speed (mph)	24.1	24.6	2.1%	22.6	-6.2%
Moving Speed	34.6	35.6	3.1%	31.8	-8.0%
Stop/Veh	0.65	0.66	1.5%	0.67	3.1%
Average Queue length	2.5	2.5	0.0%	3.0	20.0%
Maximum Queue length	13.0	15.5	19.2%	15.0	15.4%
Lake Mead - Owens/Vegas					
Vehicle trips	636	638	0.3%	635	-0.2%
Total Travel time	87.5	86.3	-1.4%	89.1	1.8%
Delay / Veh (s)	32.2	32.4	0.8%	28.3	-12.1%
St Del/Veh (s)	31.5	32.0	1.4%	27.7	-12.2%
Moving time	55.3	53.9	-2.6%	60.8	9.9%
Avg Speed (mph)	20.5	20.8	1.5%	20.1	-2.0%
Moving Speed	32.5	33.4	2.7%	29.6	-9.0%
Stop/Veh	0.89	0.89	0.0%	0.88	-1.1%
Average Queue length	4.0	4.0	0.0%	4.0	0.0%
Maximum Queue length	15.0	15.0	0.0%	15.5	3.3%
Owens/Vegas - Washington					
Vehicle trips	664	662	-0.3%	662	-0.3%
Total Travel time	100.4	99.2	-1.2%	117.4	16.9%
Delay / Veh (s)	43.6	43.7	0.2%	55.7	27.6%
St Del/Veh (s)	42.8	42.8	-0.1%	54.4	26.9%
Moving time	56.8	55.5	-2.3%	61.7	8.7%
Avg Speed (mph)	18.8	19.0	1.1%	16.1	-14.4%
Moving Speed	33.2	34.0	2.3%	30.6	-8.0%
Stop/Veh	0.80	0.78	-2.5%	0.85	6.2%
Average Queue length	6.0	5.5	-8.3%	7.0	16.7%
Maximum Queue length	21.5	21.5	0.0%	25.5	18.6%

Table 15: Changes in MOE for Changes in Vehicle Maximum Accelerations and Decelerations for VISSIM Arterial Simulation (Northbound MLK)

NORTHBOUND	Base Case	50% Increase in Max Accelerations		50% Reduction in Max. Acceleration	
		New Value	%change	New Value	%change
Washington - Owens/Vegas					
Travel time	351.5	392	11.4%	561.1	59.6%
Delay / Veh (s)	88.0	94.4	7.2%	138.2	57.0%
St Del/Veh (s)	50.4	53.9	7.0%	82.3	63.3%
Stop/Veh	**	**	**	**	**
Avg Speed (mph)	5.3	4.8	-9.6%	3.3	-37.8%
Link Flow (through vph)	1,236	1,221	-1.2%	1,045	-15.4%
Average Queue length	94.2	104.4	10.8%	135.3	43.6%
Max. Queue length	102.2	132.9	30.1%	166.8	63.2%
Owens/Vegas - Lake Mead					
Travel time	299.3	296	-1.2%	409.7	36.9%
Delay / Veh (s)	80.5	78.7	-2.2%	109.8	36.4%
St Del/Veh (s)	62.1	60.6	-2.4%	79.4	27.9%
Stop/Veh	2.83	2.70	-4.6%	2.35	-17.0%
Avg Speed (mph)	5.8	5.8	-0.5%	4.2	-28.0%
Link Flow (through vph)	1,376	1,402	1.9%	1,078	-21.7%
Average Queue length	81.9	85.1	3.9%	90.2	10.1%
Max. Queue length	124.4	124.9	0.4%	125.3	0.7%
Lake Mead - Carey					
Travel time	58.9	56	-4.3%	58.6	-0.4%
Delay / Veh (s)	12.5	10.4	-16.7%	11.9	-4.5%
St Del/Veh (s)	6.3	5.7	-9.3%	5.5	-13.7%
Stop/Veh	0.51	0.33	-36.2%	0.30	-41.1%
Avg Speed (mph)	29.2	30.4	4.1%	29.2	0.0%
Link Flow (through vph)	1,220	1,183	-3.0%	910	-25.4%
Average Queue length	0.9	1.0	5.4%	0.9	-1.2%
Max. Queue length	5.2	10.3	97.5%	12.2	134.5%

Table 15b: Changes in MOE for Changes in Vehicle Maximum Accelerations and Decelerations for VISSIM Arterial Simulation (Southbound MLK)

SOUTHBOUND	Base Case	50% Increase in Max Accelerations		50% Reduction in Max. Acceleration	
		New Value	%change	New Value	%change
Carey - Lake Mead					
Travel time	90.6	95.0	4.8%	101.1	11.4%
Delay / Veh (s)	47.0	49.2	4.7%	54.2	15.2%
St Del/Veh (s)	35.9	37.6	4.8%	37.0	3.2%
Stop/Veh	1.18	1.20	1.8%	1.15	-2.4%
Avg Speed (mph)	19.9	18.8	-5.3%	17.7	-10.9%
Link Flow (through vph)	558	579	3.8%	581	4.1%
Average Queue length	2.6	2.8	9.4%	2.7	5.7%
Max. Queue length	14.4	17.4	20.4%	19.1	32.2%
Lake Mead - Owens/Vegas					
Travel time	59.6	59.1	-1.6%	63.4	6.3%
Delay / Veh (s)	17.7	16.3	-8.0%	20.3	14.9%
St Del/Veh (s)	12.6	11.7	-7.3%	14.4	13.9%
Stop/Veh	0.43	0.38	-12.2%	0.40	-6.4%
Avg Speed (mph)	28.3	28.4	0.2%	26.3	-7.2%
Link Flow (through vph)	679	699	2.9%	714	5.2%
Average Queue length	1.2	1.2	4.1%	1.5	25.1%
Max. Queue length	10.0	13.0	29.5%	10.8	7.5%
Owens/Vegas - Washington					
Travel time	72.4	72.3	-0.6%	71.2	-2.0%
Delay / Veh (s)	31.8	31.2	-1.8%	30.1	-5.2%
St Del/Veh (s)	22.6	21.5	-5.3%	18.1	-20.3%
Stop/Veh	1.07	1.20	12.5%	0.88	-17.9%
Avg Speed (mph)	24.3	24.6	1.2%	25.0	2.8%
Link Flow (through vph)	544	517	-4.9%	479	-12.0%
Average Queue length	2.5	2.5	0.7%	2.4	-2.9%
Max. Queue length	12.3	14.8	20.6%	15.6	27.1%

Table 16: Changes in MOE for Changes in Vehicle Maximum Accelerations and Decelerations for SIMTRAFFIC Arterial Simulation (Northbound MLK)

NORTHBOUND	Base Case	50% Increase in Max Accelerations		50% Reduction in Max. Acceleration	
		New Value	%change	New Value	%change
Washington - Owens/Vegas					
Total Delay (hr)	19.3	17.3	-10.4%	19.7	2.1%
Delay / Veh (s)	57.8	51.2	-11.4%	59.9	3.6%
Stop Delay (hr)	12.6	10.7	-15.1%	12.8	1.6%
St Del/Veh (s)	37.6	31.9	-15.2%	38.8	3.2%
Stop/Veh	1.04	0.95	-8.7%	1.09	4.8%
Travel Dist (mi)	553.6	557.2	0.7%	543.2	-1.9%
Travel Time (hr)	32.3	30.2	-6.5%	32.7	1.2%
Avg Speed (mph)	17	19	11.8%	17	0.0%
Hourly Vehicle Exit Rate	1,206	1,216	0.8%	1188	-1.5%
Average Queue length	21.5	20.1	-6.3%	22.1	2.8%
Maximum Queue length	34.8	33.5	-3.6%	40.5	16.4%
Owens/Vegas - Lake Mead					
Total Delay (hr)	83.5	80.9	-3.1%	96.7	15.8%
Delay / Veh (s)	241.4	230.8	-4.4%	289.8	20.0%
Stop Delay (hr)	64.5	62.3	-3.4%	76.1	18.0%
St Del/Veh (s)	186.5	178	-4.6%	228.1	22.3%
Stop/Veh	3.93	3.82	-2.8%	4.8	22.1%
Travel Dist (mi)	616.5	623.8	1.2%	594.5	-3.6%
Travel Time (hr)	98	95.4	-2.7%	110.8	13.1%
Avg Speed (mph)	6	7	16.7%	5	-16.7%
Hourly Vehicle Exit Rate	1,189	1,204	1.3%	1144	-3.8%
Average Queue length	79.0	76.4	-3.4%	92.0	16.4%
Maximum Queue length	128.5	123.3	-4.0%	128.3	-0.2%
Lake Mead - Carey					
Total Delay (hr)	10.2	10.6	3.9%	10.6	3.9%
Delay / Veh (s)	29.4	30.3	3.1%	32	8.8%
Stop Delay (hr)	5.8	6.2	6.9%	6.1	5.2%
St Del/Veh (s)	16.7	17.6	5.4%	18.4	10.2%
Stop/Veh	0.46	0.48	4.3%	0.46	0.0%
Travel Dist (mi)	540.2	546.8	1.2%	513.7	-4.9%
Travel Time (hr)	22.9	23.4	2.2%	22.8	-0.4%
Avg Speed (mph)	24	23	-4.2%	23	-4.2%
Hourly Vehicle Exit Rate	1,237	1,246	0.7%	1179	-4.7%
Average Queue length	12.8	13.3	3.9%	12.1	-5.9%
Maximum Queue length	20.8	24.0	15.7%	20.4	-1.9%

Table 16b: Changes in MOE for Changes in Vehicle Maximum Accelerations and Decelerations for SIMTRAFFIC Arterial Simulation (Southbound MLK)

SOUTHBOUND	Base Case	50% Increase in Max Accelerations		50% Reduction in Max. Acceleration	
		New Value	%change	New Value	%change
Carey - Lake Mead					
Total Delay (hr)	6.4	6.3	-1.6%	7.5	17.2%
Delay / Veh (s)	40.6	39.7	-2.2%	47.4	16.7%
Stop Delay (hr)	4.2	4.1	-2.4%	4.8	14.3%
St Del/Veh (s)	26.4	25.8	-2.3%	30.5	15.5%
Stop/Veh	0.8	0.79	-1.3%	0.89	11.3%
Travel Dist (mi)	275.7	274.9	-0.3%	275.8	0.0%
Travel Time (hr)	12.9	12.7	-1.6%	14.1	9.3%
Avg Speed (mph)	21	22	4.8%	20	-4.8%
Hourly Vehicle Exit Rate	572	571	-0.2%	570	-0.3%
Average Queue length	16.4	17.8	8.6%	28.7	75.2%
Maximum Queue length	38.6	40.8	5.6%	52.5	36.0%
Lake Mead - Owens/Vegas					
Total Delay (hr)	7.6	7.3	-3.9%	7.7	1.3%
Delay / Veh (s)	40.9	39.3	-3.9%	41.8	2.2%
Stop Delay (hr)	5.2	5	-3.8%	5.1	-1.9%
St Del/Veh (s)	28	27.1	-3.2%	27.8	-0.7%
Stop/Veh	0.91	0.89	-2.2%	0.91	0.0%
Travel Dist (mi)	316.6	316.4	-0.1%	313.3	-1.0%
Travel Time (hr)	15.1	14.7	-2.6%	15.2	0.7%
Avg Speed (mph)	21	22	4.8%	21	0.0%
Hourly Vehicle Exit Rate	666	665	-0.2%	659	-1.1%
Average Queue length	10.0	9.6	-4.5%	10.1	0.5%
Maximum Queue length	15.2	15.2	0.3%	15.3	1.0%
Owens/Vegas - Washington					
Total Delay (hr)	9.8	9.8	0.0%	10.2	4.1%
Delay / Veh (s)	57.7	57.5	-0.3%	60.9	5.5%
Stop Delay (hr)	7.2	7.2	0.0%	7.3	1.4%
St Del/Veh (s)	42.2	42.1	-0.2%	43.6	3.3%
Stop/Veh	0.85	0.87	2.4%	0.86	1.2%
Travel Dist (mi)	326.3	326.1	-0.1%	319	-2.2%
Travel Time (hr)	17.4	17.3	-0.6%	17.7	1.7%
Avg Speed (mph)	19	19	0.0%	18	-5.3%
Hourly Vehicle Exit Rate	602	603	0.2%	591	-1.8%
Average Queue length	12.5	12.3	-2.0%	11.9	-4.8%
Maximum Queue length	17.7	17.1	-3.7%	19.0	7.3%

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