Dynamic, Integrated Model System: Sacramento-Area Application, Volume 1: Summary Report

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The Second

STRATEGIC HIGHWAY RESEARCH PROGRAM

SHRP 2 REPORT S2-C10B-RW-1

Dynamic, Integrated Model System: Sacramento-Area Application

Volume 1: Summary Report

CAMBRIDGE SYSTEMATICS, INC.

IN ASSOCIATION WITH

SACRAMENTO AREA COUNCIL OF GOVERNMENTS

UNIVERSITY OF ARIZONA

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FOREWORD

Stephen J. Andrle, *SHRP 2 Deputy Director*

This report will be of interest to professionals who use travel demand and network assignment models as part of the transportation planning process. The goal of this research was to improve urban-scale modeling and network procedures to address operations or spot improvement that affects travel-time choice, route choice, mode choice, reliability, or emissions. Such improvements may include traveler information, expanded transit service, pricing, reversible lanes, or improved bottlenecks. Operational improvements like these are difficult to model on an urban-area scale using existing tools. A secondary goal was to facilitate further development and deployment of these or similar procedures. The goals were addressed by building a proof-of-concept dynamic integrated model in two urban areas: Jacksonville, Florida, and Sacramento, California.

The report describes the Sacramento, California, integration of the activity-based demand model DaySim; a dynamic traffic assignment (DTA) model, DynusT; and a transit network simulation model, FAST-TrIPs. All are open-source products. Integration means that a feedback loop was built between the demand and network assignment model systems. All of the demographic, highway network, and transit service data required to run the model set were assembled, and the feedback between the demand model and the DTA was tested in a subarea of Sacramento and on the full urban network. A Volume 2 report describes the application of DynusT and FAST-TrIPs in detail.

A companion report and model set are available for the application in Jacksonville, Florida. This work has the same objective and uses DaySim as the demand model but uses TRANSIMS for the highway network assignment. Both model sets and software Start-up Guides are available from the Federal Highway Administration.

Travel demand models have been used for more than half a century to determine the need for and estimate the usage of proposed new highway and transit systems. The majority of such models use Traffic Analysis Zones to aggregate demographic data and estimate interzonal travel demand for large time blocks (such as morning peak period). The interzonal demand is assigned to a link and node network to estimate likely roadway volumes.

Activity-based travel demand models are based on the disaggregate travel activity of individual travelers, not the aggregate behavior of all the travelers in a zone. They have the potential to better simulate behaviors such as time-of-day choice, route choice, mode choice, and trip chaining. As with real travelers, information on the state of the network is needed to make choices. The feedback loop from the network assignment may cause a simulated "traveler" to change route, time of day, or mode in response to network congestion. The model set iterates until convergence is reached—travel volumes and modes are stable after successive iterations.

Activity-based models have been available for some time but are not widely used in production planning work. Dynamic traffic assignment models are network simulation tools that represent network travel conditions. Such simulation models are used for subarea traffic analysis but have not been linked to a demographically based demand model and used at the urban-area scale. This project integrated the supply and demand side of transportation demand forecasting in order to test operational improvements to the highway system as well as capacity enhancements.

The Sacramento Area Council of Governments (SACOG) used the model set to test transportation alternatives. The results are proof-of-concept in nature. The integrated model works and demonstrates potential improved sensitivity to policies that affect regional travel. However, the model did not converge as hoped, so it was not possible to fully calibrate it prior to testing by SACOG. The integrated model sets built for this project are available as a basis for implementing a similar approach in other urban areas.

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Executive Summary

The second Strategic Highway Research Program (SHRP 2) Project C10B, Partnership to Develop an Integrated, Advanced Travel Demand Model with Fine-Grained, Time-Sensitive Networks: Sacramento-Area Application, is an important step in the evolution of travel modeling from an aggregate, trip-based approach to a completely dynamic, disaggregate methodology. In this project, an existing disaggregate activity-based model was integrated with an existing traffic simulation model to create a new, completely disaggregate model.

At the same time that travel demand models have been evolving, traffic simulation models—which simulate the movements of vehicles through a highway network—have become more sophisticated due to improvements in computing. The product of SHRP 2 Project C10B is an integrated model that simulates individuals' activity patterns and travel and their vehicle and transit trips as they move on a real-time basis through the transportation system. It produces a true regional simulation of the travel within a region, for the first time using individually simulated travel patterns as input rather than aggregate trip tables to which temporal and spatial distributions have been applied to create synthetic patterns. A unique feature of this model is the simulation of transit vehicles as well as individual person tours using transit.

The new integrated model has been developed and implemented for the entire Sacramento, California, region. The integrated model components include (1) SACSIM, the regional travel model maintained by the Sacramento Area Council of Governments (SACOG), the regional metropolitan planning organization (MPO), and (2) DynusT, a mesoscopic traffic simulation model developed by the University of Arizona. SACSIM includes an activity-based demand model, DaySim. The transit simulation is performed by FAST-TrIPs (Flexible Assignment and Simulation Tool for Transit and Intermodal Passengers), also developed by the University of Arizona. The integrated model also includes the ability to run MOVES (Motor Vehicle Emission Simulator), the air-quality analysis program developed by the U.S. Environmental Protection Agency (EPA).

The testing of the new model was limited. A complete validation of the new model was not performed so that project resources could be reserved for a series of tests in which the model was used to estimate the effects of various policy and transportation improvement scenarios. This means that the model will need further calibration and improvements to be used in realistic planning applications.

While the C10B integrated model produces results that are reasonable for regional travel patterns and behavior within the limits of the testing that was done, the true value of the model is its ability to provide analysis results that demonstrate sensitivity to policy variables more accurately than models that use aggregate demand or assignment procedures. This sensitivity was tested through a series of policy and project tests conducted by SACOG, using the new integrated model and the existing SACSIM model with aggregate assignment.

The objective is to address key policy and investment questions by implementing an integrated, advanced travel demand model with fine-grained, time-dependent networks; the ideal approach is to combine the capabilities of an activity-based travel demand model with a traffic simulation model, adding enhancements to achieve goals such as the consideration of reliability in travel choices. Project C10B implemented this approach by using the SACSIM travel demand model for the Sacramento area; SACSIM includes the original DaySim activity-based model and the DynusT mesoscopic traffic microsimulation model. The integrated model was tested in the Sacramento metropolitan area, which is the 27th largest in the United States and has all of the desirable characteristics for testing the new model.

The Sacramento Area Council of Governments (SACOG) served as the public agency partner for this project. SACOG is the designated MPO for the metropolitan area and is responsible for all transportation planning in the region.

Model Components

The components of the integrated model developed in the SHRP 2 C10B project include SACSIM, DynusT, FAST-TrIPs, and MOVES.

SACSIM is a complete travel demand model that SACOG uses for planning in the Sacramento region. The demand for personal travel within the region is modeled by DaySim, an activity-based demand model. DaySim incorporates a variety of model features, including

- The ability to model each person in the Sacramento region separately through the use of a population synthesizer that creates a synthetic population representing each person and household in the region;
- The ability to model the complete daily activity pattern for each individual, including the number and sequencing of activities defined by seven purposes;
- A series of logit destination, mode, and time-of-day choice models at the tour and trip levels to simulate the choices for each individual;
- Estimation of the start and end times of all activities and trips to the half-hour level of resolution; and
- Parcel-level spatial resolution for home and activity locations.

Other components of SACSIM are used to model, at an aggregate level, the remaining components of regional travel—including travel into, out of, and through the region (external travel); truck travel; and travel to and from Sacramento International Airport.

DynusT is a traffic simulation model that is used in a number of areas and lends itself well to integration with both SACSIM and MOVES. DynusT is a true disaggregate simulation model that can track individual vehicles through the network—consistent with tracking traveler activities in a travel demand model. Furthermore, DynusT is a true dynamic traffic assignment (DTA) model that takes into account both the spatial and temporal effects of congestion. Travelers departing at different times are assigned to routes calculated on the basis of the traveler's actual experienced travel time, which is a critical capability for establishing a consistent and reliable traffic assignment outcome.

FAST-TrIPs is a model that assigns transit passengers within the transportation network and loads those passengers in a dynamic (time-sensitive) simulation of actual travel. FAST-TrIPs is a regionwide dynamic transit assignment model that determines an individual-specific transit route for each transit traveler in the system; it takes into account published transit schedules and transit vehicle run times that are congestion responsive and are provided by the traffic simulation component of DynusT. FAST-TrIPs deals with both transit-only and park-and-ride trips and is able to maintain multiple constraints associated with activity time-windows and the choice of modes in multimodal travel tours.

MOVES is the next-generation mobile source emission model developed by the EPA. MOVES serves as a single comprehensive system for estimating emissions from both on-road and nonroad mobile sources. It replaces EPA's MOBILE model as the approved model for state implementation plans (SIPs) and regional or project-level transportation conformity analyses. MOVES is designed to estimate emissions at scales ranging from individual roads and intersections to large regions. MOVES is a database-driven model—inputs, outputs, default activities, base modal emission rates, and all intermediate calculation data are stored and managed in MySQL database.

Software Approach

The software architecture for the integrated model allows users to access the modeling software using a web browser, with the major model components running on one or more shared servers. This allows for the efficient sharing of large data files, alleviates the need for every modeler to have a powerful desktop computer, and enables analysts to use parallel processing or other techniques as necessary to ensure adequate performance. The software architecture is efficient, modular, and maintainable, and it reduces the risk of changes to one model component affecting the operation of the model as a whole.

The software was developed using an iterative, incremental methodology that reduced risk, ensured continuous testing, and makes progress more transparent and predictable. The development approach has made virtually the entire suite of C10B products available to the transportation community. SACSIM and DynusT are available under open-source licenses, and the National Academy of Sciences (NAS) is the owner of all new software. While the tests of the model used some input data from SACSIM that were developed using a proprietary modeling software package licensed to SACOG and Cambridge Systematics, Inc., the operation of the integrated model does not require any commercial travel demand modeling or simulation software.

Model Component Revisions

To meet the objectives of the SHRP 2 C10B project, some revisions were made to the original models that make up the integrated model.

Incorporation of Variable Value of Time

One of the shortcomings of aggregately applied models is the need to use average values across broad market segments for key parameters. One example is the use of a single value of travel time for each segment for decisions about mode and route choice. The value of time determines the extent to which travelers will pay to save travel time. This is an important factor in estimating how many and which travelers might use toll roads or managed lanes.

Because an activity-based model simulates each individual, an individualized value of time for each individual can be simulated from a probability distribution. Since it incorporates both activity-based demand modeling and traffic simulation, the C10B integrated model provides an opportunity to use individual values of time throughout the modeling process. The approach used was to revise the tour mode choice model in DaySim, preserving as much of the existing model as possible.

Variable value of time is achieved in the new mode choice models by specifying a distribution for the in-vehicle time coefficient, in this case a lognormal distribution. Due to the lack of travel cost variations in the survey data set used to estimate the original tour mode choice models (there are no toll roads in the Sacramento region), value-of-time distributions were transferred from the San Francisco region.

Incorporation of Reliability

A method was developed for including reliability in the C10B analysis framework. As an input, reliability affects travelers' decisions about trip making and the choice of destination, mode, and route. It can be thought of as an extra impedance to travel over and above the average travel time generally used in demand models. Note that the original model's definition of average travel time is based solely on recurring (demand and capacity) conditions. Considering reliability means that nonrecurring sources of congestion factor into the process.

The concept of "extra impedance due to unreliable travel" is probably the best way to incorporate reliability into the modeling structure as an input. SHRP 2 Project L04, Incorporating Reliability Performance Measures in Operations and Planning Modeling Tools, used this approach: the impedance on a link can be captured as a generalized cost function that includes both the average travel time and its standard deviation (which is used as the indictor of reliability). Because Project L04 was not complete at the time of the relevant work in Project C10B, travel time equivalents were used, as discussed in Chapter 2.

The Project C10B method uses the DynusT output to estimate recurring delay and a sketch planning method to estimate incident delay, then combines the two. The steps are (1) compute the recurring delay for each link in hours per mile from the simulation model; (2) compute the delay due to incidents in hours per mile using the lookup table for a 1-h period; and (3) compute the overall mean Travel Time Index, which includes the effects of recurring and incident delay.

Model Integration

Integration of SACSIM and DynusT/FAST-TrIPs

The outputs from SACSIM that are inputs to DynusT/FAST-TrIPs in the C10B integrated model are

- The tour and trip rosters from DaySim; and
- The trip tables representing exogenous travel.

The tour and trip rosters already include most of the information required as inputs by DynusT, including the origin and destination of each trip and relevant traveler information such as the simulated value of time. The time of day is also provided, but only at the half-hour level for trips. In the C10B model, a random start time for each trip is simulated within the appropriate half-hour period. The conversion of the rosters to the input format required by DynusT is performed within the integrated model software.

The exogenous travel trip tables must be converted to trip rosters for input to DynusT. This is done using existing procedures for processing trip tables in DynusT. SACSIM has trip tables for each of four aggregate time periods (a.m. peak, midday, p.m. peak, and night). Departure time profiles from traffic count data were used to define start times for each trip in the roster.

The C10B integrated model is run in an iterative manner until convergence is achieved. Before each "big loop" after the first, the travel time information from DynusT and FAST-TrIPs from the previous big loop is fed back as input to SACSIM. The feedback process is somewhat complex because the traffic and transit simulation in DynusT/FAST-TrIPs represents nearly continuous time while the inputs to DaySim are in half-hour intervals, and the inputs to the exogenous travel components of SACSIM are for the four broad time periods. Furthermore, each trip in DynusT/FAST-TrIPs has its own trajectory through the network, with its travel time based on the conditions confronted continuously through its journey. There is no single "travel time" from one point in the network to another in DynusT.

A specialized process to compute the travel times to be fed from one big loop to the next was developed for the C10B integrated model. Stated simply, the feedback process employed in the C10B model combines information from all relevant trajectories within a time period (half hour or broad period) to estimate an average time to use for input to SACSIM. The integrated model software executes this process.

Integration of DynusT and MOVES

A significant feature available in MOVES is the ability to support quantitative project-level emissions assessments using detailed vehicle activity data. The MOVES project-scale analysis function is the most spatially resolved modeling level in MOVES; it calculates emissions from a single roadway link, a group of specific roadway links, and/or an off-network common area (e.g., a transit terminal or park-and-ride lot).

To take advantage of these detailed activity data with improved temporal and spatial resolution, the project team developed a fine-grained integrated method that links MOVES to DynusT at the individual roadway link level. The MOVES-DynusT integration is realized through data conversion functions that use DynusT activity outputs to generate MOVES project-scale inputs. This integration method ensures transition of data flow from DynusT to MOVES without manual intervention or additional data preparation.

Model Application

When applying the C10B model, there are a few key points to consider:

- The DynusT application is resource intensive on all fronts: CPU, memory, and disk space.
- In addition to the DaySim and DynusT applications, there are a number of scripts that run to perform various data management functions.
- The MOVES application is somewhat independent of the more tightly coupled loop between DaySim and DynusT. It runs separately on data processed from the final output of DynusT and does not necessarily have to be installed at the same time as DaySim and DynusT. The MOVES installer will also install MySQL.

The model software only runs on 64-bit Windows (e.g., Windows 7, Windows Server 2008). Python and the DBF Python library should be installed before installing DaySim and DynusT. The model was designed to run on hardware configurations that are typically available at most larger MPOs and state planning agencies. The specific requirements for the C10B integrated model are as follows:

- Memory: minimum 8 GB, 16 GB preferred. The configuration on which SACOG ran the policy tests included 32 GB.
- CPU: minimum four cores Intel Core i5 or better. Up to 16 cores will significantly improve performance. SACOG's configuration included Intel Core i7-3770 CPU @ 3.40 GHz.
- Hard drive: 15 GB of data are generated per run. Data are written and read back in for each iteration of DynusT, so a solid state drive is recommended to improve performance. SACOG's configuration included a solid state drive.

All software can be installed and run from the same server. However, the MOVES application and support software (MySQL) could be installed and run on a separate server from the server running DaySim and DynusT if desired.

Using the development configuration of Windows 7 Professional running on Intel Core i7-2600 CPU @ 3.40 GHz with 16 GB random access memory (RAM) and a 128 GB solid state drive (SSD), run times averaged a bit over 25 h per big loop. SACOG reported run times of 70 h for the policy test runs with three full feedback loops, with its slightly larger/faster configuration.

Model Testing

SACSIM had been validated by SACOG for a base year of 2005, prior to the beginning of the C10B project. While SACOG has continued to update SACSIM as part of its regional transportation planning process, it was not necessary for the purposes of the C10B project to implement any updates to SACSIM that took place after C10B began. The SACSIM component of the integrated model was therefore considered already validated when the project commenced.

The main difference between the integrated model and SACSIM was the replacement of the static highway and transit assignment processes with the dynamic simulation processes, DynusT and FAST-TrIPs, respectively. To demonstrate that the C10B integrated model was suitable for testing the policy/planning alternatives, the project team identified a proof-of-concept plan to test the integrated model, consistent with the overall focus of the project.

The testing conducted under this refined plan was designed to

- Identify and measure the impact of the integration of SACSIM and DynusT on SACSIM results. The integrated model does not change the basic design or structure of the demand components of SACSIM/DaySim. Thus, under the proof-of-concept plan, it is sufficient to identify changes in SACSIM results that stem from integration of SACSIM with the DynusT assignment procedures.
- Determine whether or not the SACSIM/DynusT procedure is iterating to closure. Is it getting closer to or further away from observed transit volumes, traffic volumes, and traffic speeds?
- Measure the reasonableness of the traffic and transit assignment results. Of course, the reasonableness of the assignment results depends somewhat on the impact that the SACSIM/DynusT procedure has on SACSIM.

All testing was conducted for the 2005 base year using the same socioeconomic, land use, and network data used by SACOG for SACSIM. In addition, observed traffic and transit data used for the validation of SACSIM were available.

As previously discussed, a complete validation of the C10B integrated model was not conducted.

Analysis of Policies and Alternatives of Interest to Planning Agencies

A set of five policy tests was conducted to demonstrate that the C10B integrated model is capable of analyzing the types of policies and alternatives that are part of typical urban transportation planning processes. The objective was to produce reasonable results in a real-world environment for typical transportation planning policies. With this in mind, it was decided that SACOG would perform the analyses at its offices, using its hardware and staff, with assistance from other team members. The idea was to get a sense of the type of effort that would be required for a planning agency to perform these types of analyses using the integrated model.

For each of the five tests, the results of a particular scenario related to a change in the transportation system were compared with the results from a baseline scenario, which was the same for all tests. The baseline represented year 2005 conditions in the Sacramento region. All scenarios were run using the C10B integrated model; most scenarios were also run using the original SACSIM model validated for the region.

The set of five policy and investment alternative scenarios analyzed were defined by SACOG. Note that while the scenarios are realistic and typical of the types of policies and scenarios that SACOG analyzes in its transportation planning function, they are not actual projects under consideration in the Sacramento region. The policy test scenarios were as follows:

1. *Extending transit service coverage*—extending the end of transit service for a bus route from 6:00 p.m. to midnight;
2. *Improving interchange design*—an operations-oriented interchange improvement project;
3. *Providing freeway bottleneck relief*—adding a fourth general purpose lane to a heavily congested freeway river crossing connecting to downtown Sacramento;

4. *Increasing transit frequency*—reducing service headways from 30 min to 10 min on a well-used bus line; and
5. *Deleting bus line*—deleting a well-used bus line.

Limitations on project resources resulted in taking some shortcuts in the analyses and in the preparation of the C10B integrated model. These issues are described in the following bullet points. It is hoped that further research with this type of integrated model can assist in assessing the effects of these issues and their practical implications. The issues include the following:

- Perhaps the most significant issue was the limited validation of the C10B integrated model. This resulted in some significant differences in the baseline scenario results between the C10B model and SACSIM, some of which were in the vicinity of the transportation system changes under study. This made comparison of the model results difficult in some cases.
- Another limitation was the level of convergence achieved in DynusT. The test results implied that there was still substantial "noise" in some C10B integrated model results, which affected the ability to fully evaluate the test results. There is also, of course, noise in SACSIM because it includes an activity-based demand model that simulates individual travel behavior. But there is more noise in the C10B integrated model because it includes SACSIM as well as the traffic and transit simulation components in DynusT and FAST-TrIPs.
- Another issue was that each test was run only once with each model. Ideally, simulation models should be run multiple times to get a handle on the level of noise in the results. SACOG has done this with its own validated version of SACSIM, but multiple runs were not possible within the project schedule. As the results show, some of the results appear to be questionable due to the noise level in the C10B integrated model, which is greater than in SACSIM because of the additional traffic and transit simulation components.

The test results are summarized in the following sections.

Summary of Test 1

In Test 1, the C10B integrated model behaved plausibly in an aggregate sense, shifting trips to the transit and walk modes from the auto modes and showing reasonable sensitivity and magnitude of response while maintaining a relatively constant level of demand. Boardings on the route for which service was extended increased while boardings on nearby routes declined. A significant part of the added boardings occurred in the extended service period between 6:00 p.m. and midnight. Even with the level of noise in the C10B model, it seems unlikely that the entirety of the model response is indistinguishable from random noise because the mode shifts and changes in boardings on individual routes are nearly all in the correct direction.

In terms of localized effects, however, the C10B integrated model showed only a minor impact on transit trips. The temporal shifts are also counterintuitive because trips shift from the period when the service is extended.

Summary of Test 2

In this scenario, the highway system reverted to an earlier state when a key interchange improvement was removed. Highway capacity was therefore lower, resulting—as expected—in a higher level of congestion in the affected area in both models. The higher level of congestion apparently caused some travelers to shift to transit. Overall, the C10B integrated model was more sensitive to congestion than SACSIM, shifting a significantly greater number of travelers from peak periods to adjacent time periods. The SACSIM results showed reductions in all time periods (though very small reductions) rather than any noticeable peak spreading. Interestingly, the C10B model showed a smaller reduction in trips on work tours than on nonwork tours, which is consistent with the notion that the work tours are more inelastic. SACSIM, on the other hand, showed a greater reduction in trips on work tours.

It is unclear whether the magnitude of the sensitivity of the C10B integrated model is reasonable; the SACSIM results seem too inelastic. The C10B model seems very sensitive in terms of shifts in demand from peak periods, although the relative inelasticity of the SACSIM results does not provide a worthwhile basis for comparison. The assignment results for both SACSIM and the C10B integrated model for five key roadways show changes in the expected direction, although the predicted volume levels and the magnitude of the impacts vary among roadways.

Summary of Test 3

In Scenario 3, an additional general purpose lane was incorporated on a congested segment of the Capital City Freeway, which is the most congested freeway in the region. Both models showed a small increase in the total amount of regional travel, with the C10B integrated model showing a larger increase. However, in the SACSIM model, this increase was mainly concentrated near the vicinity of the improved highway; in the C10B model, destinations near the improvement decreased while they increased farther from the improvement.

The C10B integrated model results are different from SACSIM for this segment. Both the baseline and Scenario 3 show slower speeds and higher travel times than SACSIM. It is unknown in which model's results the speeds and volumes are more accurate.

Both SACSIM and the C10B model show higher volumes on the widened highway for the test, and both show added delay in the downstream segments. The C10B model shows that the impact of higher volumes on the downstream segments is much greater than the impact shown in SACSIM, however. In other words, by widening the crossing segment, delay is reduced on that segment, but that improvement is offset by much higher delay downstream. Thus, according to the C10B model results, widening the bridge segment alone would be nearly net-zero in delay reduction.

This scenario anticipated that the increased capacity would result in a higher number of trips to the affected area, both spatially and temporally. However, such an impact is seen only in SACSIM and not in the C10B integrated model. For this particular scenario, perhaps less than ideal convergence in the C10B model may have left the model with too many localized sources of instability and congestion, which have distorted the final outcome. In the last overall iteration, the study team used a higher number of DynusT iterations; this improved convergence and reduced excessive congestion but did not eliminate the unexpected results.

Summary of Test 4

In this test, SACSIM produced an unexpectedly large shift in ridership on the route with the increased frequency. It is not clear why this occurred in SACSIM because the mode choice model should not be overly sensitive to headway assumptions, and the same mode choice model was used in the C10B integrated model. Nor should the static transit assignment process be overly sensitive to headway assumptions. This result is particularly puzzling given that the C10B integrated model had a larger overall increase in transit demand (5% compared with 3% for SACSIM). Examining the reasons behind the unusual SACSIM results was beyond the scope of this project, but the C10B integrated model results were, for whatever reason, more reasonable.

Both models showed about the same (reasonable) shifts in ridership from nearby routes.

Summary of Test 5

In contrast to the results of Test 4, which used the same transit route as its basis, the results of Test 5 were more reasonable for SACSIM than for the C10B integrated model. The deletion of the route should have resulted in a decrease in overall transit ridership, but in the C10B model, the opposite occurred. Both models did show increases in ridership on nearby routes, as expected. There were some unusual results in SACSIM away from the deleted route, making some direct comparisons difficult.

Conclusions

The SHRP 2 C10B project developed and performed a limited set of tests for a completely dynamic, disaggregate travel demand and traffic and transit simulation model. The model was implemented using available software, mainly open source, as well as software developed for the project that is available through the National Academy of Sciences. The model was implemented and tested for the Sacramento, California, metropolitan area.

The new integrated model uses available data as inputs. The data needs are similar to those used in existing planning and operational models. The socioeconomic and land use data inputs are the same as those used in the existing activity-based travel demand model used by SACOG, the Sacramento MPO. The highway network data requirements are consistent with those needed for traffic simulation, although those requirements can be substantial at the regional level, and detailed actual data may have to be replaced by default data in some cases. The transit network data are generated directly from Google's General Transit Feed Specification (GTFS), which includes information for most major metropolitan areas in the United States.

The model was designed to run on software and hardware configurations that would typically be available at most larger MPOs and state planning agencies. The software only runs on a typical Windows Server configuration.

A user of the C10B integrated model should be familiar with the following:

- Travel demand modeling concepts and procedures, and interpretation of model validation and outputs;
- Traffic simulation modeling, particularly using the DynusT model and software, and interpretation of model validation and outputs; and
- The GTFS.

If the model run is to include MOVES, then familiarity with the MOVES model is also important.

DaySim is an activity-based model, and since it is a component of the C10B integrated model, users should have a fundamental understanding of the concepts of activity-based modeling. It is not necessary for a user to be facile with all of the details of the estimation of each model component, but the user should fully understand the way in which individuals' activity patterns and choices of destination, mode, and time of day are realized in the model.

Because the highway network in the C10B integrated model is maintained in DynusT, the user needs a thorough understanding of this simulation model. While most members of the project team had substantial expertise in travel demand modeling, only a few had significant experience using DynusT. Team members who would perform model runs, particularly at SACOG, underwent multiday training sessions by University of Arizona team members. Even with the training, it took a substantial amount of time for the new users to become proficient enough to perform the network coding required to create model scenarios, and to examine and interpret DynusT outputs. New users of the C10B model who are not familiar with DynusT should be prepared to spend some time becoming familiar with it.

University of Arizona team members developed the original FAST-TrIPs transit network using the GTFS information for Sacramento. Since these team members were also the developers of FAST-TrIPs, the other project team members do not have a specific estimate for the level of effort to develop a complete FAST-TrIPs network. SACOG staff who performed the policy testing were able to make the relatively simple edits required for Scenarios 1, 4, and 5. These edits, however, did not involve coding new routes; rather, a route was deleted, hours of service were extended, and frequencies were changed.

It should be noted that beyond the modeling terminology that is part of the C10B model user interface (UI), no specialized computing knowledge or experience is necessary to run the model. The UI is similar to many other Windows-based software in that users create and modify scenarios and examine the model's reports through familiar concepts such as radio buttons, tabs, and drop-down menus.

Lessons Learned and Model Improvements Needed

As previously noted, the testing of the new model was limited, and a complete model validation was not performed. Additionally, a number of challenges were experienced during the development, implementation, and testing of the C10B integrated model. Some of these issues were addressed fully or in part, while others could not be addressed within the schedule and resources available for the C10B project. These issues would need to be addressed to make the model ready for real-world applications.

Model Validation

In the early stages of the project, consideration was given to performing a full validation of the C10B model, similar to what might be done for a travel model that would be used by an MPO for transportation planning. This full validation would have included comparisons to observed data for the base year of 2005, as well as SACSIM model results and sensitivity testing using a forecast or backcast year. This concept was abandoned because other delays left too little time at the end of the project to perform both a conventional model validation and sensitivity testing, and the planned policy testing. It was decided that the policy testing would proceed, and conventional model validation and sensitivity testing would not be performed.

The model testing that was performed focused on "proof of concept," meaning that the results were examined mainly using aggregate measures, and extensive calibration of the model was not performed. It was obvious that some issues in the C10B model results would have required further work on the model had it been intended for use in an actual transportation planning setting. These issues included the following:

- *An underestimation of transit ridership.* For 2005 the C10B model estimated fewer transit riders than SACSIM and fewer than the observed ridership for that year.
- *Lower highway speeds.* The C10B model resulted in lower average travel speeds (about 8 to 10 mph) for all roadway types at all times of day.
- *Temporal distribution of travel.* The distribution of travel by time of day in the C10B integrated model results differed noticeably from the SACSIM results.

Convergence

It was found that after running three big loop iterations, each of which included 10 DynusT iterations, the systemwide model convergence reached a plateau that did not improve with more iterations. Three big loop iterations resulted in a systemwide convergence level between 10% and 15%, meaning that on average the number of trips between each zone pair changes by no more than 10% to 15% between successive big loop iterations. That is approximately what can be achieved by DynusT in 10 iterations in the Sacramento implementation.

This is not a particularly stringent convergence level for either static or dynamic traffic assignment models. The relatively high convergence level may well have affected the results of the policy tests. It would make sense to perform more tests to see if better convergence can be achieved in the simulations and what types of model changes might be considered beyond simply running more loops or iterations to improve convergence.

Noise in Model Results

It appears that the "noise" in the C10B integrated model made it difficult to identify some of the changes in travel behavior related to the tested scenarios. All simulation models, of course, are noisy since they are probabilistic in nature, and model results vary from one run to another. But there are two components to the simulation involved in the C10B integrated model: the activity-based demand model (DaySim) and the traffic and transit simulation (DynusT/FAST-TrIPs). The propagation of noise due to this double simulation approach has not been examined.

Since SACOG is using an activity-based demand model for its planning purposes, they are familiar with the issues of simulation noise. Before the C10B project, SACOG had estimated the noise level in SACSIM/DaySim and used this information in the planning process. Such an assessment should be made with the C10B integrated model before it is used in a practical setting.

In theory, a simulation model should be run multiple times with the results averaged to get the noise to an acceptable level. This seldom happens in practice with current activity-based models in the United States, even with static highway and transit assignment procedures. It may be necessary to consider doing this for integrated models.

Run Time

The run time for the model as used in the policy tests by SACOG was about 70 h, for three big loops with 10 iterations of dynamic traffic assignment with DynusT within each loop. While this is a bit longer than advanced models using static assignment in larger metropolitan areas, it is quite reasonable given that limited time and resources were available for making the model more efficient. A model with runs times such as this would be practical in most settings.

It is important to point out that run times could be longer if some of the other issues already discussed were addressed. For example, the number of big loops and DynusT iterations was chosen on the basis of tests that showed a lack of improvement in convergence with additional iterations and loops. More iterations and loops might be expected to produce a tighter convergence, and perhaps if some of the validation issues were addressed, this could be achieved. However, this could not be tested within Project C10B.

It is also important to note that run times would be greater in regions larger than Sacramento. Even in Sacramento, run times would be longer for future-year scenarios in which the number of persons simulated would be greater, and higher levels of congestion might require additional loops and iterations to converge. Further improvements to the run time of the C10B integrated model should be investigated.

Future Applications and Additional Research

There are a number of areas for future research that follow from the work on SHRP 2 C10B:

- *Model validation.* Further work is needed to determine the level of effort required to achieve a full model validation consistent with industry standards. Additionally, further discussion is warranted about what specifically should comprise the validation of an integrated model such as this. The effects of using a fully validated model in policy testing should also be examined.
- *Convergence.* A tighter level of convergence than could be achieved during Project C10B is highly desirable. It is unknown whether the ability to achieve better convergence was limited by the nature of the integrated model, the way in which DynusT works, the characteristics of the transportation system and travel demand in the Sacramento region, or some other factors. It would be valuable to examine what level of convergence can be achieved in the C10B model and what types of model changes might be considered beyond simply running more loops or iterations to improve convergence.

- *Noise in model results.* Performing multiple model runs would provide useful information in measuring the magnitude of the noise related to the simulations in the C10B integrated model. It would be worthwhile to compare estimates of the noise with those associated with the activity-based model alone, to get a handle on the propagation of noise related to the multiple simulations that are part of the integrated model. Another area of valuable research would be tests to determine the number of model runs required to achieve stable results for a variety of types of planning analyses.
- *Run times.* Several areas of further work would provide useful information regarding run times. A detailed examination of the run times for various model components could help determine where the bottlenecks in the model stream are; then, ways of making those areas more efficient could be examined. The effects of different convergence levels on run times could be tested. The effects of greater demand and higher congestion levels on run times would be useful to examine. Additionally, the effects of more powerful hardware configurations on run time could be examined.

There are other areas where further research could help make models like the C10B integrated model more useful and practical. These include the following:

- *Decreasing the learning curve.* As discussed previously, it took substantial time and effort for project team members, especially those from SACOG (who performed most of the work on the policy testing of the model), to become familiar enough with the workings of the model—particularly DynusT and FAST-TrIPs (they were already familiar with SACSIM)—to be able to efficiently and effectively perform the policy tests. While many practitioners are familiar with traffic simulation, more transportation professionals need to be proficient in demand modeling and traffic simulation if models such as these are to become more widely used. There will need to be more organized training opportunities available for planners, such as those currently provided by government and educational organizations for travel demand modeling.
- *Testing the model in other geographic areas.* Now that the effort to develop the integrated model and the software to run it is complete, it is important to gather information on how well the model would perform in other areas. It would be particularly useful to test the model in places that are larger or notably different from Sacramento. It would be interesting to know how long such tests would take and the level of effort required to get the model up and running. Developing the regional highway network for dynamic assignment is one area known to require significant effort; staff training is another. Determining what other areas require substantial effort and what differences might arise in other regions may point to requirements that were not relevant in Sacramento.

CHAPTER 1

Introduction: Project Overview and Objectives

The second Strategic Highway Research Program (SHRP 2) Project C10B, Partnership to Develop an Integrated, Advanced Travel Demand Model with Fine-Grained, Time-Sensitive Networks: Sacramento-Area Application, is an important step in the evolution of travel modeling from an aggregate, trip-based approach to a completely dynamic, disaggregate methodology. In this project, an existing disaggregate activity-based model was integrated with an existing traffic simulation model to create a new, completely disaggregate model. Both models were implemented using open-source software.

At the same time that travel demand models have been evolving, traffic simulation models—which simulate the movements of vehicles through a highway network—have become more sophisticated due to improvements in computing. The product of SHRP 2 Project C10B is an integrated model that simulates individuals' activity patterns and travel and their vehicle and transit trips as they move on a real-time basis through the transportation system. It produces a true regional simulation of the travel within a region, for the first time using individually simulated travel patterns as input rather than aggregate trip tables to which temporal and spatial distributions have been applied to create synthetic patterns. A unique feature of this model is the simulation of transit vehicles as well as individual person tours using transit.

The new integrated model has been developed and implemented for the entire Sacramento, California, region. The integrated model components include (1) SACSIM, the regional travel model maintained by the Sacramento Area Council of Governments (SACOG), the regional metropolitan planning organization (MPO), and (2) DynusT, a mesoscopic traffic simulation model developed by the University of Arizona. SACSIM includes an activity-based demand model, DaySim. The transit simulation is performed by FAST-TrIPs, also developed by the University of Arizona. The integrated model also includes the ability to run MOVES, the air-quality analysis program developed by the U.S. Environmental Protection Agency (EPA).

While the C10B integrated model produces reasonable results for regional travel patterns and behavior, the true value of the model is its ability to provide analysis results that demonstrate sensitivity to policy variables more accurately than models that use aggregate demand or assignment procedures. This sensitivity was tested through a series of policy and project tests conducted by SACOG, using the new integrated model and the existing SACSIM model with aggregate assignment.

The SHRP 2 C10B project is documented in a series of four reports:

- *Dynamic, Integrated Model System: Sacramento-Area Application. Volume 1: Summary Report*;
- *Dynamic, Integrated Model System: Sacramental-Area Application. Volume 2: Network Report*;
- *Start-up Guide for the Dynamic, Integrated Model System: Sacramento-Area Application; and*
- *Network Users Guide for the Dynamic, Integrated Model System: Sacramento-Area Application.*

This report, the first in the series, describes the development, implementation, and testing of the integrated model.

Modeling Approach

To meet the objective of addressing key policy and investment questions by implementing an integrated, advanced travel demand model with a fine-grained, time-dependent network, the ideal approach is to combine the capabilities of an activity-based travel demand model with a traffic simulation model, adding enhancements to achieve goals such as the consideration of reliability in travel choices. Furthermore, to ensure success, it is essential to test this model in a "typical" metropolitan area that is large enough to encompass the necessary characteristics. Those characteristics include significant traffic congestion, a good-sized transit system, the need to perform air-quality conformity analysis, and a growing population to test the model for forecasting. However, the area should not be so large that the resources required for model development and testing and model execution times would jeopardize the project schedule and resources.

Project C10B implemented this approach by using the SACSIM travel demand model for the Sacramento area, which includes the original DaySim activity-based model, with the DynusT mesoscopic traffic microsimulation model. The integrated model was tested in the Sacramento metropolitan area, which is the 27th largest in the United States and has all of the desirable characteristics for testing the new model. The Sacramento area is growing rapidly and has a population just over 2 million. It is one of 35 U.S. metropolitan areas with a population between 1 million and 3 million and therefore similar in size to many metropolitan areas.

The Sacramento Area Council of Governments (SACOG) served as the public agency partner for this project. SACOG is the designated MPO for the metropolitan area and is responsible for all transportation planning in the region. As the designated MPO, SACOG is responsible for implementing the region's air-quality conformity analysis required by the EPA. The California Department of Transportation (Caltrans) supported SACOG's participation in the C10B project.

The components of the integrated model developed in the SHRP 2 C10B project include SACSIM, DynusT, FAST-TrIPs, and MOVES. These components are summarized in the following subsections and described in detail in Chapter 2.

SACSIM

SACSIM is a complete travel demand model that SACOG uses for planning in the Sacramento region. The demand for personal travel within the region is modeled by DaySim, an activity-based demand model. DaySim incorporates a variety of model features, including

- The ability to model each person in the Sacramento region separately through the use of a population synthesizer that creates a synthetic population representing each person and household in the region;
- The ability to model the complete daily activity pattern for each individual, including the number and sequencing of activities defined by seven purposes;
- A series of logit destination, mode, and time-of-day choice models at the tour and trip levels to simulate the choices for each individual;
- Estimation of the start and end times of all activities and trips to the half-hour level of resolution; and
- Parcel-level spatial resolution for home and activity locations.

Other components of SACSIM are used to model, at an aggregate level, the remaining components of regional travel—including travel into, out of, and through the region (external travel); truck travel; and travel to and from Sacramento International Airport.

DynusT

DynusT is a traffic simulation model that is used in a number of areas and lends itself well to integration with both SACSIM and MOVES. DynusT is a true disaggregate simulation model that can track individual vehicles and transit travelers through the network—consistent with tracking traveler activities in a travel demand model. Furthermore, DynusT is a true dynamic traffic assignment (DTA) model that takes into account both the spatial and temporal effects of congestion. Travelers departing at different times are assigned to routes calculated on the basis of the traveler's actual experienced travel time, which is a critical capability for establishing a consistent and reliable traffic assignment outcome.

FAST-TrIPs

The Flexible Assignment and Simulation Tool for Transit and Intermodal Passengers (FAST-TrIPs) is a model that assigns transit passengers within the transportation network and loads those passengers in a dynamic (time-sensitive) simulation of actual travel. This system essentially serves as a plug-in to DynusT but is precompiled with DynusT and runs with the DynusT executable.

FAST-TrIPs is a regionwide dynamic transit assignment model that determines an individual-specific transit route for each transit traveler in the system; it takes into account published transit schedules and transit vehicle run times that are congestion responsive and are provided by the traffic simulation component of DynusT. FAST-TrIPs deals with both transit-only and park-and-ride trips and is able to maintain multiple constraints associated with activity time-windows and the choice of modes in multimodal travel tours.

MOVES

The Motor Vehicle Emission Simulator (MOVES) is the next generation mobile source emission model developed by the EPA. MOVES serves as a single comprehensive system for estimating emissions from both on-road and nonroad mobile sources. It replaces EPA's MOBILE model as the approved model for state implementation plans (SIP) and regional or project-level transportation conformity analyses. MOVES is designed to estimate emissions at scales ranging from individual roads and intersections to large regions. The MOVES design represents a significant break from the MOBILE and

EMFAC (the California air-quality analysis program that measures emission factors) design: MOVES is a database-driven model—inputs, outputs, default activities, base modal emission rates, and all intermediate calculation data are stored and managed in MySQL database. MOVES model functions query and manipulate MySQL data pursuant to scenario parameters specified in a graphical user interface (GUI). This design also provides users with flexibility in constructing and storing their own database under the unified framework in MySQL. MOVES incorporates input data that include vehicle fleet composition, traffic activities, and meteorology parameters at the macro-, meso-, or microscale and conducts modal-based emissions calculations using a set of model functions. The outputs of emissions inventories or emissions factors are functions of modal-based vehicle emission rates and detailed vehicle activities specified for the desired geographic scale.

Compared with EMFAC and MOBILE (the currently approved on-road motor vehicle emission models used in California and the rest of the United States, respectively), the MOVES model represents a fundamental shift in the methodology used to estimate on-road vehicle emissions. EMFAC and MOBILE generally derive their emissions estimates from trip-based travel activities (e.g., vehicle-miles traveled, or VMT, during a time period); they link gram per mile emissions rates to average speeds by vehicle types and technologies, taking into consideration model years and vehicle deterioration over time. MOVES, in contrast, is a modal emissions model. Emission rates in MOVES are calculated based on vehicle-specific power (VSP) that is derived from second-by-second vehicle performance characteristics for various driving modes (e.g., cruise and acceleration). VSP—a measure of the power demand placed on a vehicle under various driving modes (speed and acceleration)—has been shown to have a better correlation with emissions than trip-based average vehicle speeds. The modal nature of the MOVES emission rates allows the model to, in principle, more accurately estimate emissions at analysis scales ranging from those associated with individual transportation projects to large regional emission inventories.

Some objectives of C10B required revisions to the capabilities of the existing models. These revisions, which are described in Chapter 2, include the ability to analyze the effects of reliability and the use of distributed values of time, important for the analysis of road pricing.

Software Approach

The software architecture for the integrated model allows users to access the modeling software using a web browser, with the major model components running on one or more shared servers. This allows for the efficient sharing of large data files, alleviates the need for every modeler to have a powerful desktop computer, and enables analysts to use parallel processing or other techniques as necessary to ensure adequate performance. The software architecture is efficient, modular, and maintainable and reduces the risk of changes to one model component affecting the operation of the model as a whole.

The software was developed using an iterative, incremental methodology that reduces risk, ensures continuous testing, and makes progress more transparent and predictable. The development approach has made virtually the entire suite of C10B products available to the transportation community. SACSIM and DynusT are available under open-source licenses, and the National Academy of Sciences (NAS) is the owner of all new software. While the tests of the model described in Chapter 4 used some input data from SACSIM that were developed using a proprietary modeling software package licensed to SACOG and Cambridge Systematics, Inc., the operation of the integrated model does not require any commercial travel demand modeling or simulation software. More details on the project software are presented in Chapter 3.

The software to run SACSIM is documented by Bowman and Bradley (2006). DynusT user documentation is available at www.dynust.net. Documentation of DynusT as used in the C10B integrated model is provided in the companion report to this report, *Dynamic, Integrated Model System: Sacramento-Area Application. Volume 2: Network Report* (Chiu et al. 2014).

Report Organization

This report is structured as follows. After this introductory chapter, Chapter 2 discusses the development of the integrated model and its components. Chapter 3 describes the implementation of the model. Chapter 4 presents information about the testing of the new integrated model. And Chapter 5 provides conclusions for the project and directions for further research.

CHAPTER 2

Development of the Integrated Model

This chapter describes the individual components that make up the C10B integrated model and how they were used in the new integrated model. The first section provides details on the model components: SACSIM (including DaySim), DynusT, FAST-TrIPs, and MOVES. The next section describes the revisions made to these models as part of the SHRP 2 C10B project. The third section provides information about the integration of the components.

Original Models

This section describes the original versions of the models that are the components of the C10B integrated model.

SACSIM

This section presents a brief summary of the Sacramento regional travel simulation model (SACSIM). SACOG uses this travel demand model in the preparation of transportation plan analyses. Complete documentation of SACSIM can be found in SACOG et al. (2008). SACSIM, the original version of which was completed in 2007, is one of the first activity-based models developed in the United States. While SACOG has more recently updated SACSIM, the original 2007 version—which was in use throughout the first part of Project C10B—is used in the C10B integrated model. The flow of SACSIM is displayed in Figure 2.1.

In activity-based models, person travel is modeled from a set of activities that require travel. The activity-based component of SACSIM, the person-day activity and travel simulator (DaySim), is implemented at the parcel level. The model flow for DaySim is shown in Figure 2.2.

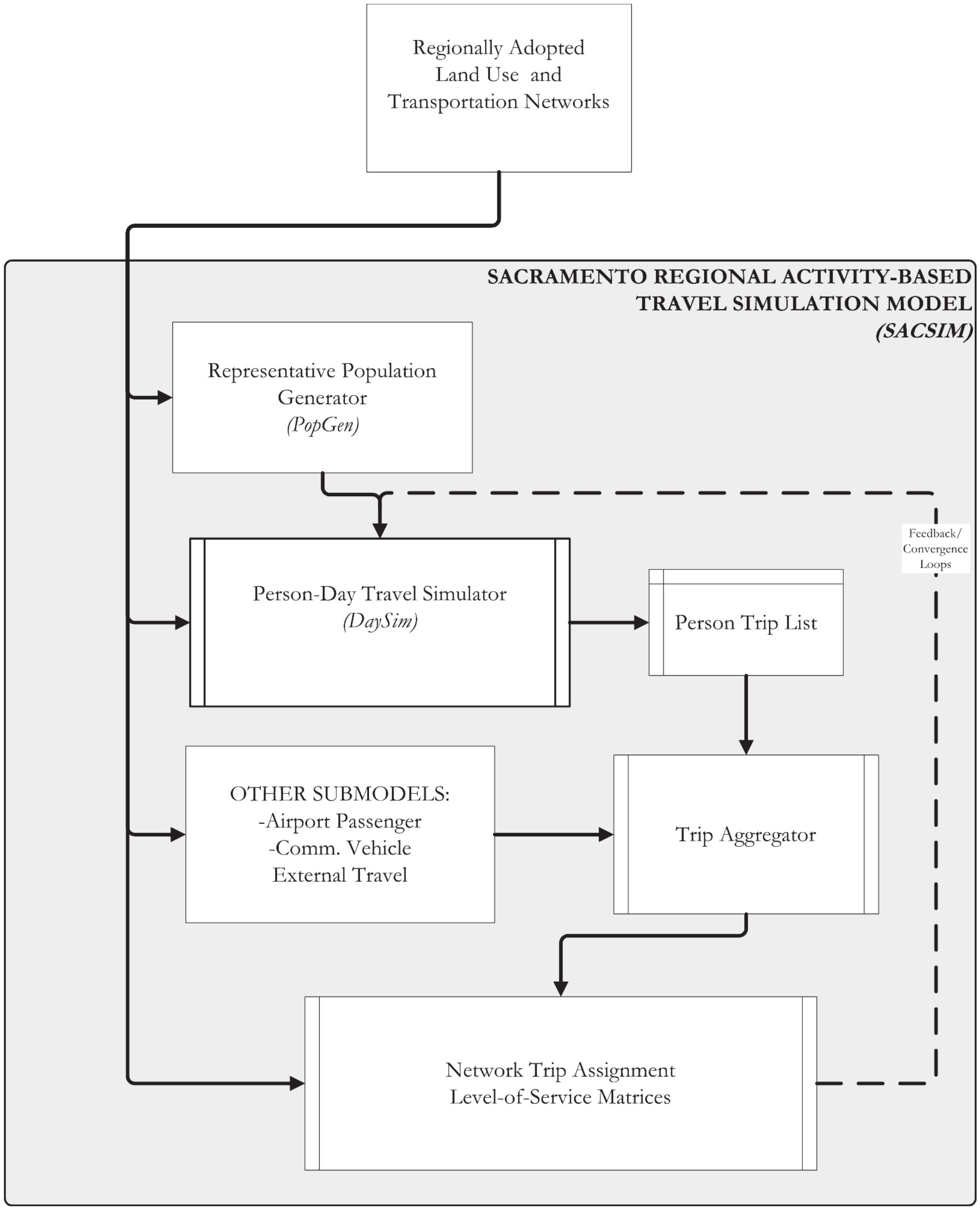
Besides DaySim, SACSIM includes other submodels, including commercial vehicle, external travel, and airport passenger ground access submodels. The major components of SACSIM are summarized in the following paragraphs.

A population synthesizer (referred to as "representative population generator," or PopGen, in Figure 2.1) creates a population database which is the basis for the activities and travel simulated in DaySim. The database comprises person records, drawn from Census Bureau Public Use Microdata Sample (PUMS) households in the Sacramento region. For each scenario, the population data set is consistent with regional residential, employment, and school enrollment forecasts in quantity, location, and key demographic variables such as age and income. Population data sets are generated for each forecast land use alternative and are treated as input files for testing transportation scenarios. The population data set can be modified directly (e.g., changing locations of specific households, changing income or age characteristics) to test the effects of different land use forecasts or demographic trend assumptions.

Within DaySim, long-term choices (work location, school location, and auto ownership) are simulated for each member of the population. DaySim creates a 1-day activity and travel schedule for each person in the population, grouping activities requiring travel into "tours" beginning and ending at the person's home. For each tour and each segment (trip) of each tour, destination, mode, and time-of-day choice at the half-hour level are simulated. The main output of DaySim is a list of all tours made by the synthetic population, including the trips on each tour.

In the version of SACSIM currently used by SACOG, the trips from the DaySim outputs are aggregated into trip matrices and combined with predicted trips for what is referred to in the C10B integrated model as "exogenous travel." Exogenous travel includes airport passenger ground access and egress travel, external travel, and commercial vehicle traffic. The exogenous travel is generated as zone-to-zone origin–destination matrices for four broad time periods. The aggregation process creates time- and mode-specific trip matrices, in person trips for transit assignment and vehicle trips for highway assignment.

The highway assignment model loads the trips from these matrices onto the highway network using a conventional



Source: SACOG et al. (2008).

Figure 2.1. SACSIM model system.

static equilibrium highway assignment process. A conventional static transit assignment process is used to load the transit person trips onto the transit network. The assignment process is performed for four broad time periods, representing the a.m. peak, midday, p.m. peak, and night periods. (For the C10B integrated model, these processes of aggregating to trip tables and performing static highway and transit assignments were replaced by DynusT and FAST-TrIPs.)

SACSIM iterates until convergence is achieved. Convergence is defined as a model's internal consistency of major data items (e.g., trip tables, traffic volumes, and level-of-service matrices) used throughout the model process.

DynusT

The dynamic traffic simulation and assignment model DynusT (**Dyn**amic **U**rban **S**ystems in **T**ransportation) is designed and implemented to perform simulation-based dynamic traffic assignment (DTA) and associated analysis. It is capable of performing DTA on regional-level networks over a long simulation period, making it particularly well-suited for

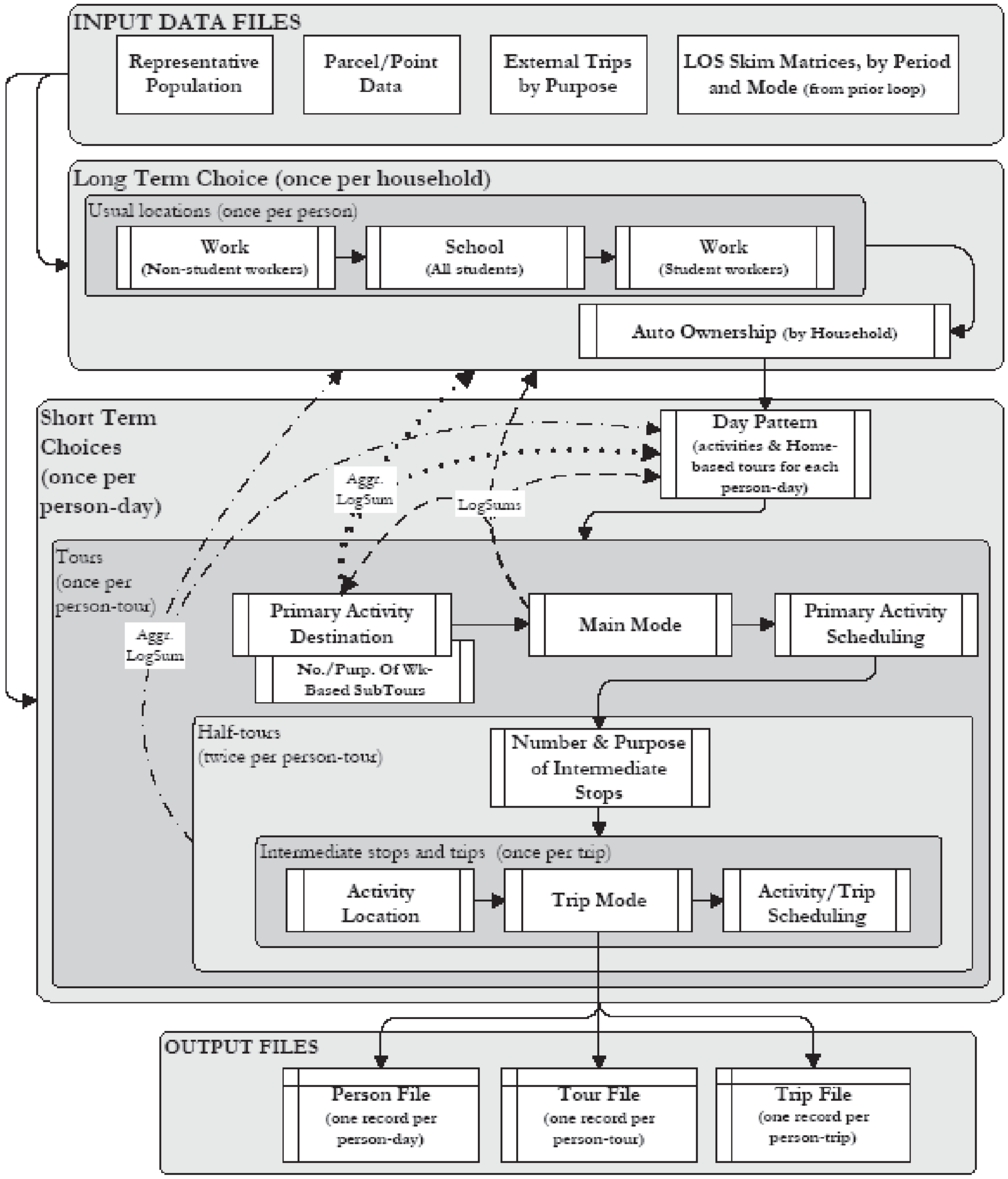


Figure 2.2. DaySim hierarchy and flow.

regional-level modeling such as regional transportation planning, corridor studies, integration with activity-based models, and mass evacuation modeling. This section briefly describes DynusT as implemented for the SHRP 2 C10B project; Volume 2 (Chiu et al. 2014) describes in detail the traffic simulation component of DynusT that captures capacity constraints, congestion, and queue propagation and allows the generation of time-dependent level-of-service (LOS) measures that are closer to traffic theory. DynusT determines the shortest-path route for each driver, a concept that is described as "user equilibrium."

DynusT consists of two main modules: traffic simulation and traffic assignment. Vehicles are created and loaded into the network based on their respective origins and follow a specific route to their intended destinations. The large-scale simulation of networkwide traffic is accomplished through the mesoscopic simulation approach that omits intervehicle car-following details while maintaining realistic macroscopic traffic properties (e.g., speed, density, and flow). More specifically, the traffic simulation is based on the Anisotropic Mesoscopic Simulation (AMS) technique (see Chiu et al. 2010) that calculates a vehicle's speed from the traffic conditions ahead of the vehicle. Specifically, at each simulation interval, a vehicle's speed is determined by a speed-density curve, the density being the number of vehicles per mile per lane within a limited forward distance.

The traffic assignment module of DynusT consists of two algorithmic components: a time-dependent shortest-path (TDSP) algorithm and a time-dependent traffic assignment, or routing. The TDSP algorithm determines the time-dependent shortest path for each origin, destination, and departure time; the traffic assignment component selects a route for each driver following some heuristic rules that lead to approximate user equilibrium, a condition in which each driver has selected the least-cost path available.

After shortest paths have been calculated and a route choice has been made, all the vehicles are simulated. DynusT uses the time gap between a vehicle's simulated travel time and the vehicle's available shortest-path time to assess the level of convergence. If the average time gap for all the vehicles in the simulation is small enough, DynusT terminates and outputs networkwide LOS measures; otherwise it continues iterating between its two models until convergence is achieved.

Although DynusT continues to evolve, the version included in this project was completed in 2012. This version included some enhancements made as part of this project to the existing DynusT version at the time. A key enhancement was the simulation of vehicles in the presence of transit vehicles with or without bus pullouts. As illustrated in Figure 2.3, when a bus pullout is present and a transit vehicle resides in the pullout, the passerby vehicles' speed-influencing regions (SIR) remain unchanged. On the other hand, without the pullout the stopped transit vehicle typically blocks one traffic lane, creating a temporal blockage to the following traffic steam. The departure from each stop involves different rules for frequency or schedule-based transit. The main difference is that for schedule-based transit operation, a transit vehicle needs to be held until the scheduled departure time if the transit vehicle is still ahead of schedule after boarding and alighting. Such vehicle holding is unnecessary in frequency-based operation.

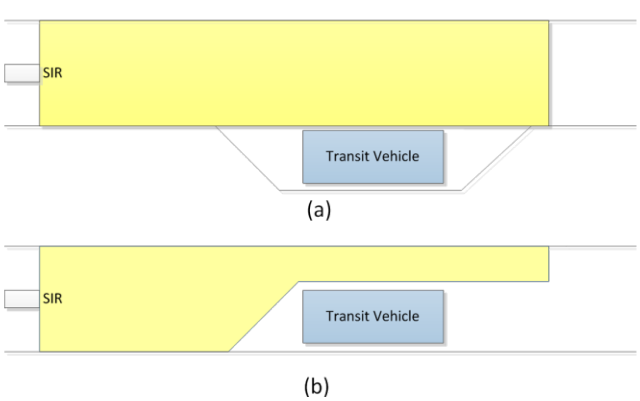


Figure 2.3. SIR areas with (a) and without (b) bus pullouts.

Another enhancement to DynusT was made to consider that in the C10B integrated model, demand is generated from a tour-based travel model (DaySim). Before this information can be used for traffic simulation purposes, it must be manipulated to meet DynusT's specific network and demand inputs. DynusT demand inputs take two forms: (1) the typical origin–destination (O-D) table for specified time periods and (2) vehicle and path files. In general, the exogenous travel components (truck, external, and airport vehicle trips) yield O-D demand files given diurnal factors, while tour/trip records yield vehicle and path demand files.

Generating DynusT's vehicle demand file is a more involved process because it requires detailed trip information as opposed to O-D demand files that simply require O-D and diurnal factors. Examples of this mandatory information include household identification (ID), traveler/person ID, tour/trip ID, origin–destination parcels/points, origin–destination zones, mode choice, travel time, value of time, and arrival/departure time. The purpose of this information is to represent a trip as realistically as possible within DynusT's node-link–based network and context. Examples of this "realistic" representation not only entail correct zone vehicle generation or destinations but, most important, also ensure that a specific person's trip reaches its destination before his or her next trip (tour) is generated. This instance is usually prevalent in networks with congestion or disruption or trips that are sequenced immediately after one another.

FAST-TrIPs

This section provides a brief summary of FAST-TrIPs as implemented in the SHRP 2 C10B integrated model. The companion document (Chiu et al. 2014) provides more details of the implementation. FAST-TrIPs interfaces with DynusT and also connects with the DaySim activity-based model.

FAST-TrIPs is a regionwide dynamic transit assignment model that determines an individual-specific transit route for each transit traveler in the system, taking into account published transit schedules and transit vehicle run times that are congestion responsive and are provided by the traffic simulation component of DynusT. FAST-TrIPs deals with both transit-only and park-and-ride trips and is able to maintain multiple constraints associated with activity time-windows and the choice of modes in multimodal travel tours. DynusT and FAST-TrIPs interoperate with each other to provide a model system in which the highway and transit assignments influence each other and are based on the same set of LOS variables.

FAST-TrIPs is divided into two main submodules: transit assignment and simulation. The transit assignment submodule plays the role of passenger assignment for given O-D pairs. For assigning transit passengers for the O-D pairs, a trip-based shortest path model is utilized by searching for a feasible path on each O-D pair. The assigned passengers, including their paths, are given to and simulated through the transit simulation submodule in FAST-TrIPs.

During the simulation, experienced arrival and departure times of transit vehicles are used to simulate boarding and alighting of passengers, considering transfers and other components (such as walking and waiting). Each passenger's trajectory (i.e., experienced path) is recorded, and dwell time for each transit route is calculated as a function of the boardings and alightings at each stop. Results of the simulation are used in the next iteration of auto-transit vehicle simulation and are also fed back to the activity-based model in the next global iteration for updating the demand.

FAST-TrIPs has an intermodal functionality embedded in its two submodules. It is capable of assigning and simulating the intermodal passengers in a mixed environment, modeling these movements for auto and transit passengers. The intermodal model consists of a park-and-ride assignment model for individual tours, a transit assignment and transit simulation model for the transit portion of the tour, and an interface with DynusT for the auto assignment and simulation.

MOVES

The Motor Vehicle Emission Simulator (MOVES) is the current regulatory mobile source emissions model developed by the EPA. MOVES serves as a single comprehensive system for estimating emissions from on-road mobile sources and is officially approved for developing state implementation plans (SIPs) and regional or project-level transportation conformity analyses. MOVES is designed to estimate emissions at scales ranging from individual roadways and intersections to large regions.

MOVES is a database-driven model. The inputs, outputs, default vehicle activities, base modal emission rates, and all intermediate calculation data of MOVES are stored and managed in MySQL databases (see Figure 2.4 for an example). MOVES model functions query and manipulate MySQL data

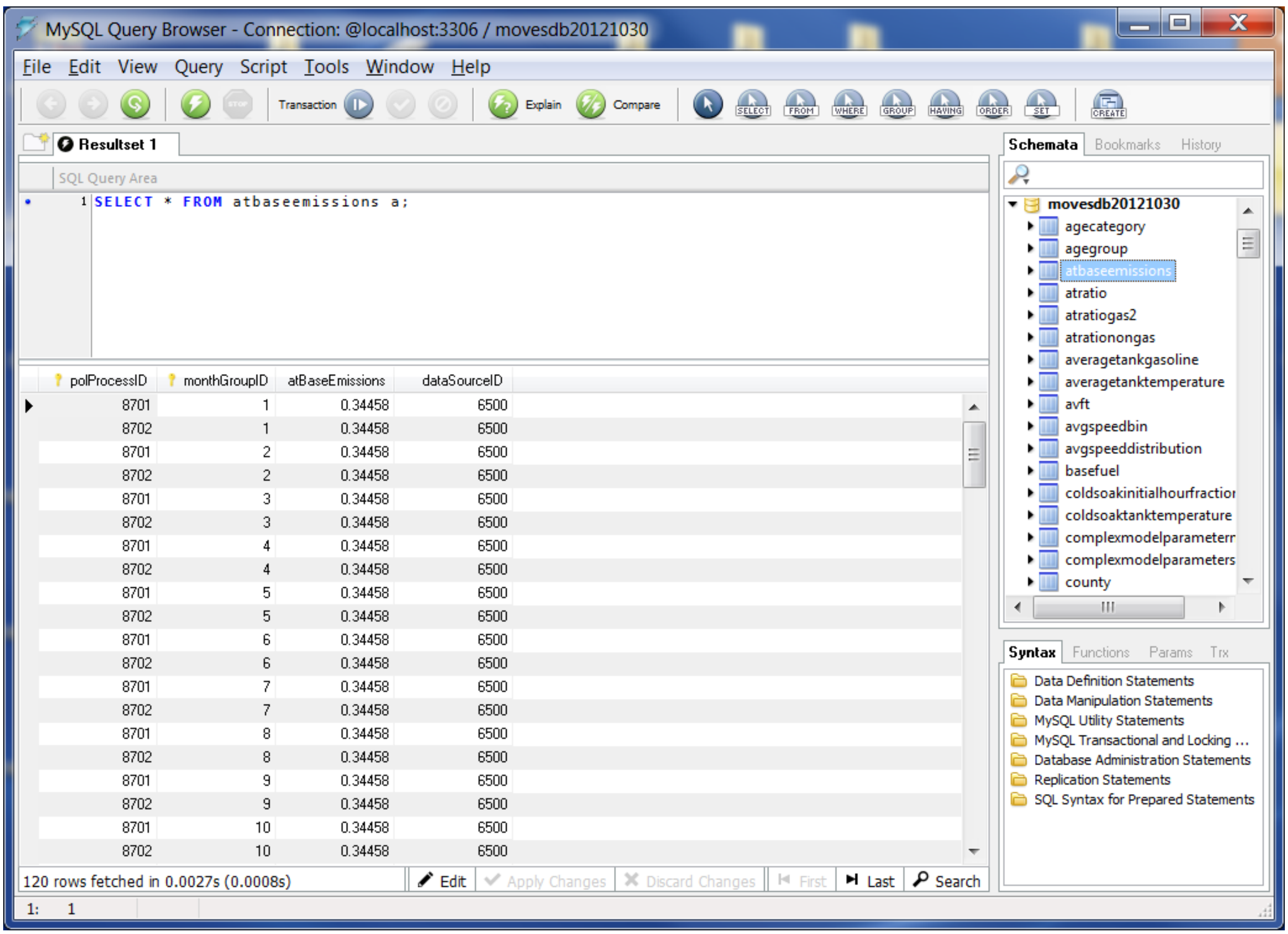


Figure 2.4. Sample emissions data table in MOVES MySQL database.

pursuant to scenario parameters specified in a graphical user interface (see Figure 2.5). This design provides users with flexibility in constructing and storing their own database under the unified framework in MySQL. The MOVES model incorporates input data that include vehicle fleet composition, traffic activities, and meteorology parameters at the macro-, meso-, or microscale, and conducts modal-based emissions calculations using a set of model functions. The outputs of emissions inventories or emissions factors are functions of modal-based vehicle emission rates and detailed vehicle activities specified for the desired geographic scale.

The MOVES model represents a fundamental shift in the methodology used to estimate on-road vehicle emissions from that of its predecessors (e.g., the MOBILE6 model, which used average speed as the only traffic-related variable to estimate vehicle emissions). MOVES is a modal emissions model in which emissions are calculated based on vehicle-specific power (VSP) derived from second-by-second vehicle performance characteristics for various driving modes (e.g., cruise and acceleration). The modal nature of the MOVES methodology allows the model to, in principle, more accurately estimate emissions at analysis scales ranging from those associated with individual transportation projects to large regional emission inventories.

Since MOVES was first released in 2005, EPA has been working to refine the model; example improvements over time include updated modeling data, calculation functions, and feature improvements. After the development of two intermediate versions of MOVES (MOVES2004 and MOVES-HVI Demo), EPA released Draft MOVES2009, MOVES2010, MOVES2010a, and MOVES2010b versions, which provide enhanced modeling functions, updated data sources, and bug

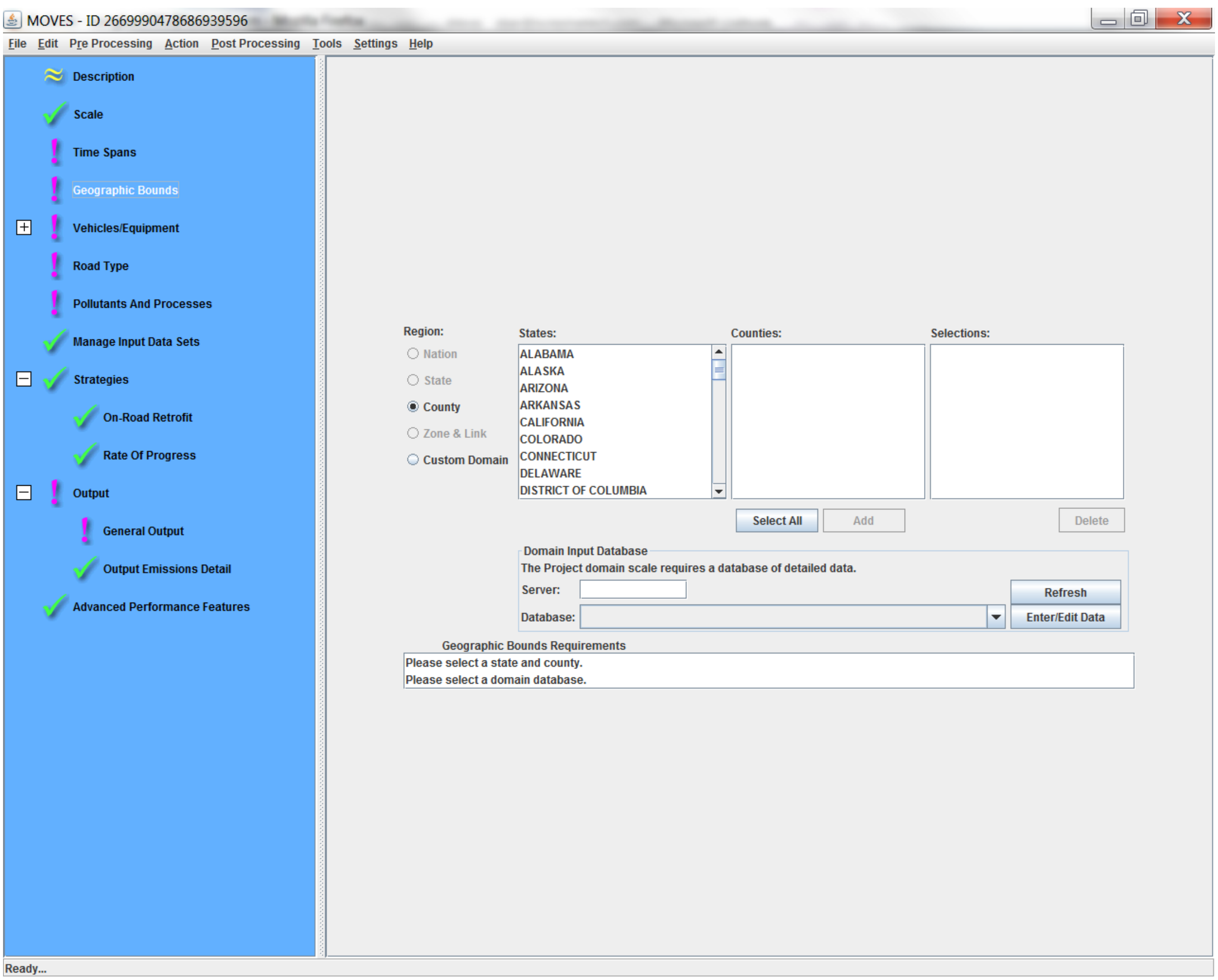


Figure 2.5. MOVES graphical user interface, geographic bounds page.

fixes (see http://www.epa.gov/otaq/models/moves/index.htm for EPA's MOVES documentation). The University of Illinois, Chicago, and Sonoma Technology, Inc., applied the most recently available MOVES versions during the course of the C10B project (i.e., MOVES2010 and MOVES2010a, released in December 2009 and August 2010, respectively). The MOVES-DynusT integration and data processing approaches are valid for all recent MOVES versions, including MOVES2010b, released by EPA in April 2012.

Revisions to Original Models for SHRP 2 C10B

To meet the objectives of the SHRP 2 C10B project, some revisions were made to the original models that make up the integrated model. This section describes these revisions.

Incorporation of Variable Value of Time

One of the shortcomings of aggregately applied models is the need to use average values across broad market segments for key parameters. One example is the use of a single value of travel time for each segment for decisions about mode and route choice. The value of time determines the extent to which travelers will pay to save travel time. This is an important factor in estimating how many and which travelers might use toll roads or managed lanes.

In conventional models, and even in existing disaggregately applied activity-based models, trade-offs between cost and time are based on relative cost and time parameters. In mode choice models, the parameters may vary by tour or trip purpose and by income level, but the assumed value of time is the same for each traveler within a purpose/income-level segment. In the aggregate route choice (highway assignment) models used in nearly all regions, the value of time is a parameter that may vary by vehicle class; but these classes are usually defined only by vehicle type (auto, truck) and vehicle occupancy level. Some newer models have begun to incorporate additional segmentation by tour/trip purpose and income level, effectively matching the type of segmentation used in mode choice.

The main drawback to this segmentation approach is that individual values of time can vary substantially within these market segments. This variation may lead to inaccurate estimates of who would use priced roadways. Because the values of time for segments are averages, they do not include the extremes of very high or low values of time. Furthermore, segmentation used to define values of time may coincide with the segmentation needed for analysis of model results. For example, if a planner wishes to estimate the impacts of a toll road project on low-income travelers, assuming that everyone in that segment behaves the same can produce unreliable results.

Because an activity-based model simulates each individual, an individualized value of time for each individual can be simulated from a probability distribution. This has been done with other activity-based models, such as the SF-CHAMP model (Sall et al. 2010) maintained by the San Francisco County Transportation Authority (SFCTA). However, since nearly all activity-based models use aggregate static assignment procedures, segmentation and averaging are still required, and the effects of the individual values of time cannot be used in the highway assignment process.

Because it incorporates both activity-based demand modeling and traffic simulation, the C10B integrated model provides an opportunity to use individual values of time throughout the modeling process. The methods incorporated into the integrated model are described in this section. The original DaySim models are documented in the SACSIM documentation (SACOG et al. 2008).

Model Specifications

The approach used was to revise the tour mode choice model in DaySim, preserving as much of the existing model as possible. The original DaySim model has models for five tour purposes: work, school, escort, other, and work-based tours. Each model is a nested logit model except the escort purpose, which was estimated as a multinomial logit (MNL) model. The revised models preserve all of the alternative-specific variables included in the original DaySim mode choice models. The only changes to the models are the specification of network LOS variables (e.g., cost and travel time) and the addition of variable value of time (VOT).

A key attribute of the original DaySim mode choice models is how out-of-vehicle time (OVT) is specified. Walk and bike access/egress times for transit have the same impact on modal utility of transit alternatives as walk and bike times for nonmotorized modes have on modal utility of walk and bike modes. However, walk and bike speeds can vary widely across individuals and depending on terrain and accessibility. Moreover, individuals may perceive nonmotorized modes in different ways from motorized modes of travel. Thus, in the revised model, walk and bike times were treated separately from other motorized mode travel times (as is the case in many other mode choice models). The new specification removed the walk and bike mode travel times from the OVT variables and created two new variables: a walk distance variable and a bike distance variable. These new variables were nonzero only for the walk and bike modes. Since the network skim variables attached to the survey data did not associate any OVT with automobile modes, the new specification has OVT variables for transit modes only.

Variable VOT is achieved in the new mode choice models by specifying a distribution for the in-vehicle time (IVT) coefficient, in this case a lognormal distribution. With a fixed cost coefficient, the VOT distribution can be described easily. Instead of estimating a fixed coefficient for OVT in the new models, the ratio of OVT to IVT (typically in the range of 2.0 to 3.0) was estimated. This means the coefficient for OVT also follows a lognormal distribution but is determined by the IVT distribution and the ratio of OVT to IVT.

Because of the lack of travel cost variations in the survey data set used to estimate the original tour mode choice models (there are no toll roads in the Sacramento region), VOT distributions were transferred from the San Francisco region. SFCTA and its consultants used stated preference data to estimate distributions of VOT for mode and time-of-day choice (Sall et al. 2010). VOT distributions were estimated for four income-level segments.

The SFCTA model was chosen as the basis for the C10B work for two reasons. First, it was conducted recently and in a nearby region similar in many ways to the Sacramento region. Second, the implications of the estimated VOT distributions seem reasonable. Figure 2.6 shows the estimated VOT distributions for each of four income categories specific to mandatory travel purposes. For nonmandatory travel purposes, mandatory VOTs are multiplied by a factor of two-thirds.

It is important to note that the only parameters imported to DaySim mode choice models from the SFCTA models are those related to the distributions shown in Figure 2.6. Ratios of OVT to IVT were not taken from the SFCTA model, nor was the scale of the SFCTA model. All parameters related to non-LOS variables were estimated using the Sacramento estimation data set.

Model Estimation Results

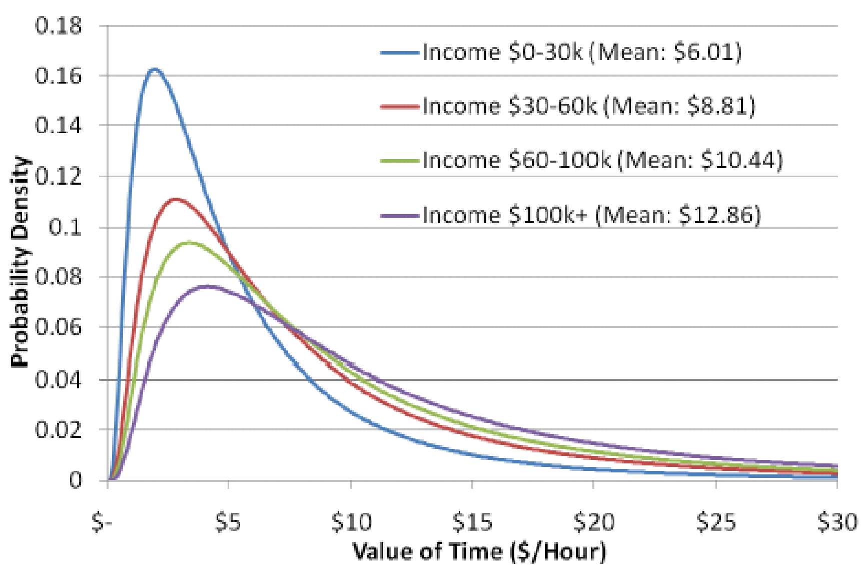
The model estimation results are shown in a set of tables, as follows:

- Table 2.1. Work Tour Mode Choice Estimation Results,
- Table 2.2. School Tour Mode Choice Estimation Results,
- Table 2.3. Escort Tour Mode Choice Estimation Results,
- Table 2.4. Home-Based Other Tour Mode Choice Estimation Results, and
- Table 2.5. Work-Based Subtour Mode Choice Estimation Results.

The first column of each table (Applicable Modes) indicates to which modes each coefficient relates. The following abbreviations are used in the tables:

- DT—drive to transit;
- WT—walk to transit;
- DA—drive alone;
- S2—shared ride, 2 occupants;
- S3—shared ride, 3+ occupants;
- BI—bicycle;
- WK—walk; and
- SB—school bus (school tours only).

Table 2.6 summarizes model fit statistics for the five models. Details of the estimation process, including several issues encountered, can be found in Lemp et al. (2011).



Source: Sall et al. (2010).

Figure 2.6. SFCTA work tour value-of-time distributions.

Table 2.1. Work Tour Mode Choice Estimation Results

Applicable Modes	Variable	Coefficient	*t*-stat
Level-of-Service			
DA, S2, S3, DT, WT	Cost-Income < $30,000	–0.1498	Constr.
DA, S2, S3, DT, WT	Cost-Income: $30,000–60,000	–0.1022	Constr.
DA, S2, S3, DT, WT	Cost-Income: $60,000–100,000	–0.0862	Constr.
DA, S2, S3, DT, WT	Cost-Income > $100,000	–0.0700	Constr.
DA, S2, S3, DT, WT	Cost-Missing Income	–0.0462	–1.15
DA, S2, S3, DT, WT	Mean IVT (min)	–0.0150	Constr.
DA, S2, S3, DT, WT	Coefficient of Variation of VOT	1.065	Constr.
DT, WT	Ratio Wait to IVT	2.50	Constr.
DT, WT	Ratio Walk/Bike to IVT	3.00	Constr.
BI	Distance (mi)	–0.302	–7.72
WK	Distance (mi)	–0.956	–7.82
Mode-Specific			
DT	Constant	–3.120	–4.96
DT	HH fewer cars than workers	–1.191	–1.36
DT	Drive time/total IVT	–0.831	–0.60
WT	LRT walk access	2.292	2.49
WT	Constant	–2.926	–6.39
WT, DT	Mixed-use density at destination	0.0109	6.54
S3	Constant	–2.175	–5.50
S2, S3	HH #children < age 5	0.361	2.67
S2, S3	HH #children age 5–15	0.283	4.40
S2, S3	HH #nonworking adults 18+	–0.122	–1.25
S2, S3	Log of auto distance (mi)	–0.201	–3.99
S3	One-person HH	–1.088	–3.02
S3	Two-person HH	–1.255	–4.07
S2	Constant	–1.700	–4.63
S2, S3	No cars in HH	–2.791	–4.17
S2, S3	HH fewer cars than drivers	0.527	3.53
S2	One-person HH	–0.725	–2.71
S2, S3	Escort stop purpose/#tours in day	3.479	9.10
S2, S3	Other stop purposes/#tours in day	0.339	2.29
DA	Constant	0.760	2.23
DA	HH fewer cars than workers	–1.093	–5.80
DA	HH income < $25,000	–0.709	–3.87
DA	Escort stop purpose/#tours in day	–2.124	–4.95
DA	Other stop purposes/#tours in day	0.127	0.92

(continued on next page)

Table 2.1. Work Tour Mode Choice Estimation Results (continued)

Applicable Modes	Variable	Coefficient	*t*-stat
BI	Constant	–2.914	–5.24
BI	Male	1.068	3.12
BI	Age > 50	–0.769	–2.22
BI	Davis zones	2.818	7.79
BI	Mixed-use density at origin	0.0105	2.66
WK	Male	–0.717	–2.12
WK	Mixed-use density at origin	0.00661	1.85
All	Mode nesting parameter	0.773	5.14

Table 2.2. School Tour Mode Choice Estimation Results

Applicable Modes	Variable	Coefficient	*t*-stat
Level-of-Service			
DA, S2, S3, WT	Cost-Income < $30,000	–0.1947	Constr.
DA, S2, S3, WT	Cost-Income: $30,000–60,000	–0.1328	Constr.
DA, S2, S3, WT	Cost-Income: $60,000–100,000	–0.1121	Constr.
DA, S2, S3, WT	Cost-Income > $100,000	–0.0910	Constr.
DA, S2, S3, WT	Cost-Missing Income	–0.0585	Constr.
DA, S2, S3, WT	Mean IVT (min)	–0.0130	Constr.
DA, S2, S3, WT	COV of VOT	1.065	Constr.
DA, S2, S3, WT	Ratio OVT to IVT	2.20	Constr.
BI	Distance (mi)	–0.445	–5.47
WK	Distance (mi)	–0.711	–10.42
Mode-Specific			
SB	Constant	–1.295	–4.05
SB	Child < age 5	–0.666	–0.82
SB	Adult age 18+	–3.735	–3.61
WT	Constant	–2.653	–5.05
WT	No cars in HH	1.314	2.38
WT	HH fewer cars than drivers	0.662	1.80
WT	Child < age 5	–4.000	Constr.
WT	Adult age 18+	1.721	4.00
WT	Child age 16–17	1.229	2.65
WT	Mixed-use density at origin	0.0120	2.57
WT	Mixed-use density at destination	0.00590	1.31

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Table 2.2. School Tour Mode Choice Estimation Results (continued)

Applicable Modes	Variable	Coefficient	*t*-stat
S3	Constant	–0.0168	–0.05
S3	One- or two-person HH	–1.096	–4.36
S2	One-person HH	–1.224	–1.15
S2	Constant	–0.568	–1.81
S2, S3	No cars in HH	–2.116	–3.54
S2, S3	HH income < $25,000	–0.605	–3.20
S2, S3	HH income: $25,000–50,000	–0.402	–2.83
S2, S3	Child < age 5	1.447	2.53
S2, S3	Escort stop purpose/#tours in day	1.450	5.00
S2, S3	Other stop purposes/#tours in day	0.258	2.41
DA	Constant	1.725	4.40
DA	HH fewer cars than drivers	–1.245	–5.07
DA	HH income < $25,000	–1.408	–4.26
DA	HH income > $75,000	0.490	1.81
DA	Child age 16–17	–1.878	–7.47
DA	Escort stop purpose/#tours in day	–2.352	–2.56
DA	Other stop purposes/#tours in day	0.297	1.38
BI	Constant	–2.213	–5.29
BI	Male	0.693	2.41
BI	Davis zones	3.152	10.07
BI	Adult age 18+	0.837	2.55
WK	Intersection density at origin	0.00782	2.00
All	Mode nesting parameter	0.850	Constr.

Table 2.3. Escort Tour Mode Choice Estimation Results

Applicable Modes	Variable	Coefficient	*t*-stat
Level-of-Service			
S2, S3	Cost-Income < $30,000	–0.2995	Constr.
S2, S3	Cost-Income: $30,000–60,000	–0.2043	Constr.
S2, S3	Cost-Income: $60,000–100,000	–0.1724	Constr.
S2, S3	Cost-Income > $100,000	–0.1400	Constr.
S2, S3	Cost-Missing Income	–0.0900	Constr.
S2, S3	Mean IVT (min)	–0.0200	Constr.
S2, S3	COV of VOT	1.065	Constr.
WK	Distance (mi)	–3.071	–5.41

(continued on next page)

Table 2.3. Escort Tour Mode Choice Estimation Results (continued)

Applicable Modes	Variable	Coefficient	*t*-stat
Mode-Specific			
S3	Constant	–0.830	–1.01
S3	HH #children < age 5	0.908	6.28
S3	HH #children age 5–15	0.465	7.60
S3	HH #children age 16–17	–0.371	–2.85
S2	Constant	0.0284	0.03
S2, S3	No cars in HH	–6.096	–4.69
WK	Age > 50	–0.664	–0.89
WK	Intersection density at destination	0.0178	2.23
WK	HH #children < age 5	1.041	2.83
WK	HH #children age 5–15	0.447	2.18
WK	HH #children age 16–17	–1.621	–2.64
All	Mode nesting parameter	1.00	Constr.

Table 2.4. Home-Based Other Tour Mode Choice Estimation Results

Applicable Modes	Variable	Coefficient	*t*-stat
Level-of-Service			
DA, S2, S3, WT	Cost-Income < $30,000	–0.2696	Constr.
DA, S2, S3, WT	Cost-Income: $30,000–60,000	–0.1839	Constr.
DA, S2, S3, WT	Cost-Income: $60,000–100,000	–0.1552	Constr.
DA, S2, S3, WT	Cost-Income > $100,000	–0.1260	Constr.
DA, S2, S3, WT	Cost-Missing Income	–0.0810	Constr.
DA, S2, S3, WT	Mean IVT (min)	–0.0180	Constr.
DA, S2, S3, WT	COV of VOT	1.065	Constr.
DA, S2, S3, WT	Ratio OVT to IVT	2.70	Constr.
BI	Distance (mi)	–0.192	–6.36
WK	Distance (mi)	–1.200	–17.75
Mode-Specific			
WT	Constant	–4.569	–6.60
WT	No cars in HH	3.009	4.12
WT	Intersection density at origin	0.00744	1.44
WT	Mixed-use density at destination	0.00593	1.32
WT	Shopping tour	–1.3488	–1.45
WT	Meal tour	1.600	2.08

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Table 2.4. Home-Based Other Tour Mode Choice Estimation Results (continued)

Applicable Modes	Variable	Coefficient	*t*-stat
S3	Constant	–0.916	–3.13
S2, S3	HH #children < age 5	0.483	4.55
S2, S3	HH #children age 5–15	0.0785	1.62
S2, S3	HH #nonworking adults 18+	0.168	3.80
S2, S3	Log of auto distance (mi)	0.204	6.05
S3	One-person HH	–2.769	–12.10
S3	Two-person HH	–1.500	–16.45
S2	Constant	–0.892	–3.08
S2, S3	No cars in HH	–0.816	–2.03
S2, S3	HH fewer cars than workers	–0.305	–1.25
S2	One-person HH	–1.301	–9.74
S2, S3	Escort stop purpose/#tours in day	1.249	3.16
S2, S3	Other stop purposes/#tours in day	0.343	2.32
S2, S3	Shopping tour	0.191	2.22
S2, S3	Meal tour	1.710	11.37
S2, S3	Social/recreational tour	0.427	4.44
DA	Constant	0.778	2.74
DA	HH fewer cars than drivers	–0.618	–6.80
DA	Escort stop purpose/#tours in day	–0.796	–1.91
DA	Other stop purposes/#tours in day	0.185	1.24
BI	Constant	–3.976	–8.17
BI	Male	0.770	2.56
BI	Age > 50	–0.416	–1.38
BI	Davis zones	2.296	6.67
BI	Intersection density at origin	0.00453	1.08
BI	Mixed-use density at origin	0.00977	2.23
BI	Social/recreational tour	0.606	1.81
WK	Age > 50	–0.322	–1.67
WK	Davis zones	0.993	3.36
WK	Intersection density at origin	0.0055	2.64
WK	Meal tour	1.112	3.15
WK	Social/recreational tour	0.969	4.70
All	Mode nesting parameter	0.850	Constr.

Table 2.5. Work-Based Subtour Mode Choice Estimation Results

Applicable Modes	Variable	Coefficient	*t*-stat
Level-of-Service			
DA, S2, S3, WT	Cost-Income < $30,000	–0.2995	Constr.
DA, S2, S3, WT	Cost-Income: $30,000–60,000	–0.2043	Constr.
DA, S2, S3, WT	Cost-Income: $60,000–100,000	–0.1724	Constr.
DA, S2, S3, WT	Cost-Income > $100,000	–0.1400	Constr.
DA, S2, S3, WT	Cost-Missing Income	–0.0900	Constr.
DA, S2, S3, WT	Mean IVT (min)	–0.0200	Constr.
DA, S2, S3, WT	COV of VOT	1.065	Constr.
DA, S2, S3, WT	Ratio OVT to IVT	2.80	Constr.
BI	Distance (mi)	–0.202	–0.64
WK	Distance (mi)	–1.314	–8.08
Mode-Specific			
WT	Constant	–4.094	–5.08
S3	Constant	–2.612	–2.64
S2	Constant	–3.710	–3.74
S2, S3	Drive alone to work	2.115	2.37
S2, S3	Shared ride to work	2.265	2.59
DA	Constant	–4.092	–2.93
DA	HH income < $25,000	–0.607	–1.31
DA	HH income: $25,000–50,000	–0.288	–1.22
DA	Drive alone to work	4.243	3.32
DA	Shared ride to work	3.163	2.49
BI	Constant	–11.380	–2.96
BI	Male	2.200	0.70
BI	Davis zones	8.506	3.23
BI	Bike to work	7.500	Constr.
WK	Mixed-use density at origin	0.00670	2.80
WK	Walk to work	5.500	Constr.
All	Mode nesting parameter	0.750	Constr.

Table 2.6. Model Fit Statistics

Measure	Work	School	Escort	Other	Work-Based
Observations	3,063	1,484	877	4,526	573
Log likelihood	1,961.7	1,825.4	–603.9	4,306.4	–572.2
Log likelihood @ zero	4,993.1	2,560.8	–897.8	7,293.1	–950.1
Log likelihood constants only	2,870.1	2,246.4	–744.9	5,244.8	–655.7
Pseudo Rho squared @ zero	0.607	0.287	0.327	0.410	0.398
Pseudo Rho squared constants only	0.317	0.187	0.189	0.179	0.127

Incorporation of Reliability

A method was developed for including reliability into the C10B analysis framework. This section describes the method and how it was implemented in DynusT.

The reliability procedure is based at the link level, not the O-D level. The primary purpose was to get reliability estimates as an output from the model, as additional performance measures. However, it is noted that as an input to traveler behavior models, it is the trip reliability that should ideally be used. The method developed for incorporating reliability was a compromise based on a number of constraints:

- The scenario method—as explored in SHRP 2 Projects L04, L08, and several previous studies—was ruled out because it would involve multiple runs of the model for each improvement type tested, and run time of the model is high. (The scenario approach is based on defining multiple runs for studying a single improvement type, each made with varying input levels for the factors affecting reliability, such as incidents and demand.) Furthermore, developing scenarios for incidents and work zones on a regional basis is problematic: Where and when to do they start? Focusing on an individual facility would have helped with this problem; but the model only deals with the reliability of trips on that facility, not regionally. This is a big issue moving forward in incorporating reliability into regional models.
- Project L04 developed a vehicle trajectory processor for simulation models which would have been useful—it could have been used to develop trip-based reliability; but the project schedules did not coincide. The reliability procedure needed to be easily accommodated by SACSIM without any adjustments of recalibration. Therefore, the project team opted for an approach that is based on using indirect measures for assessing reliability. This method is based on the idea that travelers perceive each minute of travel under different conditions with a certain weight [see, for example, Small et al. (1999) and Levinson et al. (2004)]. The concept was originally developed to account for travelers valuing a unit of time under congestion more highly than uncongested time. The project team adapted this approach by assuming that the weight associated with perceived travel time was the reliability component of travel on a link, adjusted for the reliability ratio so that it equilibrates with average travel time. This results in a travel time value that is inflated over what it otherwise would be, a "travel time equivalent." In the traditional weighting approach, the travel time weights are scaled to increase with increasing link volume-to-capacity (v/c) level. Because unreliability increases as base congestion grows, the travel time equivalents also increase with v/c level. The activity-based model portion of the SACSIM model treats the travel time equivalent in the same manner as it would an average travel time without the need for internal adjustments, mechanically speaking, that is. Functionally, how this inflated travel time would affect a model that has been calibrated to average travel time only is unknown.

In the future, it will be desirable to account for reliability directly in the traveler behavior modeling process.

Quantifying Reliability

As an input, reliability affects travelers' decisions about trip making and the choice of destination, mode, and route. It can be thought of as an extra impedance to travel over and above the average travel time generally used in demand models. Note that the original model's definition of average travel time is based solely on recurring (demand and capacity) conditions. Considering reliability means that nonrecurring sources of congestion factor into the process.

The concept of "extra impedance due to unreliable travel" is probably the best way to incorporate reliability into the modeling structure as an input. SHRP 2 Project L04 (Stogios et al. forthcoming) used this approach, in which the impedance on a link can be captured as a generalized cost function that includes both the average travel time and its standard deviation (which is used as the indictor of reliability). Because Project L04 was not complete at the time of the relevant work in Project C10B, this project used travel time equivalents.

To apply this method, a method must exist for predicting the standard deviation of travel time. SHRP 2 Project L03 (Cambridge Systematics, Inc., et al. 2013) developed such methods from empirical data, using the Travel Time Index (*TTI*) as the dependent variable. The *TTI* is defined as the ratio of the actual travel time to the travel time under free-flow conditions, or equivalently:

$$TTI = FreeFlowSpeed / ActualSpeed \quad (2.1)$$

Equation 2.1 is a generalized equation for *TTI*. The following discussion defines several versions of the *TTI* for use in reliability estimation. In addition to the *TTI* calculation, free-flow speed is required for estimating delay. In DynusT networks, each link is specified with a free-flow speed, so such a value can be readily used for *TTI* calculation.

Because of limitations of the procedures being adapted here, the smallest time period for which travel time performance measures can be calculated is 1 h. The same computation applies for a different time period, such as 30 min, but with a different aggregation/average period. The equations for versions of the *TTI* follow, as Equations 2.2 through 2.10.

Performance Measures for Urban Freeways

$$95th\ Percentile\ TTI = 1 + 3.6700 * \ln(MeanTTI) \quad (2.2)$$

$$90th\ Percentile\ TTI = 1 + 2.7809 * \ln(MeanTTI) \quad (2.3)$$

$$80th\ Percentile\ TTI = 1 + 2.1406 * \ln(MeanTTI) \quad (2.4)$$

$$MedianTTI = MeanTTI^{0.8601} \quad (2.5)$$

$$StdDevTTI = 0.71 * (MeanTTI - 1)^{0.56} \quad (2.6)$$

Performance Measures for Signalized Arterials

$$95th\ Percentile\ TTI = 1 + 2.6930 * \ln(MeanTTI) \quad (2.7)$$

$$80th\ Percentile\ TTI = 1 + 1.8095 * \ln(MeanTTI) \quad (2.8)$$

$$MedianTTI = MeanTTI^{0.9149} \quad (2.9)$$

$$StdDevTTI = 0.3692 * (MeanTTI - 1)^{0.3947} \quad (2.10)$$

MeanTTI is the grand (overall) mean. Since it was developed from continuous detector data, it includes all of the possible influences on congestion (e.g., incidents and inclement weather). Currently, DynusT only provides an estimate of recurring congestion related to volume and capacity (bottlenecks). Therefore, a *MeanTTI* based on current DynusT output cannot be used. The following method should be used to estimate the true *MeanTTI*. The method uses the DynusT output to estimate recurring delay and a sketch planning method to estimate incident delay, then combines them. The steps are these:

1. Compute the recurring delay for each link in hours per mile from the simulation model (Equation 2.11):

$$RecurringDelay = AverageTravelRate - (1/FreeFlowSpeed) \quad (2.11)$$

   where *AverageTravelRate* is the inverse of the DynusT speed.
2. Compute the delay due to incidents (*IncidentDelay*) in hours per mile using the lookup table for a 1-h period from the ITS Deployment Analysis System (IDAS) User Manual (Cambridge Systematics, Inc., and ITT Industries 2001). This requires the ratio and the number of lanes. The lookup table is shown in Table 2.7. This is the base incident delay.

Table 2.7. Incident Delay Rates: IDAS Delay Rates for 1-Hour Peak (Vehicle-Hours of Incident Delay per Vehicle-Mile)

Volume-to-Capacity Ratio	Number of Lanes		
	2	3	4+
0.05	3.44E-08	1.44E-09	4.39E-12
0.10	5.24E-07	4.63E-08	5.82E-10
0.15	2.58E-06	3.53E-07	1.01E-08
0.20	7.99E-06	1.49E-06	7.71E-08
0.25	1.92E-05	4.57E-06	3.72E-07
0.30	3.93E-05	1.14E-05	1.34E-06
0.35	7.20E-05	2.46E-05	3.99E-06
0.40	0.000122	4.81E-05	1.02E-05
0.45	0.000193	8.68E-05	2.34E-05
0.50	0.000293	0.000147	4.93E-05
0.55	0.000426	0.000237	9.65E-05
0.60	0.0006	0.000367	0.000178
0.65	0.000825	0.000548	0.000313
0.70	0.001117	0.000798	0.000528
0.75	0.001511	0.001142	0.00086
0.80	0.002093	0.001637	0.00136
0.85	0.003092	0.002438	0.002115
0.90	0.005095	0.004008	0.003348
0.95	0.009547	0.007712	0.005922
≥1.0	0.01986	0.01744	0.01368

If incident management programs have been added as a strategy or if a strategy lowers the incident rate (frequency of occurrence), then the "after" delay is calculated as follows (Equation 2.12):

$$D_a = D_u * (1 - R_f) * (1 - R_d)^2 \quad (2.12)$$

where
- D_a = adjusted delay (hours of delay per mile);
- D_u = unadjusted (base) delay (hours of delay per mile, from the incident rate tables);
- R_f = reduction in incident frequency expressed as a fraction (with $R_f = 0$ meaning no reduction, and $R_f = 0.30$ meaning a 30% reduction in incident frequency); and
- R_d = reduction in incident duration expressed as a fraction (with $R_d = 0$ meaning no reduction, and $R_d = 0.30$ meaning a 30% reduction in incident duration). Changes in incident frequency are most commonly affected by strategies that decrease crash rates. However, crashes are only about 20% of total incidents. So, a 30% reduction in crash

rates alone would reduce overall incident rates by $0.30 \times 0.20 = 0.06$.

3. Compute the overall *MeanTTI*, which includes the effects of recurring and incident delay:

   Remember that Equation 2.1 (*TTI = FreeFlowSpeed/ActualSpeed*) is a general equation for *TTI*. *TTI* can also be computed as:

$$ActualTravelTime/FreeFlowTravelTime \text{ or}$$

$$ActualTravelRate/FreeFlowTravelRate$$

To be able to use Equations 2.2 through 2.10, an estimate of the overall mean *TTI* from a distribution of *TTI*s (which are just converted travel times) is needed. The overall mean *TTI* includes all sources of congestion because the equations were based on a year of data at each location. For simplicity, it is assumed that the mean *TTI* has two components: a recurring mean (from DynusT) and an incident mean (from IDAS). To use the IDAS numbers, which are in terms of delay, everything must be converted into delay and then converted back to *TTI*.

Rewriting the original Equation 2.12 yields Equations 2.13A and 2.13B:

$$MeanTTI = MeanTravelRate/FreeFlowTravelRate \qquad (2.13A)$$

$$MeanTTI = \frac{v_f}{v} = \frac{t}{t_f} = \frac{d/v}{d/v_f} = \frac{1/v}{1/v_f} \qquad (2.13B)$$

From $MeanTTI = \frac{t}{t_f}$, it follows that $MeanTTI = \frac{t}{t_f} = \frac{t_f + \theta}{t_f}$, where θ is the total delay (in hours), defined as the additional travel time on top of the free-flow travel time, which is the sum of recurring delay θ_r and incident induced delay θ_i; that is, $\theta = \theta_r + \theta_i$.

Consequently,

$$MeanTTI = \frac{t}{t_f} = \frac{t_f + \theta}{t_f} = 1 + \frac{\theta}{t_f} = 1 + \frac{\theta_r + \theta_i}{t_f}$$

$$= 1 + \frac{d\left[\left(\frac{1}{v} - \frac{1}{v_f}\right) + \theta_i\right]}{d/v_f} = 1 + v_f\left[\left(\frac{1}{v} - \frac{1}{v_f}\right) + \theta_i\right]$$

The final equation becomes this:

$$MeanTTI = \frac{\left[\frac{1}{v} + \theta_i\right]}{\frac{1}{v_f}}$$

This essentially means that *MeanTTI* is the ratio of the sum of the recurring congestion-induced trip rate and the incident-induced trip rate, to the free-flow trip rate.

The term θ_i is the delay due to incidents (*IncidentDelay*) and is proposed using the IDAS table in Table 2.7. The table estimates the vehicle-hour of incident delay per vehicle-mile based on v/c ratio for a two-, three-, and four-plus–lane facility.

To facilitate the implementation of this table in DynusT, the table is transformed into three polynomial equations that best fit the tabulate data. Each of the fitted curves has an R^2 value of at least 0.99, meaning that using this approach is consistent with the original data, but the polynomial equations speed up the value lookup using v/c values. The three equations are shown and graphed in Figures 2.7 through 2.9.

The following is an example for a three-lane roadway:

- Free-flow speed = 60 mph;
- DynusT speed = 45 mph; and
- IDAS delay = 0.000798 h/mi (from Table 2.7 or Figure 2.7).

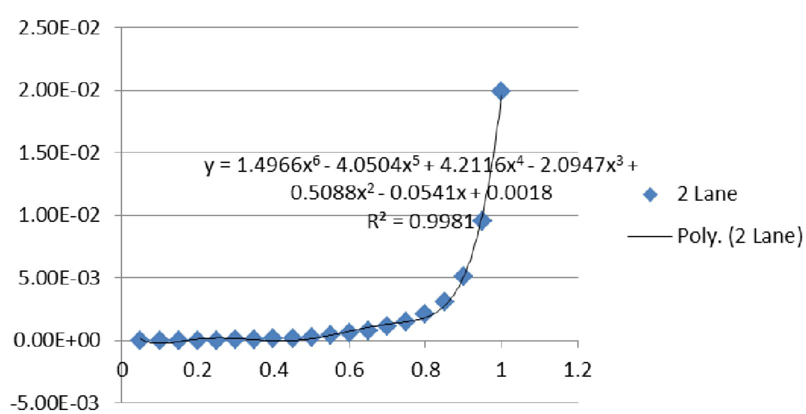


Figure 2.7. Incident delay for two-lane roadways.

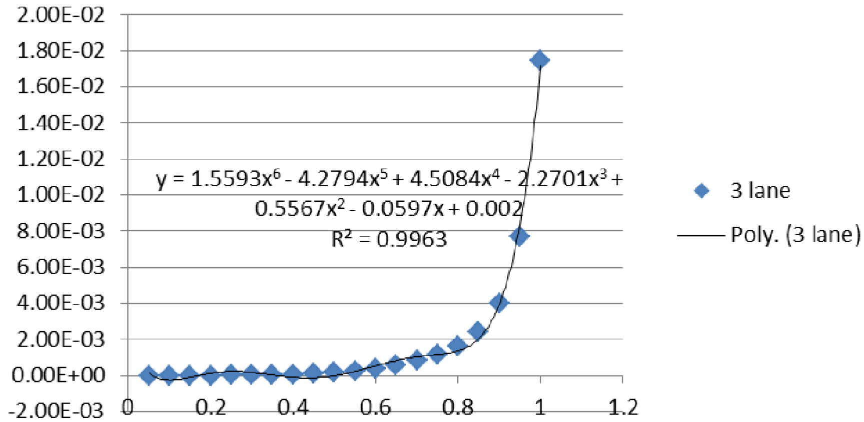


Figure 2.8. Incident delay for three-lane roadways.

$$MeanTTI = \frac{\frac{1}{45} + 0.00798}{\frac{1}{60}} = 1.381$$

Note that since the SHRP 2 L03 equations predict the *TTI*, the travel time can be computed as follows (Equation 2.14):

$$TravelTime = TTI * FreeFlowSpeed \quad (2.14)$$

At the time the reliability calculations were incorporated into the C10B integrated model, coefficients for the reliability utility function had not yet been developed by Project L04. An alternate method is to compute travel time equivalents for reliability. For this purpose, empirical results developed by Small et al. (2005) were used. The authors defined unreliability as the difference between the 80th percentile travel time and the 50th percentile travel time and found the value of unreliability to be approximately equal to the value of time.

Based on this result, Equation 2.15 was used to calculate travel time equivalents for a trip:

$$TTE = MTT + a * (80\%TT - 50\%TT) \quad (2.15)$$

where

TTE = the travel time equivalent on the link;
MTT = the mean travel time (min);
a = the Reliability Ratio (assumed value is 0.8);
$80\%TT$ = the 80th percentile travel time (min); and
$50\%TT$ = the 50th percentile travel time (min).

MTT, 80%TT, and *50%TT* are computed with the equations presented earlier. The "*a*" parameter reflects the value of unreliability relative to mean travel time. Based on currently available information, a value of 0.8 was used for this parameter.

TTE is used as a replacement for the average travel time in the feedback loop to the activity model. It is basically an inflated value of travel time over the average that accounts for how travelers value reliability.

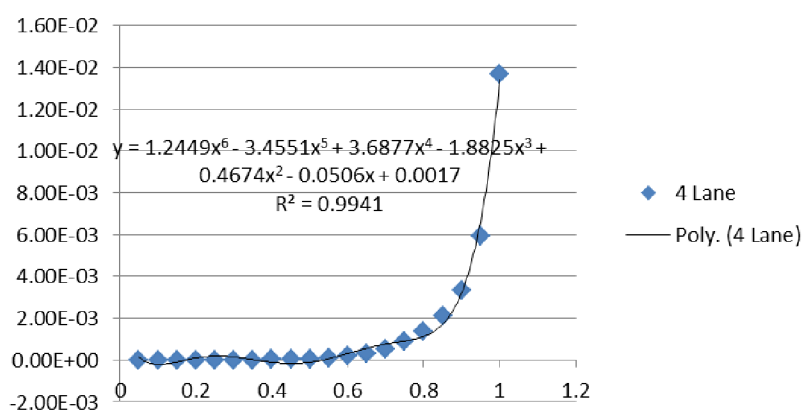


Figure 2.9. Incident delay for four-plus–lane roadways.

This completes the "input" (demand) side of reliability inclusion. To produce estimates of the economic impact of reliability, total equivalent delay is computed based on the *TTE*, as shown in Equation 2.16.

$$TotalEquivalentDelay = (TTE - FreeFlowTravelTime) * VMT \quad (2.16)$$

Delay may be decomposed into passenger and commercial portions using different travel time equivalents and VMT values. Delay is valued with the usual unit costs for the value of (average) travel time applied to the travel time equivalent. The adjustment for reliability has already been made.

DynusT Implementation Details

The necessary inputs for the reliability calculation are specified in a newly created input file called "reliability_input.dat." The contents are these: The first block after the headlines is the coefficients of the polynomial equations resulting from the incident-induced delay specified in Table 2.7. Blocks two and three are the coefficients of the equations specified for freeways and arterials (Equations 2.2 through 2.10). The final block is the "*a*" reliability ratio.

The file that includes the network skim data includes two columns in addition to the original field representing the mean travel time. These two columns are the toll-related cost, and the computed value $a * (80\%TT - 50\%TT)$. These entries are in units of minutes. In this version the skim interval input has been changed to be part of the file *epoch.dat.* The first number in the first line is the skim output interval (30 min).

Model Integration

Integration of SACSIM and DynusT/FAST-TrIPs

The outputs from SACSIM that are inputs to DynusT/FAST-TrIPs in the C10B integrated model are

- The tour and trip rosters from DaySim; and
- The trip tables representing exogenous travel.

The tour and trip rosters already include most of the information required as input by DynusT, including the origin and destination of each trip and relevant traveler information, such as the simulated value of time (see the previous section on incorporating the variable VOT). The time of day is also provided but only at the half-hour level for trips. In the C10B model, a random start time for each trip is simulated within the appropriate half-hour period. The conversion of the rosters to the input format required by DynusT is performed within the integrated model software.

The exogenous travel trip tables must be converted to trip rosters for input to DynusT. This is done using existing procedures for processing trip tables in DynusT. There are trip tables from SACSIM for each of four aggregate time periods (a.m. peak, midday, p.m. peak, and night). Departure time profiles from traffic count data were used to define start times for each trip in the roster.

The C10B integrated model is run in an iterative manner until convergence is achieved, as discussed in Chapter 3. The term "big loop" is used to refer to an iteration that includes a complete run of SACSIM and a complete run of DynusT and FAST-TrIPs (which includes internal iterations of its own). Before each big loop after the first, the travel time information from DynusT and FAST-TrIPs from the previous big loop is fed back as input to SACSIM.

The feedback process is somewhat complex because the traffic and transit simulation in DynusT/FAST-TrIPs represents nearly continuous time while the inputs to DaySim are in half-hour intervals, and the inputs to the exogenous travel components of SACSIM are for the four broad time periods. Furthermore, each trip in DynusT/FAST-TrIPs has its own trajectory through the network with its travel time based on the conditions confronted continuously through its journey. There is no single travel time from one point in the network to another in DynusT.

A specialized process to compute the travel times to be fed back from one big loop to the next was developed for the C10B integrated model. Stated simply, the feedback process employed in the C10B model combines information from all relevant trajectories within a time period (half hour or broad period) to estimate an average time to use as input to SACSIM. The integrated model software executes this process.

Integration of DynusT and MOVES

A significant feature available in MOVES is the ability to support quantitative project-level emissions assessments using detailed vehicle activity data. The MOVES project-scale analysis function is the most spatially resolved modeling level in MOVES; it calculates emissions from a single roadway link, a group of specific roadway links, and/or an off-network common area (e.g., a transit terminal or park-and-ride lot). [See U.S. Environmental Protection Agency (2012) for additional information.]

DynusT is capable of performing up to 24-h simulations of dynamic traffic assignment on roadway networks with sizes ranging from corridor to regional level. DynusT uses iterative interactions between traffic simulation and traffic assignment modules to provide detailed and finely resolved travel activity data, such as vehicle trajectories (i.e., when and where a vehicle is located), volume, speed, and density.

To take advantage of detailed activity data with improved temporal and spatial resolution, the project team developed a fine-grained integrated method that links MOVES to DynusT at the individual roadway link level. The MOVES-DynusT integration is realized through data conversion functions that use DynusT activity outputs to generate MOVES project-scale inputs. This integration method ensures transition of data flow from DynusT to MOVES without manual intervention or additional data preparation.

Detailed DynusT data can be processed in two ways for MOVES project-scale modeling use: (1) drive schedules, in the form of second-by-second speed trajectories, and (2) operating mode distributions, in the form of vehicle running time associated with operating modes defined by speed and vehicle-specific power (VSP) bins. Although MOVES accepts both types of data for calculating link-level emissions, using second-by-second speed trajectories may involve working with a very large data file (especially when modeling a sizable roadway network, as opposed to a small group of roadway links) and significantly increases MOVES modeling time. Therefore, the MOVES-DynusT integration method mainly focuses on using DynusT data to generate operating mode distributions inputs for MOVES.

Figure 2.10 presents a flowchart that illustrates the linkage between the MOVES and DynusT models and shows how data files are organized in the integration process. During a simulation run that generates detailed vehicle activity data, DynusT uses an intermediate data file (move_input .dat) that contains required data items for calculating hourly operating mode distributions for each roadway link. The key data used by DynusT in this process include roadway parameters (e.g., link ID, hour, and road grade), vehicle type, vehicle count (used for developing traffic volumes), and speed for each simulation interval (for calculating VSP and vehicle operating modes). The operating mode distribution data and other processed travel activity data are organized into multiple data tables and used as MOVES input files. In addition to travel activity data converted from DynusT outputs, the MOVES model runs also require non-travel activity data inputs. These inputs—such as vehicle age distribution, fuel supply and formulation, inspection and maintenance program status, and meteorological data (e.g., temperature and relative humidity)—are prepared outside of the MOVES-DynusT integration framework and are consistent with DynusT scenarios (i.e., during the same time range and for the same geographic area).

Three major data files associated with DynusT modeling runs are used to generate MOVES travel-activity input data:

- *Network.dat.* This DynusT input file, including parameters that describe the roadway network configuration, is used to populate MOVES link attribute inputs, such as link ID, road type, and link length.
- *Speed.txt.* This DynusT output file, including speeds on roadway links for each simulation interval and averaged over a number of intervals, is used to calculate vehicle-specific power and operating mode bins in MOVES.
- *OutAccVol.data.* This DynusT output file, including cumulative number of vehicles that go through the midpoint of the link at each minute, is used to calculate vehicle running times and proportions for various operating mode bins.

The core data processing to link MOVES and DynusT involves calculation of VSP and operating mode fractions. For each vehicle during a modeled hour, VSP was calculated using the following equation:

$$VSP = (A/M)\times v + (B/M)\times v^2 + (C/M)\times v^3 + (a + g\times\sin\theta)\times v \qquad (2.17)$$

where

VSP = vehicle specific power in kilowatt/tonne;

A = load coefficient in (kilowatt-second)/(meter-tonne);

B = load coefficient in (kilowatt-second^2)/(meter^2-tonne);

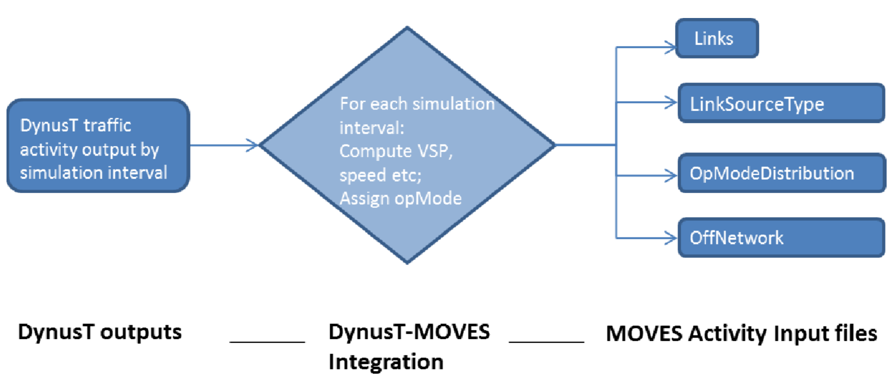


Figure 2.10. Data flow and organization of MOVES and DynusT integration.

C = load coefficients in (kilowatt-second^3)/(meter^3-tonne);
M = mass of the vehicle in kilograms;
g = acceleration due to gravity (9.8 m/s^2);
v = vehicle speed in meters per second;
a = vehicle acceleration/deceleration in meters per second^2; and
$sin\theta$ = road grade (fractional).

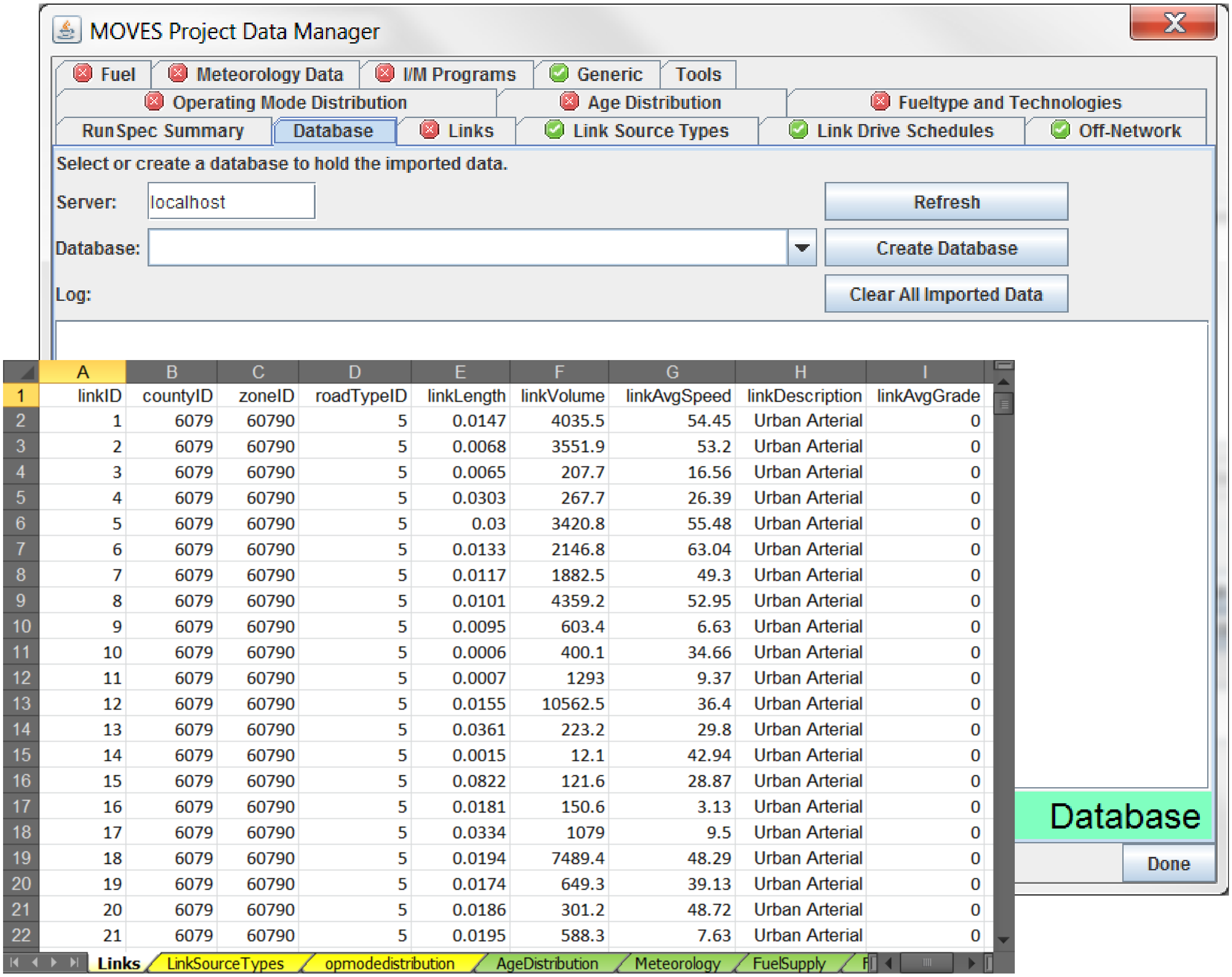
Based on DynusT VSP calculations and speed data, the corresponding operating mode bins can be identified for MOVES use. DynusT volume data and simulation interval information were also used to calculate vehicle time distributions associated with various operating mode bins for each roadway link during an analysis hour. Once these operating mode distribution data are ready for MOVES use, there are two steps to set up a MOVES project-scale modeling run.

- *Step 1. Create MOVES Runspec file.* The MOVES Runspec file, typically generated through the MOVES graphical user interface, specifies a MOVES scenario run and contains the following model run information:
  - Description: Brief summary of the purpose of the modeled scenario;
  - Scale: Definition of the level of analysis (project-scale in this integration framework);
  - Time spans and aggregation level: Years, months, days, and hours, as well as aggregation by a specified time unit;
  - Geographic bound: Location to be modeled—for example, the county where the roadway links belong;
  - Vehicle types: Vehicle types as specified by engine type, fuel type, and other vehicle technologies (e.g., gasoline passenger car and gasoline passenger truck);
  - Road types: On-road roadway link or off-network link in urban/rural environment;
  - Pollutants and processes: Each pollutant that would be generated by one or more emission processes (e.g., running exhaust oxides of nitrogen); and
  - Additional user databases: Other user-specified information.
- *Step 2. Prepare and load MOVES input data through the MOVES project data manager (PDM) user interface.* As shown in Figure 2.11, each tab in the PDM interface window defines the data item required, including travel activity data tables (e.g., "Links," "LinkSourceTypes," and "OpmodeDistribution," generated by processing DynusT data) and nontravel activity data tables (e.g., "AgeDistribution," "Meteorology," and "FuelSupply," populated using the MOVES default database or other appropriate data sources).

The project-scale MOVES modeling allows for emissions calculation for a given hour during a specific month and analysis year in a single MOVES run. To generate emissions estimates for multiple hours (e.g., daily emissions), batch mode features in MOVES must be employed.

MOVES generates two types of emissions outputs, which are stored in a MySQL database: (1) emission inventories with quantity of emissions and/or energy consumption within a region (e.g., for the modeled roadway network) and time span and (2) emission rates with quantity of emissions per unit of activity (e.g., grams per mile). The C10B MOVES-DynusT integration effort focused on using MOVES CO_2 emission inventories for demonstration purposes.

In summary, the project team developed a MOVES-DynusT integration framework with specific approaches to process DynusT travel activity data for MOVES project-scale modeling runs. MOVES requires traffic-related input data at a resolution much higher than can typically be provided by traditional travel demand models. The integration methodology developed under the C10B project allows for using detailed travel activity data, generated from DynusT, with improved temporal and spatial resolution, to develop modal-based emissions estimated with MOVES. The MOVES-DynusT integration framework and data processing approaches can potentially be used for modeling vehicle emissions at both the regional scale (e.g., a roadway network for a metropolitan area or county) and the project scale (e.g., a highway corridor or local transportation project).



linkID	countyID	zoneID	roadTypeID	linkLength	linkVolume	linkAvgSpeed	linkDescription	linkAvgGrade
1	6079	60790	5	0.0147	4035.5	54.45	Urban Arterial	0
2	6079	60790	5	0.0068	3551.9	53.2	Urban Arterial	0
3	6079	60790	5	0.0065	207.7	16.56	Urban Arterial	0
4	6079	60790	5	0.0303	267.7	26.39	Urban Arterial	0
5	6079	60790	5	0.03	3420.8	55.48	Urban Arterial	0
6	6079	60790	5	0.0133	2146.8	63.04	Urban Arterial	0
7	6079	60790	5	0.0117	1882.5	49.3	Urban Arterial	0
8	6079	60790	5	0.0101	4359.2	52.95	Urban Arterial	0
9	6079	60790	5	0.0095	603.4	6.63	Urban Arterial	0
10	6079	60790	5	0.0006	400.1	34.66	Urban Arterial	0
11	6079	60790	5	0.0007	1293	9.37	Urban Arterial	0
12	6079	60790	5	0.0155	10562.5	36.4	Urban Arterial	0
13	6079	60790	5	0.0361	223.2	29.8	Urban Arterial	0
14	6079	60790	5	0.0015	12.1	42.94	Urban Arterial	0
15	6079	60790	5	0.0822	121.6	28.87	Urban Arterial	0
16	6079	60790	5	0.0181	150.6	3.13	Urban Arterial	0
17	6079	60790	5	0.0334	1079	9.5	Urban Arterial	0
18	6079	60790	5	0.0194	7489.4	48.29	Urban Arterial	0
19	6079	60790	5	0.0174	649.3	39.13	Urban Arterial	0
20	6079	60790	5	0.0186	301.2	48.72	Urban Arterial	0
21	6079	60790	5	0.0195	588.3	7.63	Urban Arterial	0

Figure 2.11. MOVES project data manager interface and sample travel activity data inputs.

CHAPTER 3

Model Implementation

This chapter describes the implementation of the C10B integrated model: the software implementation, the model input data, the model implementation requirements, and the testing of the model.

Software Implementation Process

The software architecture for the C10B integrated model allows users to access the modeling software using any web browser, with the major model components running on one or more shared servers. This allows for efficient sharing of large data files, alleviates the need for every modeler to have a powerful desktop computer, and enables the use of parallel processing and other techniques to ensure adequate performance. The software design implemented clean boundaries and interfaces between the model components. The resulting software architecture is efficient, modular, and maintainable and minimizes the risk of changes to one model component affecting the operation of the model as a whole.

The integrated model software was developed using an iterative, incremental methodology that reduced risk, ensured continuous testing, and made progress more transparent and predictable. The software developers delivered a total of four software iterations during the project. The methodology included rigorous quality assurance and testing procedures and high standards and specifications for documenting the software design.

The preexisting model components, SACSIM/DaySim and DynusT, are available—along with modifications made during the C10B project—under open source licenses. FAST-TrIPs is also available under an open-source license. The National Academy of Sciences (NAS) is the owner of the other software developed for the project.

The C10B integrated model does not depend on any commercial travel demand modeling or simulation software. The tests performed using the project software, including interim tests done by the project team and the policy tests described in Chapter 4, used skims for the initial model iteration prepared using the existing SACSIM model networks, which use Citilabs' Cube software. This was done for convenience. Initial skims could be prepared using other means, including the DynusT network, which was used to create skims for subsequent model iterations. The C10B integrated model implementation for Sacramento also uses exogenous travel data from SACSIM. Skims for these model components are also run using Cube. However, exogenous trip tables can come from any source which provides them in zonal origin–destination format.

Summary of Software Development Iterations

The following section summarizes what was performed in each of the four software iterations.

Iteration 1

The initial user interface (UI) for the model was developed in Iteration 1. After Iteration 1, the application supported the creation and running of scenarios that go through the following phases:

- Configure and run the DaySim component of SACSIM;
- Convert the DaySim trip outputs to a DynusT vehicle roster;
- Configure and run DynusT using the converted trip roster;
- Convert the DynusT outputs to a form to be imported into the application database; and
- Import the converted DynusT outputs.

This iteration supported limited configuration of DaySim and DynusT. For DaySim, the population sample percentage could be selected. The UI also supported marking the scenario as a baseline, setting the forecast year, and choosing the population file. However, in this iteration these settings did not affect the DaySim output.

Basic summary output statistics were available to users via the UI.

Iteration 2

The application as developed after Iteration 2 supported creating and running scenarios that go through the following phases, in addition to those supported after Iteration 1:

- Produce, at the user's option, additional DynusT outputs to be used as input to MOVES; and
- Configure and run MOVES based on the scenario settings and using the DynusT outputs.

For DynusT, this iteration adds the ability to indicate whether exogenous travel should be included.

Running MOVES can optionally be added to a scenario by checking a checkbox in the UI. This enables additional MOVES settings; for example, the month can be specified so that MOVES can incorporate appropriate climate information, and the year can be specified so that MOVES can incorporate vehicle age characteristics. The most important setting is for the specific hours that MOVES simulates. In this version of the software, MOVES was configured to run its simulation on a single fixed highway section, El Dorado Freeway West.

The outputs available via the UI were expanded in this iteration.

Iteration 3

The application as developed after Iteration 3 supported creating and running scenarios that go through the following phases, in addition to those supported after Iteration 1:

- Use DaySim to incorporate variable value of time information and attach this information to tour records;
- Take the DaySim tour outputs and attach to DynusT inputs;
- Configure and run DynusT using the converted trip roster and tour information;
- In the DynusT version, make use of tour and variable value of time information from DaySim;
- Feed back (if specified by the user) the DynusT skim information to DaySim, rerunning the above steps;
- Produce additional DynusT outputs to be used as input to MOVES; and
- Configure and run MOVES based on the scenario settings and using the DynusT outputs.

For DynusT, in Iteration 3, the user could select either the Rancho Cordova or Test Subarea network. MOVES would run for a selection of links depending on which network was chosen.

Iteration 3 added an option to redirect output from DynusT back as inputs to DaySim in a feedback loop, with the number of loops specified by the user. The user has the option to save results for intermediate iterations.

Iteration 4

The final iteration completed the development of the model software. The main additions to previous iterations included the incorporation of FAST-TrIPs and the ability to run the model for the entire Sacramento region. Other changes improved overall performance and incorporated the final C10B version of DynusT, which incorporated the reliability functionality as described in Chapter 2.

Additional performance enhancements were made, including the ability to run the model on a 64-bit multicore server machine. The application saves intermediate scenario data; thus, when a scenario has been stopped or has had an error and is subsequently restarted, in many cases the scenario run will start from the last point completed rather than from the beginning.

Additional output summaries were added during Iteration 4. These include transit demand summaries and results for user-predefined jurisdictions.

Summary of Application Execution Procedure

The following is a summary of steps the user performs in executing the C10B integrated model application.

1. *Code the highway and transit networks in DynusT/FAST-TrIPs.* Usually, a regional planning network is the primary source for the highway network, while the General Transit Feed Specification (GTFS) is used for transit network development. A description of how the highway and transit networks were developed appears in the next section.
2. *Prepare the socioeconomic data inputs required by SACSIM/DaySim.* These are stored in flat files as described in the SACSIM user documentation (Bowman and Bradley 2006).
3. *Develop the exogenous travel trip tables (airport, truck, and external).* For the work done to date, these have come from the validated 2005 SACSIM model.
4. *Create a scenario in the UI.* The user specifies the following through the interface:
    - Scenario name;
    - Analysis year;
    - Source for synthetic population (e.g., baseline) and percentage of population to use (e.g., 100%);

- Which types of exogenous trips to include (airport, external, commercial);
- Which network area to use (SACOG region, Rancho Cordova subarea, or test subarea);
- Number of feedback iterations;
- Various DynusT settings; and
- Whether MOVES will be run and if so, for what month and year, and the start and end hours for the emissions analysis.

5. *Run the scenario through the UI.*
6. *Examine outputs using the summaries available through the UI.* Examine DynusT outputs or DaySim outputs as needed.

Model Inputs

Socioeconomic/Land Use Data

The socioeconomic data inputs for the C10B integrated model are the same as those used in the original SACSIM model. The regional population and employment forecasts, as well as future transportation networks, are treated as exogenous inputs to SACSIM. Currently, SACOG generates these land use forecast data sets as scenarios within the Place3s land use model. Place3s builds up the regional forecast data sets from parcel-level land use data. For each forecast year, regional control totals are established by SACOG's board-adopted growth allocations and demographic trend assumptions.

SACSIM uses parcel/point land use input data rather than aggregating data to transportation analysis zones (TAZs). The parcel-level land use data, combined with the population synthesis approach, provides a fine-grained level of model sensitivity and detail with regard to the representation of land use and its effects on travel behavior. The model was designed and developed with the intention of capturing land use and transportation interrelationships, which are masked or missed altogether in models based on TAZs.

The variables included in SACSIM at parcel- or point-level include

- Households and population;
- Employment by sector (e.g., retail, office, manufacturing, medical, service, government);
- K–12 school enrollment;
- University enrollment;
- Street pattern/connectivity;
- Distance to nearest transit station/stop; and
- Number of paid, off-street parking spaces.

These variables are used in SACSIM as parcel/point values (i.e., quantity and type of use on that parcel). The variables also are used as "buffered" parcel/point values (e.g., the quantity and type of a use within ¼ or ½ mi of a parcel).

Highway Network

The University of Arizona created a regional DynusT network for the Sacramento area. DynusT networks are created using information from the regional model networks, in this case SACSIM. This type of network creation includes a number of steps. Key steps included the following:

- *SACSIM-DynusT zone mapping.* A one-to-one mapping of zones between SACSIM and DynusT was created.
- *Link names.* These were imported from the planning model to create the *Linkname.dat* input file for DynusT. Link names were placed on intersections and streets of interest. The boundaries of corridors used in analysis and reference points were specified.
- *Centroids and centroid connectors.* Centroid nodes and connectors were not removed from the SACSIM network. A script was developed to create generation links downstream of centroid connectors. Destination nodes were assigned to nodes downstream of the corresponding centroid nodes.
- *Check and update link speeds and times.* SACSIM speeds/times were imported. Maximum speeds were verified with observed data on a spot check basis.
- *Check and update link types.* SACSIM link types were imported. The start and end points of all HOV lanes were checked.
- *Ramps.* Directionality was checked for correctness. Curvature was created for on/off-ramps.
- *Link lanes.* The number of lanes was checked for consistency with actual infrastructure, including auxiliary lanes on freeways.
- *Intersection geometry.* For all inbound links to major and signalized intersections, left/right-turn bays were added as required.
- *Link grades.* These were provided for critical locations in the network.
- *Intersection control type.* These were updated using observed data.
- *Traffic signals.* Signal timing was generated (discussed in the following paragraphs).

The SACSIM regional model includes about 3,000 signalized intersections. The C10B team was able to collect signal timing data for about 600 intersections. However, the effort required to code all of these signals would have been enormous, given the different formats of the data collected from different jurisdictions. For each signal, the intersection would first need to be located in the regional model, and then signal timing sheets would have to be interpreted and hard-coded.

Given the amount of time needed to hard code those signals and that about 80% of the intersections had no available timing data, it was decided by the project team, including University of Arizona and SACOG, to generate signal timings using the following process:

- A set of default signal timings was developed based on the collected existing signal timing data. Separate default signal timings were developed to reflect the differences among various locations (e.g., downtown Sacramento and suburban areas). The default signal timings reflected signal actuation, which is adaptive to real-time traffic demand with long maximum green and short minimum green. This is robust enough to cope with most traffic flow conditions. Additionally, default intersection geometries were coded based on the number of midblock lanes entering the intersection from each street.
- The real traffic demand was loaded to run the regional model to identify oversaturated signalized intersections ("hot spots").
- The identified hot spots were verified using Google Maps (for geometry) and signal timing data (if available), and modifications were made accordingly. If actual signal timings were not available, signal timing data for nearby locations were used for reference, along with engineering judgment.
- The regional model was run again, and a new list of hot spots identified and addressed.
- Once the regional network was created, a check was performed by running the regional DynusT model using year 2005 demand. Problem areas were identified and addressed, including hot spots and network continuity issues. Since the work performed for the C10B project involved the first usable regional traffic simulation, the network checking process required a substantial level of effort by project team members, especially SACOG and the University of Arizona.

Transit Network

FAST-TrIPs uses Google's General Transit Feed Specification (GTFS) files. The GTFS files currently allow a transit agency to provide its routes and schedules to Google Maps. However, this same route and schedule data are often made publicly available by transit agencies, allowing others to develop applications using these data. Sacramento Regional Transit (RT) is one of the many transit agencies providing GTFS data to Google and to the public.

The GTFS files contain the geographic representation of routes and stops, typically in geographic information system (GIS) shape files. The data also contain either (1) the formal schedule of service (in the case of GTFS) or (2) the frequency information (in the case of traditional line files) associated with each transit route and direction. The GTFS data or line files are converted into route networks that are compatible with the DynusT road network. This process is partly automated, using existing shape files for the road and transit networks; but considerable manual processing may be necessary to adjust the network to ensure that road segments are consistent and that transit stop locations are placed at appropriate locations in the road network. Finally, the schedule (the so-called "stop-times" in GTFS) also serves as input to the transit assignment. The transit network and service data should ideally be based on the GTFS. This is useful because the actual service schedule and individual stops can be modeled explicitly. This provides a more dynamic modeling of the transit passenger behavior than a traditional four-step model. The GTFS data can be used to represent the base year, perhaps by making some manual adjustments to the existing (i.e., 2010 for the C10B implementation) GTFS schedule data to make it comparable to the base year.

The detail with which transit routes are defined in a schedule-based format such as GTFS may pose problems when dealing with future year forecasts. A transit network for the future will require designating routes, stops, and schedules. This information may be easily adapted from existing schedules if only more modest changes are envisioned. However, for more significant changes in the transit network, this could require significant effort to develop appropriate GTFS data. Whether to develop this GTFS input, or simply use a future line file (from a four-step model), would be a decision likely made jointly by the local MPO (e.g., SACOG) or the local transit agency (e.g., Sacramento RT).

It should be noted that not every transit route in the Sacramento region was coded in the C10B integrated model network. Some of the region's smaller providers were not included in GTFS at the time the network was created, and some RT routes were not included, either because they were very minor in nature or because they have been discontinued since the model base year of 2005.

Exogenous Travel

As discussed in the first section of this chapter, estimates of exogenous travel can come from any source and are provided as inputs in zonal origin–destination format. In the tests performed as part of the SHRP 2 C10B project, exogenous travel trip tables were developed using SACSIM model runs. If the user wanted to have the exogenous travel consistent with the network assumptions of the integrated model, then the SACSIM runs would have to have network assumptions consistent with the DynusT network.

In typical planning situations, an integrated model scenario is defined starting from a baseline scenario. If transportation system changes are part of the new scenario, the baseline network is modified in DynusT. If the changes are expected to significantly affect exogenous travel, then it makes sense to make the same changes in SACSIM and rerun the model to get new exogenous trip tables to use as input to the integrated model. If the network changes are expected to result in no significant changes to exogenous travel, the user may choose to use the same exogenous travel estimates as in the baseline scenario.

Model Application

When applying the C10B model, there are a few key points to be aware of:

- The DynusT application is resource intensive on all fronts: CPU, memory, and disk space.
- In addition to the DaySim and DynusT applications, there are a number of scripts that run to perform various data management functions.
- The MOVES application is somewhat independent of the more tightly coupled loop between DaySim and DynusT. It runs separately on data processed from the final output of DynusT and does not necessarily have to be installed at the same time as DaySim and DynusT. The MOVES installer also installs MySQL.

Software Requirements

The software only runs on 64-bit Windows (e.g., Windows 7, Windows Server 2008). Python and the DBF Python library should be installed before installing DaySim and DynusT.

Hardware Configuration

The model was designed to run on hardware configurations that would typically be available at most larger MPOs and state planning agencies. The specific requirements for the C10B integrated model are as follows:

- Memory: minimum 8 GB, 16 GB preferred. The configuration on which SACOG ran the policy tests described in Chapter 4 included 32 GB.
- CPU: minimum four cores Intel Core i5 or better. Up to 16 cores significantly improves performance. SACOG's configuration included Intel Core i7-3770 CPU @ 3.40 GHz.
- Hard drive: 15 GB of data are generated per run. Data are written and read back in for each iteration of DynusT, so a solid state drive (SSD) is recommended to improve performance. SACOG's configuration included a solid state drive.

All software can be installed and run from the same server. However, the MOVES application and support software (MySQL) can be installed and run on a separate server from the server running DaySim and DynusT if desired.

Run Times

Using the development configuration of Windows 7 Professional running on Intel Core i7-2600 CPU @ 3.40 GHz with 16 GB RAM and a 128 GB SSD, run times break down as follows:

- 2.5 h per DaySim iteration;
- 1 h per DynusT iteration (10 to 20 iterations typical);
- 1 h transit simulation;
- Each full transit simulation requires a full set of DynusT iterations;
- 1 h to generate feedback data from transit simulation to DynusT;
- 1 h to generate feedback skims from DynusT to DaySim; and
- Each full feedback loop requires a DaySim run followed by the full set of transit and DynusT simulations.

For example, a scenario consisting of two full feedback loops with two transit iterations and 10 iterations within DynusT would take a total of $2 * (2.5\text{ h} + 2 * (10\text{ h} + 1\text{ h}) + 1\text{ h}) + 1\text{ h}$, for a total of 52 h. With its slightly larger/faster configuration, SACOG reported run times of 70 h for the policy test runs with three full feedback loops.

Model Testing

The travel demand model used in the C10B integrated model, SACSIM, had been validated by SACOG for a base year of 2005, before the beginning of the C10B project. While SACOG has continued to update SACSIM as part of their regional transportation planning process, it was not necessary for the purposes of the C10B project to implement any updates to SACSIM that took place after C10B began. The SACSIM component of the integrated model was therefore considered already validated when the project commenced.

The main difference between the integrated model and SACSIM was the replacement of the static highway and transit assignment processes with the dynamic simulation processes, DynusT and FAST-TrIPs, respectively. To demonstrate that the C10B integrated model was suitable for testing the policy/planning alternatives, the project team, in consultation with the project's Technical Expert Task Group (TETG), identified a proof-of-concept plan to test the integrated model, consistent with the overall focus of the project.

The testing conducted under this refined plan was designed to

- *Identify and measure the impact of the integration of SACSIM and DynusT on SACSIM results.* The integrated model does not change the basic design or structure of the demand components of SACSIM/DaySim. Thus, under the proof-of-concept plan, it is sufficient to identify changes in SACSIM results that result from integrating SACSIM with the DynusT assignment procedures.

- *Determine whether or not the SACSIM/DynusT procedure is iterating to closure.* Is it getting closer to or further away from observed transit volumes, traffic volumes, and traffic speeds?
- *Measure the reasonableness of the traffic and transit assignment results.* Of course, the reasonableness of the assignment results is somewhat dependent on the impact that the SACSIM/DynusT procedure has on SACSIM.

All testing was conducted for the 2005 base year using the same socioeconomic, land use, and network data used by SACOG for SACSIM. In addition, observed traffic and transit data used for the validation of SACSIM were available.

The proof-of-concept testing consisted of comparisons of various C10B integrated model and SACSIM results and checks of model convergence. The checks are described in the remainder of this section. A separate process, used to test the integration between DynusT and MOVES, is described at the end of this section.

Comparisons Between the C10B Integrated Model and SACSIM Results

Table 3.1 compares the number of personal tours in the C10B integrated model with those generated in SACSIM. Overall, the C10B model predicts 3.8 million tours, compared with 3.5 million tours simulated by SACSIM. The C10B model predicts 7% more drive alone tours, 2% more shared ride 2 tours, and 27% more 3+ tours. For other tours, such as walk, the C10B model predicts a modest decrease. Nonauto tours are higher in the C10B model. Table 3.2 breaks down the number of transit tours by purpose.

Average travel times by tour purpose in SACSIM and the C10B integrated model are shown in Table 3.3. Most of the differences are minor, with the average travel time being 11.4 min in both models.

Table 3.4 shows average model output speeds by facility type and time period for the integrated model and the original SACSIM implementation. For every facility type and time period, DTA speeds are lower than the SACSIM speeds. DynusT daily speeds on freeways are 10 mph lower than SACSIM, while the difference on arterials is 8 mph.

Table 3.5 shows the VMT by facility type and peak period. Static and dynamic assignments produce approximately the same daily VMT, but the breakdown is different. The most notable difference—which is evident across all time periods—is the split between freeways and arterials. SACSIM in all time periods except evening has an even split between arterials and freeway links. In contrast, DynusT consistently assigns more flow on arterials than on freeway links.

Table 3.6 shows the total modeled volume for the screenlines used for calibrating and validating the SACSIM model. Figure 3.1 shows the screenline locations. Screenlines 1, 2, 3, and 4 cover important streets to and from downtown Sacramento; Screenlines 5 and 16 represent important bridges along the American River to the north of downtown Sacramento.

Table 3.1. Number of Tours Generated in C10B and SACSIM Models

Tour Mode	C10B Integrated Model	SACSIM
Drive to Transit	5,487	5,596
Walk to Transit	30,326	43,923
School Bus	77,888	73,874
Shared Ride 3+	1,059,727	823,039
Shared Ride 2	918,167	894,269
Drive Alone	1,497,482	1,408,492
Bike	40,994	61,482
Walk	178,689	206,090
Total	3,808,760	3,516,765

Table 3.2. Transit Tours by Purpose

Tour Purpose	C10B Integrated Model	SACSIM
Work	13,991	23,381
School	11,671	13,547
Escort	191	299
Personal Business	4,401	5,894
Shopping	1,332	1,468
Meal	1,679	2,184
Social/Recreational	2,548	2,746
Total	35,813	49,519

Table 3.3. Average Travel Time by Purpose, in Minutes

Tour Purpose	C10B Integrated Model	SACSIM
Work	15.8	16.1
School	12.5	13.0
Escort	10.6	8.4
Personal Business	10.5	10.9
Shopping	9.0	9.5
Meal	9.8	10.3
Social/Recreational	11.4	11.7
All Trips	11.4	11.4

Table 3.4. Comparison of Model Output Speeds

Facility Type	A.M. Peak	Midday	P.M. Peak	Evening	Daily
Integrated Model Average Speeds (VMT/VHT)					
Freeway	39	48	38	45	43
Ramp	16	22	15	15	17
Arterial	24	25	21	24	24
HOV	58	49	58	47	50
Highway	33	34	26	36	33
SACSIM Average Speeds (VMT/VHT)					
Freeway	49	55	47	58	52
Ramp	25	27	24	27	26
Arterial	31	34	29	35	32
HOV	58	55	55	56	56
Highway	48	51	48	51	49

Note: VMT = vehicle-miles traveled; VHT = vehicle-hours traveled; HOV = high-occupancy vehicle.

Table 3.5. Comparison of Model Output VMT

Facility Type	A.M. Peak	Midday	P.M. Peak	Evening	Daily
C10B Integrated Model VMT					
Freeway	3,934,323	5,987,745	4,270,989	7,497,977	21,691,035
Ramp	253,170	376,998	288,706	489,409	1,408,284
Arterial	5,233,265	7,239,180	5,975,892	9,240,086	27,688,425
HOV	112,722	284,612	131,938	357,861	887,135
Highway	516,170	710,475	522,036	962,862	2,711,544
Total	10,049,650	14,599,010	11,189,561	18,548,195	54,386,423
SACSIM VMT					
Freeway	4,782,757	7,883,803	5,420,393	7,473,081	25,560,034
Ramp	310,412	437,844	325,040	397,128	1,470,424
Arterial	4,794,666	7,037,120	5,544,741	6,609,607	23,986,134
HOV	116,877	411,016	180,083	449,572	1,157,548
Highway	411,777	741,872	494,702	686,710	2,335,061
Total	10,416,489	16,511,655	11,964,959	15,616,098	54,509,201

Note: VMT = vehicle-miles traveled.

Table 3.6. Screenline Volume Comparison

Screenline	A.M. Peak	P.M. Peak	Midday	Evening	Daily
Integrated Model Volumes					
1	26,956	44,197	34,483	55,411	161,047
2	27,251	37,030	34,801	41,065	140,147
3	47,777	68,535	47,002	71,227	234,541
4	15,493	23,192	17,195	26,701	82,581
5	89,291	113,284	88,984	162,534	454,093
16	97,188	136,992	99,614	179,911	513,705
Total	303,956	423,230	322,079	536,849	1,586,114
SACSIM Modeled Volumes					
1	17,221	30,675	22,617	25,538	96,050
2	23,164	36,583	26,638	28,925	115,310
3	32,625	51,042	34,567	45,094	163,328
4	15,020	21,185	14,737	17,658	68,601
5	97,733	148,488	109,737	151,318	507,276
16	99,427	150,808	108,226	146,321	504,783
Total	285,190	438,781	316,522	414,854	1,455,348

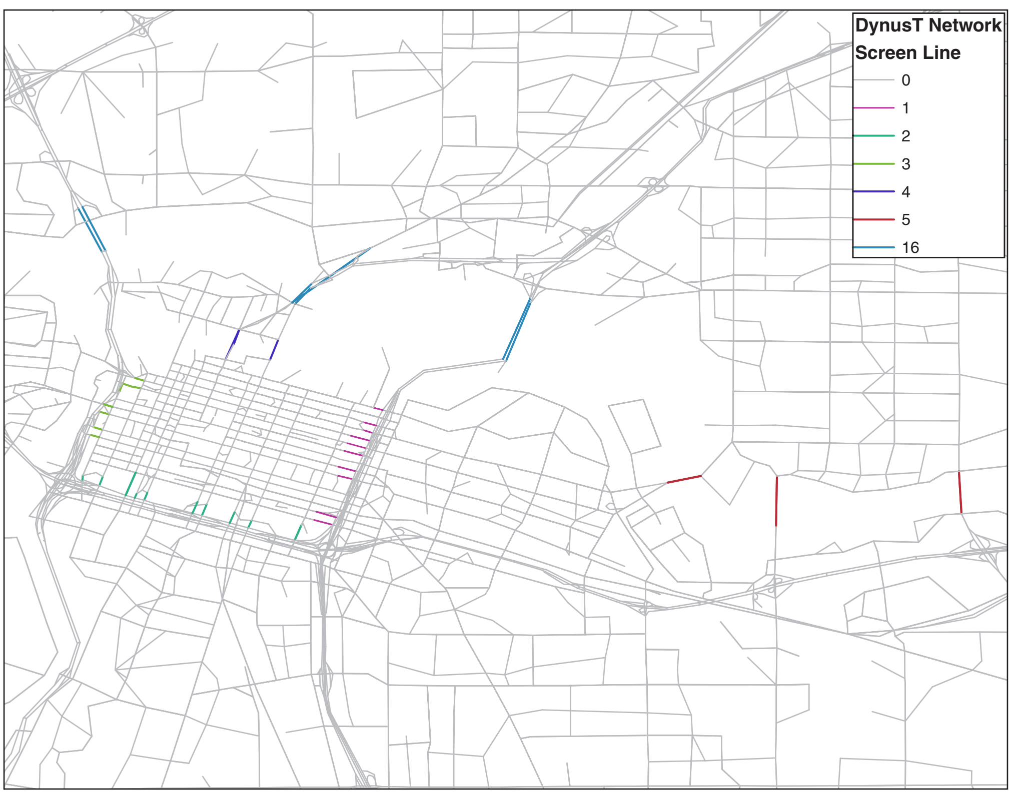


Figure 3.1. Screenlines for SACSIM model.

Table 3.7. Percentage Differences Between C10B and SACSIM Model Screenline Volumes

Screenline	A.M. Peak	P.M. Peak	Midday	Evening	Daily
1	57%	44%	52%	117%	68%
2	18%	1%	31%	42%	22%
3	46%	34%	36%	58%	44%
4	3%	9%	17%	51%	20%
5	–9%	–24%	–19%	7%	–10%
16	–2%	–9%	–8%	23%	2%
Total	57%	44%	52%	117%	68%

Table 3.7 presents the percentage difference between the modeled volumes on the screenlines for the C10B integrated and SACSIM models, with SACSIM serving as the base. The DTA module of the integrated model results in about 9% additional volume through all the screenlines. Differences related to screenlines 5 and 16, which correspond to bridge crossings along the American River, are less pronounced compared with the rest of the screenlines, which correspond to highway streets. Also, in all time periods except evening, the total screenline volume does not differ that much although its distribution among individual screenlines does. In general DTA volumes are not expected to match static assignment volumes unless there is little if any congestion. The more congestion there is, the more the volumes and travel times will differ between the two assignment methodologies.

Convergence Checks

Equilibrium between demand and supply is a fundamental economic principle that is applied in many disciplines and has been followed by transportation practitioners for decades. When dealing with advanced demand-side models, both static and dynamic traffic assignment models are integrated using the same equilibrium principles and techniques applied to traditional demand models.

Equilibrium ensures the consistency and stability of the overall model system and optimality at the supply level. At equilibrium, the expected level of service (LOS) used by travelers to make decisions in the demand model is the same as the realized LOS in the supply model that assigns travelers' patterns to the network and determines congestion. Inconsistency between the expected and realized LOS, as in reality, provides an incentive to travelers to change their short- or long-term travel behavior, which can include departure time or activity location changes that can cascade to longer-term location changes.

In state-of-the-practice four-step models, the equilibration between demand and supply is achieved by performing a number of "big loop" iterations between demand (i.e., trip distribution and mode choice) and static assignment. A measure frequently used for model system convergence in four-step models is the absolute average percentage change in zone-to-zone trips between two successive big loop iterations. This same measure can be applied in advanced activity-based DTA models such as the C10B integrated model. Mathematically, the absolute average percentage change is defined as

$$\frac{\sum_{ijt}\left|q_{ijt}^{k}-q_{ijt}^{k-1}\right|}{\sum_{ijt}q_{ijt}^{k-1}}$$

where q_{ijt}^{k} is the number of trips between O-D pair ij at time interval t and for big loop iteration k.

When the entire model system is at equilibrium, travelers' decisions in the demand model are stable. Overall stability is translated as stability in location, time of day, tour, and trip stability between zones. As a result, in an equilibrated model, the difference between the number of trips q_{ijt}^{k} between zone i and zone j at time interval t in big loop iteration k and the number of trips between the same zone in the previous big loop iteration k–1, q_{ijt}^{k-1}, is minimal and bounded from the bottom only by the inherent randomness in travel demand and network supply microsimulation.

Unlike four-step models, which exhibit a great degree of determinism resulting from modeling aggregate quantities and using static assignment, activity-based and DTA models are by design inherently random. As a result, these advanced models do not converge to a single point; rather, they contain a level of noise in their results that needs to be taken into account in scenario evaluation. Even though noise in model results can complicate scenario evaluation by requiring more runs and careful comparison, it is not a drawback of the more advanced models and can be seen as a more realistic representation of the transportation system—which is inherently stochastic.

In the C10B integrated model implementation, for each big loop iteration the travelers' choices in the demand model are calculated once based on the transportation LOS provided by DynusT in the previous iteration. In contrast, multiple iterations of DynusT are run as part of each big loop iteration to allow travelers to adjust their route choices to avoid congestion and make optimal decisions to minimize generalized travel time. The convergence of the DTA model is determined by the relative gap measure. Its functional form is similar to the computation shown in the preceding equation, which determines the overall system convergence defined in this section and measures the degree of optimality and stability in travelers' LOS in percentage terms.

In C10B integrated model implementation, the DTA model comprises the majority of the model run time.

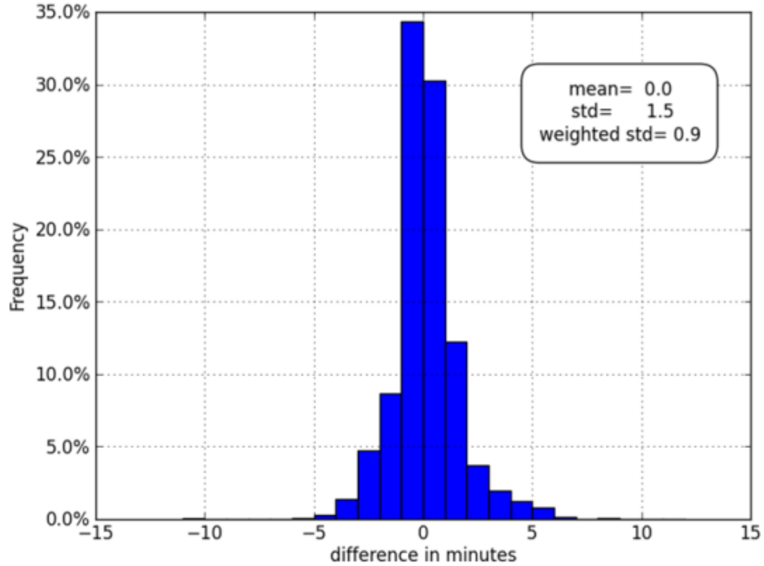


Figure 3.2. Differences in mean travel times between Iterations 10 and 20, 8:00 a.m.

Therefore, reducing the number of iterations of the DTA model without severely affecting the convergence of the overall model system became a priority. Specifically, it was found that the DTA zone-to-zone LOS (represented by the time-dependent skim matrices) converges faster than travelers' travel times. Individual travel times in DynusT in the Sacramento implementation converge after 20 or 30 iterations to a relative gap significantly less than 10%, whereas zone-to-zone travel times (skims) converge to the same level much faster, often in 10 iterations. Given that only skim travel times and not individual travel times are used as an input to the demand model, it was decided to apply the DTA model iteratively 10 times in each big loop iteration, cutting the overall run time in half compared with the 20 or even 30 iterations of the DTA model.

Figure 3.2 and Figure 3.3 show some of the quantitative results on which the conclusions are based. Figure 3.2 shows a histogram of differences in skim travel times in the

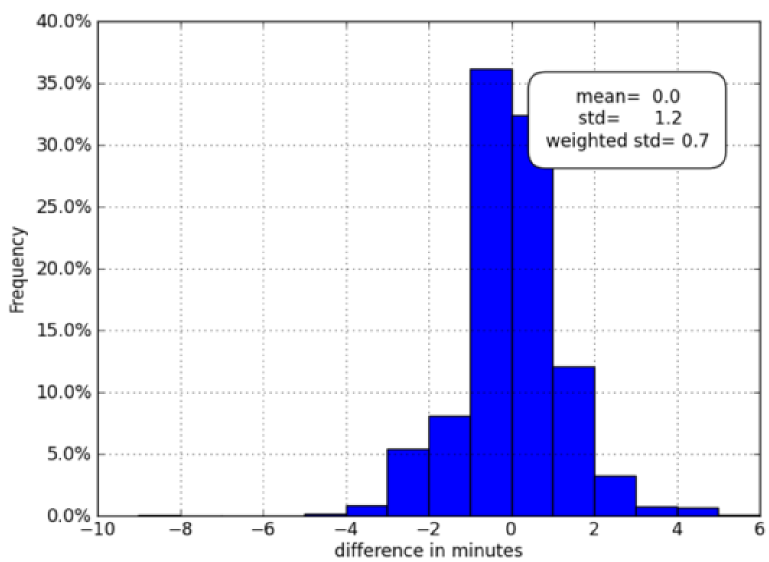


Figure 3.3. Differences in mean travel times between Iterations 20 and 21, 8:00 a.m.

Sacramento DynusT implementation between Iterations 10 and 20. The average skim values for the two iterations are the same while the standard deviation of the differences is 1.5 min. Interestingly, as shown in Figure 3.3, the standard deviation between the consecutive Iterations 20 and 21, which can be considered mostly noise, is 1.2 min, which is very close to the reported difference between Iterations 10 and 20. Additional quantitative investigations with the DTA skims after 30 iterations established the finding that the skims converge much faster than the overall DTA application as measured by the relative gap measure. As a consequence, the study team decided to run the DTA model in 10 iterations, saving time without compromising the quality of the skim tables.

The overall model system convergence in the C10B integrated model, as is always the case in deterministic four-step applications, is driven by the properties of the demand and supply models and cannot be lower than the level of convergence in the supply model. More specifically, model system convergence is bounded at the bottom by the convergence achieved by the DTA supply model. In the C10B integrated model, several big loop iterations are run between supply and demand to determine which combination of big loop and DTA iterations yields the best results, taking into account run time.

It was specifically found that after running three big loop iterations, each of which consists of 10 supply iterations, the systemwide model convergence reached a plateau that did not improve with more iterations. It was found that three big loop iterations result in a systemwide convergence level that is between 10% and 15%, meaning that on average the number of trips between each zone pair changes by no more than 10% to 15% between successive big loop iterations, which is approximately what can be achieved by DynusT in 10 iterations in the Sacramento implementation. This conclusion is also supported by the skim comparison shown in subsequent sections and by examining screenline flow fluctuation within a DTA run and between big loop iterations.

Screenline Volume Stability

Table 3.8 presents the screenline volumes from big loop Iterations 1 and 3 while Table 3.9 displays the percentage differences between them. Overall the total volume across the screenlines in Iteration 3 has been reduced by 2%. However, given the noise in DTA results, this number may imply that the difference is even smaller. Individual screenline volumes can differ significantly, up to 18%, especially in the a.m. peak period.

Table 3.8. Screenline Volume Comparison for Big Loops 1 and 3

Screenline	A.M. Peak	P.M. Peak	Midday	Evening	Daily
Big Loop 1 Screenline Volumes					
1	26,956	44,197	34,483	55,411	161,047
2	27,251	37,030	34,801	41,065	140,147
3	47,777	68,535	47,002	71,227	234,541
4	15,493	23,192	17,195	26,701	82,581
5	89,291	113,284	88,984	162,534	454,093
16	97,188	136,992	99,614	179,911	513,705
Total	303,956	423,230	322,079	536,849	1,586,114
Big Loop 3 Screenline Volumes					
1	26,784	42,935	35,130	55,355	160,204
2	22,993	33,297	35,886	40,301	132,477
3	43,903	63,686	47,935	71,443	226,967
4	13,176	19,693	19,336	25,928	78,133
5	72,895	117,255	93,944	167,307	451,401
16	88,352	132,931	98,851	181,942	502,076
Total	268,103	409,797	331,082	542,276	1,551,258

Table 3.9. Percentage Differences Between Screenline Volumes for Big Loops 1 and 3

Screenline	A.M. Peak	P.M. Peak	Midday	Evening	Daily
1	–1%	–3%	2%	0%	–1%
2	–16%	–10%	3%	–2%	–5%
3	–8%	–7%	2%	0%	–3%
4	–15%	–15%	12%	–3%	–5%
5	–18%	4%	6%	3%	–1%
16	–9%	–3%	–1%	1%	–2%
Total	–12%	–3%	3%	1%	–2%

DTA Volume Stability

The screenline volumes after 10, 20, and 30 iterations of DynusT were compared to determine the stability of the flows in different stages of execution. Tables 3.10a–c show the comparisons between the screenline volumes for model runs for different numbers of iterations. It was found that DTA volumes stabilize after the 10th iteration with little change in subsequent iterations that is not attributable to simulation noise. Specifically, it was found that the overall change in volumes between Iteration 10 and Iteration 30 is less than 2%, with individual screenlines showing somewhat greater fluctuations. Comparatively, there is an overall change of about 1% between Iterations 20 and 30 with a high level of DTA simulation noise when comparing Iterations 20 and 21. For some analyses, it may be necessary to

Table 3.10a. Screenline Volume Comparisons for Different Numbers of Iterations: 10 and 30

Screen-line	A.M. Peak	P.M. Peak	Midday	Evening	Daily
Iteration 10 Volumes					
1	24,001	42,194	34,424	54,217	154,836
2	19,355	30,610	31,287	38,920	120,172
3	39,913	63,408	44,838	75,056	223,215
4	11,888	21,657	15,764	26,877	76,186
5	73,223	126,804	88,230	171,990	460,247
16	85,426	144,697	100,383	191,249	521,755
Total	253,806	429,370	314,926	558,309	1,556,411
Iteration 30 Volumes					
1	23,205	39,870	31,580	54,420	149,075
2	17,539	27,711	28,289	34,062	107,601
3	39,038	61,129	44,368	70,570	215,105
4	11,401	20,865	17,320	28,823	78,409
5	73,283	127,601	90,621	166,699	458,204
16	85,708	143,424	98,838	193,128	521,098
Total	250,174	420,600	311,016	547,702	1,529,492
Percentage Differences—Iterations 10 and 30					
1	–3%	–6%	–8%	0%	–4%
2	–9%	–9%	–10%	–12%	–10%
3	–2%	–4%	–1%	–6%	–4%
4	–4%	–4%	10%	7%	3%
5	0%	1%	3%	–3%	0%
16	0%	–1%	–2%	1%	0%
Total	–1%	–2%	–1%	–2%	–2%

Table 3.10b. Screenline Volume Comparisons for Different Numbers of Iterations: 10 and 20

Screen-line	A.M. Peak	P.M. Peak	Midday	Evening	Daily
Iteration 10 Volumes					
1	24,001	42,194	34,424	54,217	154,836
2	19,355	30,610	31,287	38,920	120,172
3	39,913	63,408	44,838	75,056	223,215
4	11,888	21,657	15,764	26,877	76,186
5	73,223	126,804	88,230	171,990	460,247
16	85,426	144,697	100,383	191,249	521,755
Total	253,806	429,370	314,926	558,309	1,556,411
Iteration 20 Volumes					
1	23,525	40,253	33,016	54,757	151,551
2	18,050	28,301	29,270	35,630	111,251
3	39,576	61,933	44,372	72,547	218,428
4	11,697	20,986	17,610	27,757	78,050
5	73,547	127,414	90,499	168,555	460,015
16	85,738	143,437	99,221	192,014	520,410
Total	252,133	422,324	313,988	551,260	1,539,705
Percentage Differences—Iterations 10 and 20					
1	–2%	–5%	–4%	1%	–2%
2	–7%	–8%	–6%	–8%	–7%
3	–1%	–2%	–1%	–3%	–2%
4	–2%	–3%	12%	3%	2%
5	0%	0%	3%	–2%	0%
16	0%	–1%	–1%	0%	0%
Total	–1%	–2%	0%	–1%	–1%

Table 3.10c. Screenline Volume Comparisons for Different Numbers of Iterations: 20 and 21

Screen-line	A.M. Peak	P.M. Peak	Midday	Evening	Daily
Iteration 20 Volumes					
1	23,525	40,253	33,016	54,757	151,551
2	18,050	28,301	29,270	35,630	111,251
3	39,576	61,933	44,372	72,547	218,428
4	11,697	20,986	17,610	27,757	78,050
5	73,547	127,414	90,499	168,555	460,015
16	85,738	143,437	99,221	192,014	520,410
Total	252,133	422,324	313,988	551,260	1,539,705
Iteration 21 Volumes					
1	25,023	43,945	35,562	57,936	162,466
2	22,073	34,487	32,985	41,127	130,672
3	41,602	65,287	46,837	74,346	228,072
4	12,064	21,928	17,033	29,564	80,589
5	75,788	131,773	92,892	171,272	471,725
16	86,188	143,409	98,522	194,278	522,397
Total	262,738	440,829	323,831	568,523	1,595,921
Percentage Differences—Iterations 20 and 21					
1	6%	9%	8%	6%	7%
2	22%	22%	13%	15%	17%
3	5%	5%	6%	2%	4%
4	3%	4%	–3%	7%	3%
5	3%	3%	3%	2%	3%
16	1%	0%	–1%	1%	0%
Total	4%	4%	3%	3%	4%

run the DTA model for more than 10 iterations to ensure that individual link DTA volumes are stable enough; but for more aggregate analyses, 10 iterations appear to be sufficient.

Comparisons Between Big Loop Runs

There is a small percentage decrease, 5% or less, in the average zone-to-zone LOS between big loop Iterations 1 and 3. This decrease in average skim travel times is more prominent in the peak periods and less pronounced in the off-peak periods, which may be attributed to travelers changing their departure times to avoid congestion or selecting destinations which can be reached with less delay. For example, as shown in Figure 3.4, the average skim travel times for big loop Iteration 3 at 5:00 p.m. are 1.7 min lower than skim travel times in big loop Iteration 1. It should be noted that the difference in average skim values varies by 30-min time period. For example, between 5:00 p.m. and 7:00 p.m. the average travel time decrease is about 1.5 min; in the hour 4:00 p.m. to 5:00 p.m. (see Figure 3.5), average skim travel times did not change significantly, with the period from 16:00 to 16:30 showing a slight increase in travel times of 0.4 min, an indication that drivers might be shifting their departure times to avoid congestion. Interestingly, not all origin–destination pairs registered a decrease in skim travel times between big loop iterations; some of them showed a moderate increase which was offset by the larger number of pairs that exhibited a decrease.

Comparison of Static and Dynamic Skims

Activity-based models so far have used static highway assignment models that provide average LOS for multihour peak time periods. One of the main objectives of the C10B research is to take advantage of DTA models' simulation of drivers' route choices and interactions with other drivers and their ability to provide more realistic travel times at finer time resolutions. Despite the differences in the static and dynamic network assignment models, the study team found that, on average, the static and dynamic zone-to-zone travel times do not differ although individual zone-to-zone values can differ significantly. This is an encouraging research result because it increases the compatibility and substitutability of DTA models in an activity-based model setup that already uses static assignment.

Analyzing the differences between the static and dynamic skims is important in developing the theoretical framework to be used in integrating activity-based models and DTA models, given that the activity-based model interacts with the DTA model only through the skims.

Figure 3.6 is a scatterplot that shows static skim travel times versus dynamic skim travel times. For the C10B integrated model, dynamic skim travel times are calculated every 30 min, but in this plot dynamic times are computed for the time period from 3:00 p.m. to 6:00 p.m., which coincides with the p.m. peak period used in SACSIM. In the scatterplot, there are more than 2 million zone-to-zone data points shown. Instead of showing the points themselves as in a regular scatterplot, the density of the points is displayed using the colorbar on the right of the figure. Points change colors based on the logarithm of the density. A red color indicates that there are 10,000 (10^4) points in a particular location on the graph. Most but not all of the outliers in the lower part of the figure are due to differences in the zone connector structures. The clustering of points around the diagonal means that, on average, there is little difference between the static and dynamic skims. Had the average skim values been different, substantial recalibration of SACSIM would have been necessary. (It is important to note that this finding applies only to skim values and not to individual vehicle travel times, which may differ significantly.)

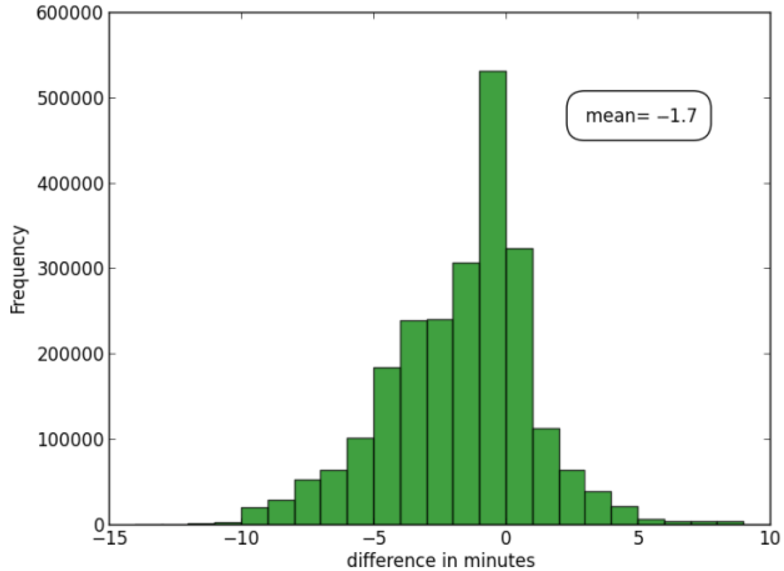


Figure 3.4. Skim differences between big loop Iterations 1 and 3, 5:00 p.m.

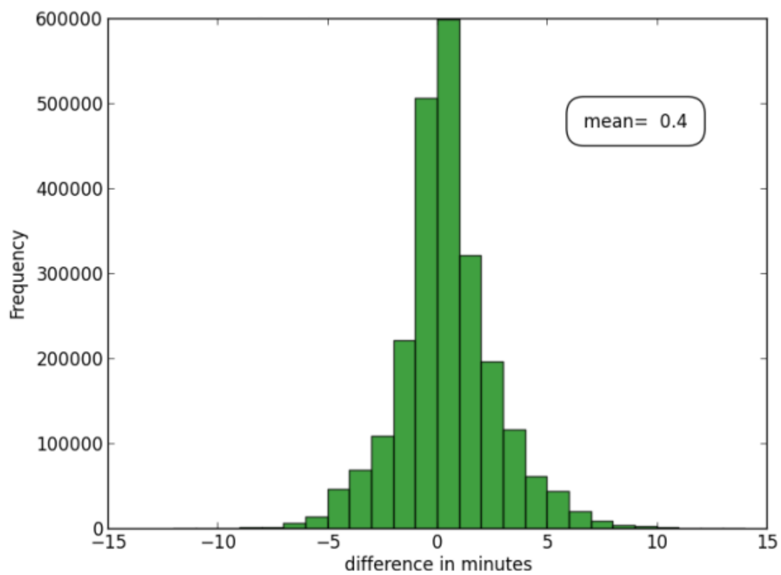


Figure 3.5. Skim differences between big loop Iterations 1 and 3, 4:00 p.m.

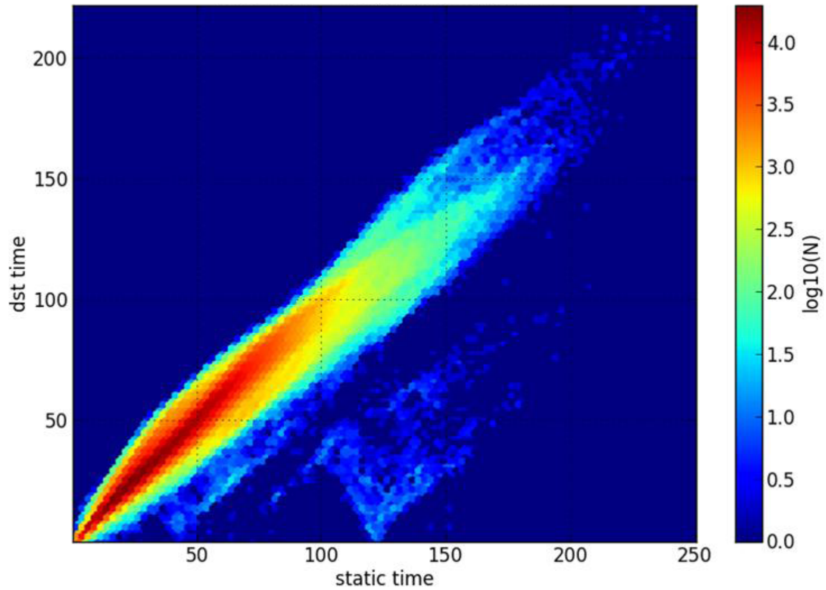


Figure 3.6. Static skim travel times versus dynamic skim travel times, from 3:00 p.m. to 6:00 p.m.

Figure 3.7 is a histogram of the differences of individual zone-to-zone travel times between the static and the dynamic network models in the a.m. peak period. It is interesting to note that the average difference is 0.9 min—about a 2% difference, with the average skim value of about 45 min.

Figure 3.8 shows the distribution of static and dynamic travel times in the a.m. peak period. Again the average static and dynamic skim travel times are very close. Rather than showing the data aggregated into multihour periods that correspond to the static assignments, the figure shows the DTA results for a small number of 30-min intervals from 7:30 a.m. to 9:00 a.m. Average skim travel times range from 44.3 min to 47.9 min, while the average a.m. peak static travel time is 45.5 min.

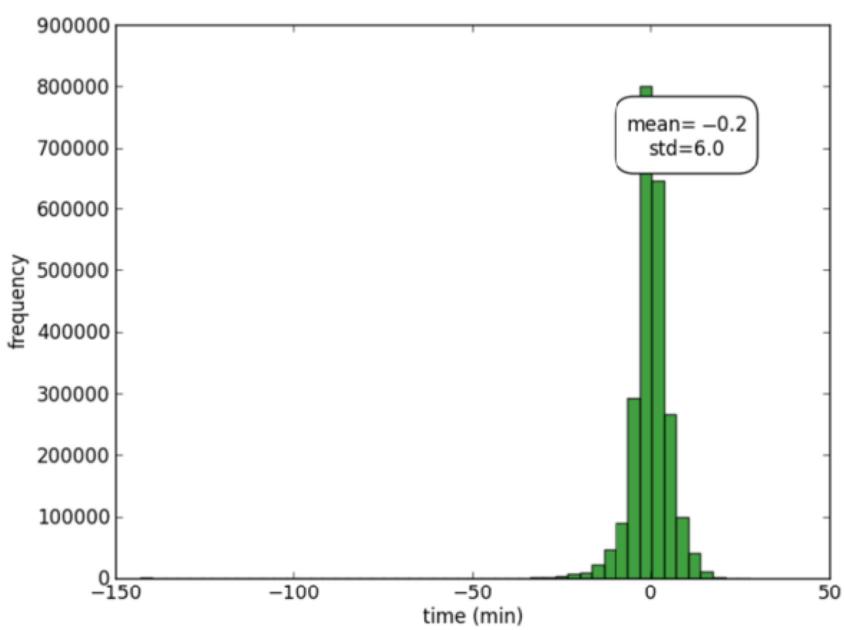


Figure 3.7. Differences between static and dynamic travel times, a.m. peak period.

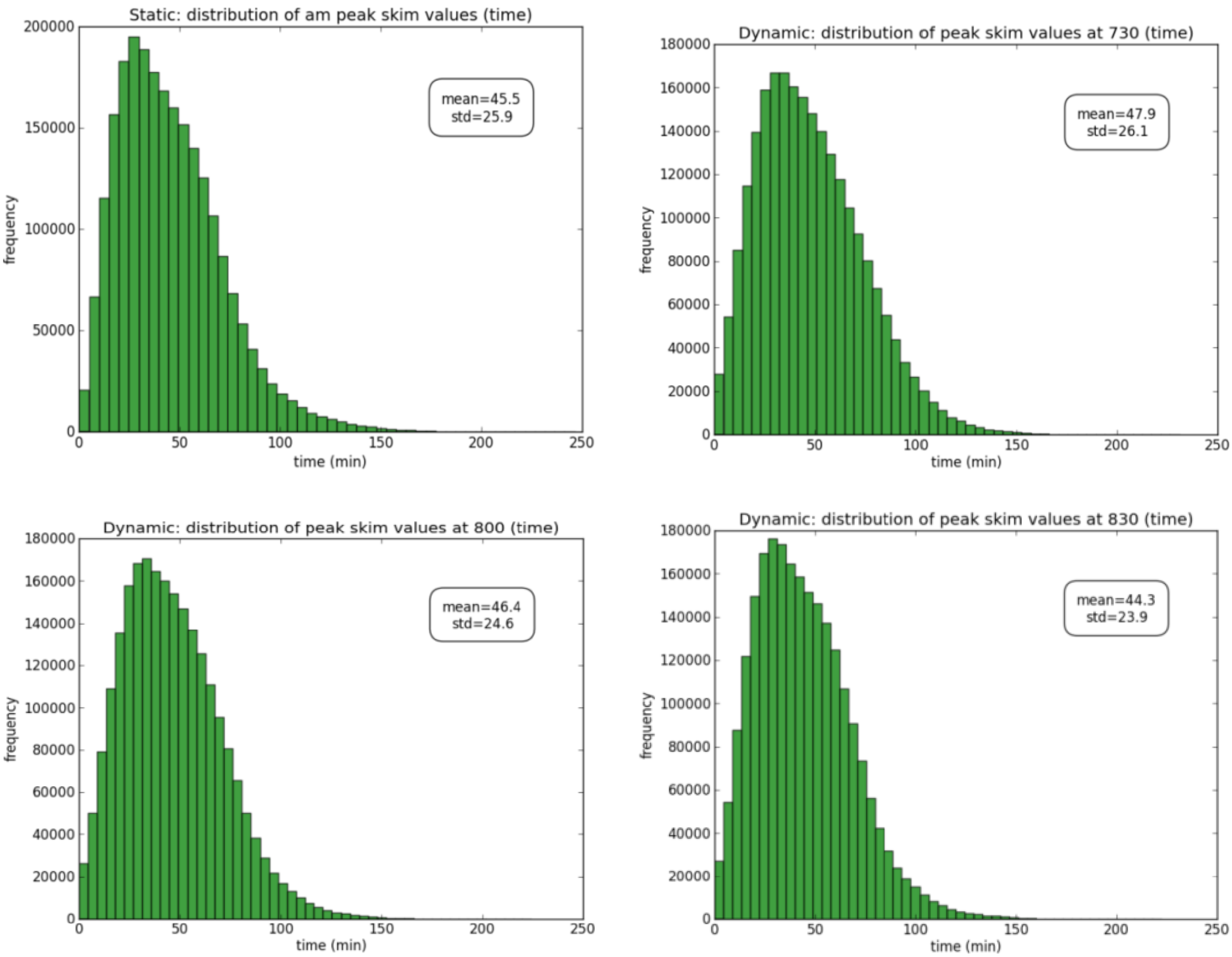


Figure 3.8. Static and dynamic skim differences, a.m. peak period.

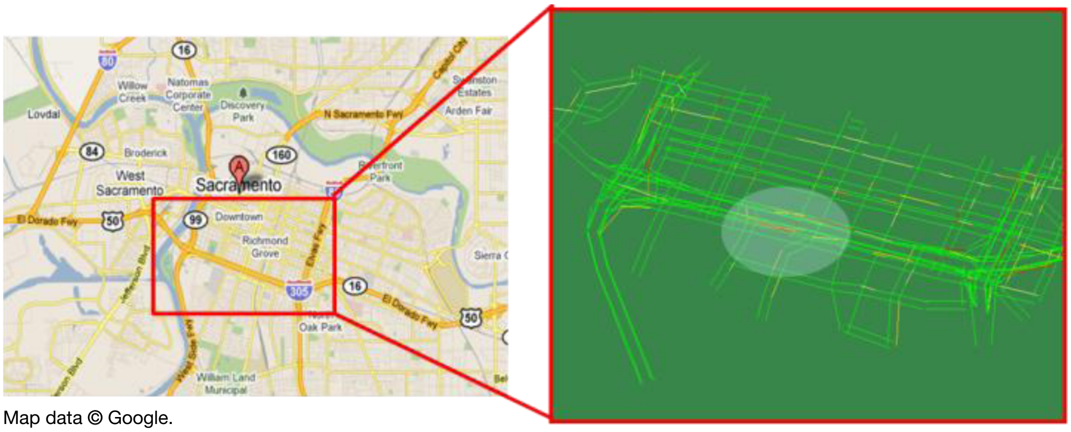
Testing of the DynusT-MOVES Integration

This section summarizes the set-up, data preparation, and CO_2 emissions results for a brief sample case to illustrate the MOVES-DynusT integration process. During the preparation of this sample case study, MOVES2010a was the latest available version and was used for calculating CO_2 emissions with DynusT-based travel activity data. The study team observed no changes in CO_2 emissions model outputs between MOVES2010a and MOVES2010b. Therefore, the discussions presented in this section should remain valid if MOVES2010b is used in place of MOVES2010a.

Network Descriptions and Scenario Setup

The proposed MOVES-DynusT integration framework was carried out and examined with a downtown network (see Figure 3.9) in Sacramento, California, where State Highway 50 traverses the center of the network and Interstate 80 and State Highway 99 intersect Highway 50 on the west- and east-side of the network, respectively. This roadway network as represented in DynusT consists of 437 nodes and 768 links. The simulation was performed for a morning peak time period (between 6:00 a.m. and 10:00 a.m.) on a weekday in February 2009. As a hypothetical case study, a total of 66,150 vehicles were generated in this time period and the hourly travel demand distributions were 10%, 19%, 28%, and 43%, with a much higher demand in the last hour (9:00 a.m. to 10:00 a.m.). The surge of demand was intended to allow the examination of how MOVES emissions estimation is affected by congestion level. The fleet mix was set to consist of 90% passenger vehicles and 10% heavy-duty vehicles.

Two scenarios were considered: a baseline scenario and an intersection improvement scenario. The intersection



Map data © Google.

Source: DynusT simulation.

Figure 3.9. Illustration of case study roadway network in DynusT.

improvement scenario included off-ramp capacity expansion and a downstream intersection signal retiming strategy to alleviate the westbound traffic congestion caused by the off-ramp traffic spillback. Both the baseline and improvement scenarios were modeled in DynusT to generate travel activity data, such as detailed vehicle trajectories, speed, and hourly VMT changes (see Figure 3.10). These data were then processed to populate data tables for MOVES project-scale modeling runs.

Note that hours 1 through 4 represent each hour during the morning peak from 6:00 to 10:00 a.m.

For the three key MOVES input data tables (i.e., "Links," "LinkSourceTypes," and "OpmodeDistribution"), external quality checking was performed to ensure data completeness and consistency. Specifically, the following checks were conducted on the DynusT-based MOVES input data for CO_2 emissions modeling (these checks are typically related to common areas in which project-scale MOVES input data may have completeness and consistency issues):

- For each hour, checked if there were links with missing traffic volume data in the "Links" data table;
- For each hour, checked data completeness in the "LinkSourceTypes" and "OpmodeDistribution" input tables; ensured that, for each link with nonzero traffic volume, there were source type distribution data in the

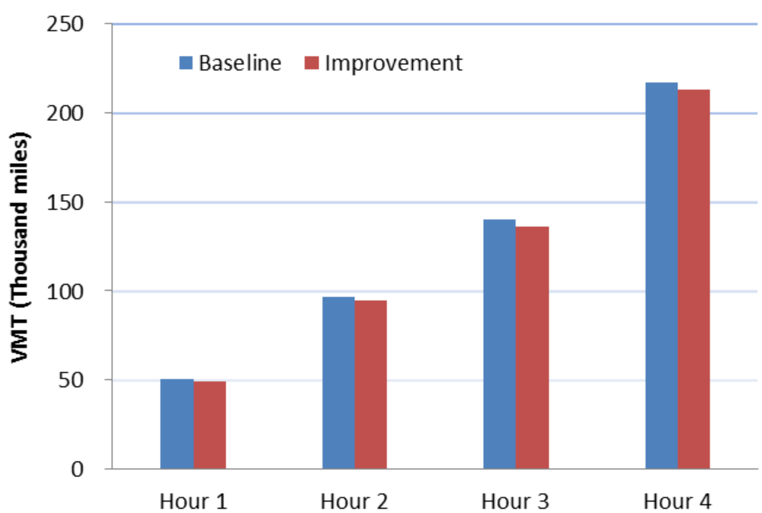


Figure 3.10. Variation in VMT of all source types from DynusT simulation by hour for baseline and intersection improvement scenarios.

Table 3.11. Comparison of Travel Activity Estimates Between Baseline and Improvement Scenarios

Activity	Baseline	Improvement	Change
VHT (hours)	3,569	3,130	–12.3%
VMT (miles)	139,730	136,247	–2.5%
Total stop time (hours)	550	338	–38.5%

"LinkSourceTypes" table and operating mode distribution data (by source type) in the "OpmodeDistribution" table; and

- Ensured that the operating mode data were processed appropriately (based on vehicle speed and VSP data) and fractions data were correctly assigned to the corresponding operating mode bins in MOVES.

Travel Activity and CO_2 Emissions Estimates

For the two scenarios in this case study, the general patterns of the travel activity and CO_2 emissions estimates from the MOVES-DynusT simulations were evaluated. The comparison focused on assessing whether CO_2 emissions estimates and the corresponding travel activity changes were consistent with the use of the MOVES-DynusT integration framework and data processing approaches.

Baseline Versus Improvement Scenario

Compared with the baseline condition, traffic operation in the improvement scenario was improved. As shown in Table 3.11, the off-ramp capacity increase and signal timing optimization resulted in reductions in vehicle-miles traveled (VMT) and vehicle-hours traveled (VHT). Significant improvement in total vehicle stop time at signals (in hours) was also observed.

As shown in Figure 3.11, speed space-time contour diagrams were used to compare temporal variation in congestion levels between the baseline and the improvement scenarios. A space-time contour diagram typically shows how speed changes by time (in the x-axis) along a roadway segment (distance in the y-axis). For example, Figure 3.11 suggests that, in general, higher vehicle speeds were observed in the improvement scenario (right), relative to the baseline scenario (left), especially in the upstream traffic during Hour 4 (9:00 a.m. to 10:00 a.m.).

The operating mode distributions, which are directly related to emissions estimation in MOVES, were compared between the baseline and the improvement scenarios. Figure 3.12 shows the comparison results for Hour 1 (6:00 a.m. to 7:00 a.m.) data, in which operating mode distributions are aggregated into three speed ranges: low (0 to 25 mph), medium (25 to 50 mph) and high (>50 mph). The pie charts indicate that more operating modes were shifted from medium- to high-speed categories. Accordingly, greenhouse gas emissions are expected to be lower in the improvement scenario due to better energy efficiency associated with higher-speed operating modes.

Hour-by-hour comparisons (see Figure 3.13 and Figure 3.14) suggest that (a) the overall CO_2 equivalent (referred as CO_2E) emissions were reduced across source types in the improvement scenario; (b) there were larger percentage reductions of CO_2E emissions than reductions in VMT; and (c) for some hours, reduced CO_2E emissions were observed in the improvement scenario despite increased VMT over the

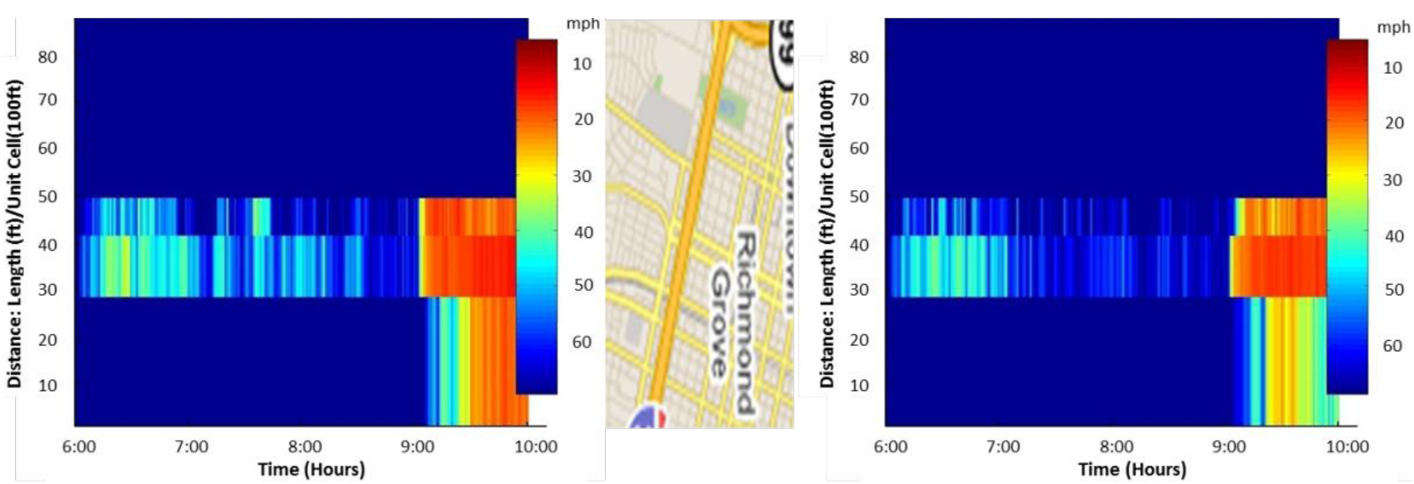


Figure 3.11. Comparison of speeds between baseline (left) and improvement (right) scenarios.

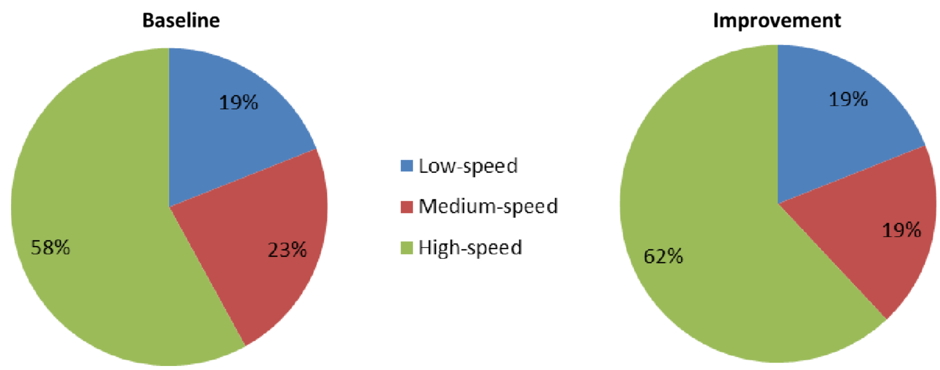
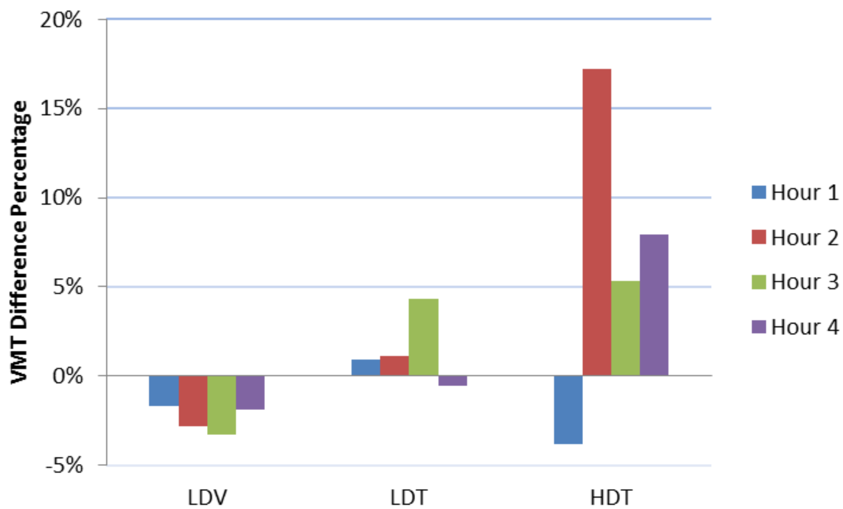
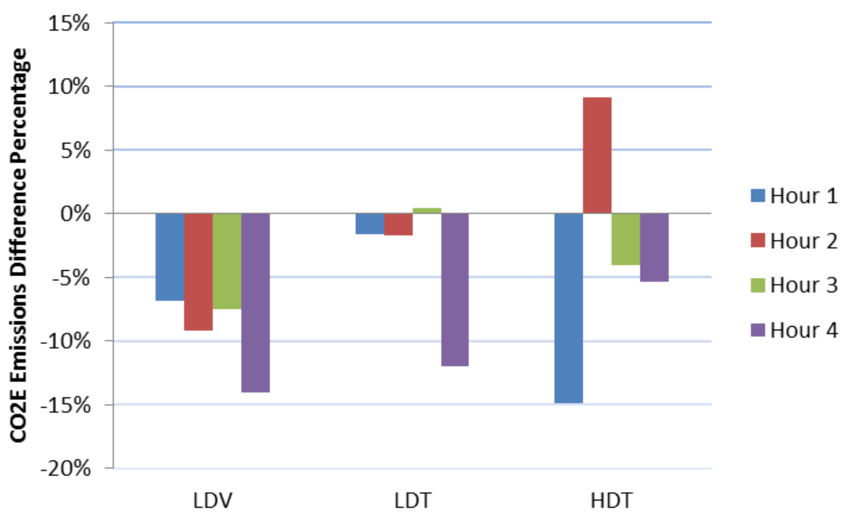


Figure 3.12. Comparison of operating mode distributions between scenarios from 6:00 a.m. to 7:00 a.m.



Note: LDV = light-duty vehicle; LDT = light-duty truck; HDT = heavy-duty truck.

Figure 3.13. Percent change in VMT: Improvement versus baseline scenario.



Note: LDV = light-duty vehicle; LDT = light-duty truck; HDT = heavy-duty truck.

Figure 3.14. Percent change in CO_2E emissions: Improvement versus baseline scenario.

baseline. These comparison results indicated that, in addition to VMT changes, the shift in operating mode distributions (reduced stop time and improved travel speed) were associated with the CO_2E emissions reductions.

Default Drive Schedules Versus Local Operating Mode Distributions

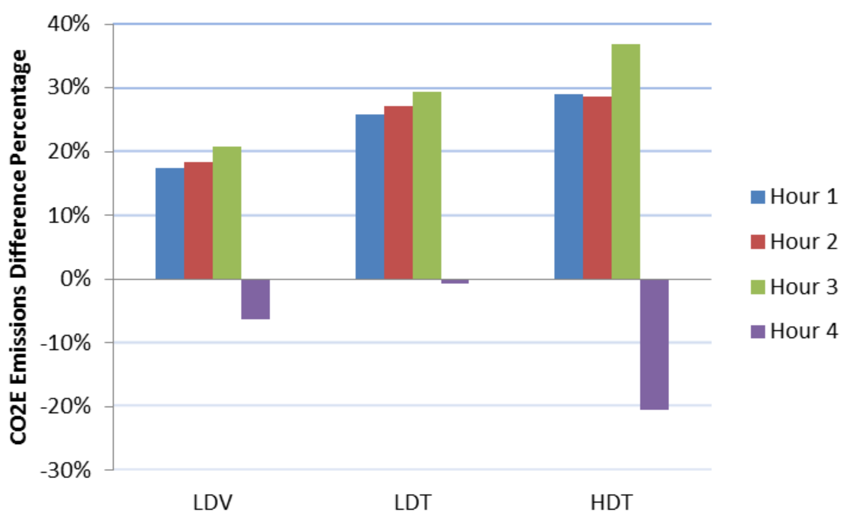
Under the MOVES-DynusT integration framework, operating mode distributions used as the major inputs in MOVES are calculated based on DynusT simulation data. This approach is theoretically sound and presumably produces more reasonable emissions estimates than using the MOVES default drive schedule or average speed data. Note that using operating mode distributions to develop emissions estimates in MOVES reflects a modeling approach based on local travel activity information. Alternatively, MOVES allows use of its default drive schedule (second-by-second speed) data for calculating emissions, which requires relatively less modeling effort. The team was interested in evaluating how emissions estimates differ when using MOVES default drive schedules and when using user-supplied operating mode distributions (e.g., generated from DynusT-based activity data).

To set up the comparison, the same baseline scenario was used as presented previously in the brief case study; MOVES was run separately with (a) link average speeds (i.e., using MOVES default drive schedules) and (b) user-supplied operating mode distributions developed in DynusT. Figure 3.15 illustrates the hour-by-hour CO_2E emissions comparison results. Note that in this comparison, the two approaches (the default drive schedule approach and the operating mode distribution approach) were conducted using the same VMT data generated from the DynusT baseline simulation.

As discussed earlier, VMT in the baseline scenario increased and the sample network became more congested from Hour 1 to Hour 4. The emissions results for the first 3 h show a consistent pattern (i.e., using MOVES default drive schedules yields up to 37% higher CO_2E emissions than using the localized operating mode distributions generated by DynusT). However, the comparison results in Hour 4 indicate a reversed pattern, in which lower CO_2E emissions were estimated under a more congested traffic condition with the default drive schedule modeling approach.

Further investigation found a problem with MOVES itself: zero emissions were being estimated for heavy-duty vehicles traveling on links with average speeds below 5.8 mph, which led to inaccurate emissions estimates in highly congested conditions. This meant that, when default drive schedules were used as activity inputs, MOVES provided no emissions estimates for heavy-duty vehicles for links with an average speed lower than 5.8 mph. Similarly, emissions were not generated for light-duty vehicles when average link speed was below 2.5 mph (see Table 3.12). Travel activities of low speeds are typically associated with high pollutant emissions. Hence, using the default drive schedule approach in MOVES, which omitted emissions estimates associated with low-speed links, resulted in underestimated emissions.

Consequently, it is noteworthy that under a highly congested condition, using localized operating mode distribution



Note: LDV = light-duty vehicle; LDT = light-duty truck; HDT = heavy-duty truck.

Figure 3.15. Percent difference in CO_2E emissions by hour and source type: MOVES default drive schedule approach versus user-supplied operating mode distribution approach.

Table 3.12. MOVES Allowable Average Speed Input Range for Project-Level Analysis by Source Type

SourceTypeID	SourceTypeName	Minimum Speed (mph)	Maximum Speed (mph)
11	Motorcycle	2.5	73.8
21	Passenger Car	2.5	73.8
31	Passenger Truck	2.5	73.8
32	Light Commercial Truck	2.5	73.8
41	Intercity Bus	4.6	72.8
42	Transit Bus	15.0	72.8
43	School Bus	15.0	72.8
51	Refuse Truck	2.2	71.7
52	Single Unit Short-haul Truck	4.6	72.8
53	Single Unit Long-haul Truck	4.6	72.8
54	Motor Home	4.6	72.8
61	Combination Short-haul Truck	5.8	71.7
62	Combination Long-haul Truck	5.8	71.7

Source: U.S. Environmental Protection Agency (2012).

data is of particular importance to produce more reasonable emissions results.

Discussion

Through a brief case study, it was verified that the MOVES-DynusT integration framework and data processing approach can take advantage of local operating mode distribution data, produce reasonable and informative CO_2 emissions results, and reflect simulated impacts of assumed analysis strategies. The preliminary results of analysis suggest that, using DynusT-based travel data and MOVES project-scale modeling functions, CO_2 emissions changes can be reasonably modeled with the shift in operating mode distributions. The case study also indicated the importance of using the localized operating mode, instead of MOVES default drive schedule data, for generating emissions estimates especially under highly congested conditions.

CHAPTER 4

Analysis of Policies and Alternatives of Interest to Planning Agencies

A set of policy tests was conducted to demonstrate that the C10B integrated model is capable of analyzing the types of policies and alternatives that are part of typical urban transportation planning processes. The objective was to produce reasonable results in a real-world environment for typical transportation planning policies. With this in mind, it was decided that SACOG would perform the analyses at its offices, using its own hardware and staff, with assistance from other team members. The idea was to get an idea of the type of effort that would be required for a planning agency to perform these types of analyses using the integrated model. A discussion of SACOG's experience in performing these analyses is provided in Chapter 5. Team member Fehr and Peers provided assistance with some tests, and additional assistance was provided by Cambridge Systematics, Inc., and the University of Arizona.

Originally, eight tests were planned. The final number of tests completed by SACOG was five, as described in the first section of this chapter. Three tests related to transit service changes, and two related to highway system changes. Because of the differences in the types of system changes, the performance measures used to evaluate the tests varies among the alternatives. These are described in more detail in the second section of the chapter.

For each of the five tests, the results of a particular scenario that related to a change in the transportation system were compared with the results from a baseline scenario, which was the same for all tests. The baseline represented year 2005 conditions in the Sacramento region. All scenarios were run using the C10B integrated model; most scenarios were also run using the original SACSIM model validated for the region.

Limitations on project resources resulted in some shortcuts taken in the analyses and in the preparation of the C10B integrated model. These issues are described in the following list. It is hoped that further research with this type of integrated model can assist in assessing the effects of these issues and their practical implications. The issues include the following:

- Perhaps the most significant issue was the limited validation of the C10B integrated model, as described in the Chapter 3 section on model testing. This resulted in some significant differences in the baseline scenario results between the C10B model and SACSIM; some of the differences were in the vicinity of the transportation system changes under study, making comparison of the model results difficult in some cases.
- Another limitation was the level of convergence achieved in DynusT, also described in the Chapter 3 section on model testing. The test results implied that there was still substantial noise in some C10B integrated model results which affected the ability to fully evaluate the test results. There is, of course, also noise in SACSIM since it includes an activity-based demand model that simulates individual travel behavior. But there is more noise in the C10B integrated model since it includes SACSIM as well as the traffic and transit simulation components in DynusT and FAST-TrIPs. It would have been desirable to have tighter convergence in DynusT, but efficiency considerations prevented this.
- Another issue was that each test was run only once with each model. Ideally, simulation models should be run multiple times to get a handle on the level of noise in the results. SACOG has done this with its own validated version of SACSIM, but it was not possible within the project schedule to run each test several times. As the results presented later show, some of the results appear questionable due to the noise level in the C10B integrated model, which is greater than in SACSIM because it includes the additional traffic and transit simulation components.

Test Scenarios

The set of five policy and investment alternative scenarios analyzed were defined by SACOG. While the scenarios are realistic and typical of the types of policies and scenarios that SACOG analyzes in its transportation planning function, it must be made clear that the scenarios are not actual projects under consideration in the Sacramento region.

Each test was performed using the C10B integrated model, and most tests were also performed using SACSIM. In all tests, the effects of a project scenario (labeled "Scenario 1," "Scenario 2," etc.) reflecting the specific transportation system change were compared with a baseline no-project scenario. So, for example, in the results for Test 1, the results of Scenario 1 were compared with the baseline scenario; for Test 2, the results of Scenario 2 were compared with the baseline scenario; and so on. For each test, the effects were compared with one or more hypothesized or expected results for direction or sign of effect and for magnitude of effect relative to random effects.

Table 4.1 shows the five policy test scenarios. Test 1 was performed using only the C10B integrated model since SACSIM does not have the capability of analyzing this type of transit service change. The other four scenarios were analyzed using both the C10B model and SACSIM, and the results from the two models were compared.

An additional test to analyze signal coordination on a major arterial corridor was initially run. This test was abandoned after examining the level of noise in the C10B model results—this policy change was too subtle to test using the C10B model without multiple runs.

As discussed earlier, due to run time and resource limitations, the test results discussed in this chapter reflect only one run per scenario. The limited tests indicate that the number of iterations in the DTA and DaySim models play a significant role in the results and may need to be tailored to each particular scenario and level of congestion to obtain the level of sensitivity required for comparisons. The lower the level of random variability in a dynamic assignment model and the more its convergence approaches what is customarily found in static assignment models, the higher the substitutability between dynamic and static models in an integrated modeling framework will be.

Table 4.1. Policy Test Scenarios

Test	Description
Extend transit service coverage	Test of extending the end of transit service for a bus route from 6:00 p.m. to midnight
Improve interchange design	Test of operations-oriented interchange improvement project
Relieve freeway bottleneck	Test of adding fourth general purpose lane to a heavily congested freeway river crossing connecting to downtown
Increase transit frequency	Test of reducing service headways from 30 min to 10 min on a well-used bus line
Delete bus line	Test of deleting a well-used bus line

Testing and Performance Metrics

For each scenario, up to three general categories of testing were conducted:

- *Demand testing* focused on the number, mode, destination location, and timing of person trips or person tours. Demand testing utilized the standard person tour and person trip segment output files of DaySim05, which were common to both the C10B and SACSIM travel demand models. Some aspect of demand testing was included in all of the tests.
- *Traffic assignment testing* focused on vehicle volumes and vehicle speeds in and around the test segments, for the two scenarios involving roadway projects (2 and 3). The DynusT traffic assignment results and output files produced using the C10B model for these tests include much more temporal detail than SACSIM model output files; the policy testing includes comparisons of the level of detail provided using the C10B model.
- *Transit assignment testing* focused on total line passenger boardings, passenger boardings by time period, and vehicle loading by time period. Testing included the routes changed in the scenarios, plus several nearby routes likely to be affected by changes in service on the tested routes. Transit assignment testing was performed for three transit-related scenarios (1, 4, and 5). FAST-TrIPs produces much more temporal detail than SACSIM; and, like the traffic assignment testing, the transit policy testing includes comparisons of the level of detail provided using the C10B model.

Table 4.2 shows the test metrics used for the policy testing. To manage and evaluate random variation and "noise-to-signal" issues in the policy testing, the following process was used:

- For test effects on demand, recent evaluations by SACOG of randomness and noise on the SACSIM model were used. Testing of random variation in SACSIM resulted in a range of expected variation for various metrics. For SACSIM, the expected range of variation was used to perform a simple "greater than/less than" test for each test effect. No testing of random variation was done for the C10B model, but variation was significantly higher than with the SACSIM model. For test effects on demand for the C10B model runs, three times the SACSIM variation was used as a proxy for the policy testing; these effects should be considered cautiously due to their very approximate nature.

Table 4.2. Test Metrics Used for Policy Testing of C10B, SACSIM, or Both

Metric	Test 1	Test 2	Test 3	Test 4	Test 5	Notes
Demand						
Person trips by mode	Both	Both	Both	Both	Both	Changes in mode choice
Person trips by depart time		Both	Both			Changes in depart time
Person tours by tour destination		Both	Both			Changes in location of activities
Traffic Assignment						
Segment daily volume	Both	Both	Both	Both	Both	Compare changes in volumes across models
Segment volume by hour		C10B	C10B			Changes in vehicle volumes and timing of trips
Segment volume by aggregate time period		SACSIM	SACSIM			Changes in vehicle volumes and timing of trips
Segment average speed by hour		C10B	C10B			Changes in speed over time
Segment average speed by aggregate time period		SACSIM	SACSIM			Changes in speed over time
Vehicle-hours of delay by aggregate time period		Both				Freeway only, using 35 mph as threshold speed
Transit Assignment						
Transit line daily passenger boardings	C10B			Both	Both	Compare changes across models
Transit boardings by hour	C10B			C10B	C10B	Changes in volumes and timing of trips
Transit boardings by aggregate time period	SACSIM			SACSIM	SACSIM	Changes in volumes and timing of trips
Maximum load on vehicles by hour	C10B			C10B	C10B	Effects of vehicle capacity

- Other than the limited tests described in Chapter 3, no evaluations of random variations for traffic or transit assignments were available for either the SACSIM or C10B models. For these tests, no evaluations of random variation or the likelihood of test effects exceeding random variation were performed.

Test Results

In summary, the policy testing results were conditioned by two general themes or patterns: (1) The C10B integrated model is more noisy than SACSIM since it includes simulation in the traffic and transit assignment components in addition to the simulation that is characteristic of DaySim and (2) the tests performed were, in general, too fine-grained to distinguish the test effects from random variation. Repeated runs of the baseline and test scenarios would be necessary, with statistical aggregation of the multiple runs. Because of run time considerations, multiple runs were impractical for this project, and policy testing results were inconclusive for most of the tests.

- Although the C10B integrated model often reports feasible and reasonable results, other times the results are counterintuitive. Overall, the project team concludes that the policy test results are inconclusive and attributes this finding to the higher level of noise found in the C10B model compared with SACSIM. The results indicate that the C10B model is sensitive to the policy scenarios tested, and an integrated ABM and DTA model shows promise if the issues of noise and convergence are quantified and better understood.
- The C10B integrated model provides a staggering degree of detail and flexibility in its outputs; the basic outputs, though inconclusive for the policy testing performed for this project, were, in the main, reasonable. The detail and flexibility is mainly based on the treatment of time in the modeling outputs. For purposes of these tests, the C10B integrated model outputs were aggregated to 1-h time slices, but the model would support much smaller time intervals, as well.

Table 4.3 summarizes the demand testing results for all five scenarios. There are four columns for each for the results

Table 4.3. Policy Testing—Demand Effects Summary

Hypothesis/Expectation	SACSIM				C10B			
	Test Effect	Random Effects (+/–)	"Correct" Sign?	Test Effect > Random?	Test Effect	Random Effects (+/–)	"Correct" Sign?	Test Effect > Random?
Test 1. Transit Service Coverage—Test Extends Service on Rte. 11 from 6:00 p.m. to Midnight								
Increase in transit person trips	n/a	n/a	n/a	n/a	+1.3%	Unknown	Yes	Unlikely
Increase in walk person trips	n/a	n/a	n/a	n/a	+1.6%	Unknown	Yes	Likely
Decrease in private auto mode person trips	n/a	n/a	n/a	n/a	–0.07%	Unknown	Yes	Unlikely
Increase in transit person trips after 6 p.m.	n/a	n/a	n/a	n/a	–1.5%	Unknown	No	n/a
Test 2. Operations-Oriented Interchange—Test Removes Interchange Improvements from I-80/Douglas								
Decrease in tour destinations around interchange	–0.12%	0.04%	Yes	Yes	+0.57%	Unknown	No	Likely
• Roseville West	+0.45%	0.04%	No	Yes	+0.48%	Unknown	No	Likely
• Roseville East	–0.74%	0.04%	Yes	Yes	+1.04%	Unknown	No	Likely
• Granite Bay	+0.11%	0.04%	No	Yes	+1.97%	Unknown	No	Likely
• Citrus Heights	+0.14%	0.04%	No	Yes	–0.08%	Unknown	Yes	Unlikely
Decrease in total number of tours	–0.02%	0.04%	Yes	No	–0.05%	Unknown	Yes	Unlikely
Decrease in % of local area trip destinations during peak hours	–0.34%	Unknown	Yes	n/a	–9.56%	Unknown	Yes	n/a
• Work trips	–0.40%	Unknown	Yes	n/a	–13.27%	Unknown	Yes	n/a
• All other trips	–0.32%	Unknown	Yes	n/a	–8.19%	Unknown	Yes	n/a
• Work trips change less than nonwork trips	n/a	Unknown	No	n/a	n/a	Unknown	No	n/a
Test 3. Freeway Bottleneck—Add Lanes to Congested Segment								
Increase in tour destinations around bridge	+0.18%	0.04%	Yes	Yes	–0.59%	Unknown	No	Likely
• Downtown	+0.41%	0.04%	Yes	Yes	–1.31%	Unknown	No	Likely
• North Sacramento	+0.03%	0.04%	Yes	No	–0.81%	Unknown	No	Likely
• Arden Arcade	+0.14%	0.04%	Yes	Yes	–1.31%	Unknown	No	Likely

(continued on next page)

Table 4.3. Policy Testing—Demand Effects Summary (continued)

	SACSIM				C10B			
Hypothesis/Expectation	**Test Effect**	**Random Effects (+/−)**	**"Correct" Sign?**	**Test Effect > Random?**	**Test Effect**	**Random Effects (+/−)**	**"Correct" Sign?**	**Test Effect > Random?**
• East Sacramento	+0.001%	0.04%	Yes	No	−0.68%	Unknown	No	Likely
• Carmichael	+0.24%	0.04%	Yes	Yes	−0.14%	Unknown	No	Likely
• Antelope/North Highlands	+0.19%	0.04%	Yes	Yes	+1.53%	Unknown	Yes	Likely
Increase in total number of tours	+0.03%	0.04%	Yes	No	+0.28%	Unknown	Yes	Likely
Increase in % of local area trip destinations during peak hours	+0.18%	Unknown	Yes	n/a	−7.51%	Unknown	No	n/a
• Work trips	+0.04%	Unknown	Yes	n/a	−8.16%	Unknown	No	n/a
• All other trips	+0.25%	Unknown	Yes	n/a	−7.12%	Unknown	No	n/a
• Work trips change less than nonwork trips	n/a	Unknown	Yes	n/a	n/a	Unknown	No	n/a
Other Changes—No hypothesis/expectation								
Change in transit person trips	+3.63%	1.06%	n/a	Yes	+5.64%	Unknown	n/a	Likely
Change in bike/walk person trips	−0.03%	0.30%	n/a	No	+0.07%	Unknown	n/a	Unlikely
Change in private auto mode person trips	+0.14%	0.04%	n/a	Yes	+1.05%	Unknown	n/a	Likely
Test 4. Transit Route Frequency (30-to-10-minute headway)								
Increase in transit person trips	+3.15%	1.06%	Yes	Yes	+5.12%	Unknown	Yes	Likely
Increase in walk person trips	+0.38%	0.30%	Yes	Yes	+1.46%	Unknown	Yes	Likely
Decrease in private auto mode person trips	−0.06%	0.04%	Yes	Yes	−0.09%	Unknown	Yes	Unlikely
No change in total person trips	+0.002%	0.04%	n/a	No	+0.10%	Unknown	No	Unlikely
Test 5. Transit Route Presence (bus line deleted)								
Decrease in transit person trips	−1.75%	1.06%	Yes	Yes	+1.76%	Unknown	No	Unlikely
Increase in walk person trips	+0.29%	0.30%	Yes	No	+0.74%	Unknown	Yes	Unlikely
Increase in private auto mode person trips	+0.02%	0.04%	Yes	No	+0.01%	Unknown	Yes	Unlikely
No change in total person trips	+0.02%	0.04%	n/a	No	+0.08%	Unknown	Yes	Unlikely

Notes: Shaded areas indicate results which were not the correct sign *and* the test effect was greater than, or likely to be greater than, the random effect. Random effects are unknown for C10B model. Estimate of random effect for purposes of evaluation was three times the SACSIM random effect. C10B model test effects greater than three times SACSIM random effect were deemed likely to be greater than random.

Table 4.4. Person Trips by Mode—Test 1

Mode	Baseline	Scenario 1	Difference	Percent Difference
Transit auto access	10,999	10,915	–84	–0.8%
Transit walk access	59,759	60,765	+1,006	+1.7%
Transit (total)	70,758	71,680	+922	+1.3%
School bus	91,627	92,248	+621	+0.7%
Shared ride 3+	2,264,407	2,261,893	–2,514	–0.1%
Shared ride 2	2,044,692	2,042,891	–1,801	–0.1%
Drive alone	3,615,848	3,615,022	–826	–0.0%
Bike	97,686	99,043	+1,357	+1.4%
Walk	521,898	530,005	+8,107	+1.6%
Total	8,706,916	8,712,782	+5,866	+0.1%

using SACSIM and the C10B integrated model. "Test effect" shows the percentage change from the baseline scenario for each measure. "Random Effects (+/–)" shows the expected range of variation (available only from SACSIM for certain measures). "Correct Sign?" is an indicator of whether the model results changed in the expected direction for the given measure. "Test Effect > Random?" is an indicator of whether the change in results exceeds the expected range of variation. For the C10B integrated model, this last indicator is shown as "likely" if the difference is greater than three times the SACSIM variation and "unlikely" otherwise. No analysis of changes to highway assignment was included in the transit related tests (1, 4, and 5).

The results for the individual scenarios are discussed in the following subsections.

Test 1 Results

This test was performed using only the C10B integrated model. Scenario 1 extended service coverage on one bus route, the #11-Truxel route, which connects the Natomas neighborhoods to Downtown Sacramento, just to the south of Natomas and across the American River. The route currently runs from 6:00 a.m. to 6:00 p.m. on 30-min headways during the commute peaks, and hourly headways during the midday. The test involved extending service coverage beyond 6:00 p.m. to midnight, at 60-min headways. Because SACSIM is limited to representing day-long service in two generic peak and off-peak service periods, the effect of extending service coverage is impossible to explicitly model using SACSIM. Highlights of this test include the following:

- Demand effects conformed to the expected direction of the result for three metrics, as shown in Table 4.4. These metrics are
  - Transit person trips (increase);
  - Walk person trips (increase); and
  - Private auto person trips (decrease).

  Table 4.4 provides details of the trips by mode for the baseline and Scenario 1, and Table 4.5 provides details of the transit trips in the vicinity of the revised route by time period. The test effects were unlikely to exceed random effects for two of the three metrics. Oddly, for Scenario 1 compared with the baseline, the test resulted in slightly fewer total transit person trips made between 6:00 p.m. and 8:00 p.m., which is a significant part of the test. Most of the added transit person trips occurred between 10:00 a.m. and 3:00 p.m., and between 8:00 p.m. and midnight. While this result seems likely to be the result of the stochastic nature of the simulation, it does indicate that some of the "new" riders after 6:00 p.m. are attracted from other transit routes.

- Transit assignment effects conform to the expected direction of result. Under Scenario 1, Route 11 generated

Table 4.5. Transit Trips by Time Period—Test 1 in Localized Test Area

Time Period	Transit Trips		Difference	
	Baseline	Test	#	%
5 a.m. to 10 a.m.	13,411	13,380	–31	–0.2%
10 a.m. to 3 p.m.	5,448	5,592	+144	+2.6%
3 p.m. to 6 p.m.	7,527	7,513	–14	–0.2%
6 p.m. to 8 p.m.	1,269	1,219	–50	–3.9%
After 8 p.m.	793	812	+19	+2.4%
Total	28,448	28,516	+68	+0.2%

Table 4.6. Summary of Transit Passenger Boardings—Test 1

Test Metric	Count	SACSIM Baseline	C10B Baseline	C10B Scenario 1	C10B Percent Increase
Daily Boardings on Test Route					
Route 11	940	631	948	984	+3.8%
Other Nearby Routes					
Rte 13 (near Rte 11)	480	309	168	159	–5.4%
Rte 86 (near Rte 11)	2,240	1,797	1,700	1,610	–5.3%
Rte 88 (near Rte 11)	1,280	1,586	1,163	1,166	+0.3%
Sum of nearby routes	4,000	3,692	3,031	2,935	–3.2%
All other RT buses in C10B model	49,100	49,634	48,996	49,591	+1.2%

about 50 additional passenger boardings compared with the baseline (see Table 4.6). About 80 boardings were after 6:00 p.m. (see Figure 4.1), implying some rescheduling of trips due to the extended service.

In summary, in Test 1, the C10B integrated model behaved plausibly in an aggregate sense, shifting trips to the transit and walk modes from the auto modes and showing reasonable sensitivity and magnitude of response while maintaining a relatively constant level of demand. Boardings on the route for which service was extended increased while boardings on nearby routes declined. A significant part of the added boardings occurred in the extended service period between 6:00 p.m. and midnight. Even with the level of noise in the C10B model, it seems unlikely that the entirety of the model response is indistinguishable from random noise since the mode shifts and changes in boardings on individual routes are nearly all in the correct direction.

In terms of localized effects, however, the C10B integrated model showed only a minor impact on transit trips. The temporal shifts are also counterintuitive since trips shifted from the period when the service was extended.

Test 2 Results

Scenario 2 involved "uncoding" an operations-oriented interchange design improvement from the baseline scenario. The project location was the Douglas Boulevard interchange of Interstate 80 in the City of Roseville. The improvement that was removed involved three major components: (1) construction of a direct connector ramp from the eastbound Douglas

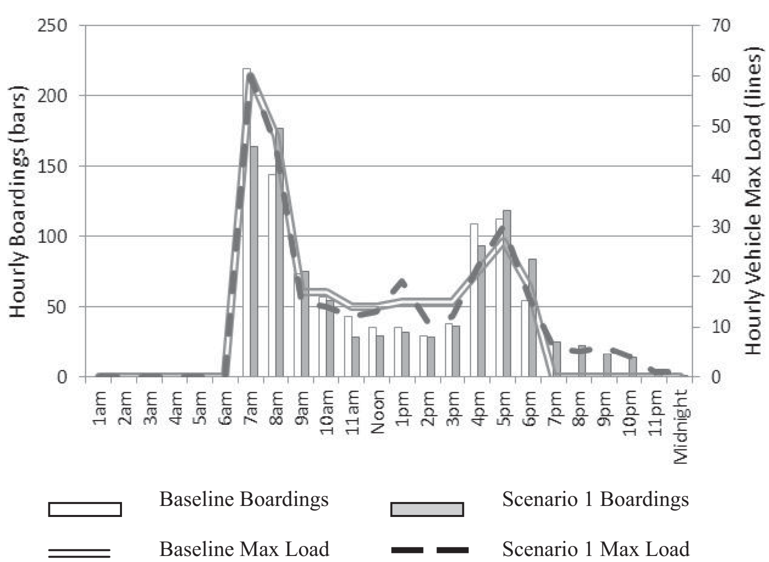


Figure 4.1. Route 11 transit boardings and vehicle loads for Scenario 1.

Boulevard overcrossing to southbound Sunrise Boulevard, a major north/south arterial just east of the interchange; (2) construction of a tunnel and direct ramp connection from northbound Sunrise Boulevard to eastbound/northbound I-80, with the tunnel running below the Douglas Boulevard overcrossing and other ramps; and (3) widening of the westbound Douglas Boulevard overcrossing itself, and addition of a second point of access to the westbound Douglas–to–westbound/southbound I-80 loop on-ramp. Highlights of this test include the following:

- A major impact on traffic patterns was expected (given that the test removes a significant improvement), resulting in higher congestion in the project area and fewer tour destinations in the project area. For both models, however, testing showed that tour destinations increased to most subareas around the project. The summary Table 4.3 demonstrates these effects. Table 4.7 presents details for the neighborhoods near the project location. One exception was for Roseville East for the SACSIM model, which showed the expected decrease; the decrease was large enough that the overall number of tour destinations decreased across all subareas.
- Another expected result of the demand testing was a decrease in the number of peak-period trips made with destinations in the project area. Both models showed this expected result (see Table 4.3 for the summary and Table 4.8 for details). However, the magnitude of the C10B model test effect—nearly a 10% reduction—is questionable.
- The traffic assignment results on the two new direct connectors for the two models (see Table 4.9) were fairly consistent:
  - The C10B integrated model showed about 12,000 daily vehicles using the northbound Sunrise to eastbound/northbound I-80 ramp (which was part of the interchange improvement and therefore appears only in the baseline scenario) compared with 10,500 for the same link for SACSIM.
  - The C10B integrated model showed about 17,500 daily vehicles using the eastbound Douglas to southbound Sunrise connector (which was part of the interchange improvement and therefore appears only in the baseline scenario) compared with about 15,000 for the same link for SACSIM.
- Table 4.9 also provides summaries of total volumes on relevant highway segments. Overall, the C10B model shows greater sensitivity to the change of segment volumes on ramps and arterials (a decrease of 4.5% in daily volumes compared with a 0.2% decrease for the SACSIM model) and on I-80 as well (2.5% decrease in total daily volumes compared with a 1.1% decrease for the SACSIM model).
  - The C10B model showed significant changes in total volumes on I-80 westbound, north of Douglas (−11%). Changes of this magnitude on I-80 were not expected as test results.
  - Both models showed an increase in traffic on Douglas Boulevard east of I-80, and some level of increase makes sense—some of the traffic which uses the new direct ramps to/from I-80 and Sunrise might shift to Douglas when those facilities were taken out. However, the magnitude of the increase in the C10B model (about 30% compared with about 15% for the SACSIM model) seems high.
- Figure 4.2 provides segment-by-segment graphical representations of C10B and SACSIM model results. As mentioned earlier, the most remarkable difference is in the level of detail in results for the C10B model. While SACSIM can provide total volumes for aggregate periods ranging from 3 to 13 h in length, the C10B model provides results for any time periods that the analyst wishes to define (for these figures, the results were aggregated to individual hours for the entire 24-h day).

Table 4.7. Person Tour Primary Destinations Near Project—Test 2

Tour Destination	SACSIM				C10B Integrated Model			
	Baseline	Scenario 2	Difference	Percent Difference	Baseline	Scenario 2	Difference	Percent Difference
Roseville West	95,600	96,029	+429	+0.4%	105,541	106,045	+504	+0.5%
Roseville East	150,651	149,540	–1,111	–0.7%	157,201	158,839	+1,638	+1.0%
Granite Bay	20,142	20,164	+22	+0.1%	21,903	22,334	+431	+2.0%
Citrus Heights	139,596	139,784	+188	+0.1%	147,325	147,205	–120	–0.1%
Combined areas	405,989	405,517	–472	–0.1%	431,970	434,423	+2,453	+0.6%
All other areas	3,110,819	3,110,647	–172	–0.0%	3,377,289	3,376,375	–914	–0.0%
All destinations	3,516,808	3,516,164	–644	–0.0%	3,809,259	3,810,798	+1,539	+0.0%

Table 4.8. Timing of Person Trips on Tours to Local Test Area—Test 2

Timing	SACSIM Model				C10B Model			
	Baseline	Scenario 2	Difference	Percent Difference	Baseline	Scenario 2	Difference	Percent Difference
Trips on Work Tours								
A.M. peak (3 hrs)	43,059	43,171	+112	+0.3%	47,915	38,029	–9,886	–20.6%
P.M. peak (3 hrs)	53,196	52,696	–500	–0.9%	61,144	56,562	–4,582	–7.5%
Total peak period	96,255	95,867	–388	–0.4%	109,059	94,591	–14,468	–13.3%
Midday (5 hrs)	35,332	35,049	–283	–0.8%	43,425	45,758	+2,333	+5.4%
Late evening/early A.M. (13 hrs)	50,484	50,209	–275	–0.5%	59,218	64,180	+4,962	+8.4%
Total off-peak period	85,816	85,258	–558	–0.7%	102,643	109,938	+7,295	+7.1%
Total weekday	182,071	181,125	–946	–0.5%	211,702	204,529	–7,173	–3.4%
Trips on All Nonwork Tours								
A.M. peak (3 hrs)	128,482	128,200	–282	–0.2%	148,263	124,393	–23,870	–16.1%
P.M. peak (3 hrs)	160,092	159,459	–633	–0.4%	146,244	146,004	–240	–0.2%
Total peak period	288,574	287,659	–915	–0.3%	294,507	270,397	–24,110	–8.2%
Midday (5 hrs)	253,768	253,203	–565	–0.2%	248,074	250,861	+2,787	+1.1%
Late evening/early A.M. (13 hrs)	232,659	232,581	–78	–0.0%	237,508	219,603	–17,905	–7.5%
Total off-peak period	486,427	485,784	–643	–0.1%	485,582	470,464	–15,118	–3.1%
Total weekday	775,001	773,443	–1,558	–0.2%	780,089	740,861	–39,228	–5.0%
All Tours								
A.M. peak (3 hrs)	171,541	171,371	–170	–0.1%	196,178	162,422	–33,756	–17.2%
P.M. peak (3 hrs)	213,288	212,155	–1,133	–0.5%	207,388	202,566	–4,822	–2.3%
Total peak period	384,829	383,526	–1,303	–0.3%	403,566	364,988	–38,578	–9.6%
Midday (5 hrs)	289,100	288,252	–848	–0.3%	291,499	296,619	+5,120	+1.8%
Late evening/early A.M. (13 hrs)	283,143	282,790	–353	–0.1%	296,726	283,783	–12,943	–4.4%
Total off-peak period	572,243	571,042	–1,201	–0.2%	588,225	580,402	–7,823	–1.3%
Total weekday	957,072	954,568	–2,504	–0.3%	991,791	945,390	–46,401	–4.7%

In summary, in this scenario, the highway system reverted to an earlier state in that a key interchange improvement was removed. Highway capacity was therefore lower, resulting—as expected—in a higher level of congestion in the affected area in both models. The higher level of congestion apparently caused some travelers to shift to transit, as shown in Table 4.3. Overall, the C10B integrated model was more sensitive to congestion than SACSIM, shifting a significantly greater number of travelers from peak periods to adjacent time periods. The SACSIM results showed reductions in all time periods (though very small reductions) rather than any noticeable peak spreading. Interestingly, on the one hand, the C10B model showed a smaller reduction in trips on work tours than on nonwork tours; this result is consistent with the notion that work tours are more inelastic. SACSIM, on the other hand, showed a greater reduction in trips on work tours.

It is unclear whether the magnitude of the sensitivity of the C10B integrated model is reasonable; the SACSIM results seem too inelastic. The C10B model seems very sensitive in terms of shifts in demand from peak periods, but the relative inelasticity of the SACSIM results does not provide a worthwhile basis for comparison. The assignment results for both SACSIM and the C10B integrated model for five key roadways showed changes in the expected direction although the predicted volume levels and the magnitude of the impacts vary among roadways.

Test 3 Results

Scenario 3 involved coding an additional general purpose freeway lane on a congested segment of the Capital City Freeway (I-80 Business) at its crossing of the American River,

Table 4.9. Vehicle Volumes on Roads In/Around Local Test Area—Test 2

Roadway	Segment	Lane Type	Direction	Lanes		Weekday Total Volume				Notes
				Baseline	Test	Baseline	Scenario 2	Difference	Percent Difference	
SACSIM Model										
I-80 freeway	South of Douglas	General purpose	EB	3	3	94,393	94,189	–204	–0.2%	No large changes expected on I-80
	North of Douglas	General purpose	EB	3	3	84,884	84,095	–789	–0.9%	
	South of Douglas	General purpose	WB	3	3	95,071	96,234	+1,163	+1.2%	
	North of Douglas	General purpose	WB	3	3	84,373	80,407	–3,966	–4.7%	
I-80/Douglas Blvd. ramps	From I-80 EB to EB Douglas	Diagonal	n/a	1	1	19,059	17,994	–1,065	–5.6%	No large change expected
	From I-80 EB to WB Douglas	Loop	n/a	1	1	3,007	2,991	–16	–0.5%	No large change expected
	From WB Douglas to I-80 EB	Diagonal	n/a	1	1	2,057	10,893	+8,836	+429.6%	Change in expected direction
	From I-80 WB to WB Douglas	Diagonal	n/a	1	1	11,936	5,598	–6,338	–53.1%	Change in expected direction
	From WB Douglas to I-80 WB	Loop	n/a	1	1	18,151	15,805	–2,346	–12.9%	No large change expected
	From EB Douglas to I-80 WB	Diagonal	n/a	1	1	4,482	5,618	+1,136	+25.3%	No large change expected
Douglas Blvd.	West of I-80	Arterial	EB	2	2	15,286	13,308	–1,978	–12.9%	No large change expected
	I-80 overcrossing	Arterial	EB	2	2	6,124	11,046	+4,922	+80.4%	Change in expected direction
	East of I-80	Arterial	EB	2	2	24,432	28,297	+3,865	+15.8%	No large change expected
	East of I-80	Arterial	WB	3	2	28,432	32,877	+4,445	+15.6%	No large change expected
	I-80 overcrossing	Arterial	WB	3	2	30,136	25,720	–4,416	–14.7%	No large change expected
	West of I-80	Arterial	WB	2	2	13,839	12,152	–1,687	–12.2%	No large change expected
Sunrise Blvd.	South of I-80 interchange/Douglas	Arterial	NB	2	2	24,700	23,102	–1,598	–6.5%	Change in expected direction
	South of I-80 interchange/Douglas	Arterial	SB	2	2	26,285	22,027	–4,258	–16.2%	Change in expected direction
Direct connectors	From NB Sunrise Blvd.	On-ramp	n/a	1		10,500	—	–10,500		
	To SB Sunrise Blvd.	Connector	n/a	1		14,757	—	–14,757		
Subtotal of all ramps and arterials without new direct connectors						227,926	227,428	–498	–0.2%	Change in expected direction
Subtotal of freeway segments						358,721	354,925	–3,796	–1.1%	Change in expected direction

(continued on next page)

Table 4.9. Vehicle Volumes on Roads In/Around Local Test Area—Test 2 (continued)

Roadway	Segment	Lane Type	Direction	Lanes		Weekday Total Volume				Notes
				Baseline	Test	Baseline	Scenario 2	Difference	Percent Difference	
C10B Integrated Model										
I-80 freeway	South of Douglas	General purpose	EB	4	4	96,492	97,097	+605	+0.6%	No large changes expected on I-80
	North of Douglas	General purpose	EB	4	4	89,678	87,600	–2,078	–2.3%	
	South of Douglas	General purpose	WB	3	3	88,582	89,568	+986	+1.1%	
	North of Douglas	General purpose	WB	4	4	76,712	68,305	–8,407	–11.0%	
I-80/Douglas Blvd. ramps	From I-80 EB to EB Douglas	Diagonal	n/a	1	1	18,684	17,006	–1,678	–9.0%	No large change expected
	From I-80 EB to WB Douglas	Loop	n/a	1	1	4,464	4,553	+89	+2.0%	No large change expected
	From WB Douglas to I-80 EB	Diagonal	n/a	1	1	4,375	12,062	+7,687	+175.7%	Change in expected direction
	From I-80 WB to WB Douglas	Diagonal	n/a	3	1	33,053	11,014	–22,039	–66.7%	Change in expected direction
	From WB Douglas to I-80 WB	Loop	n/a	2	1	5,079	10,357	+5,278	+103.9%	Large change not expected
	From EB Douglas to I-80 WB	Diagonal	n/a	3	1	39,844	21,920	–17,924	–45.0%	Large change not expected
Douglas Blvd.	West of I-80	Arterial	EB	2	2	23,620	22,897	–723	–3.1%	
	I-80 overcrossing	Arterial	EB	2	2	7,533	16,453	+8,920	+118.4%	Change in expected direction
	East of I-80	Arterial	EB	2	2	25,537	33,624	+8,087	+31.7%	Large change not expected
	East of I-80	Arterial	WB	2	2	29,954	38,664	+8,710	+29.1%	Large change not expected
	I-80 overcrossing	Arterial	WB	2	2	30,723	30,990	+267	+0.9%	No large change expected
	West of I-80	Arterial	WB	2	2	17,396	16,171	–1,225	–7.0%	No large change expected
Sunrise Blvd.	South of I-80 interchange/Douglas	Arterial	NB	2	2	19,230	16,606	–2,624	–13.6%	Change in expected direction
	South of I-80 interchange/Douglas	Arterial	SB	2	2	24,166	18,612	–5,554	–23.0%	Change in expected direction
Direct connectors	From NB Sunrise Blvd.	On-ramp	n/a	1		11,959		–11,959	–100.0%	
	To SB Sunrise Blvd.	Connector	n/a	1		17,544		–17,544	–100.0%	
Subtotal of all ramps and arterials without new direct connectors						283,658	270,929	–12,729	–4.5%	Change in expected direction
Subtotal of freeway segments						351,464	342,570	–8,894	–2.5%	Change in expected direction

Notes: EB = eastbound; WB = westbound; NB = northbound; SB = southbound.

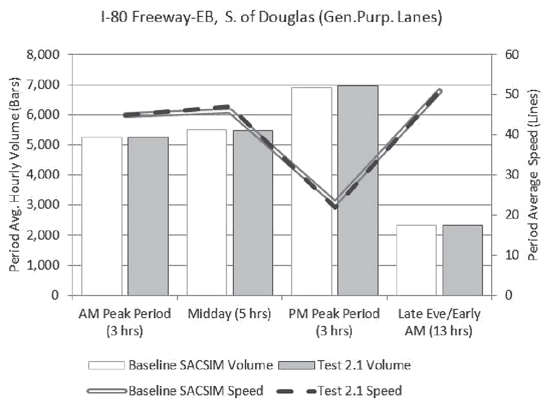
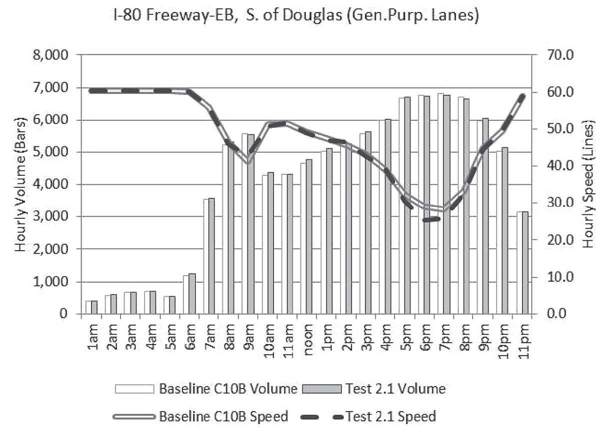
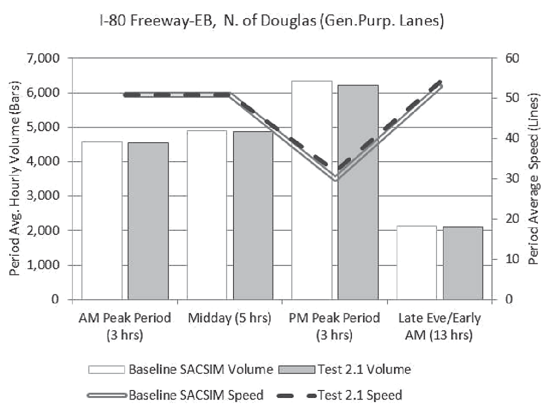
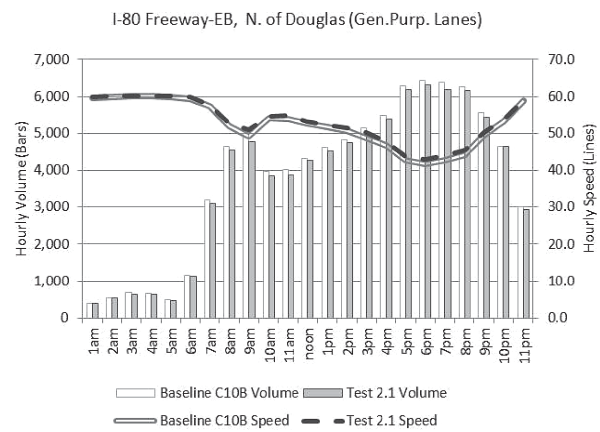
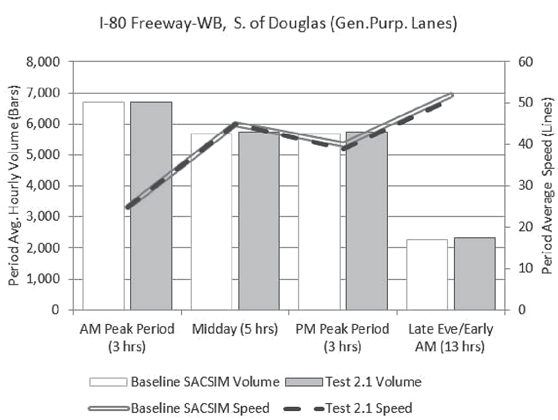
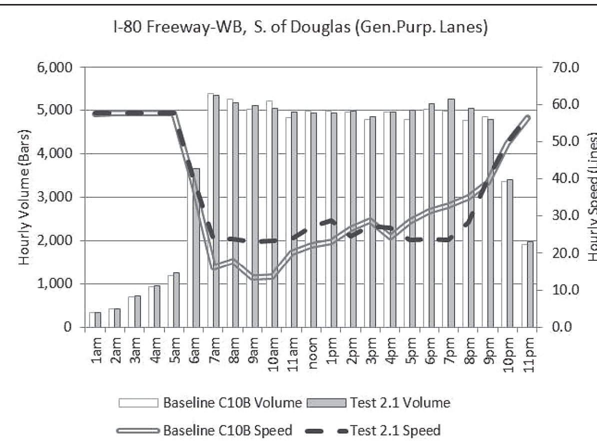
Segment	SACSIM	C10B Integrated Model
Fig. 4.2A I-80 freeway eastbound, south of Douglas, general purpose lanes		
Fig. 4.2B I-80 freeway eastbound, north of Douglas, general purpose lanes		
Fig. 4.2C I-80 freeway westbound, south of Douglas, general purpose lanes		

Figure 4.2. Vehicle volumes and speeds on key test segments—Test 2. (Continued on next page.)

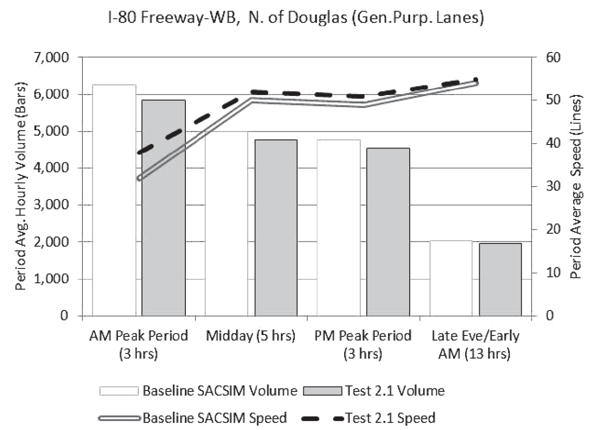
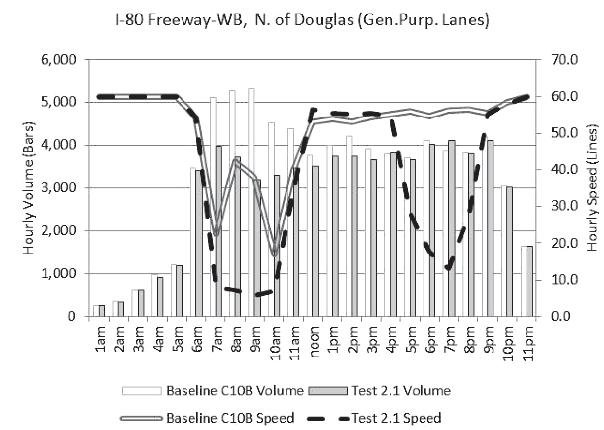
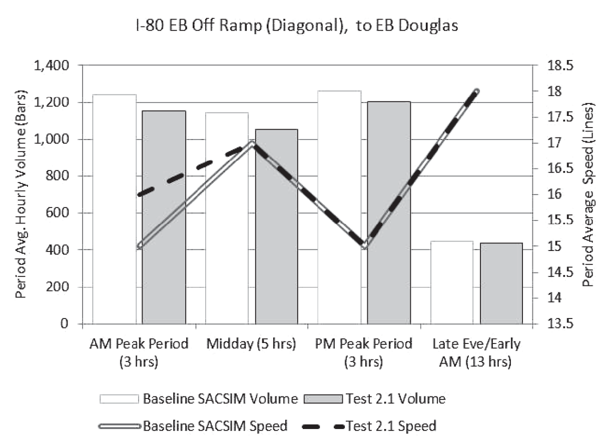
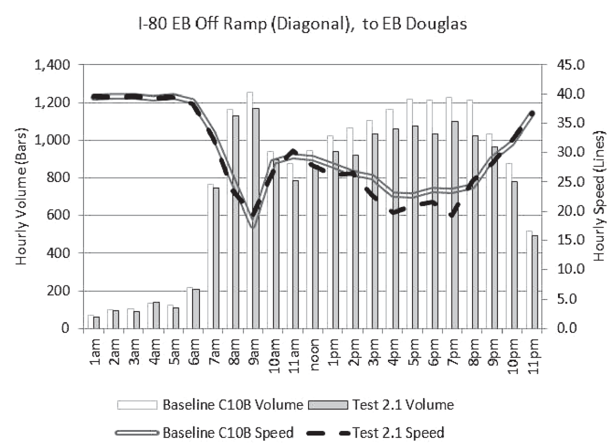
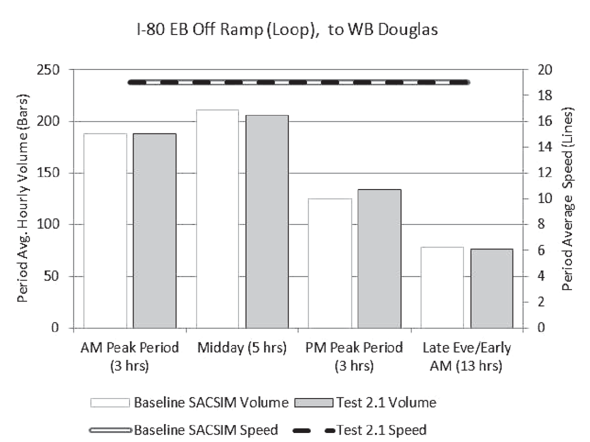
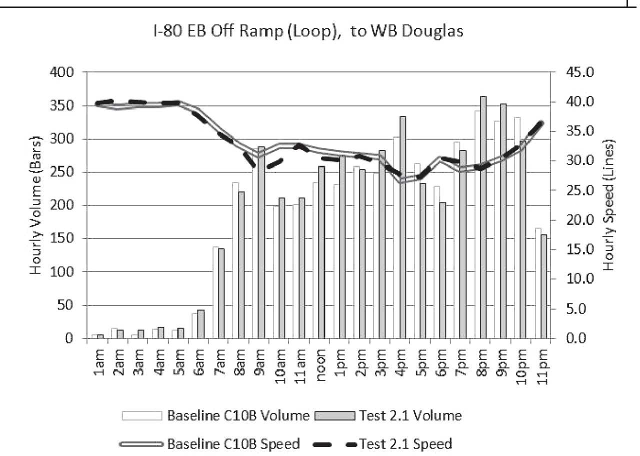
Segment	SACSIM	C10B Integrated Model
Fig. 4.2D I-80 freeway westbound, north of Douglas, general purpose lanes		
Fig. 4.2E I-80 eastbound off-ramp to eastbound Douglas		
Fig. 4.2F I-80 eastbound off-ramp to westbound Douglas		

Figure 4.2. Vehicle volumes and speeds on key test segments—Test 2 (continued).

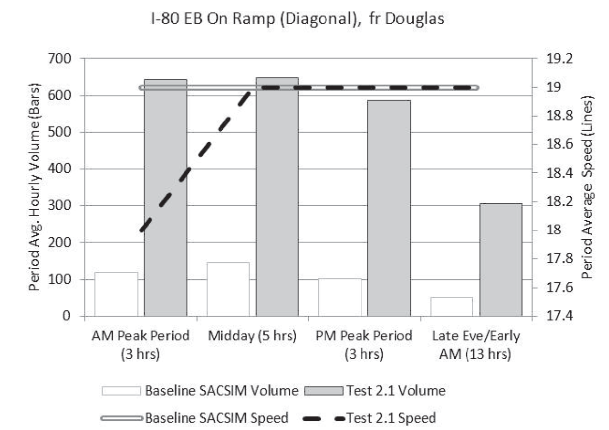
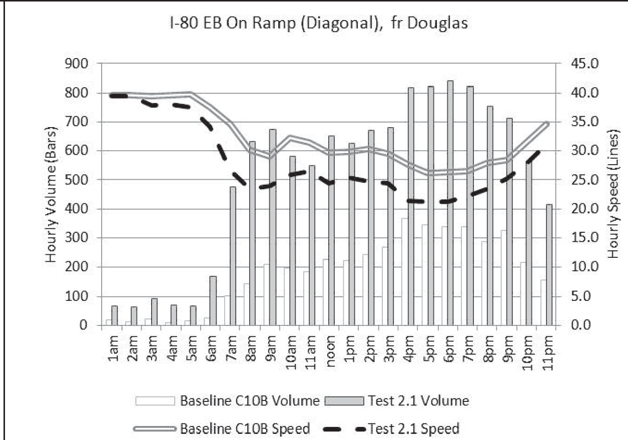
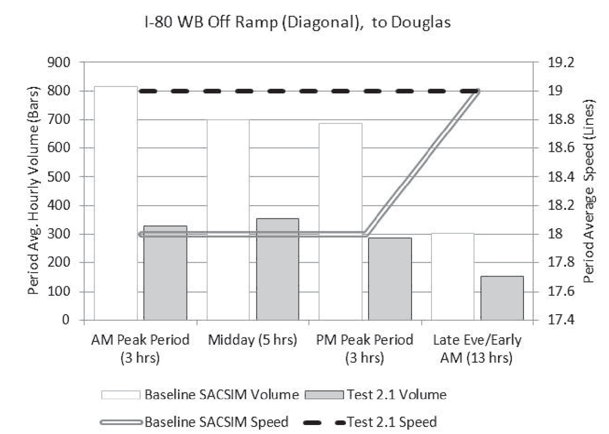
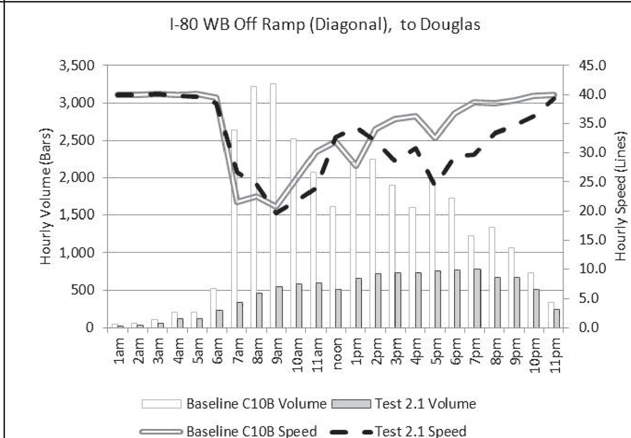
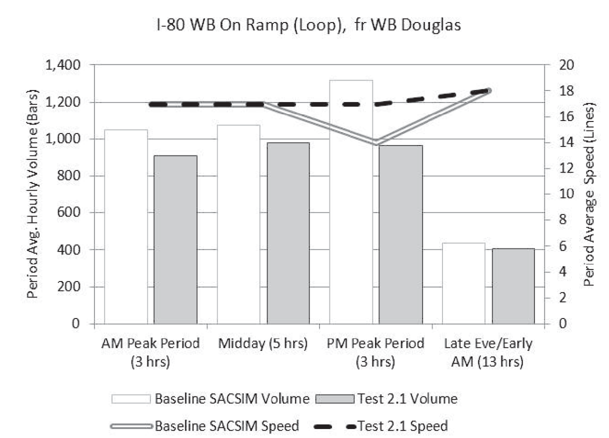
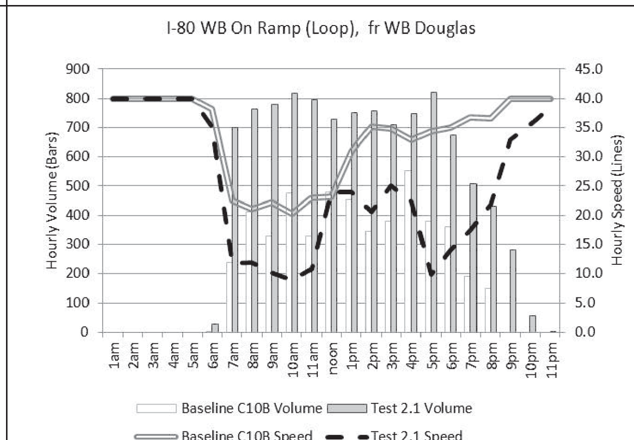
Segment	SACSIM	C10B Integrated Model
Fig. 4.2G I-80 eastbound on-ramp from Douglas		
Fig. 4.2H I-80 westbound off-ramp to Douglas		
Fig. 4.2I I-80 westbound on-ramp from westbound Douglas		

Figure 4.2. Vehicle volumes and speeds on key test segments—Test 2 (continued).

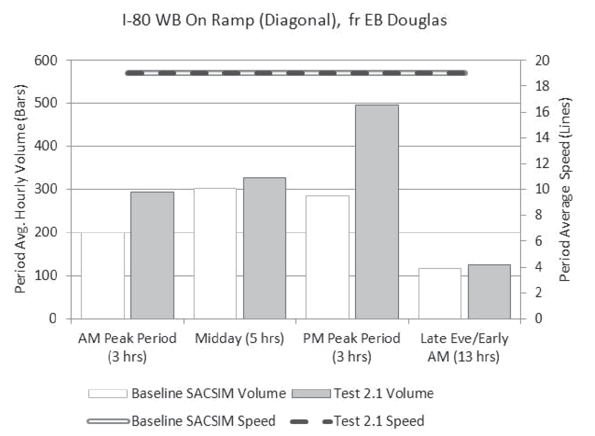
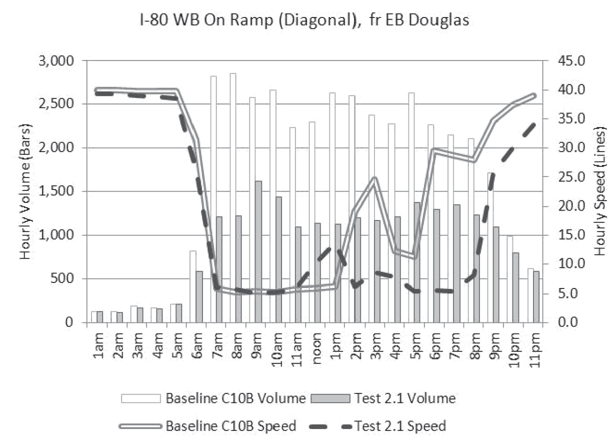
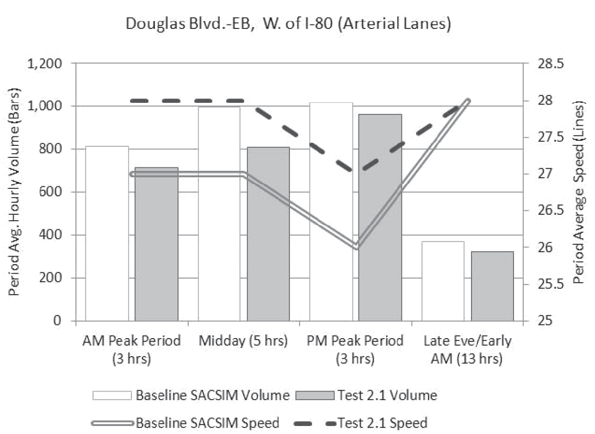
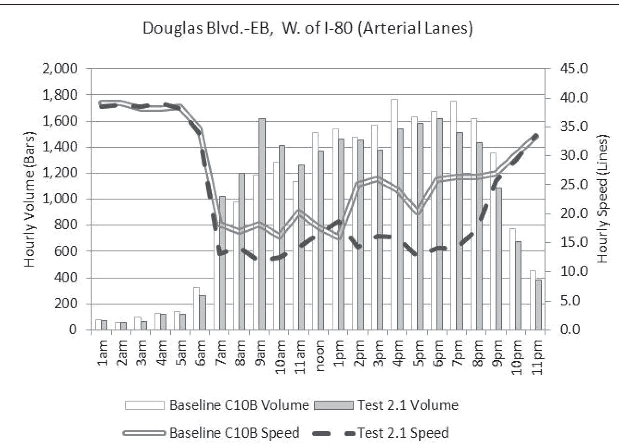
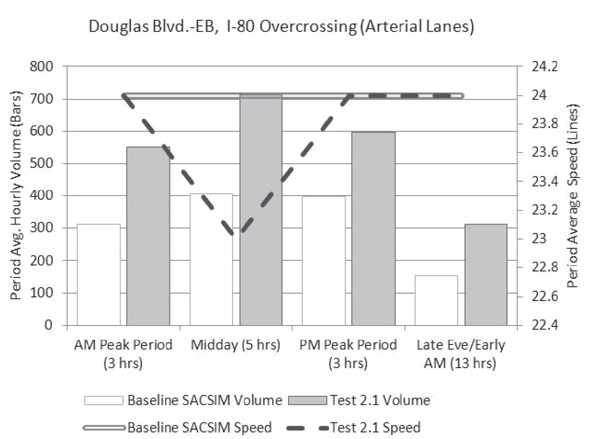
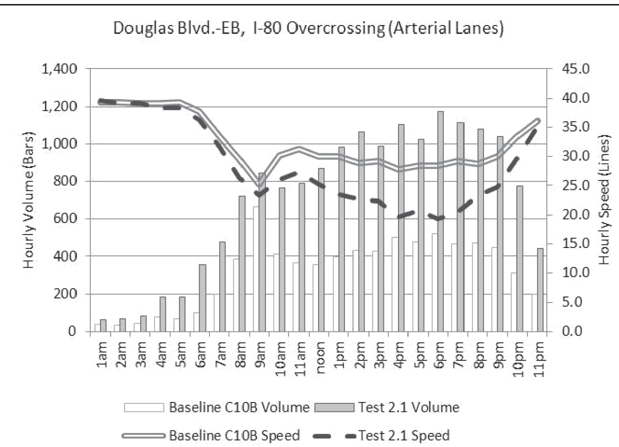
Segment	SACSIM	C10B Integrated Model
Fig. 4.2J I-80 westbound on-ramp from eastbound Douglas		
Fig. 4.2K Douglas Blvd. eastbound, west of I-80 ramps		
Fig. 4.2L Douglas Blvd. eastbound on overcrossing		

Figure 4.2. Vehicle volumes and speeds on key test segments—Test 2 (continued).

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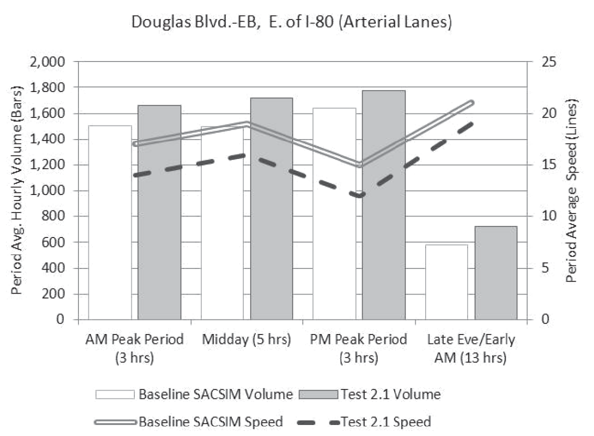
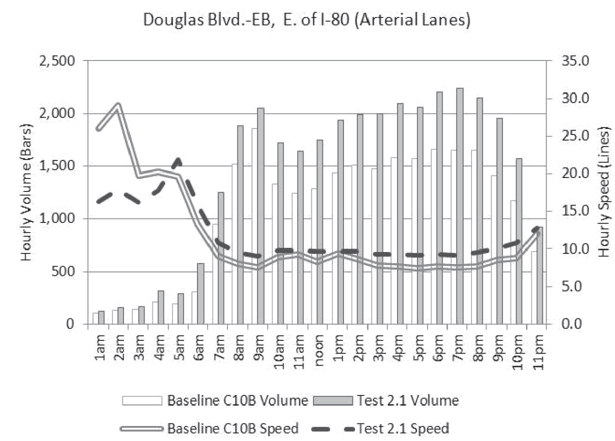
east of I-80 ramps</td><td>
</td><td>
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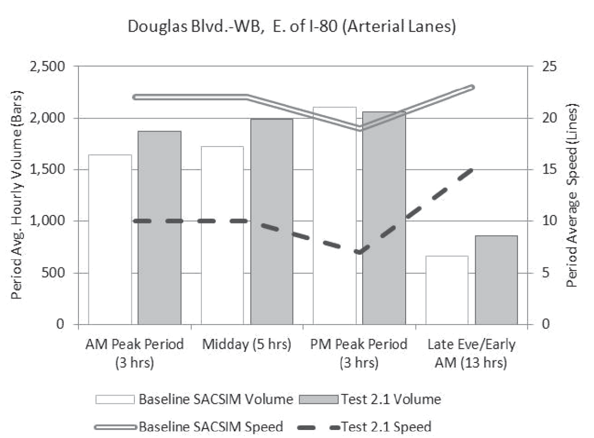
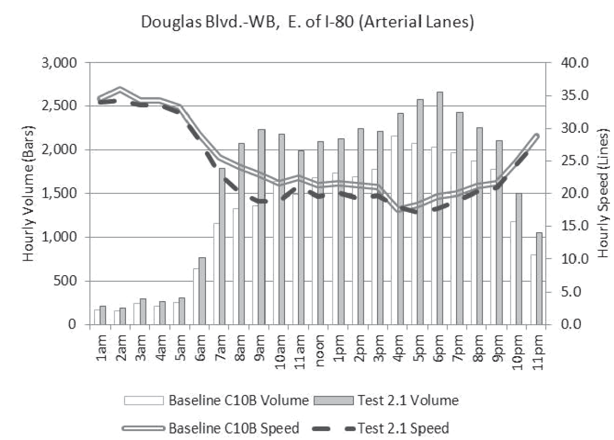
east of I-80 ramps</td><td>
</td><td>
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Douglas Blvd. westbound

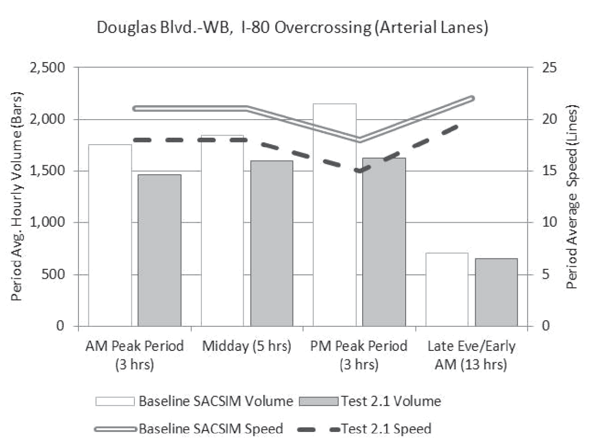
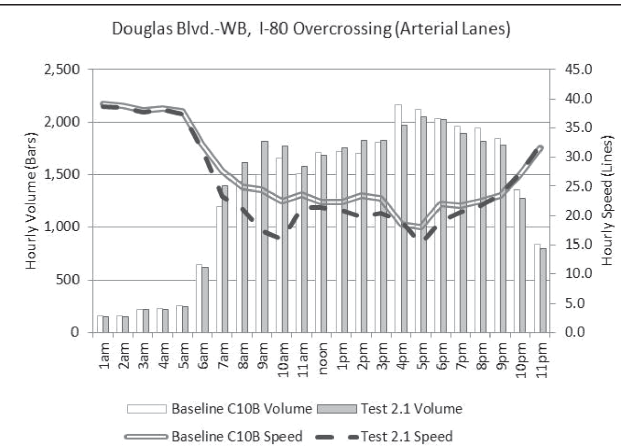
on I-80 overcrossing</td><td>
</td><td>
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Figure 4.2. Vehicle volumes and speeds on key test segments—Test 2 (continued).

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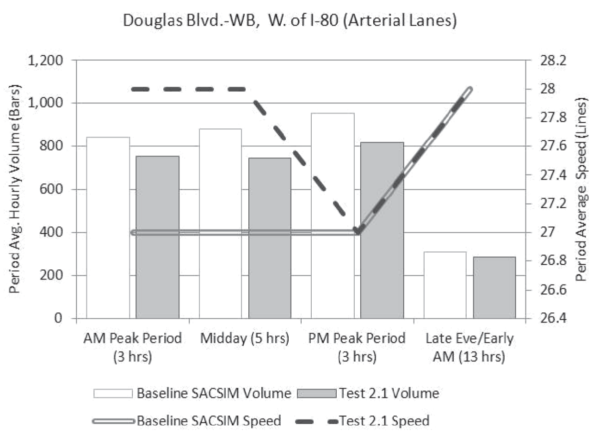
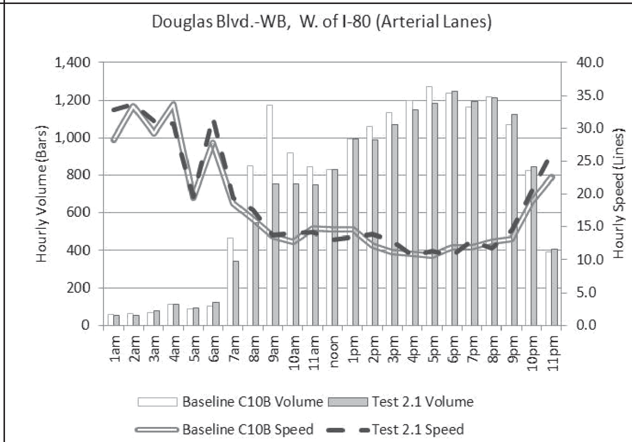
west of I-80 ramps</td><td>
</td><td>
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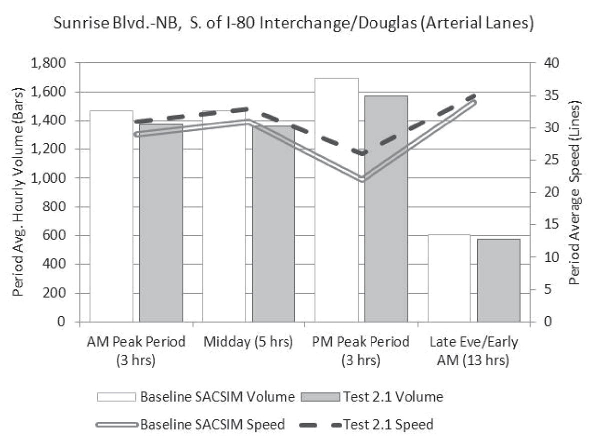
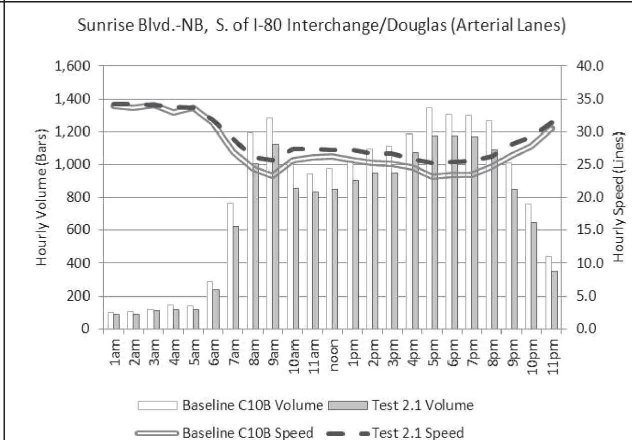
Sunrise Blvd. northbound,

south of I-80 interchange</td><td>
</td><td>
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<tr><td>Fig. 4.2R

Sunrise Blvd. northbound,

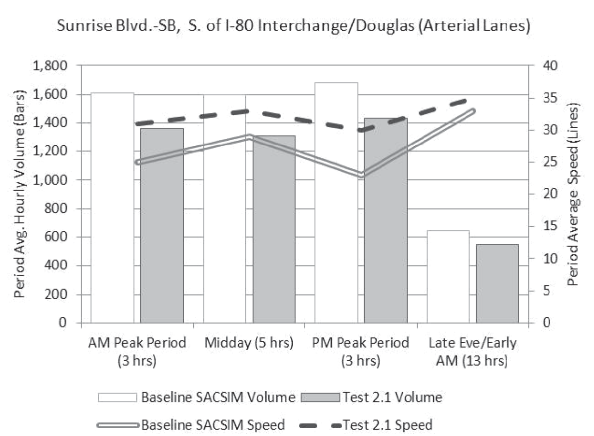
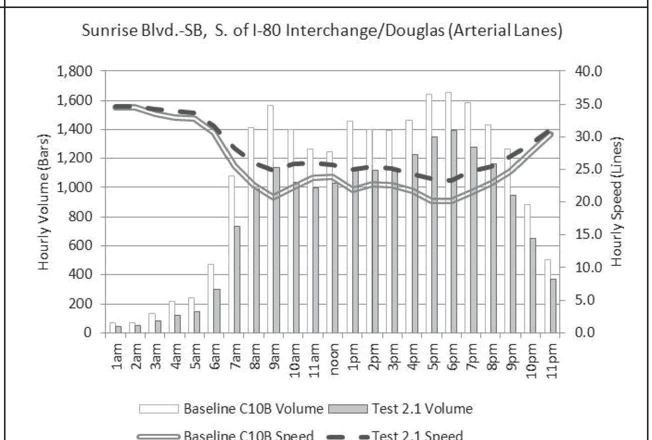
south of I-80 interchange</td><td>
</td><td>
</td></tr>
</table>

Figure 4.2. Vehicle volumes and speeds on key test segments—Test 2 (continued).

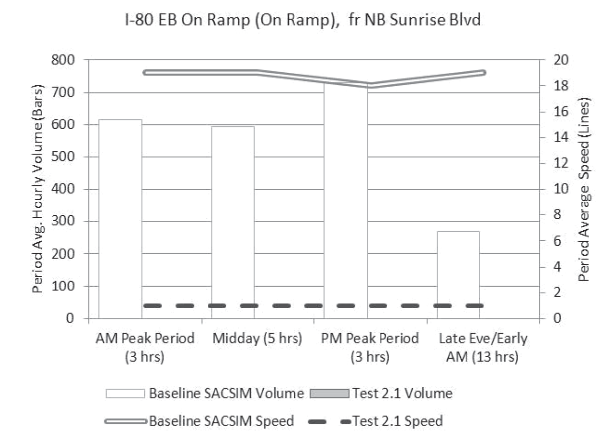
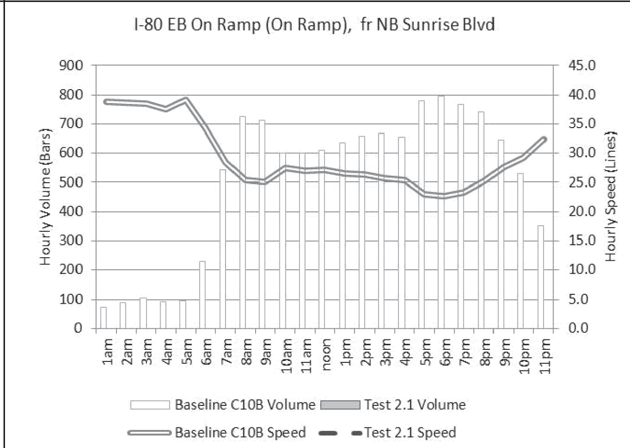
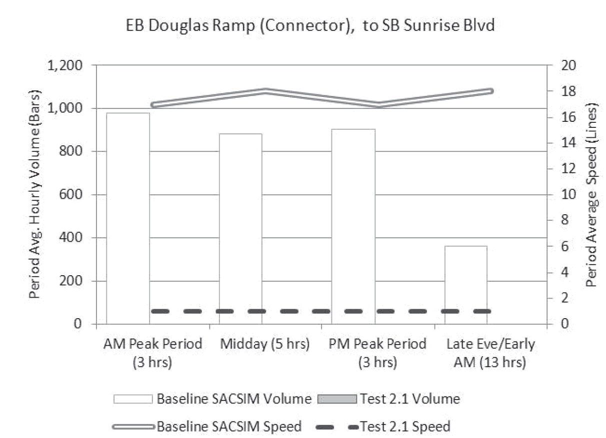
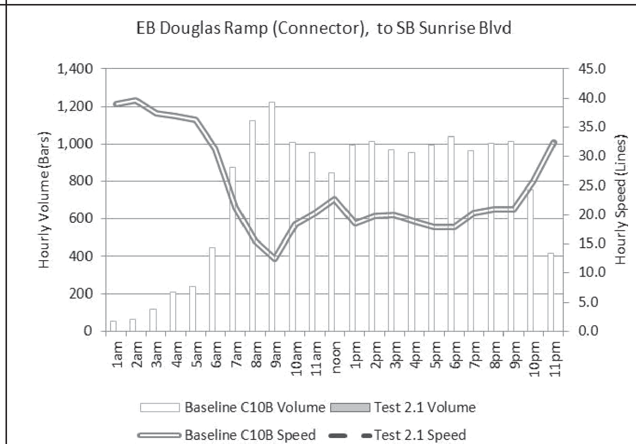
<table>
<tr><th>Segment</th><th>SACSIM</th><th>C10B Integrated Model</th></tr>
<tr><td>Fig. 4.2S
I-80 eastbound on-ramp
from northbound Sunrise
(direct ramp taken away in Test 2)</td><td>
</td><td>
</td></tr>
<tr><td>Fig. 4.2T
Douglas Blvd. eastbound
connector to southbound Sunrise
(direct ramp taken away in Test 2)</td><td>
</td><td>
</td></tr>
</table>

Figure 4.2. Vehicle volumes and speeds on key test segments—Test 2 (continued).

between the North Sacramento and Arden-Arcade areas and downtown Sacramento. This segment consistently comes up as one of the most congested freeway segments in the region. The test scenario added a fourth general purpose lane between the E Street and Exposition Boulevard interchanges. Highlights of this test include the following:

- A major impact on demand was expected, given that the test adds significant capacity on a highly congested, high-volume roadway segment; adding capacity was expected to increase the number of tours with destinations in and around the test area. The SACSIM results conformed to this expectation, with a 0.2% increase over the baseline scenario. The biggest effect was on downtown Sacramento, with a 0.4% increase. (In addition to the summary provided in Table 4.3, Table 4.10 provides further details.) The C10B model showed the opposite, counterintuitive result—a decrease in tour destinations in and around the test area.
- Another expected result of the demand testing was an increase in the number of peak-period trips made with destinations in the project area, assuming that the higher congestion in the baseline scenario had caused some peak spreading. SACSIM showed a small increase, but the C10B model showed a decrease of about 8%. (In addition to the summary provided in Table 4.3, Table 4.11 provides additional details.) The effect on timing of travel was expected to be greater for nonwork, discretionary trips than for work trips; this result was borne out in the SACSIM results but not in the results for the C10B integrated model.
- Traffic assignment results on the two test segments varied significantly between the two models (see Table 4.12):
  - SACSIM showed balanced increases in both directions (+5.4% eastbound, +6.4% westbound).

Table 4.10. Person Tour Primary Destinations Near Project—Test 3

Tour Destination	SACSIM				C10B Integrated Model			
	Baseline	Scenario 3	Difference	Percent Difference	Baseline	Scenario 3	Difference	Percent Difference
Downtown	277,046	278,180	+1,134	+0.4%	321,117	316,927	–4,190	–1.3%
North Sacramento	131,128	131,162	+34	+0.0%	146,843	145,648	–1,195	–0.8%
Arden Arcade	196,925	197,193	+268	+0.1%	216,477	213,634	–2,843	–1.3%
East Sacramento	232,428	232,431	+3	+0.0%	260,984	259,205	–1,779	–0.7%
Carmichael	67,112	67,272	+160	+0.2%	71,756	71,654	–102	–0.1%
Antelope-North Highlands	181,089	181,424	+335	+0.2%	191,791	194,718	+2,927	+1.5%
Combined areas	1,085,728	1,087,662	+1,934	+0.2%	1,208,968	1,201,786	–7,182	–0.6%
All other areas	2,430,436	2,429,560	–876	–0.0%	2,600,291	2,618,140	+17,849	+0.7%
All destinations	3,516,164	3,517,222	+1,058	+0.0%	3,809,259	3,819,926	+10,667	+0.3%

Table 4.11. Timing of Person Trips on Tours to Local Test Area—Test 3

Tour Timing	SACSIM Model				C10B Model			
	Baseline	Scenario 3	Difference	Percent Difference	Baseline	Scenario 3	Difference	Percent Difference
Trips on Work Tours								
A.M. peak (3 hrs)	153,833	153,545	–288	–0.2%	180,292	151,595	–28,697	–15.9%
P.M. peak (3 hrs)	203,781	204,228	+447	+0.2%	242,494	236,692	–5,802	–2.4%
Total peak period	**357,614**	**357,773**	+159	+0.0%	**422,786**	**388,287**	–34,499	–8.2%
Midday (5 hrs)	131,855	131,877	+22	+0.0%	162,893	177,244	+14,351	+8.8%
Late evening/early A.M. (13 hrs)	209,858	209,560	–298	–0.1%	241,942	261,098	+19,156	+7.9%
Total off-peak period	**341,713**	**341,437**	–276	–0.1%	**404,835**	**438,342**	+33,507	+8.3%
Total weekday	**699,327**	**699,210**	–117	–0.0%	**827,621**	**826,629**	–992	–0.1%
Trips on All Nonwork Tours								
A.M. peak (3 hrs)	298,202	298,985	+783	+0.3%	340,622	282,904	–57,718	–16.9%
P.M. peak (3 hrs)	377,627	379,106	+1,479	+0.4%	351,438	359,901	+8,463	+2.4%
Total peak period	**675,829**	**678,091**	+2,262	+0.3%	**692,060**	**642,805**	–49,255	–7.1%
Midday (5 hrs)	626,030	628,225	+2,195	+0.4%	653,334	667,418	+14,084	+2.2%
Late evening/early A.M. (13 hrs)	538,063	538,188	+125	+0.0%	573,705	591,718	+18,013	+3.1%
Total off-peak period	**1,164,093**	**1,166,413**	+2,320	+0.2%	**1,227,039**	**1,259,136**	+32,097	+2.6%
Total weekday	**1,839,922**	**1,844,504**	**4,582**	+0.2%	**1,919,099**	**1,901,941**	–17,158	–0.9%
All Tours								
A.M. peak (3 hrs)	452,035	452,530	+495	+0.1%	520,914	434,499	–86,415	–16.6%
P.M. peak (3 hrs)	581,408	583,334	+1,926	+0.3%	593,932	596,593	+2,661	+0.4%
Total peak period	**1,033,443**	**1,035,864**	+2,421	+0.2%	**1,114,846**	**1,031,092**	–83,754	–7.5%
Midday (5 hrs)	757,885	760,102	+2,217	+0.3%	816,227	844,662	+28,435	+3.5%
Late evening/early A.M. (13 hrs)	747,921	747,748	–173	–0.0%	815,647	852,816	+37,169	+4.6%
Total off-peak period	**1,505,806**	**1,507,850**	+2,044	+0.1%	**1,631,874**	**1,697,478**	+65,604	+4.0%
Total weekday	**2,539,249**	**2,543,714**	**4,465**	+0.2%	**2,746,720**	**2,728,570**	–18,150	–0.7%

Table 4.12. Vehicle Volumes on Roads In and Around Local Test Area—Test 3

Roadway	Segment	Lane Type	Direction	Lanes		Weekday Total Volume				Notes
				Baseline	Test	Baseline	Scenario 3	Difference	Percent Difference	
SACSIM Model										
Capital City Freeway	South of E St.	General purpose	EB	3	3	81,496	86,095	+4,599	+5.6%	South of test segment—expected increase
	South of Exposition Blvd.	General purpose	EB	3	4	89,004	93,828	+4,824	+5.4%	**Test segment—expected increase**
	South of Arden Way	General purpose	EB	2	2	59,562	62,368	+2,806	+4.7%	North of test segment—expected increase
	North of Arden Way	Auxiliary	EB	1	1	10,893	10,837	–56	–0.5%	No large change expected
	North of Arden Way	General purpose	EB	4	4	86,247	87,693	+1,446	+1.7%	North of test segment—expected increase
	North of Arden Way	General purpose	WB	4	4	101,635	103,731	+2,096	+2.1%	North of test segment—expected increase
	South of Arden Way	General purpose	WB	3	3	68,761	71,661	+2,900	+4.2%	North of test segment—expected increase
	South of Arden Way	Auxiliary	WB	1	1	3,648	4,442	+794	+21.8%	North of test segment—expected increase
	South of Exposition Blvd.	General purpose	WB	3	4	95,150	101,213	+6,063	+6.4%	**Test segment—expected increase**
	South of E St.	General purpose	WB	3	3	69,153	73,789	+4,636	+6.7%	North of test segment—expected increase
	South of E St.	HOV	WB	1	1	19,057	19,751	+694	+3.6%	North of test segment—expected increase
16th St.	South of N B St.	Arterial	NB/EB	3	3	35,966	34,618	–1,348	–3.7%	Expected decrease
12th St.	South of N B St.	Arterial	SB/WB	4	4	32,412	31,259	–1,153	–3.6%	Expected decrease
SR 160	West of Royal Oaks	General purpose	EB	2	2	26,413	25,325	–1,088	–4.1%	Expected decrease
	West of Royal Oaks	General purpose	WB	2	2	34,794	33,618	–1,176	–3.4%	Expected decrease
Exposition Blvd.	East of Bus 80	Arterial	EB	3	3	28,882	29,180	+298	+1.0%	No large change expected
	East of Bus 80	Arterial	WB	3	3	17,896	18,697	+801	+4.5%	No large change expected
Arden Way	East of Bus 80	Arterial	WB	4	4	15,211	15,007	–204	–1.3%	No large change expected
	East of Bus 80	Arterial	EB	4	4	21,138	20,562	–576	–2.7%	No large change expected
	West of Bus 80	Arterial	EB	4	4	19,398	19,367	–31	–0.2%	No large change expected
	West of Bus 80	Arterial	WB	4	4	26,497	26,085	–412	–1.6%	No large change expected
Subtotal of freeway segments						684,606	715,408	+30,802	+4.5%	Expected increase
Subtotal of arterial segments						258,607	253,718	–4,889	–1.9%	Expected decrease

(continued on next page)

Table 4.12. Vehicle Volumes on Roads In and Around Local Test Area—Test 3 (continued)

Roadway	Segment	Lane Type	Direction	Lanes		Weekday Total Volume				Notes
				Baseline	Test	Baseline	Scenario 3	Difference	Percent Difference	
C10B Integrated Model										
Capital City Freeway	South of E St.	General purpose	EB	3		72,896	78,240	+5,344	+7.3%	South of test segment—expected increase
	South of Exposition Blvd.	General purpose	EB	3		90,548	93,834	+3,286	+3.6%	**Test segment—expected increase**
	South of Arden Way	General purpose	EB	2		63,919	63,267	–652	–1.0%	North of test segment—expected increase
	North of Arden way	Auxiliary	EB	1		19,565	18,770	–795	–4.1%	No large change expected
	North of Arden Way	General purpose	EB	4		92,241	92,202	–39	–0.0%	North of test segment—expected increase
	North of Arden Way	General purpose	WB	4		108,024	109,606	+1,582	+1.5%	North of test segment—expected increase
	South of Arden Way	General purpose	WB	3		62,094	71,032	+8,938	+14.4%	North of test segment—expected increase
	South of Arden Way	Auxiliary	WB	1		11,008	11,215	+207	+1.9%	North of test segment—expected increase
	South of Exposition Blvd.	General purpose	WB	3		94,223	112,221	+17,998	+19.1%	**Test segment—expected increase**
	South of E St.	General purpose	WB	3		69,800	81,511	+11,711	+16.8%	North of test segment—expected increase
	South of E St.	HOV	WB	1		11,387	15,124	+3,737	+32.8%	North of test segment—expected increase
16th St.	South of N B St.	Arterial	NB/EB	3		42,217	43,189	+972	+2.3%	Expected decrease
12th St.	S of N B St.	Arterial	SB/WB	4		37,157	35,357	–1,800	–4.8%	Expected decrease
SR 160	West of Royal Oaks	General purpose	EB	2		40,590	41,764	+1,174	+2.9%	Expected decrease
	West of Royal Oaks	General purpose	WB	2		33,448	28,964	–4,484	–13.4%	Expected decrease
Exposition Blvd.	East of Bus 80	Arterial	EB	3		19,740	21,492	+1,752	+8.9%	No large change expected
	East of Bus 80	Arterial	WB	3		17,086	21,044	+3,958	+23.2%	No large change expected
Arden Way	East of Bus 80	Arterial	WB	4		30,960	30,431	–529	–1.7%	No large change expected
	East of Bus 80	Arterial	EB	4		32,060	33,075	+1,015	+3.2%	No large change expected
	West of Bus 80	Arterial	EB	4		17,155	18,791	+1,636	+9.5%	No large change expected
	West of Bus 80	Arterial	WB	4		20,959	21,058	+99	+0.5%	No large change expected
Subtotal of freeway segments						695,705	747,022	+51,317	+7.4%	Expected increase
Subtotal of arterial segments						291,372	295,165	+3,793	+1.3%	Expected decrease

Notes: EB = eastbound; WB = westbound; NB = northbound; SB = southbound.

- The C10B integrated model showed asymmetrical increases, with only a +3.6% change eastbound, but a +19.1% change westbound. Such a wide difference by direction does not seem to make sense.

- There are differences between the results of the two models in terms of speeds and delays, in terms of the magnitudes, the locations of the delays, and the time of day. (For this study, delay was defined by SACOG using a base speed of 35 mph. The specific measure of delay is the difference between actual travel time and travel time at 35 mph, when the actual travel speed is less than 35 mph. In other words, delay is not accrued if travel speeds exceed 35 mph.) Table 4.13 compares the volumes, speeds, travel times, and total vehicle delay for the river crossing segment (the section that is widened in Scenario 3), the segments immediately downstream from the improvement, and the total of all segments of the relevant section of I-80 between the two models, for the p.m. peak period (3:00 to 6:00). The volumes are lower in all cases for the C10B integrated model, as are the speeds. On the widened highway segment, there is more total vehicle delay in the C10B model results for both the baseline scenario and Scenario 3, and a lower percentage decrease in delay due to the improvement. Downstream, however, the C10B model shows a higher percentage increase in delay, nearly offsetting the decrease in delay on the improved segment.
- The differences in speed results between the two models by time of day are illustrated in Table 4.14. The generally higher speeds in SACSIM are evident across all time periods, especially the p.m. peak and evening periods. For the river crossing segment and upstream links, the C10B integrated model shows greater percentage increases in speed for all periods except the p.m. peak. Downstream from the improvement, the C10B model shows substantial speed reductions while SACSIM shows only minor decreases. Table 4.15 shows the corresponding results for vehicle delay. The delays across the segment for the p.m. peak period are illustrated in Figure 4.3.
- Figure 4.4 provides segment-by-segment graphical representations of C10B and SACSIM model results. As already mentioned, the most remarkable difference is in the level of detail in results for the C10B model. Where SACSIM can provide total volumes for 3- to 13-h demand periods, the C10B model provides results for any time period the analyst wishes to define (for these figures, the results were aggregated to individual hours for the entire 24-h day).

Table 4.13. Travel Volume, Time, and Delay Summary and Comparison—Test 3: P.M. Peak Period Eastbound (Peak Period and Direction)

Segment/ Scenario	Volume (vpd)		Speed (mph)		Travel Time (minutes)		Total Vehicle Delay (hours per day)	
	SACSIM	C10B	SACSIM	C10B	SACSIM	C10B	SACSIM	C10B
River crossing segment								
Baseline	19,058	13,857	29.5	15.6	4.30	9.52	261.6	1,225.9
Scenario 3	20,533	15,454	41.25	16.7	3.09	7.63	44.4	1,066.4
Difference	+1,475	+1,597	+11.8	+1.1	–1.21	–1.88	–217.3	–159.5
Change	+8%	+12%	+40%	+7%	–28%	–20%	–83%	–13%
Average of downstream segments (Exposition Blvd. to North of Arden)								
Baseline	15,631	12,579	38.8	36.4	2.59	2.29	103.4	39.3
Scenario 3	16,415	12,645	36.5	28.3	2.94	2.96	182.1	155.2
Difference	+783	+66	–2.3	–8.1	+0.35	+0.67	+78.7	+116.0
Change	+5%	+1%	–6%	–22%	+13%	+29%	+76%	+295%
All segments (E Street to North of Arden)								
Baseline	17,629	13,310	29.7	17.7	6.89	11.81	365.1	1,265.1
Scenario 3	18,800	14,309	34.0	19.7	6.03	10.59	226.5	1,221.6
Difference	+1,171	+999	+4.3	+2.0	–0.86	–1.22	–138.6	–43.5
Change	+7%	+8%	+14%	+11%	–13%	–10%	–38%	–3%

Note: vpd = vehicles per day.

Table 4.14. Travel Speeds by Segment, Capital City Freeway Eastbound/Northbound—Test 3

Segment	Direction	Lanes		Distance (mi)	Travel Speed (mph)											
					Baseline				Scenario 3				Percentage Difference			
		Baseline	Scenario 3		A.M.	Midday	P.M.	Evening	A.M.	Midday	P.M.	Evening	A.M.	Midday	P.M.	Evening
SACSIM																
South of E St.	EB	3	3	0.50	47	48	37	53	45	46	30	52	–4%	–4%	–19%	–2%
North of E St.	EB	3	4	0.26	46	48	27	54	53	54	45	57	15%	13%	67%	6%
River Crossing	EB	3	4	0.64	46	48	27	54	53	54	45	57	15%	13%	67%	6%
South of Exposition Blvd.	EB	3	4	0.68	46	48	27	54	53	54	45	57	15%	13%	67%	6%
Between Exposition Blvd. ramps	EB	3	3	0.16	51	52	45	53	51	51	43	53	0%	–2%	–4%	0%
South of Arden Way	EB	3	3	0.14	51	52	45	53	51	51	43	53	0%	–2%	–4%	0%
South of Arden Way	EB	2	2	0.69	46	45	25	48	44	42	21	47	–4%	–7%	–16%	–2%
North of Arden Way	EB	4	4	0.36	50	49	40	50	50	49	39	50	0%	0%	–3%	0%
			Total	3.43	47	48	30	52	49	49	34	53	5%	3%	14%	2%
C10B Integrated Model																
South of E St.	EB	3	4	0.50	28	32	7	9	49	49	14	20	72%	54%	92%	128%
North of E St.	EB	3	4	0.26	28	29	10	10	42	43	16	20	50%	45%	54%	103%
River Crossing	EB	3	4	0.71	30	32	19	17	40	48	20	21	31%	53%	9%	25%
South of Exposition Blvd.	EB	3	4	0.68	30	30	26	32	22	22	17	19	–26%	–26%	–35%	–40%
Between Exposition Blvd. ramps	EB	3	3	0.16	47	46	38	46	33	26	22	26	–31%	–43%	–43%	–45%
South of Arden Way	EB	3	3	0.14	43	41	26	37	22	16	15	19	–50%	–60%	–44%	–49%
South of Arden Way	EB	2	2	0.69	41	38	32	39	32	28	27	34	–21%	–26%	–15%	–14%
North of Arden Way	EB	4	4	0.35	56	55	49	53	55	53	50	54	–2%	–3%	1%	2%
			Total	3.48	34	35	18	19	33	33	20	23	–2%	–6%	11%	20%

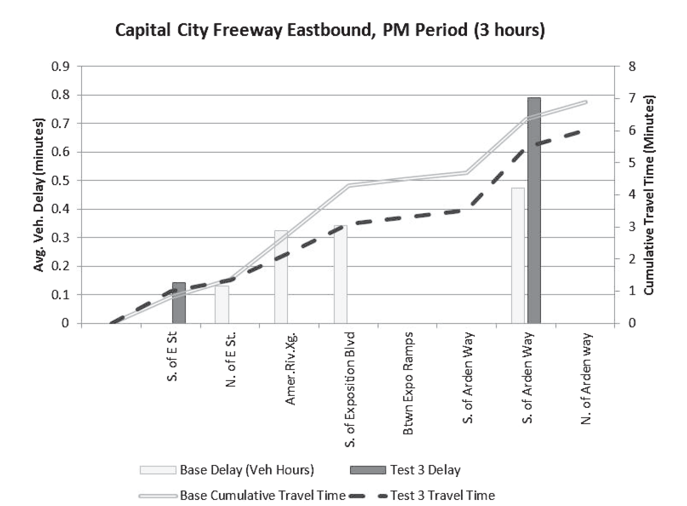
Note: EB = eastbound.

Table 4.15. Total Vehicle-Hours of Delay by Segment, Capital City Freeway Eastbound/Northbound—Test 3

					Vehicle-Hours of Delay											
		Lanes		Distance (mi)	Baseline				Scenario 3				Percentage Difference			
Segment	Direction	Baseline	Scenario 3		A.M.	Midday	P.M.	Evening	A.M.	Midday	P.M.	Evening	A.M.	Midday	P.M.	Evening
SACSIM																
South of E St.	EB	3	3	0.50	0	0	0	0	0	0	44	0	—	—	n/a	—
North of E St.	EB	3	4	0.26	0	0	43	0	0	0	0	0	—	—	–100%	—
River Crossing	EB	3	4	0.64	0	0	106	0	0	0	0	0	—	—	–100%	—
South of Exposition Blvd.	EB	3	4	0.68	0	0	113	0	0	0	0	0	—	—	–100%	—
Between Exposition Blvd. ramps	EB	3	3	0.16	0	0	0	0	0	0	0	0	—	—	—	—
South of Arden Way	EB	3	3	0.14	0	0	0	0	0	0	0	0	—	—	—	—
South of Arden Way	EB	2	2	0.69	0	0	103	0	0	0	182	0	—	—	77%	—
North of Arden Way	EB	4	4	0.36	0	0	0	0	0	0	0	0	—	—	—	—
			Total	3.43	0	0	365	0	0	0	227	0	—	—	–38%	—
C10B Integrated Model																
South of E St.	EB	3	4	0.50	49	53	611	1,315	0	0	319	636	–100%	–100%	–48%	–52%
North of E St.	EB	3	4	0.26	25	35	259	699	0	0	148	378	–100%	–100%	–43%	–46%
River Crossing	EB	3	4	0.71	63	89	259	864	31	0	270	741	–51%	–100%	4%	–14%
South of Exposition Blvd.	EB	3	4	0.68	48	78	97	161	203	299	329	782	323%	283%	239%	386%
Between Exposition Blvd. ramps	EB	3	3	0.16	0	0	3	0	7	29	32	75	—	—	967%	—
South of Arden Way	EB	3	3	0.14	0	0	17	16	30	87	64	131	—	—	276%	719%
South of Arden Way	EB	2	2	0.69	0	0	19	26	24	79	59	105	—	—	211%	304%
North of Arden Way	EB	4	4	0.35	0	0	0	0	0	0	0	0	—	—	—	—
			Total	3.48	185	254	1,265	3,081	295	493	1,222	2,849	59%	94%	–3%	–8%

Note: EB = eastbound.

SACSIM



C10B Integrated Model

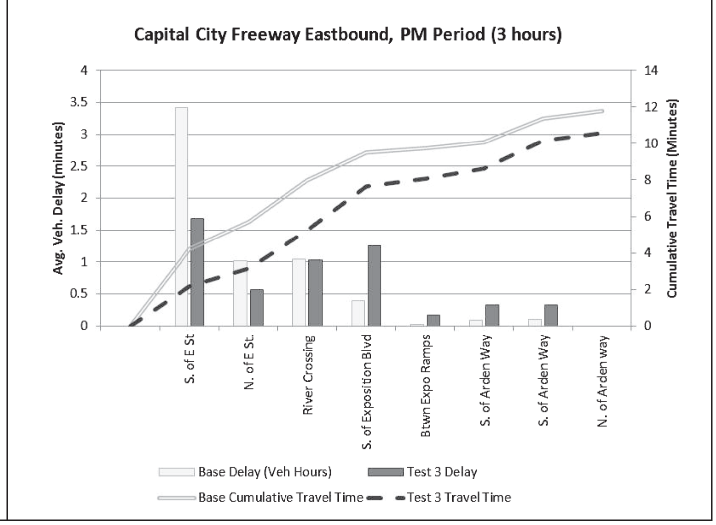


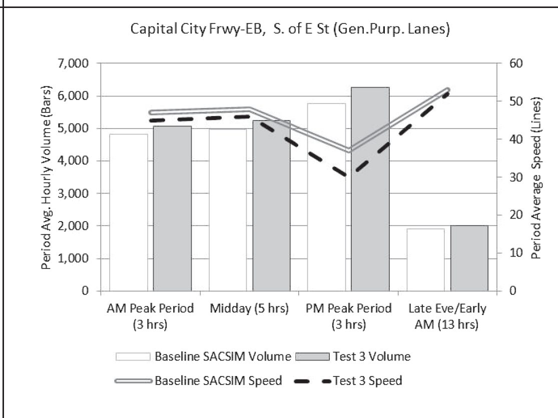
Figure 4.3. Travel time and average delay by segment, p.m. peak period—Test 3.

Segment | **SACSIM Model** | **C10B Model**

Fig. 4.4A

Capital City Freeway EB,

south of E St.



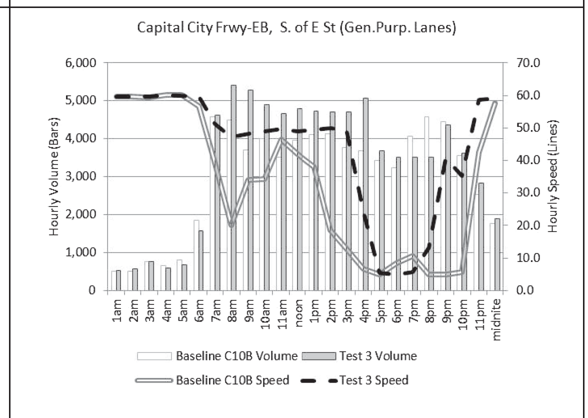
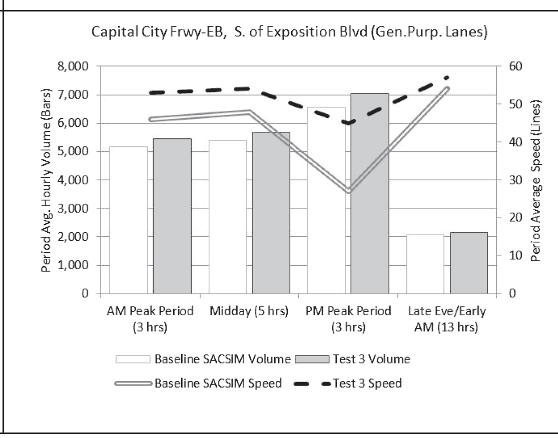


Fig. 4.4B

Capital City Freeway EB,

south of Exposition Blvd.



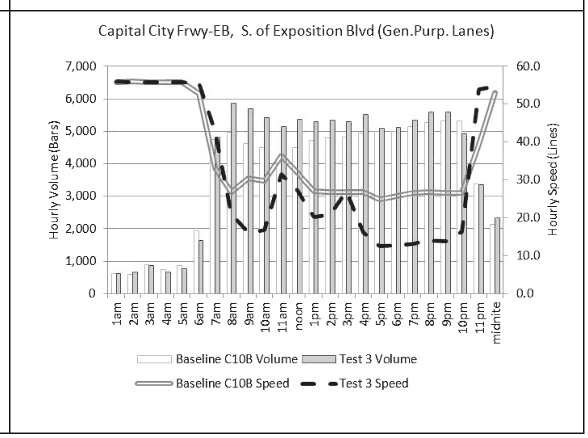
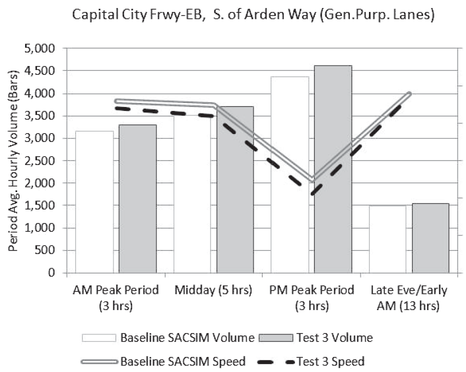
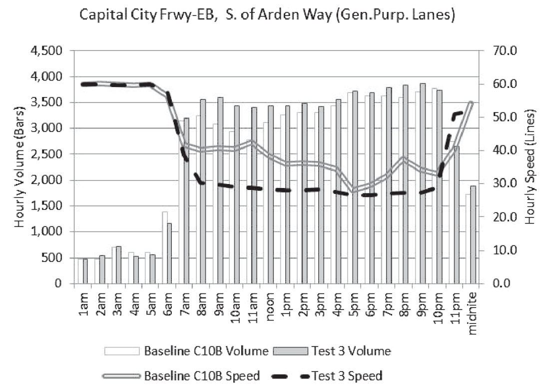


Figure 4.4. Vehicle volumes and speeds on key test segments—Test 3. (Continued on next page.)

<table>
<tr><th>Segment</th><th>SACSIM Model</th><th>C10B Model</th></tr>
<tr><td>Fig. 4.4C

Capital City Freeway EB,

south of Arden Way</td><td>
</td><td>
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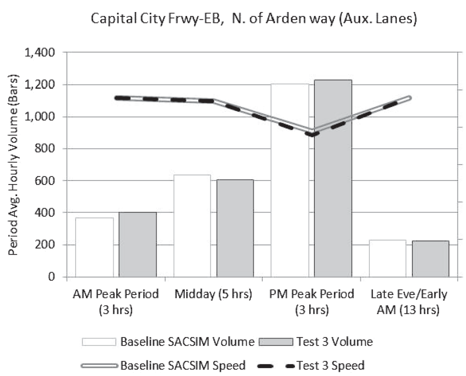
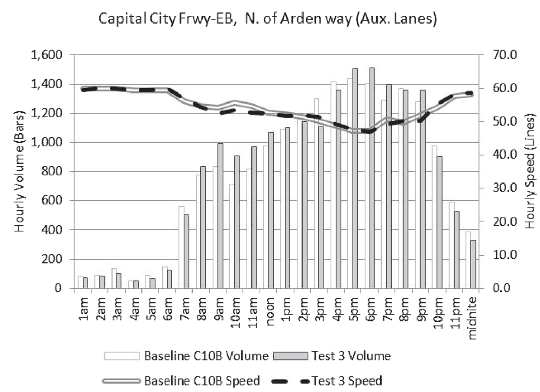
<tr><td>Fig. 4.4D

Capital City Freeway EB,

north of Arden Way,

auxiliary lanes</td><td>
</td><td>
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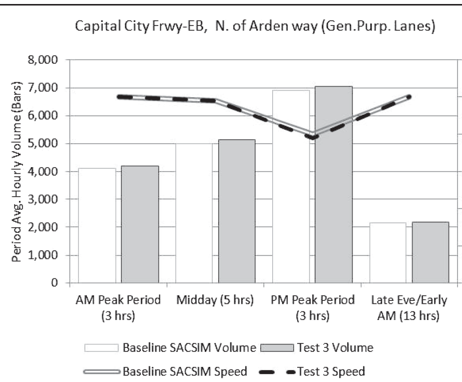
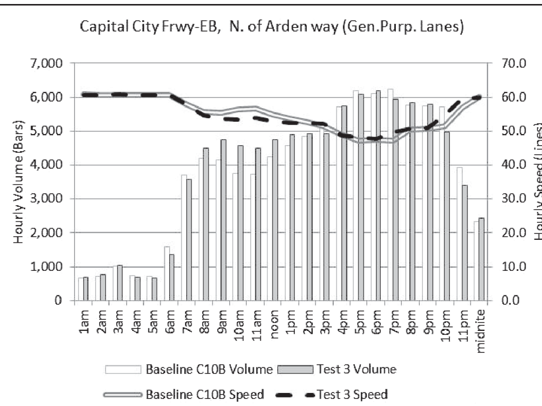
<tr><td>Fig. 4.4E

Capital City Freeway EB,

north of Arden Way,

general purpose lanes</td><td>
</td><td>
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<tr><td>Fig. 4.4F

Capital City Freeway WB,

north of Arden Way,

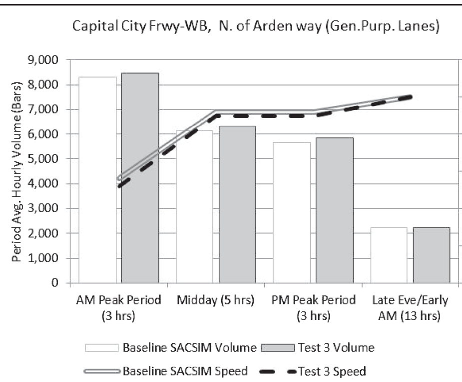
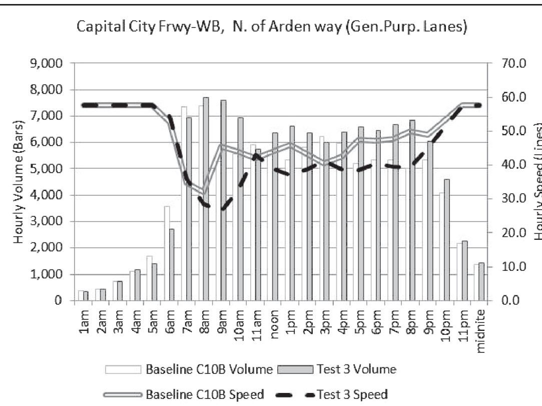
general purpose lanes</td><td>
</td><td>
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Figure 4.4. Vehicle volumes and speeds on key test segments—Test 3 (continued).

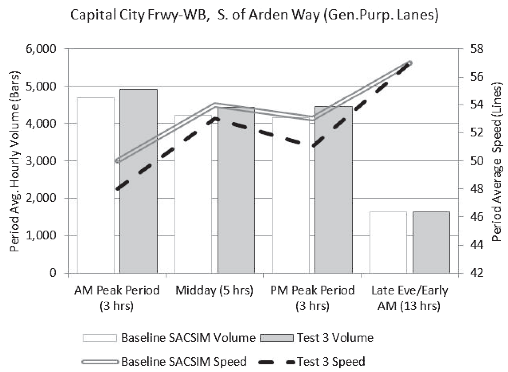
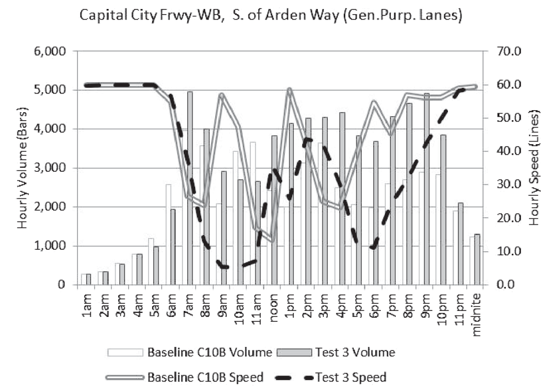
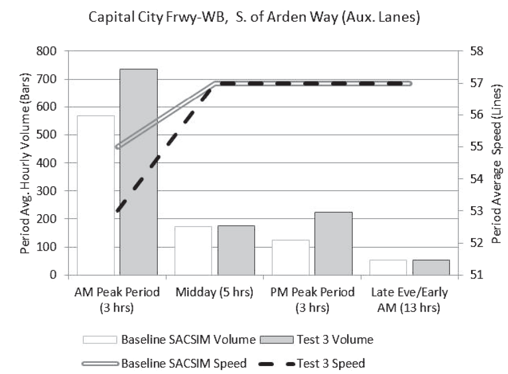
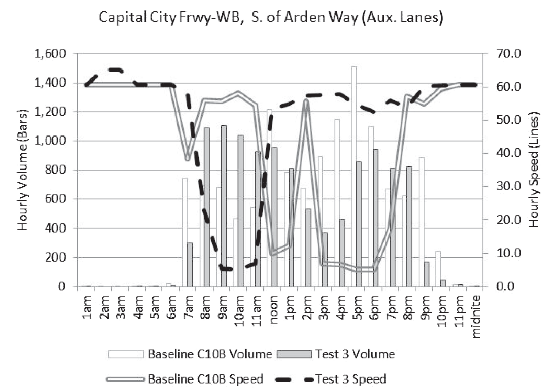
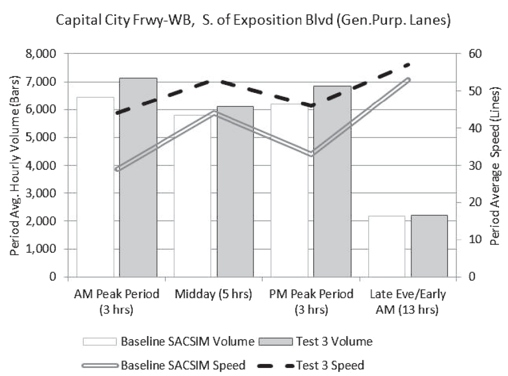
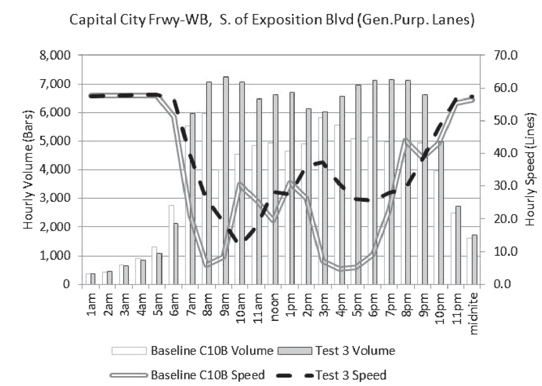
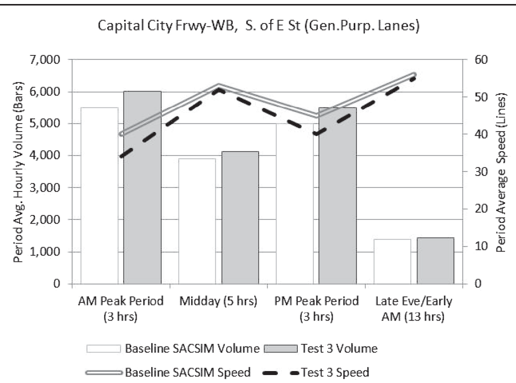
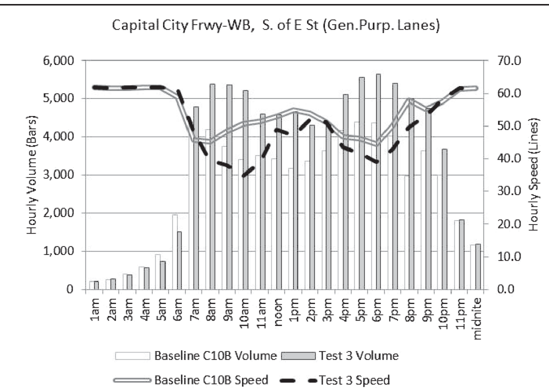
Segment	SACSIM Model	C10B Model
Fig. 4.4G Capital City Freeway WB, south of Arden Way, general purpose lanes		
Fig. 4.4H Capital City Freeway WB, south of Arden Way, auxiliary lanes		
Fig. 4.4I Capital City Freeway WB, south of Exposition Blvd., general purpose lanes (widened from 3 to 4 lanes in Test 3)		
Fig. 4.4J Capital City Freeway WB, south of E St., general purpose lanes (widened from 3 to 4 lanes in Test 3)		

Figure 4.4. Vehicle volumes and speeds on key test segments—Test 3 (continued).

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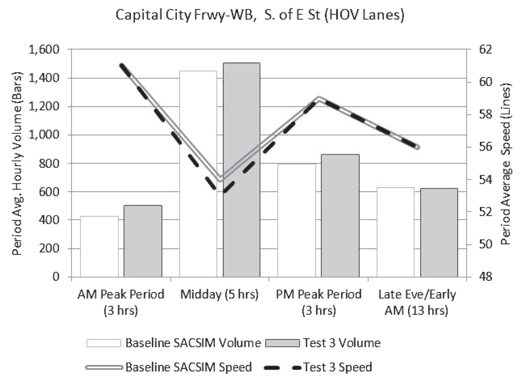
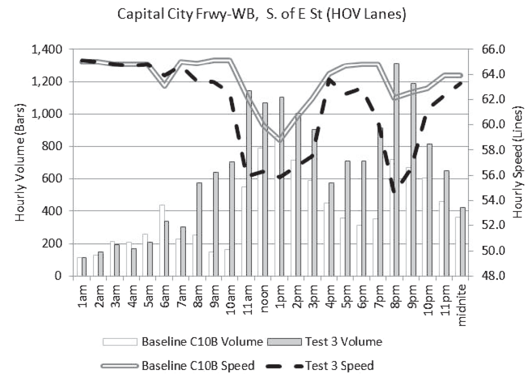
<tr><th>Segment</th><th>SACSIM Model</th><th>C10B Model</th></tr>
<tr><td>Fig. 4.4K

Capital City Freeway WB,

south of E St.,

HOV lanes</td><td>
</td><td>
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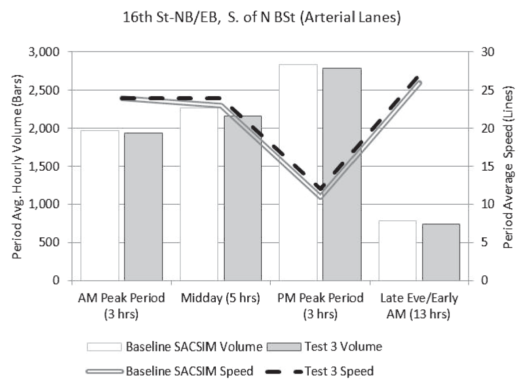
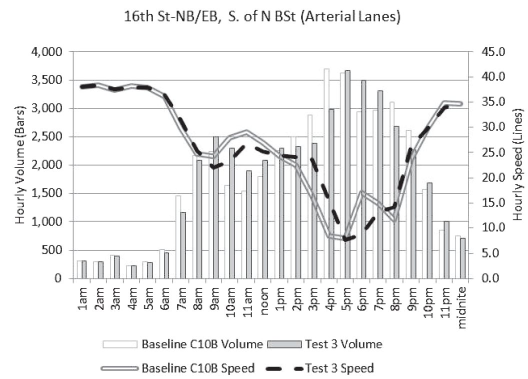
16th St. NB/EB,

south of N B St.</td><td>
</td><td>
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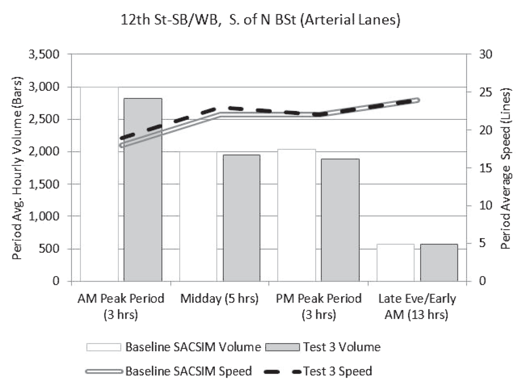
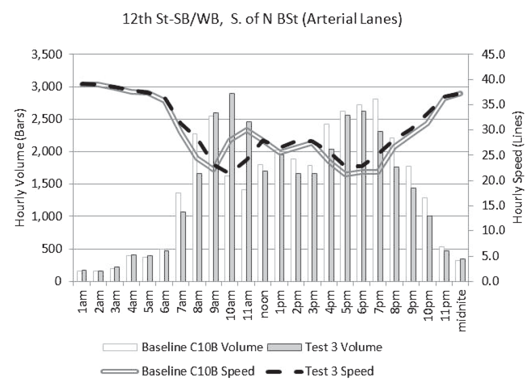
<tr><td>Fig. 4.4M

12th St. SB/WB,

south of N B St.</td><td>
</td><td>
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<tr><td>Fig. 4.4N

SR 160 EB,

west of Royal Oaks,

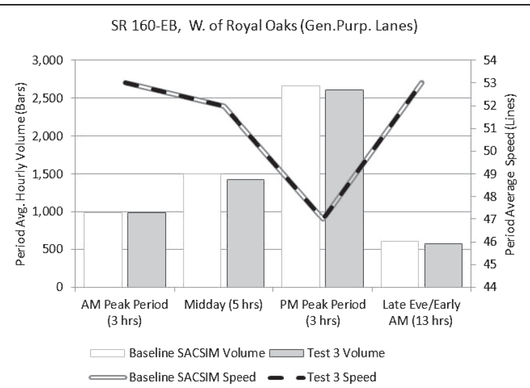
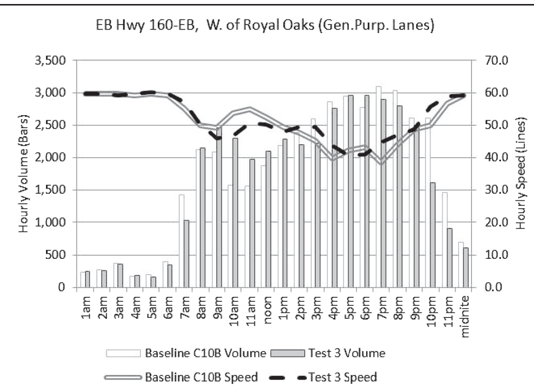
general purpose lanes</td><td>
</td><td>
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Figure 4.4. Vehicle volumes and speeds on key test segments—Test 3 (continued).

<table>
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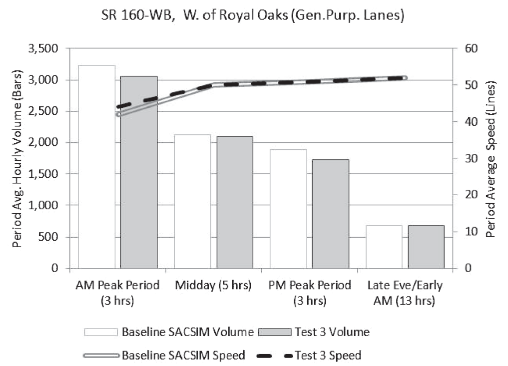
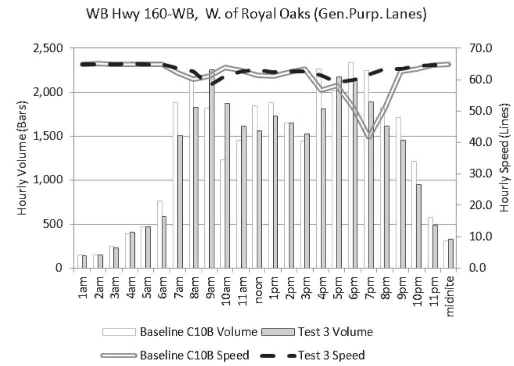
SR 160 WB,
west of Royal Oaks,
general purpose lanes</td><td>
</td><td>
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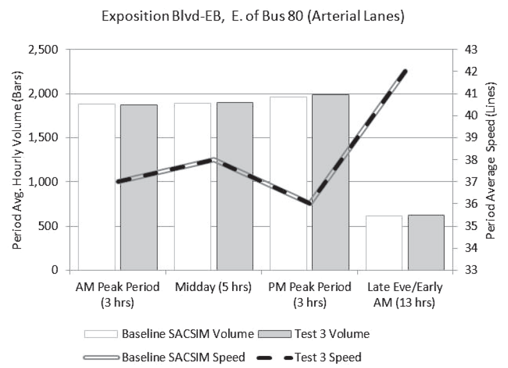
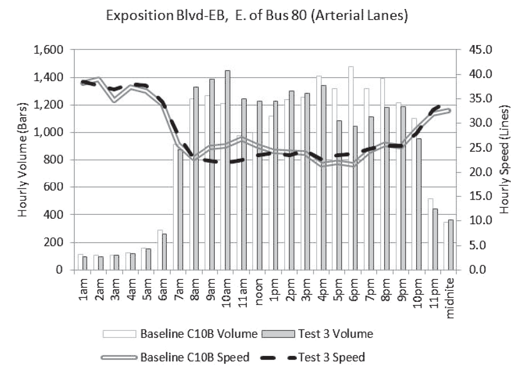
<tr><td>Fig. 4.4P
Exposition Blvd. EB,
east of Capital City Freeway</td><td>
</td><td>
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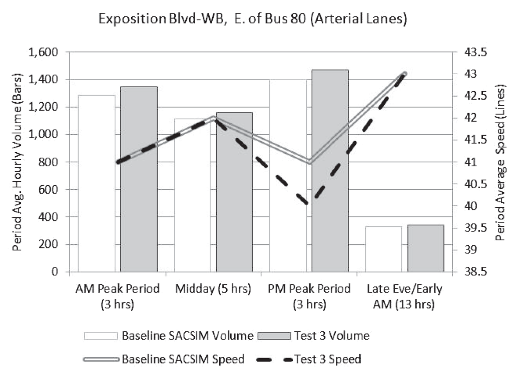
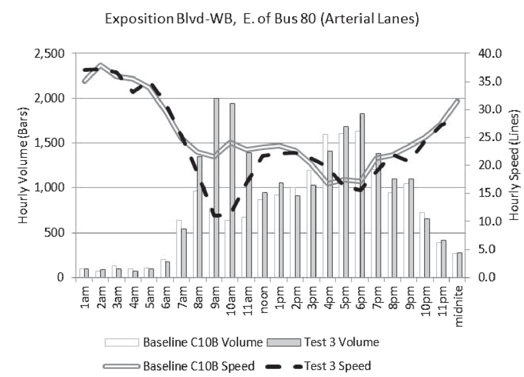
<tr><td>Fig. 4.4Q
Exposition Blvd. WB,
east of Capital City Freeway</td><td>
</td><td>
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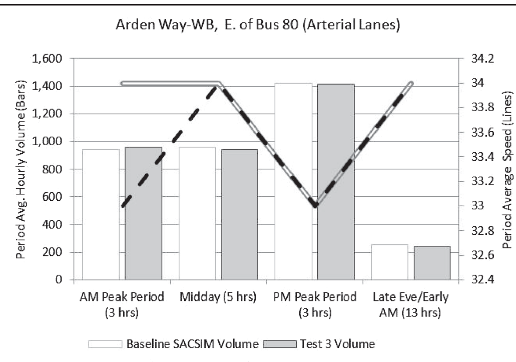
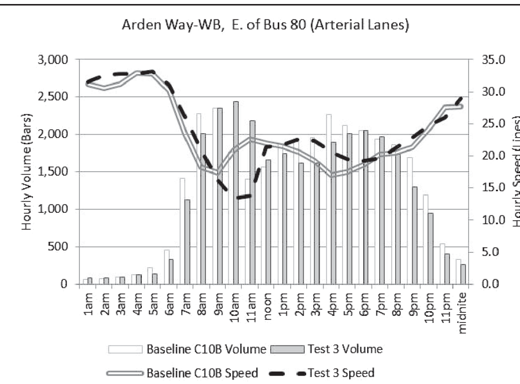
<tr><td>Fig. 4.4R
Arden Way WB,
east of Capital City Freeway</td><td>
</td><td>
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Figure 4.4. Vehicle volumes and speeds on key test segments—Test 3 (continued).

<table>
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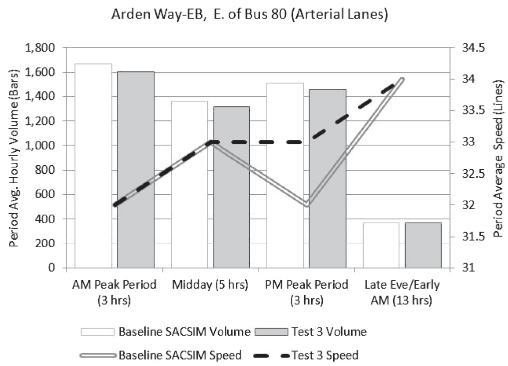
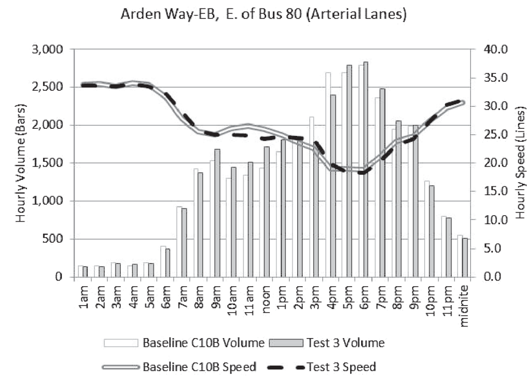
<tr><td>Fig. 4.4S
Arden Way EB,
east of Capital City Freeway</td><td>
</td><td>
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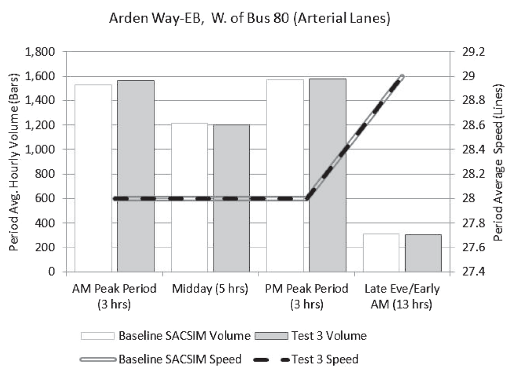
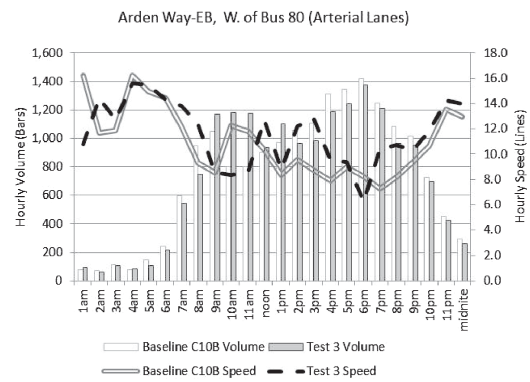
<tr><td>Fig. 4.4T
Arden Way EB,
west of Capital City Freeway</td><td>
</td><td>
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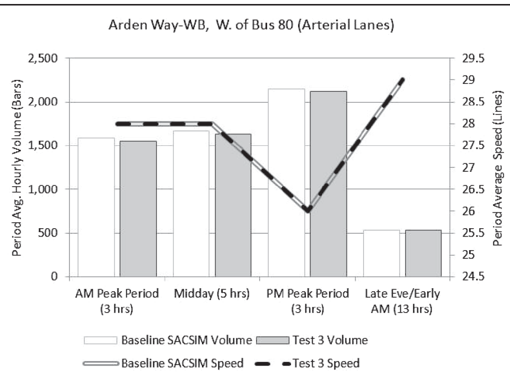
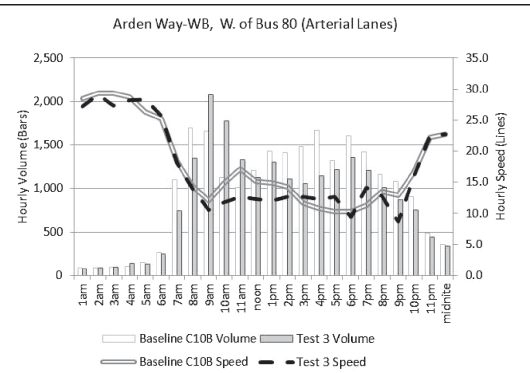
Arden Way WB,
west of Capital City Freeway</td><td>
</td><td>
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Figure 4.4. Vehicle volumes and speeds on key test segments—Test 3 (continued).

A general note on why the C10B model delay estimates are so much higher than the SACSIM estimates is needed. The delay measure, as already mentioned, is based on a threshold travel speed of 35 mph. Because SACSIM models aggregate time periods (e.g., 3-h peaks and a 13-h late evening/early morning period), modeled travel speeds are blended across all hours in the aggregate period. The highs and lows are blended out. The C10B model operates at very small time slices, which for this set of estimates are aggregated to hours. The highs and lows which occur within the aggregate time periods are specifically modeled in the C10B model. Stated more simply, to calculate delay relative to the 35 mph threshold, the aggregate time period travel speed would have to be below 35 mph for the SACSIM model. For the C10B model, delay can accrue for each time slice within the aggregate time period—any time slice within the aggregate period can generate delay.

In summary, in Scenario 3, an additional general purpose lane was incorporated on a congested segment of the Capital City Freeway which is the most congested freeway in the region. Both models showed a small increase in the total amount of regional travel, with the C10B integrated model showing a larger increase. However, in the SACSIM model this increase was mainly concentrated near the vicinity of the improved highway; in the C10B model, destinations near the improvement decreased while they increased farther away from the improvement.

The C10B integrated model results are different from SACSIM for this segment. Both the baseline and Scenario 3 show slower speeds and higher travel times than SACSIM. It is unknown in which model's results the speeds and volumes are more accurate.

Both SACSIM and the C10B model show higher volumes on the widened highway for the test, and both show added delay in the downstream segments. But the C10B model shows the impact of higher volumes on the downstream segments to be much greater than SACSIM. In other words, by widening the crossing segment, delay is reduced on that segment, but that improvement is offset by much higher delay downstream. Widening the bridge segment alone would be nearly net-zero in delay reduction, according to the C10B model results.

In this scenario it was anticipated that the increased capacity would result in a higher number of trips to the affected area both spatially and temporally. However, such an impact is seen only in SACSIM, not in the C10B integrated model. For this particular scenario, perhaps less than ideal convergence in the C10B model may have left the model with too many localized sources of instability and congestion which have distorted the final outcome. The study team tested using a higher number of DynusT iterations in the last overall iteration, which improved convergence and reduced excessive congestion, but this did not eliminate the counterintuitive results.

Test 4 Results

Scenario 4 involved tripling the service frequency on the "23–El Camino" bus route. The route currently runs at 30-min headways from about 5:30 a.m. to 9:00 p.m. on weekdays; Scenario 4 reduced the headways to 10 min for the entire service period. Highlights of this test include the following:

- An increase in person trips by transit modes (+3.1% with SACSIM, +5.1% with C10B), and an increase in walk trips (+0.4% with SACSIM, +1.5% with C10B). These changes conformed to expectations on direction of change. (In addition to the summary provided in Table 4.3, Table 4.16 provides further details.)
- As shown in Table 4.17, transit boardings on the test route nearly tripled in SACSIM, from about 2,300 to 8,700 daily boardings. This increase seems unreasonably large. The test effect estimated with C10B was about 66%, from 2,800 to 4,700 daily boardings, which is more reasonable. Boardings on surrounding transit routes decreased in both models.
- Figure 4.5 shows the transit boardings on Route 23 by time of day. SACSIM produces summaries only for the aggregated peak and off-peak periods while the C10B model estimates volumes by bus run (the volumes are summarized by hour in Figure 4.5). The C10B model is also able to estimate maximum loads of passengers, also shown by hour. In the baseline scenario, for 2 h in the morning and 2 h in the afternoon, buses reached the maximum loads on the bus (40 seated, 20 standees, total 60). For the test scenario, buses in only 1 h did so.

In summary, in this test, SACSIM produced an unexpectedly large shift in ridership on Route 23 as a result of the

Table 4.16. Person Trips by Mode—Test 4

Mode	SACSIM				C10B Integrated Model			
	Baseline	Scenario 4	Difference	Percent Difference	Baseline	Scenario 4	Difference	Percent Difference
Transit auto access	11,920	11,268	–652	–5.5%	10,999	11,855	+856	+7.8%
Transit walk access	85,977	89,709	+3,732	+4.3%	59,759	62,525	+2,766	+4.6%
Transit (total)	97,897	100,977	+3,080	+3.1%	70,758	74,380	+3,622	+5.1%
School bus	132,096	131,801	–295	–0.2%	91,627	93,813	+2,186	+2.4%
Shared ride 3+	1,580,119	1,578,941	–1,178	–0.1%	2,264,407	2,265,069	+662	+0.0%
Shared ride 2	2,180,452	2,178,753	–1,699	–0.1%	2,044,692	2,037,101	–7,591	–0.4%
Drive alone	3,568,112	3,566,803	–1,309	–0.0%	3,615,848	3,616,052	+204	+0.0%
Bike	142,852	142,430	–422	–0.3%	97,686	99,224	+1,538	+1.6%
Walk	524,481	526,456	+1,975	+0.4%	521,898	529,507	+7,609	+1.5%
Total	8,226,009	8,226,161	+152	+0.0%	8,706,916	8,715,146	+8,230	+0.1%

Table 4.17. Transit Passenger Boardings Summary for Test 4

Test Metric	Count	Base Model Boardings		Scenario 4 Boardings		Percent Increase from Base	
		SACSIM	C10B	SACSIM	C10B	SACSIM	C10B
Daily boardings on Test Route 23	2,550	2,289	2,804	8,684	4,666	+279.4%	+66.4%
Other nearby routes							
Route 22 (near Route 23)	520	727	494	589	453	–19.0%	–8.3%
Route 25 (near Route 23)	1,160	1,197	1,427	928	1,192	–22.5%	–16.5%
Route 82 (near Route 23)	2,130	2,400	2,870	2,457	2,752	+2.4%	–4.1%
Sum of nearby routes	3,810	4,324	4,791	3,974	4,397	–8.1%	–8.2%
All other RT buses **IN** C10B model	49,100	49,634	48,996	49,652	50,071	+0.0%	+2.2%
RT buses **NOT IN** C10B model	10,110	14,139		10,811			
RT light rail (all lines)	48,300	42,278	20,864	42,581	21,397	+0.7%	+2.6%
All RT system boardings	117,870	116,356	69,860	119,439	71,468	+2.6%	+2.3%

Source: SACOG.

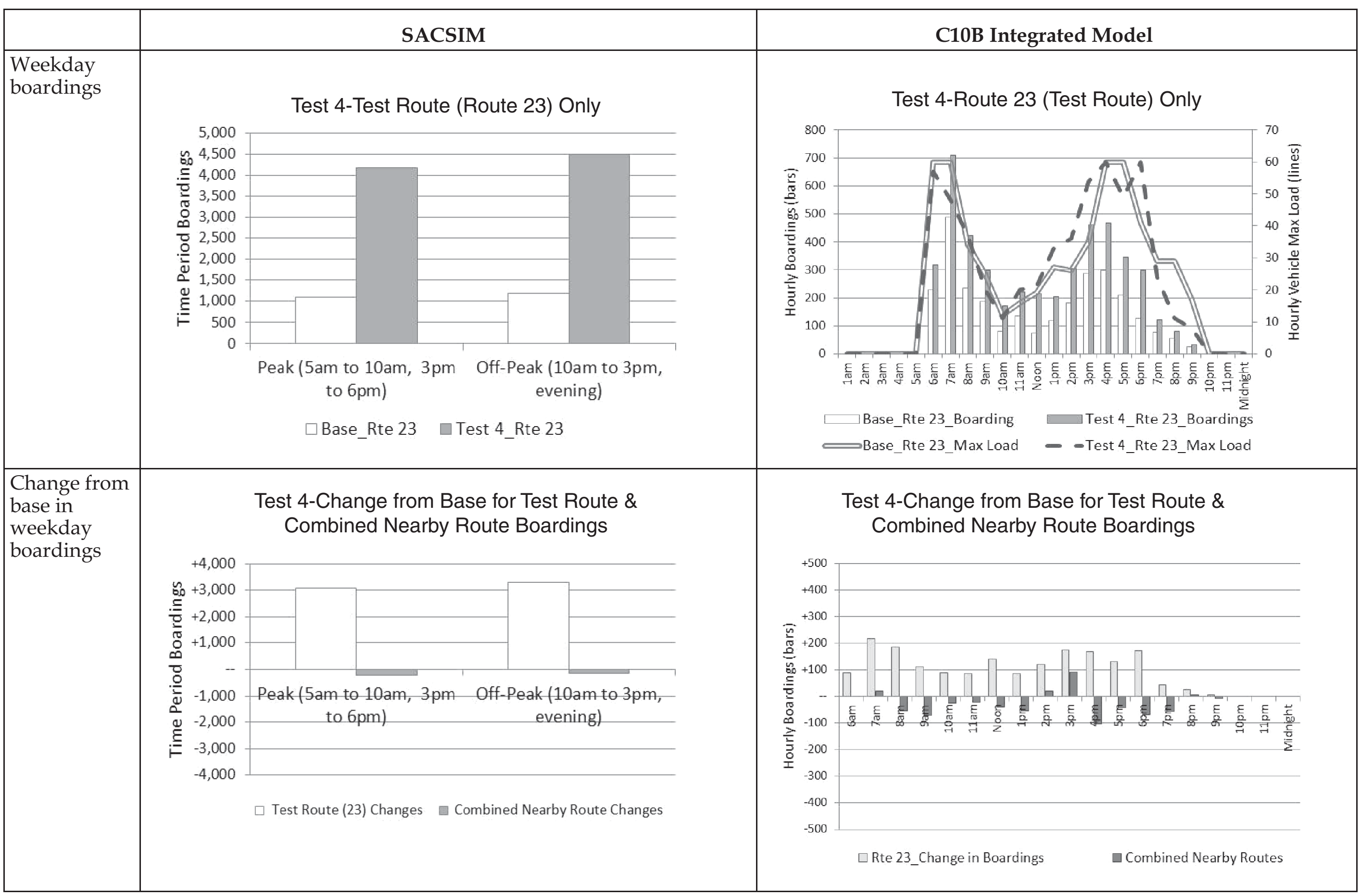

Figure 4.5. Boarding summaries for C10B integrated model—Test 4.

decreased headway. It is not clear why this should occur in SACSIM since the mode choice model should not be overly sensitive to headway assumptions, and the same mode choice model is used in the C10B integrated model. Nor should the static transit assignment process be overly sensitive to headway assumptions. This result is particularly puzzling given that the C10B integrated model had a larger overall increase in transit demand (5% compared with 3% for SACSIM). Examining the reasons behind the unusual SACSIM results was beyond the scope of this project; for whatever reason, the C10B integrated model results were more reasonable.

Both models showed about the same (reasonable) shifts in ridership from nearby routes.

Test 5 Results

Scenario 5 involved deleting the "23–El Camino" bus route. Highlights of Test 5 include the following:

- A decrease in total regional transit person trips and walk person trips was expected. The SACSIM model test effects conformed to this expectation. (In addition to the summary provided in Table 4.3, Table 4.18 provides further details.) The C10B model showed an increase of 1.8% in transit person trips, counter to expectation.
- Both models showed an increase in passenger boardings for some surrounding routes (see Table 4.19), but the increases only partly offset the loss of passenger boardings on the test route; so overall transit boardings decreased in both models. Interestingly, both models showed similar increases on nearby routes. However, the C10B integrated model showed increases on other Sacramento Regional Transit District (RT) bus routes as well as the light rail lines. It is interesting that SACSIM showed substantial decreases in ridership on the RT routes not included in the C10B integrated model. These are generally low ridership routes that are mainly not in the vicinity of Route 23. More than half of the decrease in total regional transit boardings in SACSIM occurs on these routes, which is also an anomalous result that skews the direct comparisons of the results from the two models.
- Figure 4.6 illustrates the change in boardings on the test route and those on the combined surrounding routes. The SACSIM model produces summaries only for the aggregated peak and off-peak periods while the C10B model estimates volumes by bus run (the volumes are summarized by hour in Figure 4.6). The C10B model is also able to estimate maximum loads of passengers, also shown by hour.

In summary, in contrast to the results of Test 4, which used the same transit route as its basis, the results of Test 5 were more reasonable for SACSIM than for the C10B integrated model. The deletion of Route 23 should have resulted in a decrease in overall transit ridership, but in the C10B model, the opposite occurred. Both models did show increases in ridership on nearby routes, as expected. There were some unusual results in SACSIM away from the deleted route, making some direct comparisons difficult.

Table 4.18. Person Trips by Mode—Test 5

	SACSIM				C10B Integrated Model			
Mode	Baseline	Scenario 5	Difference	Percent Difference	Baseline	Scenario 5	Difference	Percent Difference
Transit auto access	11,920	11,006	–914	–7.7%	10,999	11,257	+258	+2.3%
Transit walk access	85,977	85,179	–798	–0.9%	59,759	60,744	+985	+1.6%
Transit (total)	97,897	96,185	–1,712	–1.7%	70,758	72,001	+1,243	+1.8%
School bus	132,096	132,067	–29	–0.0%	91,627	92,276	+649	+0.7%
Shared ride 3+	1,580,119	1,581,303	+1,184	+0.1%	2,264,407	2,264,047	–360	–0.0%
Shared ride 2	2,180,452	2,179,814	–638	–0.0%	2,044,692	2,042,917	–1,775	–0.1%
Drive alone	3,568,112	3,568,654	+542	+0.0%	3,615,848	3,618,680	+2,832	+0.1%
Bike	142,852	143,798	+946	+0.7%	97,686	98,389	+703	+0.7%
Walk	524,481	525,996	+1,515	+0.3%	521,898	525,769	+3,871	+0.7%
Total	8,226,009	8,227,817	+1,808	+0.0%	8,706,916	8,714,079	+7,163	+0.1%

Table 4.19. Transit Passenger Boardings Summary—Test 5

Test Metric	Count	Base Model Boardings		Scenario 5 Boardings		Percent Increase from Base	
		SACSIM	C10B	SACSIM	C10B	SACSIM	C10B
Daily boardings on Test Route 23	2,550	2,289	2,804	0	0	–100.0%	–100.0%
Other nearby routes							
Route 22 (near Route 23)	520	727	494	727	606	—	+22.7%
Route 25 (near Route 23)	1,160	1,197	1,427	1,525	1,879	+27.4%	+31.7%
Route 82 (near Route 23)	2,130	2,400	2,870	2,391	2,871	–0.4%	+0.0%
Sum of nearby routes	3,810	4,324	4,791	4,643	5,356	+7.4%	+11.8%
All other RT buses **IN** C10B Model	49,100	49,634	48,996	49,590	50,231	–0.1%	+2.5%
RT buses **NOT IN** C10B Model	10,110	14,139		11,214		–20.7%	
RT light rail (all lines)	48,300	42,278	20,864	42,207	21,231	–0.2%	+1.8%
All RT system boardings	117,870	116,356	69,860	111,243	71,462	–4.4%	+2.3%

Source: SACOG.

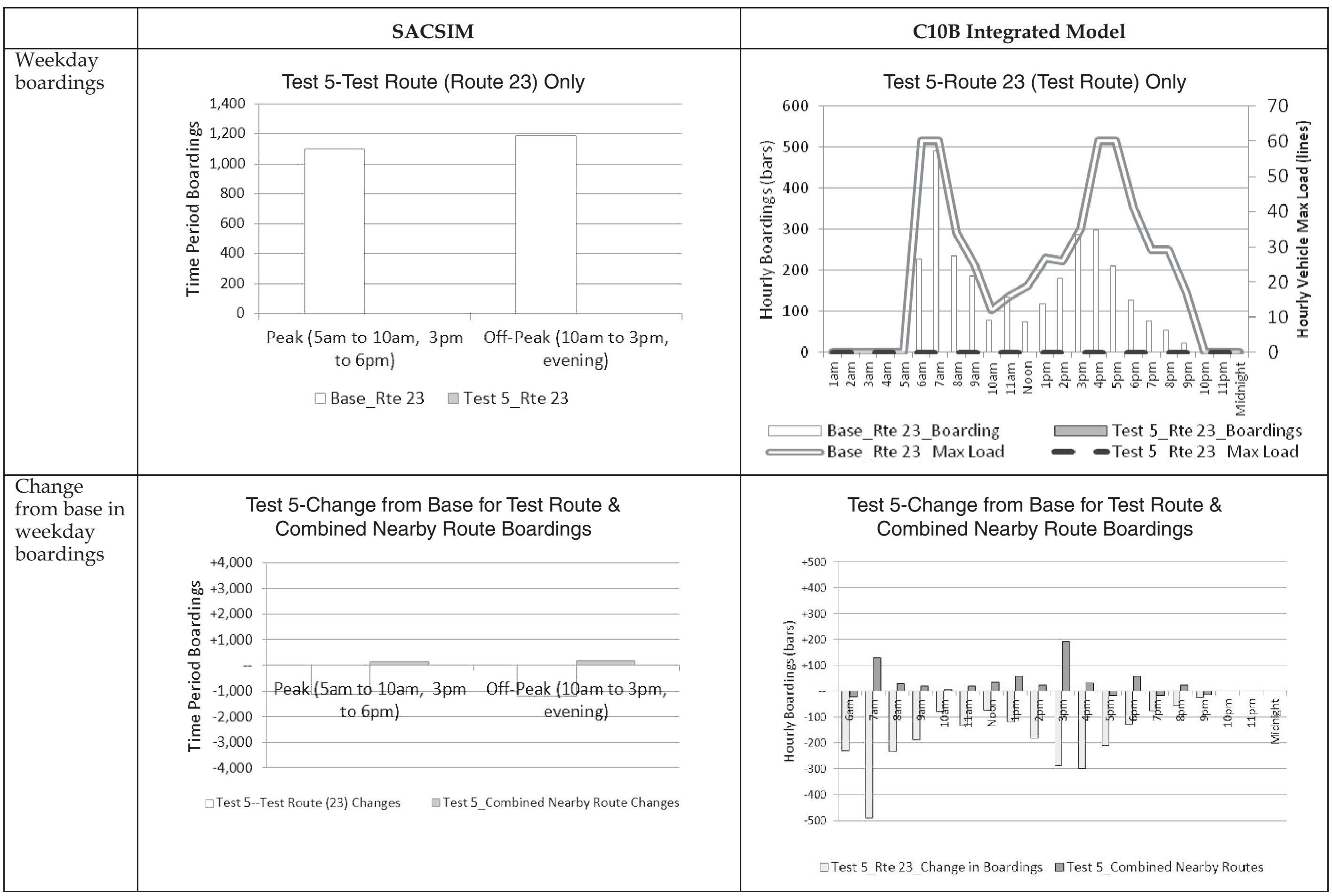

Figure 4.6. Boarding summaries for SACSIM and C10B integrated model—Test 5.

CHAPTER 5

Conclusions and Lessons Learned

The SHRP 2 C10B project developed and performed a limited set of tests for a completely dynamic, disaggregate travel demand and traffic and transit simulation model. The model was implemented using available software, mainly open source, and software developed for the project that is available through the National Academy of Sciences. The model was implemented and tested for the Sacramento, California, metropolitan area.

The new integrated model uses available data as inputs. The data needs are similar to those used in existing planning and operational models. The socioeconomic and land use data inputs are the same as those used in the existing activity-based travel demand model used by SACOG, the Sacramento MPO. The highway network data requirements are consistent with those needed for traffic simulation. Note that those requirements can be substantial at the regional level, and detailed actual data may have to be replaced with default data in some cases. The transit network data are generated directly from Google's General Transit Feed Specification (GTFS), which includes information for most major metropolitan areas in the United States.

The model was designed to run on software and hardware configurations that would typically be available at most larger MPOs and state planning agencies. The software only runs on a typical Windows Server configuration.

The testing of the new model was limited. A complete validation of the new model was not performed so that project resources could be reserved for a series of tests in which the model was used to estimate the effects of various policy and transportation improvement scenarios. This means that the model will need further calibration and improvements to be used in realistic planning applications.

What Users Need to Know to Run the C10B Integrated Model

Users of the C10B integrated model should be familiar with the following:

- Travel demand modeling concepts and procedures, and interpretation of model validation and outputs;
- Traffic simulation modeling, particularly using the DynusT model and software, and interpretation of model validation and outputs; and
- The General Transit Feed Specification (GTFS).

If the model run is to include MOVES, then familiarity with the MOVES model is also important.

It is important to recognize that, as with any advanced travel model, users should have a solid understanding of travel demand modeling to be able to understand the operation of the model and to understand and interpret the model's outputs. The exogenous travel components of the model are represented by conventional trip tables, and so an understanding of how trip tables are created is also necessary.

DaySim is an activity-based model; since DaySim is a component of the C10B integrated model, users should have a fundamental understanding of the concepts of activity-based modeling. It is not necessary to be facile with all the details of the estimation of each model component; but the way in which individuals' activity patterns and choices of destination, mode, and time of day are realized in the model should be fully understood.

Because the highway network in the C10B integrated model is maintained in DynusT, users need a thorough understanding of this simulation model as well. While most members of the project team had substantial expertise in travel demand modeling, only a few had significant experience using DynusT. Team members who were to perform model runs, particularly at SACOG, underwent multiday training sessions by University of Arizona team members, who are among those who typically perform such training for other DynusT users. Even with the training, because DynusT was new to many team members, it took a substantial amount of time for them to become proficient enough to perform the network coding required to create model scenarios, and to examine and interpret DynusT outputs. New users of the C10B model who are not familiar with DynusT should be prepared to spend some time becoming familiar with it before proceeding and may want to consider getting the formal DynusT training offered by the University of Arizona.

The original FAST-TrIPs transit network was developed by University of Arizona team members using the GTFS information for Sacramento. Since these team members were also the developers of FAST-TrIPs, the other project team members do not have a specific estimate for the level of effort to develop a complete FAST-TrIPs network. SACOG staff who performed the policy testing discussed in Chapter 4 were able to make the relatively simple edits required for Scenarios 1, 4, and 5. These edits, however, did not involve coding new routes; rather a route was deleted, hours of service were extended, and frequencies were changed.

It should be noted that a frequency change is somewhat more involved than it would be in a transit network used in a conventional model with static assignment. Since each transit vehicle run is coded separately, an increase in frequency means adding a number of runs. For example, if average headways on a bus route were reduced from 20 min to 10 min over a 3-h period, nine new bus runs would have to be added to the existing nine runs. Since transit vehicle runs are not necessarily evenly spaced (for example, runs could be scheduled to start at 8:00, 8:16, 8:38, and 9:00), the user would have to decide when to start each new run. One might, say, add a new run beginning at the midpoint between existing runs (e.g., 8:08, 8:27, and 8:49).

One task that was not done as part of the C10B project was coding a future year transit network. Since GTFS data would not be available for a future year, the transit vehicle runs would have to be generated, perhaps starting from an existing year network and adding, deleting, or revising routes and stops as needed. It might be necessary to examine future year highway speeds to help estimate the times for buses to travel from one stop to another.

It should be noted that beyond the modeling terminology that is part of the C10B model user interface (UI), there is no specialized computing knowledge or experience necessary to run the model. The UI is similar to many other Windows-based software programs in that users create and modify scenarios and examine the model's reports through familiar concepts such as radio buttons, tabs, and drop down menus.

Lessons Learned and Improvements Needed

As previously mentioned, the testing of the new model was limited, and a complete model validation was not performed. Additionally, a number of challenges were experienced during the development, implementation, and testing of the C10B integrated model. Some of these issues were addressed fully or in part, while others could not be addressed within the schedule and resources available for the C10B project. These issues need to be addressed to make the model ready for real-world applications.

This section discusses some of these challenges, how they were addressed during the project, and how they affect the model results. Some of them relate to areas of further development and research. Where applicable, recommendations for C10B model users in response to these challenges are presented.

Model Validation

In the early stages of the project, consideration was given to performing a full validation of the C10B model, similar to what might be done for a travel model that would be used by an MPO for transportation planning. This full validation would have included comparisons to observed data for the base year of 2005 as well as SACSIM model results, and sensitivity testing using a forecast or backcast year. This concept was abandoned because other delays left too little time at the end of the project to perform both a conventional model validation and sensitivity testing and the planned policy testing. It was decided that the policy testing would proceed, and conventional model validation and sensitivity testing would not be performed.

The model testing that was performed, as discussed in Chapter 3, focused on "proof of concept," meaning that the results were examined mainly using aggregate measures, and extensive calibration of the model was not performed. It was obvious that there were some issues in the C10B model results that would have required further work on the model had it been intended for use in an actual transportation planning setting. These included the following.

An underestimation of transit ridership. For 2005 the C10B model estimated fewer transit riders than SACSIM and fewer than the observed ridership for that year. It is unclear why this would happen, given that the inputs to DaySim were the same as for the original 2005 SACSIM model and the revisions made to DaySim as part of the C10B project were not focused on transit. FAST-TrIPs uses the transit tour and trip outputs of DaySim, and so that component of the integrated model would not result in any change in the number of transit tours. Given that some of the policy tests did focus on transit, it would be desirable to determine the cause of this difference before doing any additional work with the model.

Lower highway speeds. The C10B model resulted in lower travel average speeds (about 8 to 10 mph) for all roadway types at all times of day. This may be a result of the more realistic representation of traffic dynamics than in the static traffic assignment process used in SACSIM. The output speeds in SACSIM do not seem particularly high (though the original model validation did not include speed comparisons to observed data). More examination (i.e., comparisons with observed speeds) is warranted. It should be noted that traffic simulation models such as DynusT have various parameters that represent driver behavior which were not calibrated for the C10B project.

Temporal distribution of travel. Despite the differences in output speeds, the C10B model did not show substantial differences from SACSIM in terms of total travel (for example, as measured by vehicle-miles) or trip lengths. The distribution of travel by time of day, however, did differ noticeably from the SACSIM results. In particular, there was more travel in the evening period in the C10B model and less travel at other times of day, especially the midday period. It is possible that the lower speeds being fed back from DynusT resulted in a shifting of travel (in DaySim's time-of-day choice models) to less congested periods. The finer temporal resolution of the C10B integrated model points out an area where additional validation and calibration are necessary.

Convergence

As discussed in Chapter 3, it was found that after running three big loop iterations, each of which includes 10 DynusT iterations, the systemwide model convergence reached a plateau that did not improve with more iterations. It was found that three big loop iterations result in a systemwide convergence level between 10% and 15%, meaning that—on average—the number of trips between each zone pair changes by no more than 10% to 15% between successive big loop iterations; that is approximately what can be achieved by DynusT in 10 iterations in the Sacramento implementation.

This is not a particularly stringent convergence level for either static or dynamic traffic assignment models. The relatively high convergence level may well have affected the results of the policy tests described in Chapter 4. Test 3 was rerun using more iterations of DynusT because the convergence level for Scenario 3 was even higher than the level achieved in the baseline tests; but this did not substantially improve the convergence level.

It would make sense to perform more tests to see if better convergence can be achieved in the simulations and what types of model changes might be considered beyond simply running more loops or iterations to improve convergence.

Noise in Model Results

As noted in Chapter 4, it appears that the "noise" in the C10B integrated model made it difficult to identify some of the changes in travel behavior related to the tested scenarios. All simulation models, of course, are noisy since they are probabilistic in nature, and model results vary from one run to another. But there are two components to the simulation involved in the C10B integrated model: the activity-based demand model (DaySim) and the traffic and transit simulation (DynusT/FAST-TrIPs). There has not been an examination of the propagation of the noise due to this double simulation approach.

Since SACOG is using an activity-based demand model for its planning purposes, the modelers are familiar with the issues of simulation noise. Before the C10B project, they had estimated the noise level in SACSIM/DaySim and used this information in their planning process. Such an assessment should be made with the C10B integrated model before it is used in a practical setting.

In theory, a simulation model should be run multiple times with the results averaged to get the noise to an acceptable level. This seldom happens in practice with current activity-based models in the United States, even with static highway and transit assignment procedures. It may be necessary to consider doing this for integrated models.

Run Time

The run time for the model as used in the policy tests by SACOG was about 70 h, for three big loops with 10 iterations of dynamic traffic assignment with DynusT within each loop. While this is a bit longer than advanced models using static assignment in larger metropolitan areas, it is quite reasonable given the limited time and resources available for making the model more efficient. A model with runs times such as this would be practical in most settings.

It is important to point out that run times could be longer if some of the other issues already discussed were addressed. For example, the number of big loops and DynusT iterations was decided based on tests that showed a lack of improvement in convergence with additional iterations and loops. Running the model for more iterations and loops might be expected to produce a tighter convergence, and perhaps if some of the validation issues were addressed, this could be achieved. However, this could not be tested within Project C10B.

It is also important to note that run times would be greater, of course, in regions larger than Sacramento. Even in Sacramento, run times would be longer for future year scenarios in which the number of persons to be simulated would be greater and the higher levels of congestion might require additional loops and iterations to converge. Further improvements to the run time of the C10B integrated model should be investigated.

The discussion of run times, however, should note that the C10B integrated model has been designed to run on a server that a U.S. MPO might typically have available. Another way to reduce run times is to run the model on bigger, faster computers, as has been done with other complex transportation models.

Future Applications and Additional Research

There are a number of areas for future research that follow from the work on SHRP 2 Project C10B. Further work could be performed related to the challenges cited in the previous section:

- *Model validation.* Further work is needed to determine the level of effort required to achieve a full model validation consistent with industry standards. Additionally, further discussion is warranted about what specifically should constitute the validation of an integrated model such as this. The effects of using a fully validated model in policy testing should also be examined.
- *Convergence.* A tighter level of convergence than could be achieved during Project C10B is highly desirable. It is unknown whether the ability to achieve better convergence was limited by the nature of the integrated model, the way in which DynusT works, the characteristics of the transportation system and travel demand in the Sacramento region, or some other factors. It would be valuable to examine what level of convergence can be achieved in the C10B model and what types of model changes might be considered beyond simply running more loops or iterations to improve convergence.
- *Noise in model results.* Performing multiple model runs would provide useful information on measuring the magnitude of the noise related to the simulations in the C10B integrated model. It would be worthwhile to compare estimates of the noise to those associated with the activity-based model alone, to get a handle on the propagation of noise related to the multiple simulations that are part of the integrated model. Another area of valuable research would be tests to determine the number of model runs required to achieve stable results for a variety of types of planning analyses.
- *Run times.* Several areas of further work would provide useful information regarding run times. A detailed examination of the run times for various model components could help determine where the bottlenecks in the model stream are; then ways of making those areas more efficient could be examined. The effects of different convergence levels on run times could be tested. The effects of greater demand and higher congestion levels on run times would be useful to examine. Additionally, the effects of more powerful hardware configurations on run time could be examined.

There are other areas where further research could help make models like the C10B integrated model more useful and practical. These include the following:

- *Decreasing the learning curve.* As discussed previously, it took substantial time and effort for project team members—especially those at SACOG, who performed most of the work on the policy testing of the model—to become familiar enough with the workings of the model (particularly DynusT and FAST-TrIPs since they were already familiar with SACSIM) to be able to efficiently and effectively perform the policy tests. While there are many practitioners familiar with traffic simulation, a greater number of transportation professionals need to be proficient in demand modeling and traffic simulation if models such as these are to become more widely used. There will need to be more organized training opportunities available for planners, such as those currently provided by government and educational organizations for travel demand modeling.
- *Testing the model in other geographic areas.* Now that the effort to develop the integrated model and the software to run it is complete, it is important to gather information on how well the model would perform in other areas. It would be particularly useful to test the model in places that are larger or notably different from Sacramento. It would be interesting to know how long such a test would take and the level of effort required to get the model up and running. Developing the regional highway network for dynamic assignment is one area known to require significant effort; staff training is another. Determining what other areas require substantial effort and what differences might arise in other areas may point to requirements that were not relevant in Sacramento.

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