

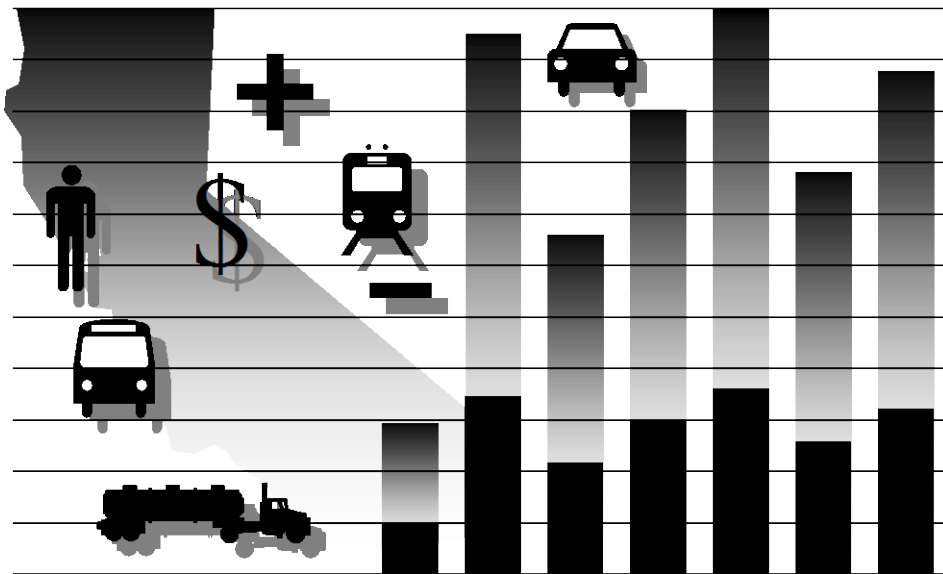


# California Life-Cycle Benefit/Cost Analysis Model (Cal-B/C)

Technical Supplement to User's Guide

Volume 3: Traffic Operations Consistency,  
Network and Corridor Analysis, New Capabilities,  
and Economic and Parameter Value Updates

Revision 2



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## I. INTRODUCTION

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This volume of the technical supplement (Volume 3) describes the changes made to Cal-B/C for versions 4.0 and 5.0. Volume 3 was first issued in February 2009 to document the development of Cal-B/C version 4.0 (Cal-B/C v4.0) between 2007 and 2009. For Cal-B/C version 5.0 (Cal-B/C v5.0), the development team made minor revisions to correct typographical errors, improve performance, and update values. Revision 2 of Volume 3 captures these changes and includes the following more significant modifications to the documentation:

- *Chapter III Updates to Economic and Parameter Values* is revised to include the latest parameter values.
- *Chapter VI Grade-Separated Rail Crossings* provides more detail about the methodology and guidance for using Cal-B/C to assess rail crossings.
- *Chapter IX Cal-B/C Corridor* is a new chapter to describe the Cal-B/C Corridor version of Cal-B/C in greater detail. Some of this material was previously provided in *Chapter VIII Network and Corridor Analysis*.

Other volumes of the technical supplement describe other aspects of Cal-B/C and early model development. Volume 1 provides details on the base model that was completed in 1999. Volume 2 describes improvements to incorporate operational improvements and projects involving weaving, Transportation Management Systems (TMS), and pavement rehabilitation prior to the 2009 update. Volume 3 describes changes made in the 2009 and 2012 revisions.

The latest version of Cal-B/C (v5.0) incorporates projects related to queuing and projects that encourage changes in Average Vehicle Occupancy (AVO). The queuing features allow Cal-B/C to evaluate rail grade-separation projects as well as projects that address highway bottlenecks. In both cases, the methodology is simple and deterministic. More detailed models can take into account stochastic queuing or potential network effects. For a select group of projects, the queuing analysis is more appropriate than the traditional Bureau of Public Roads (BPR) curve estimation.

The model also accommodates changes in AVO related to High Occupancy Vehicle (HOV) lane requirement changes, the construction of High Occupancy Toll (HOT) lanes, or the conversion of existing HOV lanes. These revisions required minor changes to the induced demand calculations and the explicit calculation of person-trips within the model. Cal-B/C does estimate the elasticities or travel shifts due to these projects. It is assumed that the data entered in Cal-B/C correctly capture behavioral changes due to projects and that these changes have been appropriately estimated outside the model.

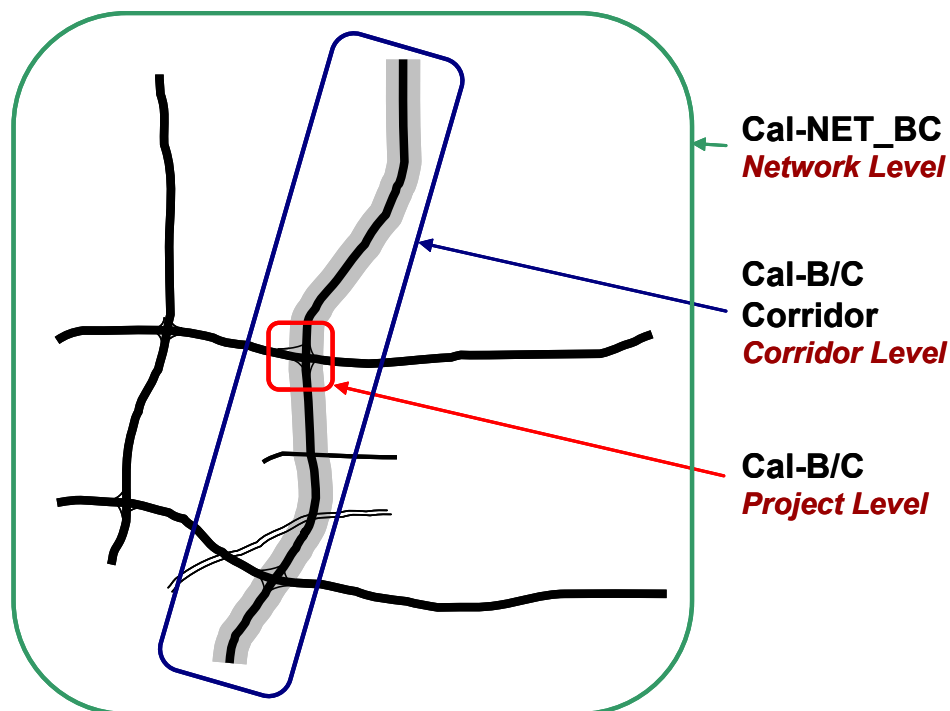
During the 2009 revision, the Cal-B/C development team conducted sensitivity testing on major Cal-B/C inputs and parameters. As a result of this testing, the development team reviewed and revised assumptions used for estimating the split of travel during the day and for estimating speeds. The development team also updated all of the economic values and added the ability to evaluate greenhouse gas emissions. These changes are detailed in this volume of the technical supplement.

During the 2012 revision, the development team considered further the sensitivity of Cal-B/C to inputs and parameters and wrote guidance for conducting Monte Carlo simulation. This guidance is available in separate documentation.

The 2009 update expanded the Cal-B/C framework to include companion tools that support link, corridor, and network analysis. These tools calculate and aggregate scenario benefits after travel impacts are evaluated using regional travel demand or simulation models. The companion tools provide better estimates of the complimentary or duplicative benefits of combination projects, if the scenarios are modeled externally.

Exhibit I-1 shows the three tools in the Cal-B/C framework: the Cal-B/C, Cal-B/C Corridor, and Cal-NET\_BC. The models use consistent analysis methods and produce comparable results. In fact, each model relies on the same Cal-B/C parameters page.

**Exhibit I-1: Cal-B/C Framework**



*Cal-B/C Corridor* uses the assumptions and parameters found in Cal-B/C, but facilitates the analysis of summary-level results from regional travel demand models and

simulation models. This tool provides a more tailored “Model Inputs” page than the basic Cal-B/C model and allows multiple segments to be calculated at once. Cal-B/C Corridor can be used when aggregate model data is available. A description of Cal-B/C Corridor is included in Chapter IX of this volume of the technical supplement.

Since Cal-B/C Corridor was developed in 2009, the California Department of Transportation (Department) and its partners have had experience running the model for several different types of projects. These evaluations demonstrated that Cal-B/C Corridor can be used with all kinds of model data. For example, travel demand and micro-simulation model data can be summarized in one mile per hour (1-mph) speed bins. In this way, Cal-B/C Corridor is capable of analyzing an entire network, not just a specific corridor. Alternatively, Cal-B/C Corridor can be used to analyze specific segments on the corridor or data generated from external vehicle miles traveled (VMT) and vehicle hours travel (VHT) analyses.

*Cal-NET\_BC* is built upon the NET\_BC model and is customized for California to ensure compatibility with Cal-B/C. Cal-NET\_BC uses the same “Parameters” page as Cal-B/C, but allows detailed, link-level benefit evaluation. Cal-NET\_BC can be used when detailed regional travel demand model or micro-simulation model data are available. Practical experience with Cal-B/C Corridor over the last several years has demonstrated that Cal-B/C Corridor is easier to use and appropriate for many of the types of analyses envisioned for Cal-NET\_BC. Separate technical documentation is available for the Cal-NET\_BC model.

*Cal-B/C v5.0* continues to provide project-level and sketch planning analysis using standard rules of thumb. Users should consult the other volumes of the technical supplement for information on the base Cal-B/C model and prior revisions. Volume 3 documents the latest updates made in 2009 and 2012.

The rest of this volume is organized in the following chapters.

- *Overview of the Revised Model* – describes the major changes made in 2009 to the Cal-B/C model. Several changes resulted from sensitivity testing to ensure the most accurate estimates. Other changes were made to accommodate requests by Department staff and to make the model more user-friendly.
- *Updates to Economic and Parameter Values* – explains the new economic and parameter values adopted in 2012 for Cal-B/C v5.0. In the 2012 revision, the Cal-B/C development team updated the economic values to 2011 dollars. In the 2009 revision, the development team converted the peak period parameter from a single value per hour to a lookup table and added the estimation of greenhouse gas emissions to the model. This chapter includes the 2009 revisions and has been revised to capture the 2012 economic value updates.

- *Traffic Operations Consistency* – discusses the issues in making Cal-B/C consistent with established procedures in the Division of Traffic Operations for assessing safety and mobility projects in the State Highway Operations and Preservation Program (SHOPP). In the 2009 revision, the Cal-B/C development team worked with Traffic Operations to establish consistency in collision values and the definition of delay as well as methodologies with the Traffic Safety Index (TSI), Priority Index Number (PIN), and the Highway Congestion Monitoring Program (HICOMP).
- *High Occupancy Toll (HOT) Lanes* – describes the modifications made to Cal-B/C in 2009 to incorporate HOT lanes and outlines many of the theoretical issues involved with the evaluation of these projects. The focus on HOT lanes also gave the Cal-B/C development team an opportunity to review the assumptions used in Cal-B/C for High Occupancy Vehicle (HOV) lanes. The result of this review is a Bureau of Public Roads (BPR) curve tailored to the estimation of speeds on HOV and HOT lanes as well as a slightly modified induced demand calculation.
- *Grade-Separated Rail Crossings* – provides an overview of the modifications made to Cal-B/C in 2009 to assess the benefits of grade-separated rail crossings. The revised Cal-B/C model can handle grade separation projects using a definition that corresponds to the one used for the Federal Aid At-Grade Highway-Rail Crossing Program (Section 130 Program). The queuing analysis approach is simple and consistent with other relevant models. The Cal-B/C framework includes the assumption that users will run a rail operations model and monetize the resulting benefits for a more detailed analysis.
- *Queues and Queuing Analysis* – explains the simple, deterministic queuing methodology incorporated into Cal-B/C for analyzing bottlenecks. This capability is consistent with the methodology used for grade-separated rail crossings and is intended only for special cases that require queuing analysis.
- *Network and Corridor Analysis* – provides an overview of new capabilities developed in 2009 to analyze corridor and network benefits using assumptions consistent with the original Cal-B/C model. The 2009 update added a suite of tools: Cal-B/C for assessing individual projects, Cal-B/C Corridor for assessing corridor benefits, and Cal-NET\_BC for assessing network benefits using the output of regional travel demand models or micro-simulation models. Cal-NET\_BC builds on the NET\_BC platform and has separate technical documentation.

- *Cal-B/C Corridor* - describes the Cal-B/C Corridor model in greater detail and provides a quasi-user guide. The Cal-B/C Corridor model developed in 2009 was a prototype. Since the 2009 version, the model has been used for several grant applications as well as Corridor System Management Plans (CSMPs). On the basis of this experience, the Cal-B/C development team modified Cal-B/C corridor to handle more model groups or links and added other features to make the model more user friendly.



## **II. OVERVIEW OF THE REVISED MODEL**

## II. OVERVIEW OF THE REVISED MODEL

The 2012 update was primarily an update of economic values and a verification of historical sources and their relevance. This chapter outlines the major updates made to Cal-B/C during the 2009 revisions. The text includes minor changes to be consistent with 2012 revisions. The Cal-B/C development team made revisions after consulting with California Department of Transportation (Department) staff and Cal-B/C users and testing the sensitivity of the model to different input variables. The first section in this chapter discusses the major revisions. The following sections describe the feedback, sensitivity testing, and requests that directed these updates.

### 1.0 MAJOR MODEL REVISIONS

Cal-B/C v5.0 updates the economic parameters to 2011. However, sensitivity testing in 2009 signaled the need for more significant changes. During the testing, the Cal-B/C development team found that the most sensitive inputs and parameters were related to the estimation of peak period traffic and travel speeds. As a result of this testing, the Cal-B/C development team decided to re-examine these sensitive inputs and parameters to make sure the values used in Cal-B/C were the latest and most defensible. In the 2012 revision, the development team also prepared documentation on how to incorporate Monte Carlo simulation analysis with Cal-B/C using an Excel add-in.

The 2009 review led to updates for the following parameters:

- *Percent Traffic in the Peak Period.* In prior versions of Cal-B/C, the Average Daily Traffic (ADT) was split between peak and non-peak travel by multiplying the number of hours in the peak period by a standard percent of ADT per peak hour. This methodology ignored the diminishing contribution that each peak hour made to total peak period traffic. The revised Cal-B/C model has a lookup table of cumulative percent of traffic in the peak period by length of the peak period. The table is based on the statewide travel survey and reflects the diminishing contribution of each additional hour.
- *New Speed Estimation Parameters.* The sensitivity testing covered all of the parameters used to estimate speeds through the Bureau of Public Roads (BPR) curve. As a result, Cal-B/C v5.0 uses separate BPR curve parameters for freeways, expressways, and conventional highways. In addition, Cal-B/C v5.0 includes a BPR curve for High Occupancy Vehicle (HOV) lanes based on current HOV lane data from California

freeways. The major factors (alpha, beta, and capacity) were converted to parameters that can be updated. The parameters are selected separately for the no-build and build cases. This allows users to adjust parameters, such as capacity, to account for operational improvements.

On the basis of input from meetings with Cal-B/C staff and other stakeholders, Cal-B/C v5.0 (like Cal-B/C v4.0) uses revised nomenclature:

- *Build/No Build.* Throughout the model, the “with project” and “without project” nomenclature is now “build” and “no build.” Likewise, “new facility” and “old facility” are “build” and “no build.” In addition, the related variable names include references to “B” and “NB.”
- *Impact Length.* Users found the “affected area” nomenclature to be confusing. This is now “impact length.”
- *Project Costs.* The Cal-B/C development team changed the input of project costs to thousands of dollars (rather than dollars) to be consistent with Department Programming reports.
- *Construction Year 1* – The name for the first year of construction was changed from “Year 0” to “Year 1.”

Cal-B/C v5.0 has the ability to evaluate High Occupancy Toll (HOT) lanes, changes in High Occupancy Vehicle (HOV) requirements, and conversions from HOV lanes to HOT lanes. These projects can significantly impact the number of people in each vehicle. Since Average Vehicle Occupancy (AVO) determines the number of trips estimated by the model, a tally of the estimated number of trips is now included on the Model Inputs page for users to review. Induced demand calculations are updated to consider the number of trips rather than the number of vehicles.

The current Cal-B/C model also includes highway-rail grade separations and projects that involve queuing at bottlenecks. Both project types required several new input variables to capture arrival and departure rates at queues. Highway-rail grade crossing separation projects required the addition of information of the number of trains and gate down times. The Cal-B/C project input page is updated to include these changes.

The Cal-B/C v5.0 Results page captures the impact of greenhouse gas emissions and reports person-hours of travel time saved. All emissions are valued by equivalent tons of carbon dioxide (CO<sub>2</sub>). The current version shows savings in emissions to be consistent with the emissions benefits. This means that the sign on the results page is reversed from Cal-B/C v4.0. As with the prior version, the delay savings in Cal-B/C v5.0 are renamed “person-hours of time saved” to be consistent with other Department documents and to avoid confusion with vehicle-hours of delay as calculated in the Highway Congestion Monitoring Program (HICOMP). The results page also allows the

user to selectively include or exclude induced demand and all project benefits other than travel time savings. An example of the results page for Cal-B/C v5.0 is shown in Exhibit II-1.

**Exhibit II-1: Cal-B/C v5.0 Results Page**

District: **HQ**

PROJECT: **Hypothetical Project**

EA:

PPNO:

**INVESTMENT ANALYSIS**  
**SUMMARY RESULTS**

		Average Annual	Total Over 20 Years
<b>Life-Cycle Costs (mil. \$)</b>	\$0.0		
<b>Life-Cycle Benefits (mil. \$)</b>	#N/A		
<b>Net Present Value (mil. \$)</b>	#N/A		
<b>Benefit / Cost Ratio:</b>	N/A		
<b>Rate of Return on Investment:</b>	N/A		
<b>Payback Period:</b>	N/A		
<b>ITEMIZED BENEFITS (mil. \$)</b>			
<b>Travel Time Savings</b>	\$0.0	\$0.0	\$0.0
<b>Veh. Op. Cost Savings</b>	\$0.0	\$0.0	\$0.0
<b>Accident Cost Savings</b>	\$0.0	\$0.0	\$0.0
<b>Emission Cost Savings</b>	#N/A	#N/A	#N/A
<b>TOTAL BENEFITS</b>	#N/A	#N/A	#N/A
<b>Person-Hours of Time Saved</b>	0	0	0
<b>CO<sub>2</sub> Emissions Saved (tons)</b>	0	0	0
<b>CO<sub>2</sub> Emissions Saved (mil. \$)</b>	#N/A	#N/A	#N/A

**Should benefit-cost results include:**

1) Induced Travel? (y/n)  Default = Y

2) Vehicle Operating Costs? (y/n)  Default = Y

3) Accident Costs? (y/n)  Default = Y

4) Vehicle Emissions? (y/n)  Default = Y  
includes value for CO<sub>2</sub>e

Other changes made to Cal-B/C as part of the 2009 update include:

- Changes in nomenclature and calculations to make Cal-B/C more consistent with the Department Traffic Safety Index (SI)
- Modifications to the new road macro so that it prompts the user to save the file.

In the 2012 update, a few additional changes were made:

- Corrections to address minor typographical errors on the parameters page
- Change in the divisor of the rail grade crossing formula to assume most traffic occurs during the day

- Increase in the number of decimals shown for percent injuries and percent fatalities on the model inputs page
- Modification to the weaving speed calculation for auxiliary lane and off-ramp improvements so it can handle one or two directional data.

In 2009, the Cal-B/C development team considered methods for incorporating shoulder widening projects and interchange projects. No updates were made to incorporate either project type. Shoulder widening projects should be modeled as general highway projects with adjusted capacities from the Highway Capacity Manual. Previous versions of Cal-B/C included a project type called “interchange projects.” To analyze “interchanges,” users should run the projects in Cal-B/C as either connectors or intersections, depending on the configuration. Complicated interchanges should be evaluated using simulation models or other operational analysis tools. The results of these tools can be imported into Cal-B/C Corridor.

These changes are documented throughout Volume 3 of the technical supplement. The next sections describe feedback, testing, and requests that guided the 2009 update.

## 2.0 CMIA LESSONS LEARNED

Voters approved Proposition 1B, a very large infrastructure bond package to help fund transportation in California, in the 2006 election. As part of Proposition 1B, the State established and voters approved the Corridor Mobility Improvement Account (CMIA) to provide funding for mobility-improving transportation investments. The California Transportation Commission (CTC) adopted guidelines for selecting projects that require the Department and partner agencies to run the Cal-B/C model for projects proposed for CMIA funding.

The model was also made available for other agencies and staff to understand how funding decisions were made and to consider the relative merits of their proposed projects. This transparency allowed several staff to review and consider the merits of the Cal-B/C model. The use of Cal-B/C for the CMIA assessment brought planners and engineers at several agencies in contact with the model. At the same time, it exposed the model to a much wider range of projects than evaluated previously and revealed limitations. For example, Cal-B/C had trouble evaluating the impacts of intersections, projects that solve queuing problems, or traffic shifts that appear to reflect induced traffic but are not actually new trips.

The Cal-B/C development team held a meeting on November 13, 2007 in Sacramento, California for Department staff and representatives from local and regional agencies to share their experiences using Cal-B/C. The objective was to identify issues and challenges with using Cal-B/C and to obtain suggestions for enhancements or

modifications that improve the model. The meeting included representatives from Department Headquarters, several districts, the Metropolitan Transportation Commission (MTC), Southern California Association of Governments (SCAG), and the Los Angeles County Metropolitan Transportation Authority (LACMTA).

The rest of this section summarizes the feedback that influenced the revisions made in 2009. Some suggestions led directly to changes in Cal-B/C. For example, the latest Cal-B/C has a box to indicate whether the input data represent travel in one or two directions. Other suggestions were explored and eventually dropped from the final model. For example, the Cal-B/C development team tested having unnecessary input data disappear after a project type was selected. While this change was easy to implement, the Cal-B/C development team decided it made the model too much of a black box and would be difficult to maintain in future releases.

The suggestions made by Cal-B/C stakeholders are listed below. These comments do not necessarily reflect the official position of the Department or the State of California.

## 2.1 Inputs

- When an improvement is for one direction only, the model needs to ask for one-way traffic inputs. The directionality of required data is not always explicit. Documentation needs to be added to the input sheets.
- The input page is too complex and big. Allow the user to pick a project type and have the model blank out all unnecessary data on the input sheet.
- Terminology should consistently reflect “Build” versus “No Build” (not “new,” “existing,” “with,” and “without”).
- Users need better guidance on how to pick the most representative volumes and input for long segments or corridors. Documentation needs to clarify when it is appropriate to run multiple segments and aggregate (including guidance on how to aggregate). The concern is that if Cal-B/C is run for each segment, impacts may extend beyond that segment (i.e., construction impacts). Guidance is also needed on when to consider segment analysis versus impacted scope and length.
- Where should microsimulation data be reported on input sheets? Various issues are included. For example, Cal-B/C is tailored to specific modes (e.g., HOV, SOV, truck). Some travel demand models have many more modes and different modes, so users would need to combine some of the modes to fit into current Cal-B/C structure.

- More guidance is needed on what speed to use (posted speed versus free-flow). Free-flow speed is defined as the posted speed limit in Cal-B/C.
- Users need clarification and more guidance on the definition of project length. For example, a 1-mile project may have a 2-mile impact. Users can easily “game” results by adjusting the affected length. District input sheets should include an input for the project “affected length.”
- Data for use in Cal-B/C can be problematic. Finding current data is relatively easy (from PeMS, traffic volume books, etc.), but it is unclear which are the “official” or recommended sources. The guidance for future volumes is even less clear.
- Fatal and injury data must come from different districts, departments (they are not in one place) and they are not consistent. Users need guidance on sources and what tables should be used. Rate tables are confusing and need more documentation. The Division of Traffic Operations also needs this information, so the Department should improve availability by placing it on internal or external websites.

## 2.2 Regional Models

- Analyzing multiple projects at once is not very common, so it may not be worth expanding Cal-B/C to do so. If Cal-B/C is linked to travel demand models, users can do most of the multiple projects analysis in the travel demand models.
- Cal-B/C and travel demand models assume uniform (average) traffic volumes and ignore the fact that congestion moves downstream.
- Cal-B/C is only a screening tool and may need to be coupled with simulation or engineering analysis.
- There is concern over how to incorporate results from regional travel demand models and microsimulation models into the Cal-B/C process. It is difficult to isolate the benefits and costs to a specific project using the output of these models. The vehicle-miles traveled (VMT) and vehicle-hours traveled (VHT) outputs for the build and no-build alternatives are important to use in Cal-B/C. These are what regional partners have been using for over 40 years in regional modeling efforts. Accident and air quality are usually smaller benefits compared to changes in VMT and VHT, but it would be nice to include those benefits as well.

## 2.3 Project Types

- Cal-B/C can not analyze intelligent transportation systems (ITS) or advanced operational improvements very well. CMIA analysis results were typically higher than anticipated. Cal-B/C can not distinguish different levels of ITS or partial implementation (i.e., fixed-time versus adaptive ramp metering or expanding freeway service patrol).
- Cal-B/C can not analyze truck-only lanes, freight, rail, goods movement, other commercial vehicle operation (CVO) projects, grade separation projects, ramp metering with pricing, using shoulders for buses, and gap closures. Since Cal-B/C already calculates rail transit, some parameters can be “tricked” to calculate freight rail. Guidance is needed.
- Cal-B/C can not analyze new roads. It was discussed whether a capability to analyze new roads would be used often. Some attendees indicated they would use this capability, but future proposed projects are likely to focus on toll roads and gap closures. If there are ways to trick Cal-B/C to analyze these new road improvements, the Department should provide guidance on how to do this, so it is not necessary to add a new improvement type to the model.

## 2.4 Using the Model

- MTC considered using Cal-B/C for its Regional Transportation Plan (RTP) and used methods derived from the model. For example, comparisons could be made among transit improvements, highway improvements, and other investments.
- One attendee acknowledged using Cal-B/C only for highway projects in the CMIA analysis.
- Attendees did not have experience using Cal-B/C for transit projects.
- Cal-B/C was used to estimate daily usage costs and help set up incentive programs.
- SCAG tried to use Cal-B/C in conducting a cost-effectiveness analysis for its RTP. Cal-B/C needs more freight capabilities and analysis methods.

## 2.5 Model Results/Performance Measures

- One user wanted first-year benefits reported on the Cal-B/C output page. Other users noted that the first-year benefits are not as useful as



the overall 20-year life-cycle. Some previous versions of Cal-B/C have reported first-year benefits.

- Projects on the State Highway System should have consistent measures. The Department plans to develop a framework for Corridor System Management Plan (CSMP) performance measures related to benefit-cost analysis.
- Travel time, reliability, and productivity are used to report performance in various efforts around the state. Reliability and productivity are not currently captured in Cal-B/C. Users expressed concern over whether these could be monetized. Some attendees thought reliability could be monetized (e.g., reliability three times the value of time), but the Department and its partners need to decide on the best approach. It was also noted that the goal of CSMPs is to find the “best packages” of strategies based on specific performance measures. This does not necessarily mean the highest B/C ratio or “best bang for the buck.”
- The definition of vehicle-hours of delay saved in the prior version of Cal-B/C was different than the HICOMP definition. Attendees suggested changing “delay” to “time saved.” Cal-B/C results cannot be compared against HICOMP, since they represent different levels of analysis. There were also concerns over comparing observed delay and delay estimated in a model.
- In the CMIA analysis, Cal-B/C seemed unable to assess gap closures or tunnel projects very well and produced lower benefits than anticipated.
- Travel time reliability is the primary benefit for goods movement projects and needs to be included in Cal-B/C if the model is used for goods movement evaluations.
- One user wanted to see delay and emissions impacts due to accidents and work zones included in the model. Some recent research claims that work zones cause more delay than they solve over the long term.
- Cal-B/C needs accurate emission and global warming metrics.

## 2.6 Parameters

- Statewide default values should be used (not national statistics or localized values for different areas of the state).
- In contrast, Cal-B/C currently uses statewide average construction costs, but these could vary by region. Adopting different costs is a politically-

sensitive issue and would result in urban projects being more favorable than rural projects.

- The truck travel time values differ by Department division and stakeholder agency. They should vary by cargo type, operational costs, and location within the state.
- The Department should provide the latest economic parameters and defaults on a website (or links to recommended values) with guidelines for use.
- One attendee questioned whether Cal-B/C should annualize traffic data using 365 days or the number of workdays (i.e., 250). Participants recommended using 365 days if data is from the traffic volume book, since this data is adjusted for seasonal variations. However, data from regional travel demand models should be annualized using workdays only.

## 2.7 Documentation

- Users proposed more extensive documentation, including weblinks, pop-ups windows, or comment fields with the page number in user's manual.
- They also suggested more guidance on traffic volume and safety data sources as well as methods for analyzing specific project types.

## 2.8 Other

- Some attendees expressed concern that the previous version of Cal-B/C was too much of a black box.
- Queuing analysis should be incorporated into Cal-B/C.
- One attendee suggested that development priorities for Cal-B/C should focus on linking Cal-B/C with other tools, such as microsimulation. Another suggested that the Department should focus on improving existing features rather than expanding.

## 3.0 SENSITIVITY TESTING

As part of the 2009 update, Cal-B/C development team tested the model's sensitivity to changes in key input data and parameters for different types of projects. The Cal-B/C development team selected a representative set of Corridor Mobility Improvement

Account (CMIA) project submissions for the tests. This section describes the results of the testing.

In the 2012 update, the development team expanded on this testing to develop guidance for incorporating Monte Carlo simulation in Cal-B/C. This is accomplished by using an Excel add-in rather than adding custom programming to Cal-B/C. A separate memorandum provides guidance on Monte Carlo simulation.

### 3.1 Approach

The sensitivity testing covered three types of highway projects:

- Ramp metering project
- Construction of HOV lanes
- Addition of auxiliary lanes.

Exhibit II-2 shows the original and modified values used for the analysis. The modified values represent an increase or decrease of 25 percent from the original inputs.

**Exhibit II-2: Cal-B/C Variables and Values Used for Sensitivity Analysis of Highway Test Cases**

Variable	Original Inputs				25% Increase			25% Decrease		
	Default	1	2	3	1	2	3	1	2	3
Maximum v/c in BPR Curve	1.4	1.4	1.4	1.4	1.75	1.75	1.75	1.05	1.05	1.05
Length of Construction Period	n/a	1.5	2	3	2	3	4	1	1	2
Length of Peak Period	5	4	4	4	5	5	5	3	3	3
Hwy Free-Flow Speed	n/a	65	70	65	81.25	87.50	81.25	48.75	52.50	48.75
Ramp Design Speed	35	n/a	n/a	35	n/a	n/a	43.75	n/a	n/a	26.25
Length - Affected Area	n/a	21	13.4	3.4	26.25	16.75	4.25	15.75	10.05	2.55
Average Hourly HOV Traffic	n/a	2064	1500	2000	2580	1875	2500	1548	1125	1500
Percent Traffic in Weave	n/a	n/a	n/a	25	n/a	n/a	31.25	n/a	n/a	18.75
Percent Trucks	9	5.16	12	9	6.45	15.00	11.25	3.87	9.00	6.75
AVO - General - Non-Peak	1.48	1.48	1.2	1.48	1.85	1.50	1.85	1.11	0.90	1.11
AVO - General - Peak	1.38	1.38	1.18	1	1.73	1.48	1.25	1.04	0.89	0.75
AVO - HOV	n/a	3	2.05	2.05	3.75	2.56	2.56	2.25	1.54	1.54
Real Discount Rate	5	5	5	5	6.25	6.25	6.25	3.75	3.75	3.75
Percent ADT in Ave Peak Hour	7.8	7.8	7.8	7.8	9.75	9.75	9.75	5.85	5.85	5.85
Capacity per General Lane	2000	2000	2000	2000	2500	2500	2500	1500	1500	1500
Capacity per HOV Lane	1500	2000	2000	2000	2500	2500	2500	1500	1500	1500

The sensitivity testing assessed the difference in the B/C ratio generated by changing variables in Cal-B/C from the values in the CMIA project analysis. The variables were classified as high, moderate, and low impact:

- High-Impact Variables (impact greater than 25 percent)
  - Percent of ADT in peak hour
  - Capacity per general lane
  - Highway free-flow speed
  - Maximum v/c in BPR curve
  - Percent Traffic in weave
  
- Moderate-Impact Variables (impact between 10 and 25 percent)
  - Length of peak period
  - Length of affected area
  - Average hourly HOV traffic
  - AVO - general traffic peak
  - Real discount rate
  
- Low-Impact Variables (impact less than 10 percent)
  - Length of construction period
  - Percent Trucks
  - AVO - general traffic non-peak
  - AVO - HOV
  - Capacity per HOV Lane
  - Ramp design speed.

Exhibit II-3 presents the B/C ratios and percents change from the sensitivity analysis when each input was varied by 25 percent.

Exhibit II-3: Cal-B/C Sensitivity Analysis Results for Highway Test Cases

Scenario	Original B/C			B/C with 25 Percent Increase			B/C with 25 Percent Decrease			Percent Difference with 25 Percent Increase			Percent Difference with 25 Percent Decrease		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Maximum v/c in BPR Curve	12.3	1.5	1.4	12.3	1.5	1.4	10.2	0.6	0.0	0.0%	0.0%	0.0%	-17.6%	-58.5%	-98.3%
Length of Construction Period	12.3	1.5	1.4	12.2	1.5	1.4	12.6	1.5	1.4	-1.4%	-2.7%	-1.7%	2.0%	2.7%	1.9%
Length of Peak Period	12.3	1.5	1.4	14.2	1.7	1.8	10.5	1.2	1.0	15.2%	16.8%	31.5%	-15.2%	-16.8%	-26.3%
Hwy Free-Flow Speed	12.3	1.5	1.4	10.9	1.3	1.0	16.3	2.3	2.3	-11.5%	-16.1%	-31.3%	32.1%	53.7%	66.2%
Ramp Design Speed	12.3	1.5	1.4	n/a	n/a	1.4	n/a	n/a	1.4	n/a	n/a	0.0%	n/a	n/a	0.0%
Length - Affected Area	12.3	1.5	1.4	14.2	1.7	1.7	10.5	1.2	1.0	15.2%	16.8%	25.0%	-15.2%	-16.8%	-24.8%
Average Hourly HOV Traffic	12.3	1.5	1.4	11.3	1.5	1.0	13.8	1.4	1.8	-8.5%	2.0%	-24.8%	11.7%	-7.4%	30.8%
Percent Traffic in Weave	12.3	1.5	1.4	n/a	n/a	2.4	n/a	n/a	1.4	n/a	n/a	75.2%	n/a	n/a	1.9%
Percent Trucks	12.3	1.5	1.4	12.5	1.5	1.4	12.2	1.5	1.3	1.0%	2.7%	4.1%	-1.0%	-2.7%	-3.9%
AVO - General - Non-Peak	12.3	1.5	1.4	12.3	1.5	1.4	12.3	1.5	1.4	0.0%	0.0%	0.1%	0.0%	0.0%	-0.1%
AVO - General - Peak	12.3	1.5	1.4	14.0	1.7	1.7	11.0	1.3	1.1	13.5%	10.7%	20.0%	-10.4%	-10.8%	-19.8%
AVO - HOV	12.3	1.5	1.4	12.3	1.6	1.4	12.3	1.4	1.4	0.0%	5.6%	0.0%	0.0%	-5.6%	0.0%
Real Discount Rate	12.3	1.5	1.4	11.0	1.3	1.2	13.9	1.7	1.6	-10.5%	-12.8%	-14.0%	12.4%	14.7%	17.1%
Percent ADT in Ave Peak Hour	12.3	1.5	1.4	32.9	4.9	7.1	8.0	0.5	-0.1	167%	226%	415%	-35.2%	-64.4%	-104%
Capacity per General Lane	12.3	1.5	1.4	9.6	0.6	0.1	28.7	5.7	5.1	-22.4%	-62.4%	-94.2%	133%	281%	271%
Capacity per HOV Lane	12.3	1.5	1.4	12.3	1.5	1.4	12.3	1.4	1.4	0.0%	0.4%	0.1%	0.0%	-4.6%	0.1%

### 3.2 High Impact Variables

Five variables were identified as having high impacts:

- *Percent of ADT in peak hour.* From all the variables analyzed, the percent of ADT in peak hour had the largest impact on the B/C ratio. Increases of 25 percent from the original value generated escalations in the B/C ratios between 167 and 415 percent. A reduction of 25 percent from the original values also had a large impact on the B/C ratios, but lower than the increase (between minus 35 and 104 percent). The B/C ratio on the auxiliary lanes project showed the largest changes in the decrease and increase cases. The signs of the changes were expected: greater shares of traffic traveling during the peak hour produced larger benefits.
- *Capacity per general lane.* A 25-percent increase from the original capacity per general lane generated a decrease of the B/C ratio between 22 and 94 percent, whereas a decrease of 25 percent increased the B/C ratio between 130 and 270 percent. The B/C ratio for auxiliary lanes showed the largest impact in the decrease and increase cases (minus 94 percent and plus 271 percent). The signs of the changes were expected: an increase in the capacity per lane increases speeds and reduces travel times, which decreases the benefits of congestion reduction projects. The opposite situation occurs if the capacity per lane decreases. These findings indicate that it is important to standardize the capacity used in benefit-cost analysis and to use the appropriate capacity for different types of roadway.
- *Highway free-flow speed.* A 25-percent increase in highway free-flow speed had a moderate effect on the B/C ratios of ramp metering and HOV lane projects, their respective B/C ratios lowered by 11 and 16 percent. However, the impact on the B/C ratio of auxiliary lanes was much larger (minus 30 percent). Conversely, a reduction of 25 percent generated significant impacts on the B/C ratios of all projects. The changes varied between 32 and 66 percent. Auxiliary lanes registered the highest impact in both the decrease and the increase cases. This is likely a result of auxiliary lanes being analyzed using a methodology to capture traffic in weaves. The signs of the changes were as expected - if free-flow speed increases compared to the original situation, travel times decrease and the gains of undertaking congestion reduction projects decrease. The opposite situation occurs if the free-flow speed decreases compared to the original situation.
- *Maximum v/c in BPR curve.* An increase of 25 percent in the maximum v/c parameter did not produce any change on the B/C ratios. This is

likely due to the sample projects not reaching the maximum  $v/c$  value. However, the decrease of 25 percent lowered the values of the B/C ratios between 18 and nearly 100 percent. The auxiliary lanes project had the largest decrease. A decline in the B/C ratios makes sense, since a lower  $v/c$  means lower congestion and thus the benefits of undertaking congestion reduction projects decrease. As described in Chapter III, the maximum  $v/c$  parameter would need to be increased to 1.56 to obtain 5 MPH speed estimates for a free-flow speed of 70 MPH.

- *Percent traffic in weave.* This variable applies to the auxiliary lane project only. An increase of 25 percent generated a rise of the B/C ratio of 75 percent. However a decrease of the same magnitude generated an increase of approximately two percent. This suggests that this variable is highly sensitive to increases, but has little or no sensitivity to decreases. This is likely the result of more vehicles being forced into the left lanes (out of the weave) and possibly creating unrealistically high volumes.

### 3.3 Moderate Impact Variables

Four variables were identified as having moderate impacts:

- *Length of peak period.* An increase in the length of the peak period of 25 percent generated increases in B/C ratios between 15 and 35 percent. A decrease of 25 percent produced declines in the B/C ratios between 15 to 26 percent, with auxiliary lanes being the most sensitive project in both the increase and decrease scenarios. The signs of the changes on the B/C ratios are expected.
- *Length of affected area.* Increasing the length of the affected area by 25 percent generated increases in the B/C ratios between 15 and 25 percent, whereas a decrease of 25 percent produced declines between 15 to 25 percent. Auxiliary lanes are the most sensitive project in both the increase and decrease scenarios. The signs of the changes of the B/C ratios are as expected - benefits increase with an increase in the length of the affected area.
- *Average hourly HOV traffic.* Changes in the B/C ratios were inconsistent among projects with modifications to the average hourly HOV traffic variable. An increase in the average hourly HOV traffic generated a decrease in the B/C ratios for ramp metering and auxiliary lanes and an increase in the B/C value for the HOV lanes project. The reverse situation applies to a decrease in the value of this variable. The signs of the changes on the B/C ratios were as expected: for ramp metering and auxiliary lanes projects, more vehicles using the HOV lanes reduce

congestion in the mixed-flow lanes. For a HOV lane project, more vehicles using the HOV lane reduces congestion in the mixed-flow lanes and increases the B/C ratio. The B/C changes varied from a two-percent increase to a 25-percent decrease when the average hourly HOV traffic variable was increased by 25 percent. Decreasing the variable by 25 percent resulted in a seven-percent decrease to 30-percent increase in the B/C ratio.

- *Average vehicle occupancy (AVO) - general traffic peak.* A 25-percent increase in the average vehicle occupancy on general traffic lanes during the peak period generated an increase in the B/C ratio between 11 and 20 percent. A decrease of 25 percent AVO reduced the B/C ratio between 11 and 20 percent. The auxiliary lane project was the most sensitive to changes. The signs of the changes are as expected since an increase in AVO during peak hour increases travel time savings by increasing the number of people per vehicle. AVO affects only travel time benefits. The other benefits (safety, emissions, and vehicle operating costs) are functions of the number of vehicles. Peak AVO would impact only peak period travel benefits (usually about 80 percent of total benefits).
- *Real discount rate.* A 25-percent discount rate decreased the B/C ratios between 11 and 14 percent, whereas a reduction of 25 percent increased B/C between 12 and 17 percent. Auxiliary lane projects were the most sensitive. The signs of the changes were as expected, being negative in the case of an increase and positive for a decrease.

### 3.4 Low Impact Variables

Six variables were identified as having low impacts:

- *Length of construction period.* A 25-percent increase in the length of the construction period reduced B/C ratios between one and three percent, whereas a reduction in the length increased B/C ratios between two and three percent. HOV lane projects were the most sensitive. The signs of the changes were as expected: longer construction periods postpone benefits and decrease B/C ratios.
- *Percent trucks.* A 25-percent increase in the percent of truck traffic raised B/C ratios between one and four percent, while a decrease in the percent of truck traffic lowered B/C ratios between one and four percent. Auxiliary lanes projects were the most sensitive. The signs of the changes were as expected. Since trucks tend to have a higher value of time than do automobiles, an increase in truck traffic increases travel time savings.



- *AVO - general traffic non-peak.* Changing the average vehicle occupancy in general traffic lanes during the non-peak generated variations in the B/C ratio for auxiliary lanes only. A 25-percent increase in the AVO increased the B/C ratio about one percent and a proportional decrease on the AVO reduced the B/C ratio by one percent. The signs on the changes are as expected since travel savings per vehicle increase as the number of people per vehicle increase. Changes in the AVO of non-peak general traffic did not produce any variations in the B/C ratios for the ramp metering and HOV lane projects because there is no delay for these examples in the non-peak period.
- *AVO - HOV.* Changing average vehicle occupancy for HOV lanes generated variations in the B/C ratio for HOV lanes projects only, because only they experienced delays in the examples. A 25-percent increase in the AVO of HOV lanes increased the B/C ratio by five percent, whereas a proportional decrease reduced the B/C ratio by five percent. The signs of the changes were as expected: a rise in AVO increases savings in travel time per vehicle.
- *Capacity per HOV Lane.* Changing the capacity per HOV lane produced changes only in HOV lane and auxiliary lane projects. The B/C ratio of ramp metering showed no impact. In addition, the changes were not consistent among projects. A 25-percent increase in the capacity of HOV lanes increased the B/C ratios of both the auxiliary lane and HOV lane projects. However, a proportional decrease in the capacity increased the B/C ratio of auxiliary lanes and reduced the HOV lane project. Both the HOV lane and auxiliary lane projects depend on the existing and projected v/c ratios. A higher HOV lane capacity means lower v/c ratio and higher speeds. The location on the curve can mean greater or smaller travel time benefits. Although the auxiliary lane project generates most of its benefits on the mainline highway, Cal-B/C does not "audit" the HOV split. The difference in benefits should occur for the HOV lanes only. Cal-B/C does not change HOV benefits for ramp metering projects.
- *Ramp design speed.* The ramp design speed variable applied only to auxiliary lanes projects. Changes on this variable did not produce any variations on the value of the B/C ratio.

## 4.0 USABILITY REQUESTS

This section identifies issues identified by Cal-B/C users after several years of experience using the model. Each issue is followed by the updates made in 2009 to Cal-B/C to address the issue.

### 4.1 Hiding Inputs

*Issue:* The project input sheet contains many input boxes. This can be confusing for users.

*Possible Solution:* The initial idea was for Cal-B/C to select the inputs needed by project type and highlight only those that are necessary (hiding all others). However, this would hide inputs that the user might want to use in an unorthodox way. The Cal-B/C development team tried hiding specific project inputs unless particular project types were selected:

- Exclusive ROW for Buses – used only for bus projects
- Ramp Design Speed – used only for auxiliary lane and off-ramp projects
- Average Hourly HOV Traffic – used only if the number of HOV lanes is greater than zero
- Percent Traffic in Weave – used only for auxiliary lane, off-ramp, freeway connector, HOV connector, and HOV drop ramp projects
- Truck Speed – used only for passing lane projects.

*Outcome:* However, the Cal-B/C development team decided not to hide inputs for Cal-B/C, since this might be confusing for users and make the model appear more black-box like. Hiding inputs would also make future updates more difficult.

### 4.2 Peak Period Definition

*Issue:* Most user benefits are functions of speed and volume. Cal-B/C calculates benefits for peak and non-peak separately, since the speeds are different under congested and non-congested conditions. However, the definition of what defines the “peak period” is vague and confuses people providing data for Cal-B/C analyses.

*Possible Solutions:* 1) Add documentation clarifying that peak period is the time a highway experiences congestion, 2) Change the “number of hours in the peak period” to percent of traffic encountering congested conditions, and 3) Tie the inputs to the HICOMP report.

*Outcome:* In the end, the Cal-B/C development team changed the percent of peak period lookup to correspond to the definitions used in regional travel demand models. This change is documented in Chapter III.

### **4.3 Highway Free-Flow Speed**

*Issue:* Users are confused about the definition of free-flow speed. This value is used to calculate speeds from volumes using a BPR curve.

*Possible Solutions:* 1) Add documentation to clarify that free-flow speed is the posted speed, and 2) Assume a free-flow speed depending on the type of highway, tied to the use of separate speed-volume curves for different road types.

*Outcome:* The latest version of Cal-B/C incorporates the first solution.

### **4.4 Multiple Speed-Volume Curves**

*Issue:* The prior version of Cal-B/C estimated speeds from volumes using the freeway speed-volume curve from the Highway Capacity Manual (HCM). This curve is not appropriate for conventional highways.

*Outcome:* The Cal-B/C development team decided to add multiple speed-volume curves to Cal-B/C. The development team researched available speed-volume curves and incorporated separate parameters for freeways, expressways, conventional highways, and HOV lanes. This methodology is documented in Chapter III. It required a new input on the project page to select the type of highway.

### **4.5 Emissions**

*Issue:* The emissions factors needed to be updated for consistency with the latest release of EMFAC. Also, emissions may vary considerably by air basin or other factors.

*Outcome:* The Cal-B/C development team researched EMFAC as part of the model parameter updates. The team examined what factors (e.g., air basin, ambient temperature, and cold starts) affected emissions and decided to use a single set of values for the state. Cal-B/C uses separate values for starting and running emissions. It also estimates the impact of transportation projects on greenhouse gases. This methodology is detailed in Chapter III.

### **4.6 Pop Ups**

*Issue:* Users can get confused by Cal-B/C entry cells and do not refer to the user instructions in the front. Pop-up messages may be a useful way to provide the user with information on what to enter. However, they may also clutter the model.

*Outcome:* The Cal-B/C development team initially modified Cal-B/C to include extensive pop-up messages. After working with the modified model, the team decided that the messages made data entry very difficult and eliminated the pop-up messages.

#### **4.7 Build/No-Build**

*Issue:* The prior version of Cal-B/C used different nomenclature in different parts of the model: “without project” and “with project” versus “existing” and “new.” This could confuse users. As an additional complication, the variables in the model referred to “E” for existing, “N” for new, “WO” for without, and “W” for with.

*Outcome:* The Cal-B/C development team standardized the nomenclature to “build” and “no-build” and the variables to “B” and NB.”

#### **4.8 Two-Way Traffic versus One-Way Traffic**

*Issue:* Cal-B/C allows users to enter two-way or one-way data. However, auxiliary lane and off-ramp projects require Cal-B/C to know whether two-way or one-way traffic is entered. This was solved in the past by requiring users to enter one-way traffic for these project types. Thus, users were confused about whether to enter the number of lanes in one direction or both directions.

*Outcome:* The latest version of Cal-B/C includes an input box to specify whether one-way or two-data is entered. This applies to the number of lanes and all traffic-related data, such as ADT.

#### **4.9 Affected Area**

*Issue:* The term “affected area” may be confusing.

*Outcome:* The term has been changed to “impacted length” starting in Cal-B/C v4.0.

#### **4.10 Year 0**

*Issue:* The prior version of Cal-B/C identified the first year of construction as Year 0. Subsequent years were listed as Year 1, 2, etc. The current ADT input was also listed as Year 0 and Cal-B/C assumed that construction started in the next year. This was confusing when compared to the benefits, which counted forward from base year 1. These assumptions do not hold if Cal-B/C is used for assessing project phasing.

*Outcome:* The Cal-B/C development team changed the first year of construction to be “Year 1.” This also required changes in the internal rate of return calculation. The current ADT was changed from Year 0 to current year. The 2009 updates to Cal-B/C do not address the issue of assessing project staging. However, both Cal-B/C Corridor and Cal-NET\_BC incorporate this ability, since project staging is more likely to be tested

using model results. Chapter VIII has more information about these models. Chapter IX provides a detailed overview of Cal-B/C Corridor.

#### 4.11 Input Sheets

*Issue:* The district input sheets that accompanied prior versions of Cal-B/C incorporated various formatting errors (e.g., cells not formatted as \$, cells not merged, etc.).

*Outcome:* The Cal-B/C development team reviewed and fixed the formatting errors.

#### 4.12 Shoulder Widening

*Issue:* Cal-B/C does not have the capability to assess shoulder widening projects. For instance, the FHWA modifies accident rates to capture safety impacts due to shoulder widening. A related question is whether Cal-B/C should consider the impact of shoulder width on the speed calculations as the Highway Capacity Manual does.

*Outcome:* This feature would not be used very often and would carry a potentially large error rate relative to the size of the impact. The Cal-B/C development team decided to ignore the impacts of shoulder widening.

#### 4.13 Traffic Operations

*Issue:* There are a number of areas where the Cal-B/C development team needed to coordinate with the Division of Traffic Operations:

- Definition and calculation of delay (daily vehicle hours of delay, DVHD)
- Priority Index Number (PIN) calculation
- Estimation of safety benefits/Safety Index (SI) calculation
- Appropriate Traffic Accident Surveillance and Analysis System (TASAS) data
- Accident cost values
- Travel time values
- Average Vehicle Occupancy (AVO) values
- Using Cal-B/C in corridor studies.

*Outcome:* The Cal-B/C development team worked with the Division of Traffic Operations on these issues. Chapter IV discusses most of the coordination efforts and the changes made to Cal-B/C. Chapter VIII discusses the new corridor analysis capabilities available for use in corridor studies. Cal-B/C and other models in the Department's benefit-cost toolkit were applied to the first round of Corridor Management System Plans (CSMPs). Lessons learned from these applications led to improvements in Cal-B/C Corridor during the 2012 revisions.

#### 4.14 Macro Button

*Issue:* Cal-B/C includes a macro that prepares data for calculating benefits on a second road. Once the button is pressed, the original analysis is lost. Users may forget to save their analyses before pressing the macro button.

*Outcome:* Starting with Cal-B/C v4.0, the macro in Cal-B/C prompts the user to save the model and automatically starts a new copy of Cal-B/C before moving any data. Cal-B/C also includes a third road. The macro affects only the first and second road.

#### 4.15 Project Costs

*Issue:* The prior version of Cal-B/C required users to enter project costs in dollars, while the Division of Programming maintains project costs in thousands of dollars.

*Outcome:* Cal-B/C was modified so costs are entered in thousands of dollars, which is consistent with the Division of Programming. Subsequent calculations are conducted in dollars and final results are reported in millions of dollars.

#### 4.16 Parameters

*Issue:* The model parameters page should be updated.

*Outcome:* The Cal-B/C development team reviewed the methodology and updated all model parameters for Cal-B/C v4.0 and v5.0. The economic and parameter updates are discussed in Chapter III. These updates address several issues and ideas discussed during model planning meetings:

- Economic values were revised to 2011 dollars in the 2012 updates.
- The discount rate was re-examined by looking at the historical rates on long-term Treasury Bonds.
- The weights used to calculate accident cost are shown separately in Cal-B/C v4.0 and v5.0.
- The accident cost methodology was made consistent with the Division of Traffic Operations (as described in Chapter IV). This includes the assumption that half of all property damage only (PDO) accidents are not reported.
- The updated AVO figures in Cal-B/C are from Traffic Operations.

#### 4.17 Project Types

*Issue:* As part of corridor analysis, Cal-B/C may be used to assess multiple types of projects simultaneously. The Department has had to assess projects that include multiple improvements. For example, a project may consist of a 0.4-mile auxiliary lane,

a 0.7-mile HOV bypass, and a 2.3-mile lane addition. The most common combinations are:

- Lane additions with HOV lanes
- TMS projects with lane additions
- Auxiliary lanes with ramp or connector projects
- Interchange improvements with lane additions
- Interchange improvements with auxiliary lanes.

*Outcome:* The Cal-B/C development team considered moving the table of project types from the parameters page to the project input page and allowing multiple project types to be selected. However, the real issue is making sure that the most common project combinations do not double-count or undercount project benefits. The Cal-B/C development team tried to ensure that project combinations make sense in Cal-B/C. However, Cal-B/C Corridor should be run using model data wherever possible, because micro-simulation models and regional travel demand models are more likely to capture appropriate impacts of multiple projects than Cal-B/C can.

#### 4.18 Values on Website

*Issue:* The use of benefit-cost analysis is expanding statewide. Department districts and other stakeholders often ask about the “official” economic valuations to use.

*Outcome:* The Department started posting official values on its website. The values presented in the first column of the Cal-B/C parameters page and the health costs of emissions should be the basis of these values:

- Current year of economic values
- Real discount rate
- Value of time for automobiles, trucks, and all vehicles
- Value for transit in-vehicle and out-of-vehicle travel time
- Per gallon fuel cost for automobiles and trucks
- Non-fuel costs for automobiles and trucks
- Economic costs of fatalities, injuries, and property damage
- Costs of fatality, injury and PDO highway accidents
- Health costs for transportation emissions, including greenhouse gases.

#### 4.19 Model Results

*Issue:* During model planning meetings, the Cal-B/C development team considered several additions to the model results page to capture a wider range of performance measures:

- Person-hours of delay (and during the peak period only)
- Vehicle-hours of delay

- Safety Index
- Delay Index
- Tons of CO<sub>2</sub>
- Total tons of emission.

*Outcome:* The final version of Cal-B/C reports results for person-hours of delay, tons of CO<sub>2</sub>, and the value of CO<sub>2</sub> in addition to the economic measures reported in previous versions of Cal-B/C. For Cal-B/C v5.0, the values and tons of CO<sub>2</sub> are reported as savings to be consistent with the other user benefits.

#### 4.20 Toggling Benefits On and Off

*Issue:* The Department occasionally excludes user benefits from analyses. While the prior version of Cal-B/C allowed users to turn off emissions benefits, it did not provide the ability to turn off other benefits. Users must delete these benefits manually.

*Outcome:* Cal-B/C allows users to turn off induced demand benefits, vehicle operating cost benefits, accident cost benefits, and emission benefits. Travel time benefits for existing users cannot be turned off, because these benefits typically comprise the largest portion of user benefits.

#### 4.21 Cost Escalation

*Issue:* Cal-B/C reports its results in constant dollars. This is consistent with analyzing projects for near-term programming. However, Cal-B/C may be used for project phasing in the future. Project phases delayed to future years will cost more (by the forecasted construction cost index). The corresponding user benefits will also be higher in nominal terms (by the GDP deflator).

*Outcome:* The Cal-B/C development team considered adding the ability to report estimates in nominal dollars. Alternatively, the constant dollar analysis could be adjusted by the difference between the highway construction cost index and the GDP deflator. The development team decided to incorporate neither of these changes in Cal-B/C, because project phasing should be analyzed using other tools in the Department benefit-cost tool suite (Cal-B/C Corridor or Cal-NET\_BC).

#### 4.22 Other Changes

Cal-B/C v4.0 and the subsequent Cal-B/C v5.0 reflect other suggestions made during model planning meetings held for the 2009 revision:

- Including a third road in the final calculations page, which is helpful for complex projects
- Analyzing queuing projects, which is described in Chapter VII



- Adding a message board with notes to user (all messages are standardized by project type and reported above the project type box on the project input page).

However, some suggestions made during the planning meetings were not included:

- Allowing user to change project start date for prioritization and phasing
- Allowing user to select the number of years in the benefit calculation
- Adding user groups for regional planning model data (implemented instead as Cal-B/C Corridor)
- Providing ability to analyze connector projects (methodology needs review).

These and other changes are detailed in the chapters that follow.

**III. UPDATES TO ECONOMIC AND  
PARAMETER VALUES**

### III. UPDATES TO ECONOMIC AND PARAMETER VALUES

This chapter describes the updates that the Cal-B/C development team made to the model parameters for Cal-B/C. The material is updated from the previous version of the Cal-B/C Technical Supplement Volume 3 to reflect changes made for the latest Cal-B/C (v5.0), which uses economic values in 2011 dollars. To the extent that the material is relevant and to provide historical context, the chapter includes information on revisions made for Cal-B/C v4.0.

In addition, the Cal-B/C development team reviewed many of the basic parameters in the update for Cal-B/C v4.0 to make sure that they are current. Some of these parameters are updated further for Cal-B/C v5.0. For example, the emissions rates reflect those found in the latest California Air Resources Board (CARB) model, EMFAC2011. Cal-B/C v5.0 retains the two biggest updates for Cal-B/C v4.0 - the conversion of the peak period parameter from a single value per hour to a lookup table and the addition of greenhouse gas emissions to the model.

The next few sections provide detailed information on updated parameters in the order that they occur in the model:

- General Economic Values
- Highway Operations Parameters
- Travel Time Parameters
- Vehicle Operating Cost Parameters
- Accident Cost Parameters
- Emissions Cost Parameters
- Greenhouse Gas Emissions
- Transit Parameters
- References

#### 1.0 GENERAL ECONOMIC VALUES

##### 1.1 Year of Current Dollars

The prior version of Cal-B/C calculates economic results in 2007 dollars. Cal-B/C v5.0 uses 2011 dollars. For economic data without new research available, the Cal-B/C development team updated the values using the Gross Domestic Product (GDP) deflator. The Office of Management and Budget (OMB) of the United States Government publish this information every February. The historical tables provide actual GDP through the prior year as well as estimates for the current year and the next five years.

Exhibit III-1 shows the GDP deflator figures from the 2012 Budget. The second column shows the Chained GDP Price Index. The third column, Year-Over-Year Inflation, shows the percent increase from one year to the next. The fourth column, Annual Inflation Factor, shows the cumulative growth annualized over the period. Cal-B/C economic values were adjusted by a factor of 1.0583 (or 1.1275/1.0654) to restate 2007 dollar values in 2011 dollars.

### Exhibit III-1: Gross Domestic Product (GDP) Deflator

Fiscal Year	Chained GDP Price Index	Year-Over-Year Inflation	Annual Inflation Factor
2007	1.0654	-	-
2008	1.0898	2.3%	2.3%
2009	1.1043	1.3%	1.8%
2010	1.1127	0.8%	1.5%
2011 est.	1.1275	1.3%	1.4%

Source: Office of Management and Budget, Budget of the United States Government, Fiscal Year 2012 Budget (FY12) Transmitted to Congress on February 14, 2011, Table 10.1 – Gross Domestic Product and Deflators Used in the Historical Tables: 1940-2016.

Revision Made to Cal-B/C: adjusted economic values without new source data by a factor of 1.0583 to restate in 2011 dollars.

## 1.2 Real Discount Rate

Starting with its 1992 Circular Number A-94, OMB has required Federal agencies to use a discount rate of seven percent for cost-effectiveness, lease purchase, and related analyses. Prior to that, OMB required a discount rate of 10 percent, due to higher interest rates on Treasury bonds and in recognition of a risk premium.

OMB now issues annual updates to its recommended rates. Exhibit III-2 shows historical nominal interest from the December 2011 update. As can be seen in the exhibit, interest rates have dropped considerably over the last several years and even further from the 2009 Cal-B/C update. At the time of the 2009 update, the nominal rates on 30-year Treasury bonds were hovering around 5 percent, which was near historical lows. At the time of the latest revision, rates are below 4 percent.

**Exhibit III-2: Table of Past Year Nominal Interest Rates from  
Appendix C of OMB Circular No. A-94, Revised December 2011**

BUDGET ASSUMPTIONS						
Nominal Treasury Interest Rates for Different Maturities (from the annual budget assumptions for the first year of the budget forecast)						
Calendar Year	3-Year	5-Year	7-Year	10-Year	20-Year	30-Year
1979	9.7	9.2	9.1	9.0	#N/A	8.9
1980	10.9	10.6	10.6	10.6	#N/A	10.4
1981	13.4	12.8	12.6	12.2	#N/A	11.8
1982	12.8	13.1	13.2	13.3	#N/A	13.0
1983	9.5	9.8	10.0	10.2	#N/A	10.3
1984	9.8	10.0	10.1	10.3	#N/A	10.4
1985	10.3	10.7	10.8	11.0	#N/A	11.0
1986	8.6	8.8	8.8	8.9	#N/A	9.1
1987	6.3	6.5	6.6	6.7	#N/A	7.0
1988	7.3	7.7	7.8	8.0	#N/A	8.1
1989	7.8	8.1	8.2	8.3	#N/A	8.2
1990	7.4	7.5	7.6	7.7	#N/A	7.8
1991	7.2	7.4	7.4	7.5	#N/A	7.7
1992	6.1	6.5	6.7	7.0	#N/A	7.1
1993	5.6	6.0	6.3	6.7	#N/A	6.8
1994	5.0	5.3	5.5	5.7	#N/A	5.8
1995	7.3	7.6	7.7	7.9	#N/A	8.1
1996	5.4	5.5	5.5	5.6	#N/A	5.7
1997	5.8	5.9	6.0	6.1	#N/A	6.3
1998	5.6	5.7	5.8	5.9	#N/A	6.1
1999	4.7	4.8	4.9	4.9	#N/A	5.0
2000	5.9	6.0	6.0	6.1	#N/A	6.3
2001	5.4	5.4	5.4	5.4	#N/A	5.3
2002	4.1	4.5	4.8	5.1	#N/A	5.8
2003	3.1	3.6	3.9	4.2	#N/A	5.1
2004	3.0	3.7	4.2	4.6	5.4	5.5
2005	3.7	4.1	4.4	4.6	5.2	5.2
2006	4.7	4.8	4.9	5.0	5.3	5.2
2007	4.9	4.9	4.9	5.0	5.1	5.1
2008	4.1	4.3	4.4	4.6	4.9	4.9
2009	2.7	3.3	3.7	4.2	4.7	4.5
2010	2.3	3.1	3.5	3.9	4.4	4.5
2011	1.4	1.9	2.4	3.0	3.9	4.2
2012	1.6	2.1	2.5	2.8	3.5	3.8

*Source: Office of Management and Budget, Memorandum M-12-06, 2012 Discount Rates for OMB Circular No. A-94, <[www.whitehouse.gov/sites/default/files/omb/assets/a94/dischist-2012.pdf](http://www.whitehouse.gov/sites/default/files/omb/assets/a94/dischist-2012.pdf)>, accessed January 5, 2012.*

Nominal interest rates need to be adjusted for inflation in order to discount user benefits in constant dollars. Exhibit III-3 shows the nominal and real discount rates suggested in the December 2011 OMB circular. The circular suggests using a much lower real discount rate (1.7 percent) than used in prior versions of Cal-B/C (5.0 percent) or the latest version (4.0 percent). In its December 2012 memorandum on discount rates, OMB clarifies that the rates presented in Appendix C should be used only for lease-purchase and cost-effectiveness analysis and that they do not apply to regulatory analysis or benefit-cost analysis of public investment.

**Exhibit III-3: Table of Suggested Discount Rates from  
Appendix C of OMB Circular No. A-94, Revised December 2011**

**Nominal Discount Rates.** A forecast of nominal or market interest rates for calendar year 2012 based on the economic assumptions for the 2013 Budget are presented below. These nominal rates are to be used for discounting nominal flows, which are often encountered in lease-purchase analysis.

**Nominal Interest Rates on Treasury Notes and Bonds  
of Specified Maturities (in percent)**

<u>3-Year</u>	<u>5-Year</u>	<u>7-Year</u>	<u>10-Year</u>	<u>20-Year</u>	<u>30-Year</u>
1.6	2.1	2.5	2.8	3.5	3.8

**Real Discount Rates.** A forecast of real interest rates from which the inflation premium has been removed and based on the economic assumptions from the 2013 Budget is presented below. These real rates are to be used for discounting constant-dollar flows, as is often required in cost-effectiveness analysis.

**Real Interest Rates on Treasury Notes and Bonds  
of Specified Maturities (in percent)**

<u>3-Year</u>	<u>5-Year</u>	<u>7-Year</u>	<u>10-Year</u>	<u>20-Year</u>	<u>30-Year</u>
0.0	0.4	0.7	1.1	1.7	2.0

Analyses of programs with terms different from those presented above may use a linear interpolation. For example, a four-year project can be evaluated with a rate equal to the average of the three-year and five-year rates. Programs with durations longer than 30 years may use the 30-year interest rate.

*Source: Office of Management and Budget, Memorandum M-12-06, 2012 Discount Rates for OMB Circular No. A-94, <[www.whitehouse.gov/sites/default/files/omb/memoranda/2012/m-12-06.pdf](http://www.whitehouse.gov/sites/default/files/omb/memoranda/2012/m-12-06.pdf)>, accessed January 5, 2012.*

From this revised language, it can be inferred that OMB still requires a discount rate of 7 percent for benefit-cost analysis, which OMB defines differently from cost-effectiveness analysis. In guidance for recent TIGER discretionary grant applications, the United States Department of Transportation (USDOT) has required applicants to use a 7-percent discount rate. It has also allowed applicants to use a lower discount rate of 3 percent for an “alternative analysis.” These two rates bracket the discount rates used in Cal-B/C over the last several years (i.e., 4 to 5 percent).

To compare these national rates with California figures, the Cal-B/C development team examined the interest earned on the Pooled Money Investment Account (PMIA) as part of the 2009 Cal-B/C update. The Cal-B/C development team has not updated this analysis for the latest update. The previous results are shown below.

The California State Treasurer’s Office is responsible for investing surplus State cash. This cash is invested in the PMIA, which is overseen by the Pooled Money Investment

Board. Real returns on the PMIA reflect the time value of money to the State. The State Treasurer's Office has historical data on PMIA annual yields since 1971/72 and monthly yields since 1977 on its website.

Exhibit III-4 shows nominal and real annual returns over different periods as of the 2009 update. The annual returns account for compound growth and real returns are adjusted from nominal returns using the GDP deflator. As can be seen in the exhibit, real returns have ranged from almost zero percent in the 1970s to over five percent in the 1980s. The averages for the last 20 and 30 years have been 2.8 and 3.2 percent respectively.

**Exhibit III-4: Nominal and Real Annual Returns on the Pooled Money Investment Account (PMIA)**

Period	Number of Years	Nominal Annual Return	Inflation Measured by GDP	Real Annual Return
1970s	9	7.3%	7.2%	0.1%
1980s	10	9.6%	4.3%	5.3%
1990s	10	5.7%	2.1%	3.6%
2000s	7	3.5%	2.6%	0.9%
Last 10 Years	10	4.1%	2.3%	1.8%
Last 20 Years	20	5.3%	2.5%	2.8%
Last 30 Years	30	6.7%	3.5%	3.2%
All Years	36	6.7%	4.1%	2.7%

*Sources: California State Treasurer's Office and OMB FY09 Budget of the United States.*

The PMIA data is backward looking, while the US Treasury data reported in the OMB circular is forward-looking. However, both data sources suggest using a real discount rate of 3.0 percent or lower. This represents a significant change from the prior version of Cal-B/C. For the 2009 update, the Cal-B/C development team felt uncomfortable changing the discount rate by a large percentage and decided to adopt a compromise value of 4.0 percent. The latest update of Cal-B/C retains this lower discount rate (compared to the 5.0 percent used in Cal-B/C prior to version 4.0). Although the lower discount rate increases life-cycle costs, it also reduces the discounting of future benefits and increases benefit-cost ratios overall.

<i>Revision Made to Cal-B/C: lowered the real discount rate to 4.0 percent</i>
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## 2.0 HIGHWAY OPERATIONS PARAMETERS

For the latest Cal-B/C update, the development team did not change any highway operations parameters adopted in the 2009 update. Once the Department completes the 2010-2011 California Household Travel Survey, the Cal-B/C development team can develop new values for the average vehicle occupancy (AVO) and the percent of travel by time of day. The household survey began in December 2011. Results will be available by March 2013. In addition, the source used to estimate the percentage trucks is no longer available. However, an analysis of 2009 truck count data corroborates the prior value.

The discussion that follows explains the updates made to the highway operations parameters for Cal-B/C v4.0. This discussion continues to be valid for the current version of the model. When the text refers to the prior version of Cal-B/C, this means Cal-B/C v3.2.

### 2.1 Average Vehicle Occupancy (AVO)

The prior version of Cal-B/C used the following average values from the Division of Traffic Operations to estimate vehicle occupancy:

- Non-Peak General Traffic - 1.15
- Peak General Traffic - 1.10
- High Occupancy Vehicle (HOV) 3+ Restriction - 3.0
- HOV 2+ Restriction - 2.05.

These values are based upon national statistics reported for California. There is no single group within the Department dedicated to collecting current average vehicle occupancy (AVO) data. The Traffic Census Program has a scheduled program of collecting traffic volume data, but AVO data is not part of its collection routine. The Highway Performance Monitoring System (HPMS) unit does not currently collect AVO data. New Federal guidelines will require AVO data collection as part of the HPMS, so the HPMS unit may have AVO data available in the future. Currently, there are a few sources available as detailed below.

*Statewide Travel Survey.* Approximately one every ten years, the Department conducts a statewide travel survey. The latest was conducted in 2000-2001. On Table 21a (page 248) of the Weekday Travel Report, the 2000-2001 Statewide Travel Survey reports the following AVO figures:

- All Trips (24 hours) - 1.42
- All Trips (7 AM to 9 AM) - 1.22
- Home-Work Trips (24 hours) - 1.14
- Home-Work Trips (7 AM to 9 AM) - 1.11



*District HOV Reports.* The Division of Traffic Operations has district HOV branches that collect AVO data twice per year through manual observations as part of their HOV studies. This information is gathered by districts for corridors with HOV lanes. Since the data are for HOV corridors only, they may not be representative of other corridors. HOV lanes tend to be constructed on congested corridors with heavy commuter traffic. The Cal-B/C development team examined district HOV reports from 2004 for District 3 (Sacramento), District 4 (San Francisco Bay Area), and District 7 (Los Angeles).

The HOV lanes in the Sacramento Area operate during the peak hours of 6:00 to 10:00 AM and 3:00 to 7:00 PM on weekdays. During these times, the use of HOV lanes is restricted to vehicles with at least two occupants. General traffic may use the lanes during all other times. Exhibit III-5 shows AVO data that District 3 collected on the three HOV facilities in the Sacramento Area. As the exhibit illustrates, AVOs have increased over the last few years. The current AVOs are higher than the default values found in the prior version of Cal-B/C.

**Exhibit III-5: AVO on HOV Corridors in the Sacramento Area**

<b>Route 99</b>						
<b>Year (# of Lanes)</b>	<b>Northbound – AM</b>			<b>Southbound - PM</b>		
	<b>HOV Lane</b>	<b>Mixed Flow Lanes</b>	<b>All Lanes</b>	<b>HOV Lane</b>	<b>Mixed Flow Lanes</b>	<b>All Lanes</b>
1998 (4)	2.19	1.08	1.29	2.17	1.20	1.36
1998 (3)	2.09	1.05	1.26	2.25	1.13	1.34
1999 (4)	2.09	1.08	1.28	2.34	1.17	1.41
1999 (3)	2.07	1.04	1.25	2.18	1.12	1.35
2000 (4)	2.16	1.10	1.38	2.21	1.17	1.38
2000 (3)	2.13	1.06	1.32	2.16	1.13	1.38
2001 (4)	2.16	1.09	1.30	2.33	1.29	1.42
2001 (3)	2.11	1.07	1.32	2.20	1.12	1.40
2002 (4)	2.26	1.08	1.38	2.24	1.21	1.39
2002 (3)	2.24	1.03	1.37	2.18	1.07	1.46
2003 (4)	2.23	1.06	1.34	2.36	1.19	1.40
2003 (3)	2.21	1.07	1.40	2.23	1.06	1.32
2004 (4)	2.24	1.10	1.37	2.32	1.15	1.46
2004 (3)	No Data Available This Year			No Data Available This Year		
2004 (5)	2.04	1.16	1.34	2.18	1.22	1.40
<b>US 50</b>						
<b>Year</b>	<b>Westbound – AM</b>			<b>Eastbound - PM</b>		
	<b>HOV Lane</b>	<b>Mixed Flow Lanes</b>	<b>All Lanes</b>	<b>HOV Lane</b>	<b>Mixed Flow Lanes</b>	<b>All Lanes</b>
2000	No HOV Lane		1.14	No HOV Lane		1.16
2002	2.26	1.02	1.19	2.67	1.07	1.22
2003	2.25	1.03	1.20	2.28	1.01	1.21
2004	2.36	1.32	1.49	2.27	1.23	1.41

Interstate 80						
Year	Westbound – AM			Eastbound - PM		
	HOV Lane	Mixed Flow Lanes	All Lanes	HOV Lane	Mixed Flow Lanes	All Lanes
2002	No HOV Lane		1.19	No HOV Lane		1.20
2003	No HOV Lane			2.30	1.11	1.18
2004	2.35	1.05	1.18	2.11	1.16	1.24

The San Francisco Bay Area has more extensive HOV system than does Sacramento. According to the 2004 HOV report for District 4, nearly 323 lane-miles of HOV lanes are in operation. Most of the HOV lanes have 2+ vehicle restrictions, although the approaches to the San Francisco Bay Bridge on I-80 and I-880 and the Carquinez Bridge are 3+ HOV lanes. The district report lists AVO measured on each corridor rather than provide an average for the district. For the corridors with 2+ restrictions, the following ranges were found:

- Peak period HOV occupancy rate: 1.9 to 2.9 persons per vehicle, with most measurements around 2.1 and an outlier on US 101 in Marin at 3.5 and 3.7 persons per vehicle
- Peak period mixed flow occupancy rate: 1.0 to 1.3 persons per vehicle, with most measurements around 1.1.

For the corridors with 3+ restrictions, the following ranges were found:

- Peak period HOV occupancy rate: 2.9 to 3.8 persons per vehicle with most measurements around 3.1 persons per vehicle (note: lower occupancies are possible due to motorcycles and two-seater vehicles.)
- Peak period mixed flow occupancy rate: 1.1 to 1.3 persons per vehicle, with most measurements around 1.2.

Los Angeles (District 7) also has an extensive HOV system, with 440 lane-miles of HOV facilities in 2004. The Los Angeles system is a mix of 2+ and 3+ occupancy requirements. For the corridors with 2+ restrictions, the following ranges were found:

- Peak period HOV occupancy rate: 2.05 to 2.88 persons per vehicle, with most measurements around 2.2 persons per vehicle
- Peak period mixed flow occupancy rate: 1.04 to 1.16 persons per vehicle, with most measurements just under 1.1.

For the single corridor with a 3+ restriction (El Monte Busway), the following ranges were found:

- Peak period HOV occupancy rate: 4.14 to 4.22 persons per vehicle, which is higher than 4.0 due to a large number of buses. The average occupancy for carpools ranges from 3.21 to 3.71.
- Peak period mixed flow occupancy rate: 1.08 to 1.12 persons per vehicle.

*Regional Demand Model Assumptions.* Metropolitan Planning Organizations (MPOs) use AVO assumptions as part of their regional travel demand models. As part of its survey of California MPOs, the Cal-B/C development team included questions about AVO figures. The team found AVO figures are calculated as implied outputs of travel demand models. Rather than adjust trips by AVO, travel demand models are calibrated to measured travel volumes and AVO figures are imputed from the trips tables and the assigned trips. For example, in its last calibrated model, the Metropolitan Transportation Commission (MTC) calculated a value of 1.34 as the AVO for all auto trips. A lower value (1.10) is used for work trips, which means that non-work trips tend to involve more people per vehicle. Since work trips frequently occur during the peak period, this would suggest that the peak period AVO is lower than the non-peak AVO.

Other MPOs indicated similar AVOs, as shown in Exhibit III-6. The following abbreviations are used in the exhibit: Alameda County Congestion Management Agency (ACCMA), Metropolitan Transportation Commission (MTC), San Diego Association of Governments (SANDAG), and Southern California Association of Governments (SCAG).

**Exhibit III-6: AVO on HOV Corridors in the Sacramento Area**

Trip Purpose	ACCMA	MTC	SANDAG	SCAG
All Auto Trips	1.23	1.345	1.361	1.39
Auto Commute Trips		1.102	1.194	1.12
Auto Non-Work-Related Trips			1.48	
Bus Vehicle Trips			102	

On the basis of these three sources, the AVO figures in the prior version of Cal-B/C appeared to be low and needed to be raised. The following values were adopted for Cal-B/C v4.0:

- Non-Peak General Traffic - 1.30
- Peak General Traffic - 1.15
- High Occupancy Vehicle (HOV) 3+ Restriction - 3.15
- HOV 2+ Restriction - 2.15.

*Revision Made to Cal-B/C: AVO figures increased based on 2000-2001 Statewide Travel Demand Survey, Departmental HOV traffic surveys, and a survey of MPOs*

## 2.2 Bureau of Public Roads (BPR) Curve

The Cal-B/C development team found that the model was particularly sensitive to estimated speeds. The prior version of Cal-B/C calculated speeds using a form of the standard Bureau of Public Roads (BPR) curve:

$$\begin{aligned} \text{Speed} &= \text{Free-Flow Speed} / (1 + 0.15*(v/c)^{10}), \text{ where} \\ v &= \text{volume} \\ c &= \text{“practical” capacity} \end{aligned}$$

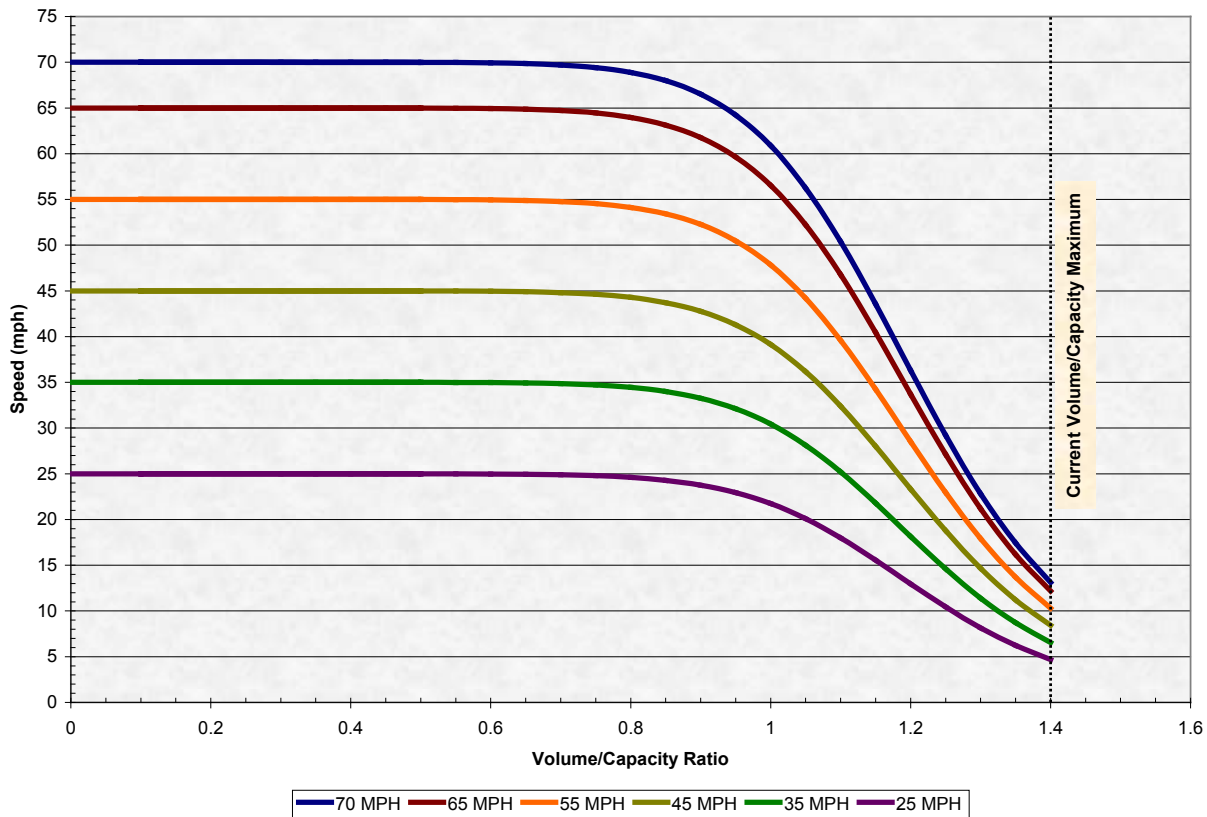
The model calculated capacity,  $c$ , as:

$$\text{Capacity} = \text{Duration of Peak Period} * \text{Number of Lanes} * \text{Capacity per Lane}$$

In the 2009 update, the BPR curve was calibrated to approximate the speed-volume relationship found in the 2000 Highway Capacity Manual (HCM) for urban freeways. Since the 2009 Cal-B/C update, the Transportation Research Board (TRB) has issued the 2010 HCM. The Cal-B/C development team decided not to re-calibrate the BPR curve for any potential difference in the new speed-volume curve.

For the prior version of Cal-B/C, the development team had estimated the parameters from HCM curves before the National Cooperative Highway Research Program (NCHRP) had issued guidance on appropriate parameters. The “ $a$ ” parameter, which is the ratio of the free-flow speed to the speed at capacity, was set to 0.15. The “ $b$ ” parameter, which determines how abruptly speeds drop from free-flow speed, was set to 10. The high exponent in the denominator (“ $b$ ” parameter) made the prior version of Cal-B/C sensitive to volume-to-capacity ratios ( $v/c$ ) in excess of 1.0.

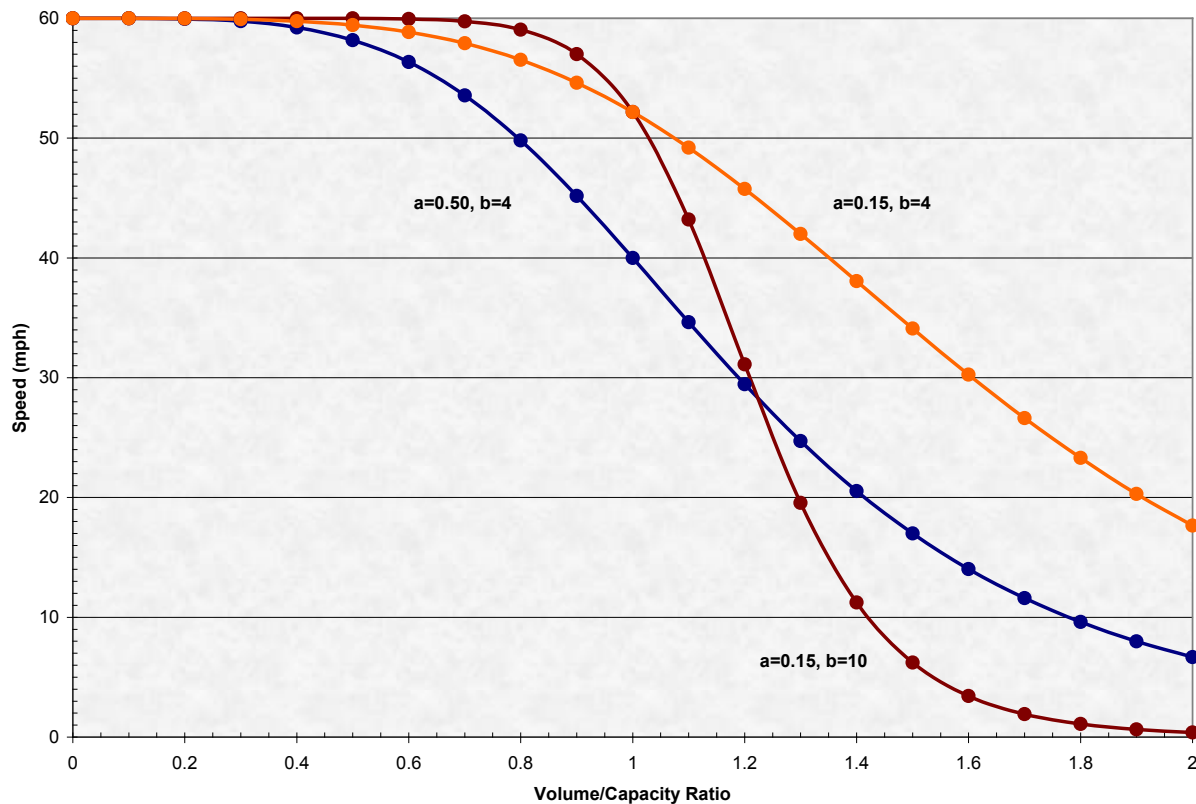
This function is inappropriate for non-freeway facilities, where speeds tend to decline more gradually in response to increases in volume. Exhibit III-7 shows the relationship between the  $v/c$  ratio and estimated speed for the BPR curve and parameters in the previous version of Cal-B/C. Separate curves are shown for different free-flow speeds. To determine the appropriateness of these coefficients and the BPR approach, the Cal-B/C development team conducted a brief literature search of speed estimation techniques.

**Exhibit III-7: Speeds Estimated Using BPR Parameter in the Prior Version of Cal-B/C**

*Literature Review.* NCHRP Report 387 (Dowling et al. 1997) provides a general overview of current approaches. As is noted in the report, the HCM is the source of speed estimation methods most frequently used by planners. The BPR curve and related v/c ratio techniques are often used for preparing Regional Transportation Plans (RTP), because they are easy to incorporate in transportation planning models. This ease of coding is also one of the reasons that Cal-B/C uses BPR curves. Dowling et al. note that speeds from BPR curves are inferior to those obtained from more sophisticated techniques for forecasting speed.

The Bureau of Public Roads (predecessor to the FHWA) developed the standard BPR curve in the late 1960s by fitting a polynomial equation of the freeway speed-flow curves found in the 1965 HCM. Dowling et al. note that many MPOs in the mid-1990s were concerned about the accuracy of the standard BPR curve and had developed updated curves (as was done for Cal-B/C) using either more recent versions of the HCM or locally collected speed flow data. The updated curves use “a” parameters ranging from 0.1 to 1.0 and “b” parameters ranging from 4 to 11. Cal-B/C falls within this range and is consistent with HCM 2000. Dowling et al. include a graph that shows the impact of different parameter values for a BPR curve set at a free-flow speed of 60 mph (see Exhibit III-8). The red line is the BPR curve used in Cal-B/C.

Exhibit III-8: Plot of BPR Curve and Several Variations



Source: Dowling, R. G., Kittelson, W., Zegeer, J., Skabardonis, A., *Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications*, Transportation Research Board, NCHRP Report 387, 1997.

Dowling et al. also provide a brief summary of BPR curve adaptations by four MPOs, with the Metropolitan Transportation Commission (MTC) one being the most relevant to Cal-B/C. At the time of the NCHRP report, MTC used a single BPR curve for both freeways and arterials with the “a” parameter equal to 0.45 and the “b” parameter equal to 4, which is similar to the blue line in Exhibit III-7. According to Dowling et al., this form was selected based on floating car runs conducted by the Department at 119 freeway locations.

At a 1999 TRB conference on the Application of Transportation Planning Models, Singh of MTC presented a paper on improved speed-flow relationships. This presentation was further refined in the conference proceedings in a paper by Singh and Dowling (1999). Singh (1999) notes that MTC calibrated a new speed-flow curve, which was similar to the 1994 HCM. The “MTC curve” uses an “a” parameter equal to 0.20 and a “b” parameter equal to 10. Singh (1999) notes that the “MTC curve” provides good results based on speed and volume validations when applied to the full MTC regional model. MTC selected an “a” parameter of 0.20 to more closely reflect local conditions in which highways with free-flow speeds of 65 mph experience a 10-mph speed drop (to 55 mph) rather than a 5-mph speed drop at a v/c ratio of 1.0.

As reported in Singh and Dowling (1999) as well as Singh (1999), MTC compared its existing BPR method to a curve developed in Australia, called an “Akçelik” curve. Singh and Dowling (1999) found that the Akçelik curve produces more accurate results than the “MTC curve.” The Akçelik curve uses more inputs than the traditional BPR curve and is probably more complicated than needed for Cal-B/C. The Akçelik curve takes the following form:

$$t = t_0 + \{0.25T[(x-1) + \{(x-1)^2 + (8J_a x/QT)\}^{0.5}]\}$$

where:

t	=	average travel time per unit distance (hours/mile)
t <sub>0</sub>	=	free-flow travel time per unit distance (hours/mile)
T	=	flow period (i.e., time interval in hours during which an average arrival demand flow rate, V, persists)
Q	=	capacity
X	=	the degree of saturation (V/Q)
J <sub>a</sub>	=	delay parameter

The “MTC Curve” provided an update to the traditional BPR curve for freeways and expressways. Skabardonis and Dowling (1999) recommend adopting a separate curve with an “a” parameter of 0.05 and a “b” parameter of 10 for estimating speeds on arterials. The authors refer to this curve as the “Updated BPR curve.”

Gong et al. (2006) conducted a brief review of speed estimation techniques to determine an appropriate approach as part of the air quality analysis in MOBILE6. As the authors note, average speed is an essential input to the estimation of emissions factors. The problem is that speed data typically comes from travel demand models, which are not calibrated to speed. In addition, models are not available in rural areas. As a result, Gong et al. used a speed estimation technique based upon the Highway Economic Requirements System (HERS).

The authors developed an Excel macro to estimate the average effective speed (AES) for highway segments in Kentucky using a Highway Performance Measurement System (HPMS) data extract for 2002. The techniques estimate free-flow speeds using a simplified version of the “Aggregate Probabilistic Limiting Velocity Model” (APLVM) based on highway geometry. The AES is estimated from the free-flow speed using other roadway characteristics (e.g., grade) and traffic condition data (e.g., presence of traffic control devices and congestion). Gong et al. found that the HERS method provides good speed estimates compared to measured speeds, but the technique requires extensive data. While these data are available through the HPMS, data validity is a concern. Given the large number of inputs, this is not an appropriate speed estimation technique for Cal-B/C.

Dowling and Skabardonis (2006) describe an effort to develop improved speed-flow relationships for urban arterial streets in Southern California. The project included a collection of intersection traffic counts and floating car runs in the City of Los Angeles during non-congested conditions (because it is difficult to measure demand during congested conditions). The authors compare actual measured speeds to speed estimates using several speed-flow relationships with the following methods.

- Linear
- Logarithmic
- Exponential
- Power
- Polynomial
- BPR
- Akçelik.

Dowling and Skabardonis find that fitted BPR, exponential, and Akçelik equations performed equally well when traffic does not exceed the highway capacity. Under congested conditions, the Akçelik equation performs best. The BPR curve underestimates delays relative to traditional queuing theory and surpasses both queuing theory and Akçelik delay estimates at higher  $v/c$  ratios. The fitted BPR used an “a” parameter of 2.248 and a “b” parameter of 1.584 – values considerably different from other modified BPR curves and the curve recommended earlier in Skabardonis and Dowling (1999) for arterials.

In 2004, ICF Consulting conducted a review of analytic methods used for estimating vehicle-miles traveled (VMT) and speeds for regional emissions analysis in small urban and isolated rural nonattainment and maintenance areas (ICF Consulting 2004). As part of the review, ICF Consulting considered the HERS method, a method developed by the Texas Transportation Institute (TTI), and the BPR curve. ICF Consulting notes that the HERS is considered accurate, but that the speeds may not be sensitive to local or regional conditions. The authors also note that the speed estimates may not be applicable to small urban areas.

Like a standard BPR curve, the TTI method estimates travel speeds using simple inputs, such as traffic volume, highway capacity, and free-flow speed. Like the HERS method, the TTI method is intended to be applied using HPMS data, but it could use any source as long as all input data are available. According to the ICF Consulting report, the TTI method uses a formula originally developed by the North Central Texas Council of Governments for the Dallas/Fort Worth area. The method begins by estimating delay, which according to the ICF Consulting report is:

$$Delay = Min \left[ Ae^{B\left(\frac{v}{c}\right)}, M \right]$$



where:

Delay	=	congestion delay (in minutes/mile)
A & B	=	volume/delay equation coefficients
M	=	maximum minute of delay per vehicle
v/c	=	time-of-day directional volume/capacity ratio

The equation in the ICF Consulting report appears to have an error – it is probably meant to include the maximum (rather than the minimum) of the two values, because M is defined as the maximum delay. The following parameters are used in applying the equations:

- For high capacity facilities (defined as interstates and freeways with more than 3,400 vehicles per hour),
  - A = 0.015
  - B = 3.5
  - M = 5 minutes
- For low capacity facilities (defined as arterials, collectors, and local roads with less than 3,400 vehicle per hour),
  - A = 0.05
  - B = 3
  - M = 10 minutes.

As can be seen in these parameters, the method contains an assumption that there is a maximum delay associated with congestion. The exponents also suggest that volume-capacity ratios have a greater delay impact on low capacity facilities than on high capacity facilities. The TTI method includes an approach for calculating highway capacities based on the 1994 HCM. This approach is described later in the section on updating capacity estimates.

Once the delays are calculated, the TTI method estimates the “congested speed” using the following formula:

$$Congested\ Speed = \frac{60}{\frac{60}{FreeFlow\ Speed} + Delay}$$

The “M” parameter places a lower bound on the speed estimates. In the case of high-capacity facilities, such as freeways, the equation cannot yield a speed lower than about 10 mph. For low-capacity facilities, the minimum speed estimate is a bit lower at about 5 mph.

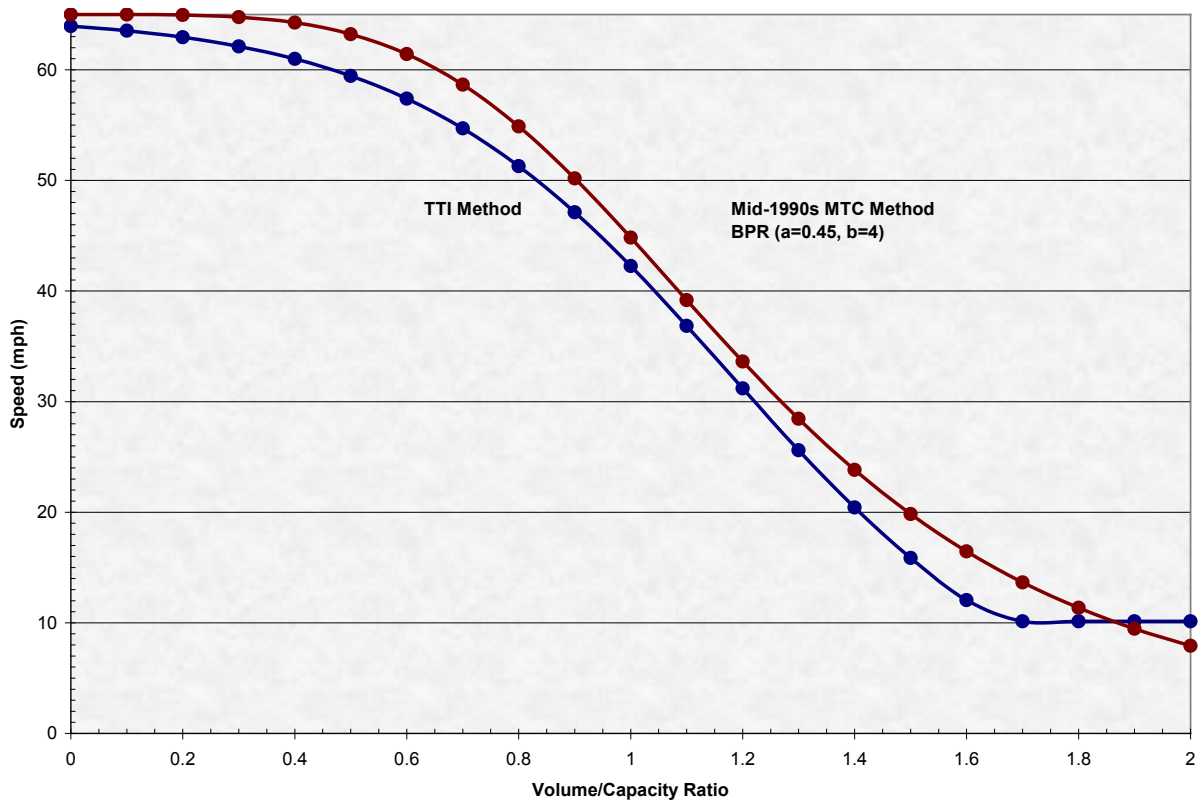
The TTI method provides default values for each of the free-flow speeds grouped by HPMS roadway functional classification and HPMS area type. The free-flow speeds generally follow what would be expected for posted speeds.

- Interstate - 70 mph
- Freeway - 65 mph
- Other principal arterial - 40 to 55 mph
- Minor arterial - 35 to 50 mph
- Major collector - 30 to 40 mph
- Minor collector - 30 to 35 mph
- Local - 30 mph.

In its review of the TTI method, ICF Consulting notes that the calculations require only three inputs (free-flow speed, capacity, and traffic volume). The authors note the advantage of this method is the ability to produce highly accurate speeds if applied properly. North Carolina used the TTI method to estimate average speeds for air quality non-attainment areas outside MPO areas. This suggests that the method might be more accurate for highways on the urban fringe than in the core urban area with congestion. The authors of the report note that accurate application requires local information on capacity and free-flow speeds. They also note that the use of lookup tables for values can lead to inaccurate estimates. North Carolina chose the TTI method for estimating VOC and NO<sub>x</sub> emissions after considering the BPR formula and the Greenshields method (another speed estimation technique).

As shown in the Exhibit III-9, the TTI method produces results similar to those produced by the BPR curve used by MTC in the mid-1990s before the “MTC curve” was adopted. This exhibit shows the speeds estimated for a freeway with a free-flow speed of 65 mph.

### Exhibit III-9: TTI Speed Estimations Compared to the Mid-1990s MTC BPR Curve

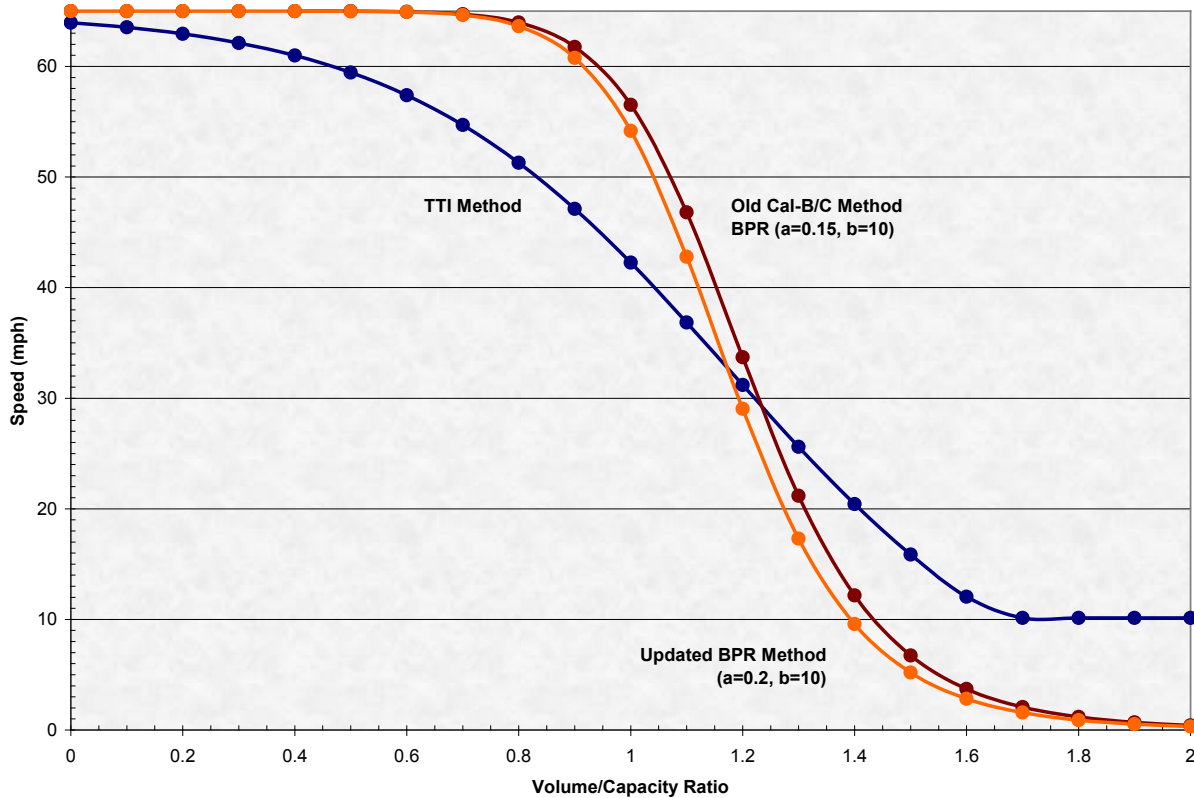


According to the ICF Consulting report, the updated BPR formula uses the parameters recommended for freeways in NCHRP 387 and for arterials in Skabardonis and Dowling (1999):

- $a = 0.05$  for facilities with signals spaced 2 miles or less
- $a = 0.20$  for all other facilities
- $b = 10$ .

Exhibit III-10 shows a comparison of the updated BPR curve proposed in NCHRP 387 for freeways with the TTI method and the method used in the prior version of Cal-B/C. As shown in the exhibit, the old Cal-B/C method did not differ substantially from the updated BPR curve proposed in NCHRP 387.

### Exhibit III-10: Comparison of Different Methods of Estimating Freeway Speeds



NCHRP 387 also recommends equations for estimating the free-flow speed. For unsignalized facilities (i.e., freeways and expressways), the following equations can be used:

$$\text{For } S_p > 50 \text{ mph, Free Flow Speed} = 0.88 \times S_p = 14$$

$$\text{For } S_p < 50 \text{ mph, Free Flow Speed} = 0.79 \times S_p = 12$$

where:

$S_p$  = posted speed limit

As shown in Exhibit III-11, this results in speeds roughly equal to 5 mph over the posted speed limit. Given the convention to drive 5 mph over the speed limit, the results shown in the exhibit should be expected.

**Exhibit III-11: Speeds Estimated For Uncontrolled Facilities  
Using the NCHRP 387 Method**

Posted Speed Limit (in mph)	Estimated Speed (in mph)
25	31.75
35	39.65
45	47.55
55	62.4
65	71.2
70	75.6

NCHRP 387 estimates the following series of equations for estimating free-flow speeds on signalized facilities:

$$\text{Free Flow Speed} = \frac{L}{L/S_{MB} + N \times (D/3600)}$$

where:

- L = length of facility (in miles)
- $S_{MB}$  = mid-block free-flow speed =  $0.79 \times \text{posted speed} + 12$  mph
- N = number of signalized intersections on length, L
- D = average delay per signal

$$D = DF \times 0.5 \times C(1-g/C)^2$$

where:

- D = total signal delay per vehicle (sec)
- G = effective green time (sec)
- C = cycle length (sec)

These formulas are complex and require a lot of information about the facility. NCHRP 387 also provides a lookup table that can be used to estimate free-flow speeds. ICF Consulting (2004) notes that a number of regions use simpler methods to estimate free-flow speeds. Examples include:

- Posted speed limits
- Posted speed limits plus 5 mph for highways
- Posted speed limit times a factor (e.g., 62 percent of speed limit for collectors).

ICF Consulting reports that regional agencies typically calibrate these posted speed limit adjustments to a sample of measured speeds. Other regions use speed measured during off-peak periods as their estimate of free-flow speeds.

*MPO Survey Findings.* The Cal-B/C development team also included questions about BPR curves when it surveyed MPOs. Many California MPOs have chosen to use Akçelik functions rather than BPR functions. However, three MPOs that use BPR functions summarized the coefficients found in their models:

- ACCMA uses  $a = 0.20$  and  $b = 6.0$  for freeways and freeway ramps. The  $v/c$  ratio is divided by 0.75.
- Los Angeles Metro uses  $a = 1.16$  and  $b = 4.33$  for freeway links and  $a = 0.15$  and  $b = 4.0$  for all other roadways.
- MTC uses  $a = 0.20$  and  $b = 6.0$  for freeways.

Based on this review, the Cal-B/C development team decided to retain the use of BPR curves for estimating speeds in Cal-B/C. However, the latest version of Cal-B/C provides separate curves for freeways/expressways and conventional highways. The “Updated BPR Curve” parameters recommended in NCHRP 387 were adopted for both curves. The parameters were added to the Parameters page of Cal-B/C rather than having them hard-coded in the model. Cal-B/C continues to use the posted speed limit for the free-flow speed.

As described in a later section of this documentation, different capacity values were adopted for each type of highway. A separate BPR curve and capacity were developed for High Occupancy Vehicle (HOV) and High Occupancy Toll (HOT) lanes. This is described in Chapter V, which covers HOT lanes. The BPR parameters and capacity figures found in the latest Cal-B/C model are summarized in Exhibit III-12.

#### **Exhibit III-12: BPR Parameters and Highway Capacities Found in Cal-B/C v4.0**

Road Type	Alpha	Beta	Capacity (vphpl)
Freeway	0.20	10	2,000
Expressway	0.20	10	2,000
Conventional Highway	0.05	10	800
HOV and HOT Lanes	0.55	8	1,600

*Revision Made to Cal-B/C:* added BPR curve parameters to the Parameters page, adopted the NCHRP 387 BPR curves, but retained use of posted speed limits for free-flow speeds

### 2.3 Maximum V/C Ratio

Forecasted travel demand can result in extraordinarily high v/c ratios. While these high ratios are accommodated in the real world by travelers shifting travel times, routes or modes, a BPR curve would estimate very low speeds that are not realistic. These speeds can also be below the minimum speeds for which theoretical research is available for estimating user benefits. For these reasons, Cal-B/C constrains the estimated v/c ratios to a default maximum. The prior model's maximum of 1.4 was intended to keep model results reasonable, but it was set arbitrarily. The Cal-B/C development team decided to review whether this maximum v/c ratio continued to make sense, because the ratio affects the sensitivity of Cal-B/C to model inputs.

As a starting point for establishing a maximum v/c ratio, the Cal-B/C development team examined the speeds that result from the BPR curve using the prior BPR coefficient (0.15) and exponent (10). Exhibit III-13 shows the speeds that resulted from a maximum v/c ratio of 1.4 for different free-flow speeds. As the exhibit illustrates, the lowest speeds estimated by the BPR curve (i.e., the speeds at the maximum v/c ratio) ranged from under 5 mph to about 13 mph. However, Cal-B/C also constrains speeds to a minimum of 5 mph, because the fuel and emissions lookup tables start at 5 mph.

**Exhibit III-13: Comparison of BPR Curve Estimates at Different Free-Flow Speeds**

Free-Flow Speed	Speed at v/c = 1.4	v/c Ratio at 5 mph
70 mph	13.1	1.56
65 mph	12.2	1.55
55 mph	10.3	1.52
45 mph	8.4	1.49
35 mph	6.6	1.45
25 mph	4.7	1.39

For most free-flow speeds, the 5-mph floor is not reached with a maximum v/c ratio of 1.4. The last column of Exhibit III-13 shows the v/c ratio needed to obtain a 5-mph speed estimate. This suggests that the v/c maximum needs to be raised to 1.56 to obtain 5-mph speed estimates for freeways with 70 mph free-flow speeds. A similar maximum resulted using the new BPR curve parameters. As a result, the development team decided to increase the maximum v/c ratio to 1.56, which allows speeds to drop as low as 5 mph, but not below.

*Revision Made to Cal-B/C: increased the maximum v/c ratio to 1.56*

## 2.4 Percent Average Daily Traffic (ADT) in Average Peak Hour

The prior version of Cal-B/C separated current and future ADT into peak and off-peak traffic volumes using the duration of the peak period (a five-hour default) and an estimate of the percentage of daily traffic during each peak hour. This percentage was the average across the entire peak period and should not be confused with the peak hour percent or “K-Factor” used in engineering analysis. This approach was unconventional. It also did not reflect the declining contribution of additional hours to peak period traffic. The Cal-B/C development team decided to review the approach, because the number of hours in the peak period was one of the more sensitive inputs in Cal-B/C.

The values found in the previous version of Cal-B/C were based on 1991 Statewide Travel Survey data. An analysis of the data found that the absolute number of trips varied considerably by the size of metropolitan region and between urban and rural areas. However, the percentage of traffic by hour followed a similar double-hump pattern regardless of region.

In every area surveyed in 1991, the top five hours accounted for about 39 percent of total daily traffic, which is an average of 7.8 percent per hour. A particular facility may be congested for a shorter or longer period, so Cal-B/C allowed the number of hours to be adjusted on the project input page. The 7.8-percent default was not changed in previous Cal-B/C revisions, because traffic counts that separated congested and non-congested travel were not available.

*Statewide Travel Survey.* The 2000-2001 California Statewide Travel Survey (2001 Survey) suggests that these defaults need to be changed. According to Table 23 of the survey, the top five travel hours range in percent of total trips from 7.2 to 8.9 percent for a total of 42.4 percent. The average of these top five hours is 8.5 percent. However, the five highest travel hours are distributed such that only one occurs in the morning and the other four occur in the evening. In the 1991 Statewide Travel Survey, the hours were distributed two in the morning and three in the afternoon.

Table 23 of the survey is reproduced below as Exhibit III-14. In the original table, the second-to-last column (“Home-Shopping Trips”) totals to 139 percent and the last column (“Total”) sums to 103 percent. The Cal-B/C development team is unable to explain why these columns do not total to 100 in the original source.



**Exhibit III-14: 2000-2001 Weekday Driver Trips in Motion (Percentage of Vehicle Minutes) by Region, Beginning Hour, and Trip Type**

In the Hour Beginning	Trip Type					Total
	Home-Other	Other-Other	Work-Other	Home-Work	Home-Shopping	
12:00 AM	0.3%	0.1%	0.1%	0.3%	0.2%	0.2%
1:00 AM	0.1%	0.0%	0.1%	0.2%	0.1%	0.1%
2:00 AM	0.1%	0.0%	0.0%	0.1%	0.0%	0.1%
3:00 AM	0.1%	0.0%	0.1%	0.2%	0.0%	0.1%
4:00 AM	0.7%	0.1%	0.4%	2.4%	0.1%	1.1%
5:00 AM	1.8%	0.6%	1.2%	5.9%	0.8%	2.9%
6:00 AM	3.9%	0.7%	3.0%	11.0%	1.0%	5.6%
7:00 AM	8.0%	1.3%	5.0%	15.7%	1.8%	8.9%
8:00 AM	7.4%	3.2%	5.3%	7.1%	4.5%	6.2%
9:00 AM	6.2%	6.1%	6.7%	3.2%	8.4%	5.4%
10:00 AM	5.9%	9.1%	6.8%	1.8%	12.7%	5.6%
11:00 AM	5.4%	11.7%	8.8%	1.9%	16.2%	6.4%
12:00 PM	5.6%	9.7%	10.3%	2.4%	13.5%	6.3%
1:00 PM	6.0%	10.1%	9.0%	2.6%	14.0%	6.5%
2:00 PM	6.9%	10.0%	9.2%	4.2%	13.8%	7.2%
3:00 PM	6.9%	9.7%	10.1%	7.7%	13.5%	8.5%
4:00 PM	6.9%	7.7%	9.7%	10.5%	10.6%	8.9%
5:00 PM	6.7%	6.8%	7.9%	11.7%	9.5%	8.9%
6:00 PM	6.4%	5.0%	3.3%	5.0%	6.9%	5.4%
7:00 PM	4.5%	3.4%	1.3%	2.1%	4.7%	3.1%
8:00 PM	4.0%	2.1%	0.7%	1.3%	2.9%	2.3%
9:00 PM	3.3%	1.5%	0.5%	1.0%	2.1%	1.8%
10:00 PM	2.0%	0.6%	0.2%	1.1%	0.9%	1.2%
11:00 PM	0.8%	0.3%	0.1%	0.7%	0.4%	0.6%
<b>Totals</b>	<b>100.0%</b>	<b>100.0%</b>	<b>100.0%</b>	<b>100.0%</b>	<b>100.0%</b>	<b>100.0%</b>

Source: California Department of Transportation, 2000-2001 California Statewide Travel Survey, Weekday Travel Report, June 2003.

The congested period is increasing in length and encompassing the midday in many parts of the state. This is indicated by the next highest travel hours falling between the morning and afternoon.

*Traffic Census Data.* The Cal-B/C development team decided to compare the Statewide Travel Survey data with actual traffic counts collected through the Traffic Census program. The Traffic Data Branch in the Division of Traffic Operations generally collects these counts on a rotating three-year basis. By examining data from three years, the Cal-B/C development team could obtain a reasonably comprehensive database of traffic conditions statewide.

The Traffic Data Branch provided the team with traffic count data for 9,885 count locations on the State Highway System from October 2003 through September 2006. These data were not adjusted for seasonality or time-of-day factors. Since they include a snapshot of travel across districts and over a three-year period, this information should be representative of time-of-day patterns without adjustment. It is worth noting that areas with less frequent traffic counting are undersampled.

From these data, the Cal-B/C development team was able to process more than 1.5 million records to examine the time-of-day patterns. To ensure that reasonable data were used in the analysis, the Cal-B/C development team filtered the data using a single quality check. The traffic census files contain two additional daily summary fields: a “24-hour count” field and an adjusted “daily total” field. The development team accepted only records where summing all 24 hourly counts matched both the 24-hour count field and the daily total field. In short, only “perfect” count data were included in the analysis.

In addition to the traffic census data, the Cal-B/C development team used data from the Department’s Geographic Information System (GIS) State Highway System Functional (FUNC) classification coverage. This file provides detailed information about the count locations, such as:

- Urban/Rural – designates rural, small urban, and urban classifications
- Route Functional Classification – describes the Federal roadway functional classification system (i.e., rural interstate, rural principal arterial, rural minor arterial, rural major collector, rural minor collector, urban freeway, urban other freeway/expressway, urban principal arterials, urban minor arterial, and urban collectors)
- Access Control – codifies type of access control to the highway facility (i.e., freeway, expressway, conventional, toll road, National Park, relinquished, adopted, and proposed).

This additional information allowed the Cal-B/C development team to aggregate the traffic census data into various classifications for analysis.

*Summary Analysis Results.* The Cal-B/C development team decided to differentiate travel patterns by geographic region. One of the key features of Cal-B/C is its ease of

use for a range of professionals from local planners looking at specific route segments to high-level regional or statewide analyses. The Cal-B/C development team wanted to continue minimizing the number of user inputs, while maintaining the highest accuracy possible for such a tool.

For example, rural, tourism-oriented California regions, such as Lake and Mono Counties, have more midday and late afternoon travel, while urban areas have more defined morning and afternoon peak periods. To illustrate, the picture in Exhibit III-15 shows midday weekday traffic on SR-29 in Lake County during the summer of 2004. As can be seen in the picture, SR-29 has a steady queue of vehicles midday during the week. Clearlake in Lake County is a major boating and fishing area with heavy summertime midday traffic, particularly on weekends.

**Exhibit III-15: Northbound SR-29 Lakeport, California August 26, 2004-1:45 PM**

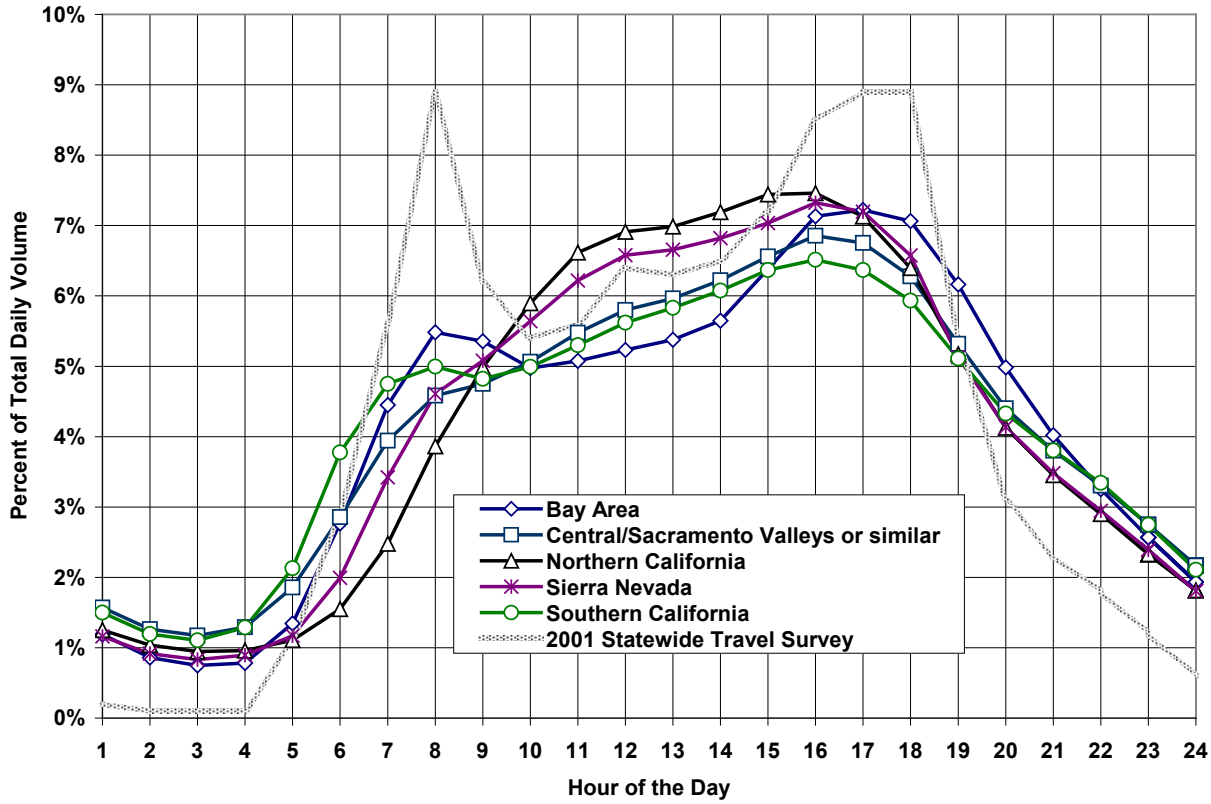


*Source: System Metrics Group, Inc.*

The Cal-B/C development team also wanted to capture these regional characteristics as accurately as possible. Each county was initially placed into a “region” using geography and a subjective assessment of county travel patterns. The regions were adjusted later to match geography more closely.

Exhibit III-16 highlights how travel on rural freeways varies by region in the state. Travel on rural freeways in rural regions tend to exhibit only a single hump, with the highest traffic as a percent of total daily traffic occurring during the midday. The “Northern California” region, which comprises the counties north of Mendocino County along the coast and north of Shasta County inland, has the lowest percent of morning traffic, but the highest midday and afternoon percentages. The “Sierra Nevada” region follows the same trend. As the regions become more urbanized, the traditional morning and evening commute peaks begin to emerge even on freeways classified as rural. Travel patterns on rural freeways show relatively sharp peaks in the San Francisco Bay Area. Southern California rural freeways show similar trends, but with less pronounced peaks.

**Exhibit III-16: Percent Daily “Rural” Freeway Traffic by Hour by Region**

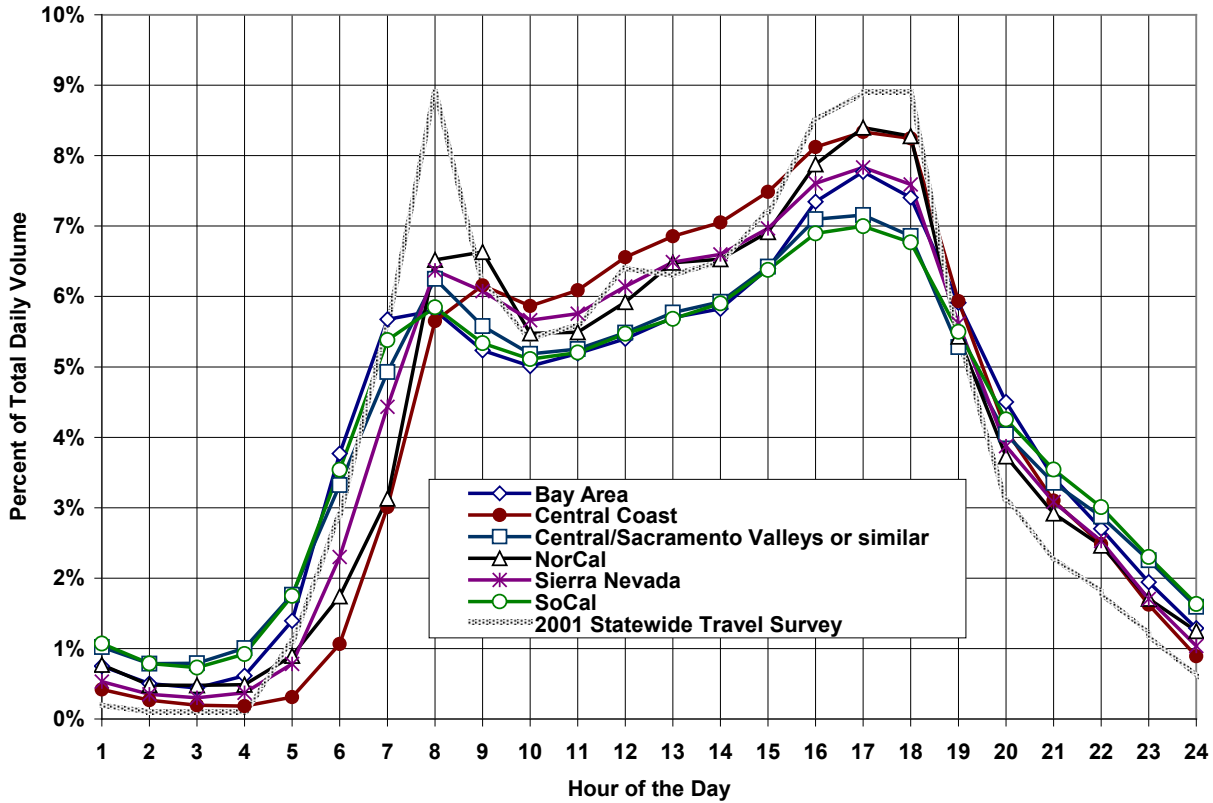


Source: SMG Analysis of Traffic Census data.

The development team also plotted the time-of-day distribution as estimated from the 2001 Statewide Travel Survey on Exhibit III-16. As can be seen in the exhibit, the Statewide Survey indicated much sharper peaks than the Cal-B/C development team estimated using the traffic census data. The difference in these lines illustrates the differences in demand versus actual travel. Actual travel during peak period is less than demand due to loss of productivity during congestion, which results in peak period spreading.

The Cal-B/C development team conducted the same analysis for small urban area freeways, as defined by the Departmental FUNC coverage. Exhibit III-17 shows these results. Data for a “Central Coast” region is available for freeways in this category. As can be seen in Exhibit III-17, the double hump pattern found in the travel survey data emerged for these areas, although the peaks are still less than the travel survey would suggest, particularly for the morning peak period.

**Exhibit III-17: Percent Daily “Small Urban” Freeway Traffic by Hour by Region**

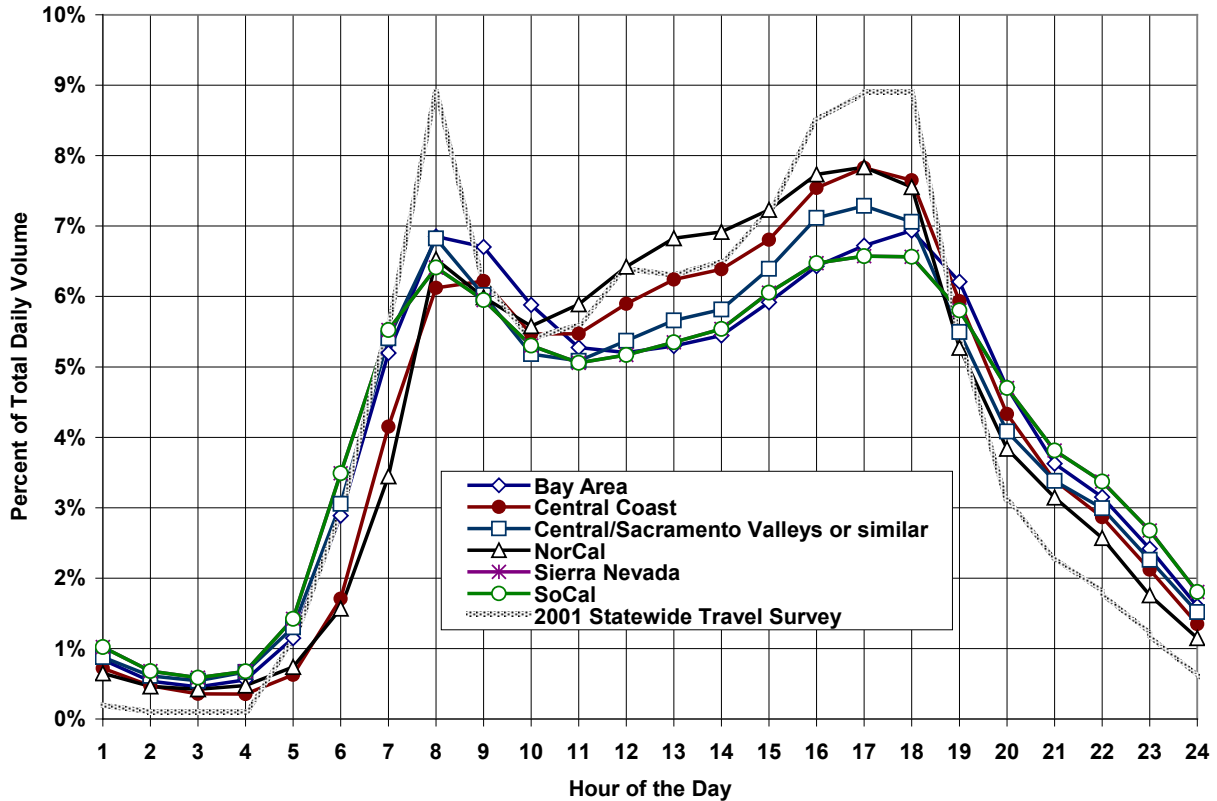


Source: SMG Analysis of Traffic Census data.

Exhibit III-18 shows similar information for urban freeways, as defined by the Departmental FUNC coverage. In this graph, the peaks become more pronounced and begin to approximate the profile found in the Statewide Travel Survey. However, there are differences between the actual traffic volume data and demand reported in the travel survey, as well as differences in traffic volumes among the regions.

Travel during the morning peak period is more diffused than the Statewide Travel Survey suggests. While the Statewide Travel Survey shows morning travel concentrated around 8 AM, travel census data suggest that the morning peak spans 7 AM through 9 AM. This may indicate that travel has changed since the survey, but more likely, the difference reflects three factors.

### Exhibit III-18: Percent Daily "Urban" Freeway Traffic by Hour by Region



Source: SMG Analysis of Traffic Census data.

The first factor is that Exhibits III-16 through III-18 show year round information (i.e., weekdays and weekends), while the Statewide Travel Survey describes only weekday behavior. The inclusion of weekend data is necessary, because Cal-B/C estimates annual benefits. However, it is interesting to note that plotting the data for weekdays only (not shown in the exhibits) increases the peaks, but not to the levels suggested by the Statewide Travel Survey.

This leads to a second factor - a potential shortcoming in stated preference surveys. People are more likely to state their desire to travel at 8 AM and forget about little (non-work) trips during the day. Since the traffic census data show patterns closer to those found in the 1991 Statewide Travel Survey, this might also indicate a problem in the design of the 2001 survey. The third factor is the reduction in productivity due to congestion discussed earlier.

Exhibit III-18 also highlights the variations in urban freeway travel patterns among regions. The rural area peaks are less pronounced than those found in the San Francisco Bay Area. The peaks for Southern California are also less defined, but this may be due to another trend; as highways in Southern California become "hyper-congested," some peak period travel is shifting to the peak period shoulders and midday, which reduces the height of the peaking.

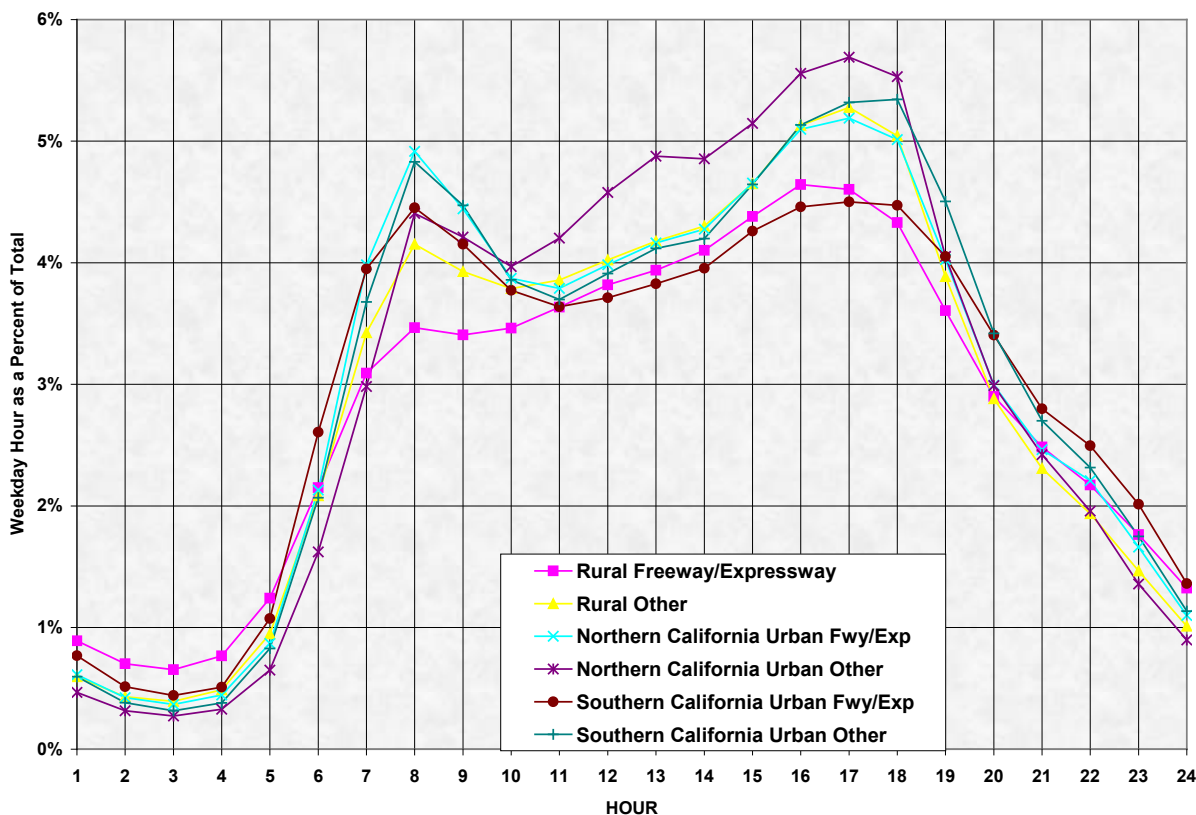


The charts for other state routes and arterials are not shown in this technical documentation, but the Cal-B/C development team conducted the same analysis for each roadway classification. On the basis of these analyses, the Cal-B/C development team decided to limit the roadway classification categories for Cal-B/C to “Freeway/Expressway” and “Other State Highway.”

The Cal-B/C development team also decided to combine the geographic areas, so only three areas are included in the model: Urban Northern California, Urban Southern California, and Rural. For consistency, these geographic categories correspond to the geographic areas used for calculating emissions analysis. The small urban area category was grouped into the two urban categories because the peaking characteristics were very similar for the two geographic areas.

Exhibit III-19 shows the results of this analysis. This exhibit plots the percent of traffic that occurs during each average weekday hour. The Cal-B/C development team plotted separate curves for the six combinations of roadway classification and geographic area. As shown in the exhibit, the patterns vary for each time of day grouping. The exhibit compares weekday travel to a “typical day” to account for the differences in weekday and weekend travel. This adjustment is described further below.

**Exhibit III-19: Hourly Weekday Traffic as a Percent of Traffic for a Typical Day**



The Cal-B/C development team grappled with how to include weekend data. Cal-B/C multiplies ADT for a typical day by 365 days to estimate total annual travel. However, the time-of-day travel patterns vary by day of the week. After summing all traffic counts, the Cal-B/C development team found that weekday travel comprises roughly 70 percent of travel, while weekend travel accounts for the other 30 percent.

The Cal-B/C development team was ready to assume that peak hours (and congestion) generally occur on weekdays, but decided to test this assumption. The Cal-B/C development team summed traffic counts for weekdays by hour, and divided that total by the total weeklong traffic counts. The Cal-B/C development team conducted the same summation for weekends, for 48 categories (24 hours × weekday versus weekend).

When the Cal-B/C development team sorted the percent of total for these categories, the team found that no weekend hours ranked above a position of 16. This is because weekend counts never make up more than 36 percent of the total, even in rural areas. The Cal-B/C development team concluded that the most congested periods occur on average during weekdays, so the weekends could be ignored.

The Cal-B/C development team planned to use traffic census data to develop lookup factors for the peak period. However, as discussed earlier in this section, the traffic census data produces substantially lower peaking than the demand data from the statewide travel demand survey. Since the BPR curves are functions that convert demand into speeds, the appropriate input data are demand rather than actual traffic volumes impacted by productivity losses and peak period spreading.

Exhibit III-20 shows the lookup table included in Cal-B/C for estimating the percent of total weekday travel. This table was developed using the weekday travel report data shown in Table 23 of the 2000-2001 Statewide Travel Survey. The lookup table shows the cumulative percentage of weekday travel by the number of hours in the weekday peak period. Since the survey data (shown in Exhibit III-14) total to 103.3 percent, the lookup table in Cal-B/C normalizes the percentages to 100 percent.

It is evident from the traffic census data that travel patterns vary by road type and location in state. The Statewide Travel Survey does have information by MPO and combined rural areas, but unlike the traffic census data, the Statewide Travel Survey does not distinguish by road type. As a matter of policy, the Department decided use a single set of factors for all locations in the state. Cal-B/C retains separate columns for three locations and two road types in case the Department chooses to make distinctions in the future.



**Exhibit III-20: Weekday Travel as a Percent of Total Weekday Travel**

Number of Hours in Weekday Peak Period	Southern California Urban Fwy/Exp	Southern California Urban Other	Northern California Urban Fwy/Exp	Northern California Urban Other	Rural Fwy/Exp	Rural Other
1	8.6%	8.6%	8.6%	8.6%	8.6%	8.6%
2	17.2%	17.2%	17.2%	17.2%	17.2%	17.2%
3	25.8%	25.8%	25.8%	25.8%	25.8%	25.8%
4	34.1%	34.1%	34.1%	34.1%	34.1%	34.1%
5	41.0%	41.0%	41.0%	41.0%	41.0%	41.0%
6	47.3%	47.3%	47.3%	47.3%	47.3%	47.3%
7	53.5%	53.5%	53.5%	53.5%	53.5%	53.5%
8	59.6%	59.6%	59.6%	59.6%	59.6%	59.6%
9	65.6%	65.6%	65.6%	65.6%	65.6%	65.6%
10	71.1%	71.1%	71.1%	71.1%	71.1%	71.1%
11	76.5%	76.5%	76.5%	76.5%	76.5%	76.5%
12	81.7%	81.7%	81.7%	81.7%	81.7%	81.7%
13	86.9%	86.9%	86.9%	86.9%	86.9%	86.9%
14	89.9%	89.9%	89.9%	89.9%	89.9%	89.9%
15	92.7%	92.7%	92.7%	92.7%	92.7%	92.7%
16	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%
17	96.7%	96.7%	96.7%	96.7%	96.7%	96.7%
18	97.9%	97.9%	97.9%	97.9%	97.9%	97.9%
19	98.9%	98.9%	98.9%	98.9%	98.9%	98.9%
20	99.5%	99.5%	99.5%	99.5%	99.5%	99.5%
21	99.7%	99.7%	99.7%	99.7%	99.7%	99.7%
22	99.8%	99.8%	99.8%	99.8%	99.8%	99.8%
23	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%
24	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

*Revision Made to Cal-B/C: adopted a new lookup table based on the 2000-01 Statewide Travel Survey with the same values for Freeway and Expressway roadway classifications and Urban Northern California, Urban Southern California, and Rural designations.*

## 2.5 Capacity per Lane (general)

Capacity per lane is one of several parameters that affect speed calculation using BPR curves. The Cal-B/C development decided to review the capacity per lane used for general purpose lanes as well as HOV lanes. This section describes the findings for general purpose lanes, while HOV lanes are described in the next section.

The prior version of Cal-B/C set the capacity per lane at 2000 vehicles per hour per lane (vphpl), which is a standard engineering value. Some districts use a higher capacity for operational analyses. For example, District 4 (the San Francisco Bay Area) has used 2200 vphpl for calculations in the Highway Congestion Monitoring Program (HICOMP) report for many years. According to data found in PeMS, automatic sensors have recorded sustained free-flow traffic volumes as high as 2600 vphpl on some highway segments in Southern California. Such differences are largely due to the traffic characteristics and geometry of each segment. In our meeting about the Corridor Mobility Improvement Account (CMIA) analysis, stakeholders suggested that the capacity parameter should be modified for particular segments given these variations.

As a matter of policy, the Department has decided that Cal-B/C should not use a different capacity number for different parts of the state. Cal-B/C uses a standard parameter to ensure that the interim highway speed calculation is consistent across projects. If users believe that the speed estimates are incorrect for a particular project, they should override the speeds with accurate speed data rather than adjust the per lane capacity. However, it is worth considering different capacity parameters for different highway types. This option is explored further below.

Dowling (1997) notes in NCHRP 387 that practitioners do not realize that the “capacity” in the standard BPR curve is actually “practical capacity,” which he suggests is approximately 80 percent of the actual capacity of the facility. Based on this discussion, Dowling provides a lookup table that provides the following ranges of practical capacities for the BPR curve:

- Freeways – 1750 vphpl
- Expressways – 800 to 1100 vphpl
- Arterials – 550 to 900 vphpl.

The freeway practical capacity corresponds to roughly 80 percent of an actual capacity of 2200 vphpl, which is the actual capacity used in District 4.

According to ICF Consulting (2004), the TTI method for speeds estimation uses default values from the 1994 HCM for roadway capacity. For interstates, the TTI method uses a default capacity of 2200 vphpl. For freeways, the method uses a default capacity of 2100 vphpl. The distinction between interstates and freeways might be meaningful in other states, but this distinction is not useful for Cal-B/C given the designations in California. The Transportation System Network (TSN) codes both types of roadways as freeways

in the highway database. California State Highways designated as interstates do not necessarily have higher capacities than other freeways.

For other classes of roadways, the TTI method estimates functional roadways using the traffic control capacity formulas in HCM. These formulas are not reproduced in this technical documentation, because they can be readily accessed in the HCM or the ICF Consulting report. The formulas take into account factors, such as effective green time ratios, lane widths, heavy vehicles, turning lanes, parking, and buses. While the equations should be applied using local estimates of the parameters, the TTI method provides a table of default vphpl capacities, which are shown in Exhibit III-21. The roadway facilities are grouped in the table by HPMS functional classification.

**Exhibit III-21: Default Hourly Capacities Used in TTI Speed Estimation Method**

HPMS Area Type	Interstate	Freeway	Other Principal Arterial	Minor Arterial	Major Collector	Minor Collector	Local
Rural	2200	2100	1003	920	836	669	502
Small Urban	2200	2100	878	805	732	585	439
Urban	2200	2100	673	673	561	448	336

*Source: ICF Consulting, Regional Emissions Analysis in Small Urban and Rural Areas, Final Report, prepared for the Federal Highway Administration, United States Department of Transportation, October 18, 2004.*

ICF Consulting (2004) also documents the capacity equations used in the HCM. The authors note that these equations are usually impractical to apply in a regional planning model and that most regions use a look-up table in lieu of the equations. The report includes the practical capacity table provided in NCHRP 387 as an example of a look-up table. The values from this table are reported in the bullets on the previous page.

On the basis of this research, the Cal-B/C development team decided to adopt separate capacities for freeways/expressways and other roadway types. These capacities are summarized earlier in this technical documentation in Exhibit III-12. The 800 vphpl may be low for some rural conventional highways and should be adjusted to 1000 vphpl.

The model selects the appropriate capacity for the no-build and build cases separately. These are shown on the parameters page of the model and can be adjusted for specific operational situations. For example, improvements due to shoulder widening can be captured by adjusting highway capacities using factors from the Highway Capacity Manual.

*Revision Made to Cal-B/C: retained the 2000 vphpl capacity for freeways and expressways and used 800 vphpl for other roadway types*

## 2.6 Capacity per HOV Lane

The prior version of Cal-B/C uses the same capacity per lane for HOV lanes (2000 vphpl) as it does for general purpose lanes. Some Cal-B/C users suggested using 1500 vphpl, because this is the threshold the Department uses for considering changes to HOV lanes (i.e., adding HOV lanes or converting them to an HOV 3+ restriction). Cal-B/C had earlier used a 1500 vphpl capacity for HOV lanes, but this was changed to 2000 vphpl for consistency with other lanes.

Chapter V on HOT lanes explores the HOV lane capacity issue extensively. Briefly, after synthesizing the HOT lanes research, the Cal-B/C development team decided to use a lane capacity of 1600 vphpl for HOV and HOT lanes in the BPR curves. The Cal-B/C development team also adopted new “a” and “b” BPR parameters for HOV and HOT lanes to be consistent with empirical data. As with the general purpose lanes, the “a” and “b” parameters were added to the Parameters page of Cal-B/C. More details about the values adopted are in the HOT lane chapter.

*Revision Made to Cal-B/C:* changed the HOV and HOT lane capacity to 1600 vphpl and included new “a” and “b” parameters for HOV and HOT lanes in the Parameters page

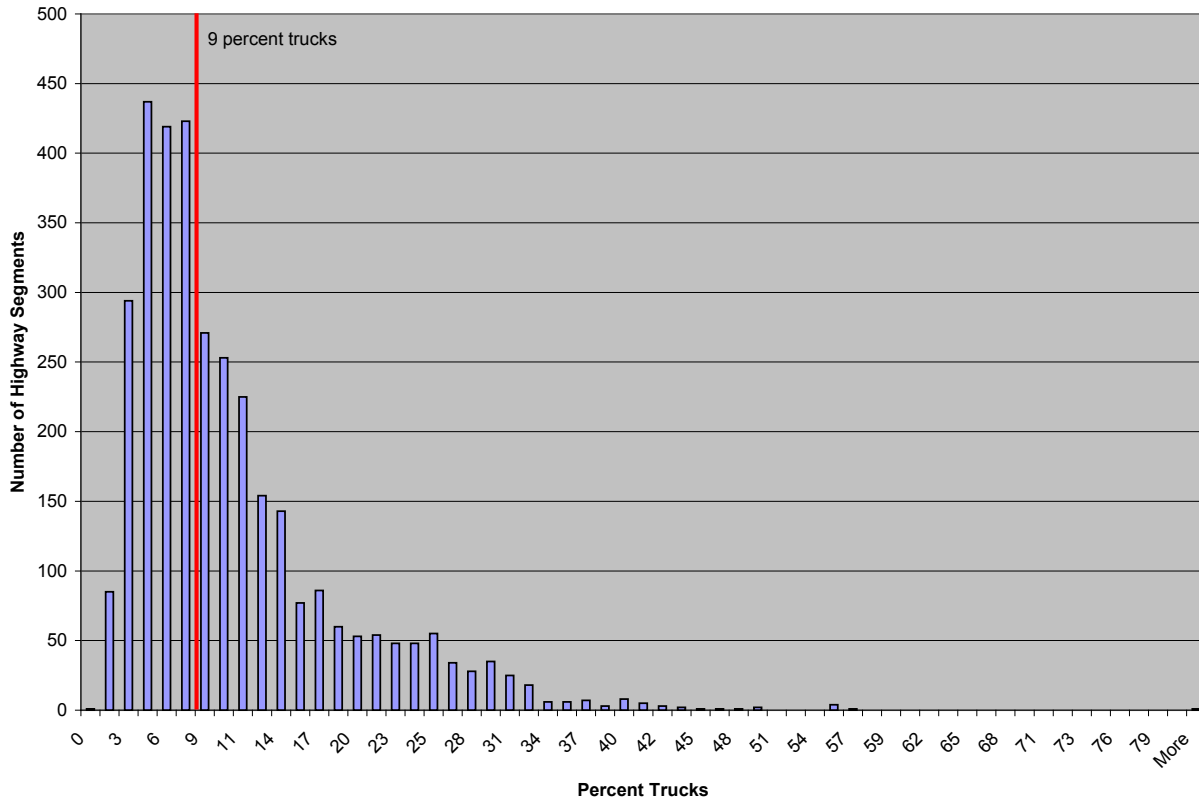
## 2.7 Percent Trucks

Cal-B/C uses the percent trucks to estimate the ADT associated with trucks. This is important for travel time calculations, which require a different value for trucks. It is also important for vehicle operating cost and emissions calculations, which use different factors for each vehicle class. In addition, the percent trucks parameter is used to determine the amount of slow-moving traffic for passing lane and truck climbing projects.

The latest version of Cal-B/C retains the statewide default value of 9 percent trucks, because Departmental statistics suggest the default is still valid. According to the “California State Highway System: Truck Miles of Travel, 1989 to 2004” published in August 2006 by the Division of Transportation System Information, there were 44.705 million daily truck miles traveled in 2004. (All trucks include 2+ axles.) This is approximately 9 percent of the 493.573 daily vehicle miles traveled in 2004 for all vehicles.

The Department has not updated the Truck Miles of Travel reference since the 2009 update to Cal-B/C. As part of the most recent update, the Cal-B/C development team reviewed the 2009 counts published by the Traffic Census program. To get an accurate estimate of the percent trucks, the truck percentage at each section should be weighted by the length and ADT in each section. The section lengths were not readily available, so the Cal-B/C development team estimated a simple average and median. These were roughly 9 to 10 percent. However, as shown in Exhibit III-22, the percentage of trucks varies considerably among highway segments.

**Exhibit III-22: Distribution of the Percent Trucks on California State Highways**



Source: SMG analysis of 2009 Traffic Census data

The Cal-B/C development team decided to retain the 9 percent truck default in Cal-B/C. However, users are encouraged to enter the appropriate percent trucks for the highway section under analysis.

*Revision Made to Cal-B/C: retained default of nine percent trucks*

**3.0 TRAVEL TIME PARAMETERS**

USDOT provides guidelines for valuing travel time in economic analyses. At the time of the 2009 Cal-B/C update, USDOT had revised its guidelines only once (in 2003) since making its first recommendations in a 1997 memorandum. USDOT recently updated the value of time guidance in a September 28, 2011 memorandum.

The latest memorandum retains the same general structure of the previous USDOT guidelines. However, the new memorandum provides references to consistent and easily available sources for estimating wages and the value of time. The latest update to Cal-B/C estimates travel time parameters following an approach consistent with previous versions of Cal-B/C, but using sources consistent with the recent federal

guidance. This section provides the discussion associated with the 2009 update as background as well as the calculation of parameters for the most recent update.

In addition to the values provided in previous guidance, the new USDOT guidance suggests that the value of time changes over the years due to increasing labor productivity. A benefit-cost analysis could use a different value of time for each year of the analysis. USDOT suggests increasing the value by 1.6 percent per year. The 2009 update to Cal-B/C adds a travel time “uprater” or escalation factor to allow the value of time to change. However, the default for this parameter is set to 0 percent, so the value of time does not change during a typical benefit-cost analysis.

In its original and revised recommendations, USDOT distinguishes among three types of automobile travel: 1) local personal travel, 2) intercity personal travel, and 3) business local and intercity travel. USDOT recommends using 50 percent of the wage rate for local personal travel, 70 percent for intercity personal travel, and 100 percent for business travel (on both local and intercity trips). While this may suggest adopting a higher ratio to the wage rate (Cal-B/C uses 50 percent), it is worth noting that business and intercity comprise relatively small portions of travel.

The current USDOT memorandum cites the 2001 National Household Travel Survey, which shows that 4.6 percent of local travel and 21.4 percent of intercity travel are for business. Intercity travel probably comprises a small amount of overall travel on most urban State Highways. State Highways in rural areas may have higher proportions of intercity travel, but the Department adopts a single value of time for automobiles as a matter of policy. For these reasons, the Cal-B/C development team chose to retain 50 percent of wage as the value of time for automobiles.

In the 2003 guidelines, USDOT calculates the local travel value using household income data from the 2000 Census. The intercity and business values are from total compensation cost per hour worked reported in the Bureau of Labor Statistics (BLS) Employer Costs for Employee Compensation (ECES), which is part of the National Compensation Survey (NCS). The 2011 guidelines update the Census data to the 2009 Census estimates of median household income and the intercity and business values to BLS Occupational Employment and Wage Estimates. The Cal-B/C development team cannot determine why USDOT chooses to: 1) use household income rather than income by individual for the local travel value estimate, and 2) use a different source from the BLS Occupational Employment and Wage Estimates.

For truck travel, USDOT recommends using 100 percent of the wage rate for full-time operators in Transportation and Material Moving occupations. Like Cal-B/C, USDOT includes fringe benefits. In the 2003 guidelines, USDOT calculates the value of time for trucks using wages from BLS Employment and Earnings and fringe benefits from BLS ECES. The 2011 guidelines make the sources consistent with intercity and business travel. The new guidelines use the BLS Occupational Employment and Wage Estimates

and take a weighted average of the median hourly wages for heavy-truck drivers and light-truck drivers.

There are three primary sources of wage data available from the Federal government. Exhibit III-23 compares these sources, as they existed in the 2009 Cal-B/C revision. USDOT used the first source, the National Compensation Survey (NCS), for its value of time calculations in its 2003 guidance, but state-level data are not available from the NCS. The second source, the Occupation Employment Statistics Survey (OES) is comparable to the NCS. BLS now calls this survey the Occupational Employment and Wage Estimates. USDOT uses this source in its 2011 guidelines. Cal-B/C used the third source, the Quarterly Census of Employment and Wages (QCEW) for its value of time calculations prior to the 2009 revision to Cal-B/C. The values shown in Exhibit III-23 are from the 2009 revision and not updated to 2011 values.

**Exhibit III-23: Comparison of Federal Sources for Wage Data  
(from 2009 Cal-B/C Revision)**

Aspect	National Compensation Survey (NCS)	Occupation Employment Statistics Survey (OES)	Quarterly Census of Employment and Wages (QCEW)*
Agency	Bureau of Labor Statistics	Bureau of Labor Statistics	Bureau of Labor Statistics
Strengths	Personal visits, more levels of work, obtains works schedules	Larger survey, more occupations, includes federal civilian employment	Includes 99.7% of all wage and salary civilian employment, subject to UI
Geographic Locations	Nation, Census divisions, metro areas	Nation, states, metro areas	Nation, states, counties, core based statistical areas (CBSAs)
Relevance	Used for USDOT Value of Time	Comparable to NCS, but available by state	Used for Cal-B/C Value of Time
Source	National Compensation Survey: Occupational Wages in the Pacific Census Division, June 2005	May 2006 State Occupational Employment and Wage Estimates - California	Private industry by State and six-digit NAICS industry: Establishments, employment, and wages, 2005 annual averages
00-0000 All Occupations	Total Mean Hourly Earnings - \$20.83 Total Mean Weekly Hours – 35.4	Median Hourly - \$16.37 Mean Hourly - \$21.24 Mean Annual - \$44,180	Annual wages per employee - \$45,684 Average weekly wage - \$879

Aspect	National Compensation Survey (NCS)	Occupation Employment Statistics Survey (OES)	Quarterly Census of Employment and Wages (QCEW)*
53-0000 Transportation and Material Moving Occupations	Total Mean Hourly Earnings - \$16.00 Total Mean Weekly Hours – 37.4	Median Hourly - \$11.81 Mean Hourly - \$14.12 Mean Annual - \$29,360	
Truck Drivers	Total Mean Hourly Earnings - \$15.69 Total Mean Weekly Hours – 39.0		
53-3032 Truck Drivers, Heavy and Tractor-Trailer		Median Hourly - \$18.05 Mean Hourly - \$18.51 Mean Annual - \$38,500	
53-3033 Truck Drivers, Light or Delivery Services		Median Hourly - \$12.39 Mean Hourly - \$13.18 Mean Annual - \$27,410	
48-49 Transportation and warehousing			Annual wages per employee - \$41,605 Average weekly wage - \$800
484 Truck transportation			Annual wages per employee - \$39,153 Average weekly wage - \$753

\* Formerly called Covered Employment and Wages program

In response to the revised 2011 USDOT guidance, the Cal-B/C development team decided to update all time values using data from the Occupational Employment and Wage Estimates (i.e., OES Survey). Using a single source makes the values of time for automobile and truck travel more consistent. The occupational focus of the OES also allows the truck driver wages to capture truck driver compensation regardless of industry. As the 1997 Transportation Satellite Accounts (TSA) reveal, many industries rely on a considerable amount of in-house truck transportation. Using wages from only the Transportation and Warehousing industry (as in previous versions of Cal-B/C) ignores the wages paid in other industries. Likewise, the latest update shifts the estimation of fringe benefits for truck drivers from an industry-based approach to an occupational approach.



The Cal-B/C development team used the following information for updating the values of time to 2011 dollars:

- **Statewide Average Hourly Wage:** According to the OES Survey, the mean hourly wage for California workers in all occupations was \$24.39 in May 2010. The BLS Employment Cost Index historical listing (Table 6) provides current dollar indices (114.5 in June 2011 and 111.5 in June 2010) for private industry workers in the Pacific Census region, which can be used to estimate 2011 wages ( $\$24.39 \times 114.5 / 111.5 = \$25.05$ ). Cal-B/C includes this new hourly wage rate, resulting in a value of time for automobile and in-vehicle transit travel of \$12.50 (i.e., half of the wage rate rounded to the nearest 5 cents).
- **Heavy and Light Truck Driver Average Hourly Wage:** According to the OES Survey, the mean hourly wage for 115,640 Heavy and Tractor-Trailer Truck Drivers (Occupation 53-3032) in California was \$20.03 in May 2010. The mean hourly wage for 90,750 Light Truck or Delivery Services Drivers (Occupation 53-3033) in California was \$16.42. After taking the weighted average using the number of employees in the two occupations  $[(\$20.03 \times 115,640 + \$16.42 \times 90,750) / (115,640 + 90,750)]$ , the average hourly rate is \$18.44. Adjusting to 2011 wages using the BLS Employment Cost Index ( $\$18.44 \times 114.5 / 111.5$ ) results in wages of \$18.94.
- **Heavy and Light Truck Driver Fringe Benefits:** According to the BLS Employment Cost Index historical listing (Table 1), the total compensation per hour worked for civilian workers in the Production, Transportation, and Material Moving occupations is \$24.20 nationally. Of this total, \$15.96 is for wages and salaries, while \$8.25 is for total benefits. To estimate the fringe benefits of California truck drivers (\$9.78), the ratio of total compensation to wages and salaries is estimated ( $\$24.20 / \$15.96 - 1$ ) and applied to the average hourly wage (\$18.94). This is a standard approach for estimating the value of benefits in human resources. Adding the benefits to wages yields a total compensation of \$28.72 per hour.
- **Value of Time for Truck Travel:** The value of time for truck travel is estimated as 100 percent of the total compensation for truck drivers (\$28.72). Beginning with the 2009 revision, the Cal-B/C development is ignoring the value of cargo when estimating the value of time for truck travel. This is consistent with USDOT guidance and compatible with potential future approaches for estimating the value of economic productivity in the Cal-B/C framework. After rounding to the nearest 5 cents, the value of time for truck travel is \$28.70.

- Composite Value of Time: Although Cal-B/C uses separate values of time for automobiles and trucks, the Department is asked occasionally to provide a composite value (e.g., in the HICOMP report) that includes automobiles and trucks. Using the default of 9-percent trucks and accounting for average vehicle occupancy of 1.3 in automobiles results in a composite value of time equal to \$17.35.

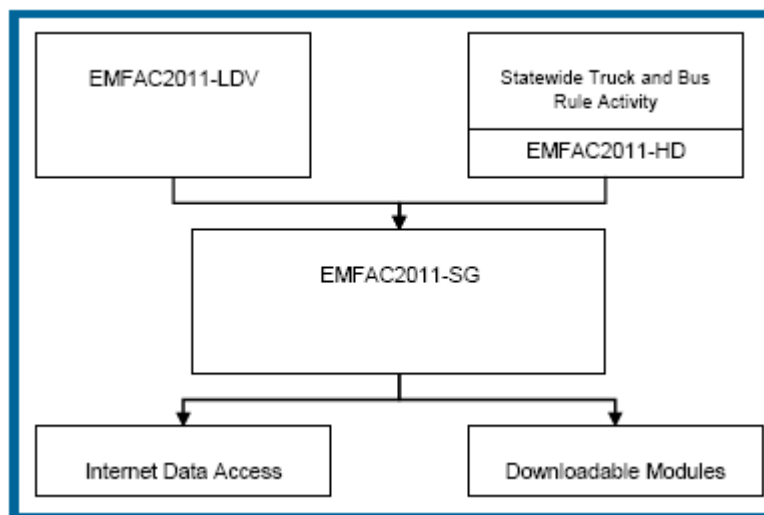
*Revision Made to Cal-B/C: Used \$12.50 for the value of time for automobiles and in-vehicle transit travel, \$28.70 for trucks, and \$17.35 as the composite value of truck and automobile travel*

## 4.0 VEHICLE OPERATING COST PARAMETERS

### 4.1 Fuel Consumption

To be consistent with the emissions factors for Cal-B/C, the development team estimated fuel consumption rates using data from the EMFAC2011 model. The California Air Resources Board (CARB) recently updated EMFAC from the previous version, EMFAC2007. This revision is more extensive than previous revisions and takes into account on-road diesel fleet rules, Pavley Clean Car Standards, and the Low Carbon Fuel Standard. As shown in Exhibit III-24, the new EMFAC2011 consists of a series of models to estimate automobile and truck emissions factors.

**Exhibit III-24: EMFAC2011 Schematic**



*Source: California Air Resources Board, EMFAC2011 Technical Documentation, September 19, 2011.*

EMFAC2011-LDV is similar to the prior EMFAC2007 model and uses the same algorithms for passenger cars. This module estimates emissions from gasoline-powered

vehicles, diesel vehicles below 14,000 pounds gross vehicle weight ratings, and urban transit buses.

EMFAC2011-HD is a new component of EMFAC2011. This module estimates emissions estimates for diesel trucks and buses with gross vehicle weight ratings greater than 14,000 pounds. The data are based upon the Statewide Truck and Bus Rule emissions inventory approved by the CARB in December 2010.

EMFAC2011-SG is another new component. This module summarizes the results from the other two modules. The results can be used by transportation planners for air quality conformity analysis. Basic emissions and emissions rates are also available via internet access from CARB. More information on the modules and rates are available in the EMFAC2011 technical documentation.

The Cal-B/C development team estimated fuel consumption curves for both automobiles and trucks. The curves are consistent with prior versions of Cal-B/C. Buses, which account for a small amount of the total vehicle travel in EMFAC, are not included in either fuel consumption curve. To estimate fuel consumption in all years of the benefit-cost analysis, Cal-B/C uses a single set of fuel consumption parameters that average figures for 2011 and 2031.

CARB estimates emissions consistent with the Pavley Clean Car Standards and the Low Carbon Fuel Standard outside EMFAC and does not directly estimate the impacts on fuel consumption. As a result, EMFAC2011 produces very similar fuel consumption figures for both 2011 and 2031. The use of a single fuel consumption curve for all years may exaggerate fuel consumption impacts slightly in later years. However, the effect depends on the reaction of vehicle manufactures to fuel efficiency standards and consumer adoption of more efficient conventional and hybrid vehicles.

Cal-B/C uses a single set of fuel consumption parameters statewide. Idling fuel consumption cannot be extracted from the EMFAC2011-LDV Burden mode, so Cal-B/C uses fuel consumption factors for 5 mph as an approximation.

## **4.2 Fuel Costs**

Cal-B/C estimates fuel costs by multiplying the fuel consumption in gallons by the average fuel cost per gallon. The resulting figure represents the out-of-pocket fuel costs paid by consumers. The fuel cost calculation in Cal-B/C excludes federal, state, and local taxes. These taxes are transfer payments and user fees used to fund transportation improvements.

The structure of transportation taxes is complicated in California. The Economic Analysis Branch publishes annual funding charts that provide detailed information on the sources and distribution of transportation funding in California. A broad overview

of these sources is provided below, but detail can be found in *Transportation Funding in California*.

Fuel-related taxes can be broken into three components:

- Federal fuel excise taxes
- State fuel excise taxes
- State and local sales taxes.

The Internal Revenue Service (IRS) collects the federal fuel excise tax (18.4¢ per gallon tax on gasoline and 24.4¢ per gallon tax on diesel fuel). These taxes are deposited in the Highway Trust Fund (HTF). About 85 percent of HTF revenues go to the Highway Account and is apportioned among the states by the Federal Highway Administration (FHWA) as matching funds for projects on the State Highway System. The remaining 15 percent of revenues go to the Transit Account. The Federal Transit Administration (FTA) allocates these funds to regional agencies and local transit providers.

California allocations do not necessarily correspond to payments. The GAO report *Trends in State Capital Investments in Highways* (GAO 1998) provides historical information on allocation to payment ratios by state. There are additional taxes on special fuels (e.g., liquefied natural gas, M85, compressed natural gas, etc.). However, Cal-B/C does not consider these taxes in estimating fuel costs because they are minor for automobile and truck users.

In 2010, the California Legislature enacted a “Fuel Tax Swap” that fundamentally changed the regime of California fuel excise taxes. Prior to the Fuel Tax Swap, the State levied the same excise tax (18¢ per gallon) on gasoline and diesel fuel. The Fuel Tax Swap lowered the sales and use tax rate applicable to gasoline, while raising the state excise tax on gasoline. In essence, state gasoline sales tax revenues were “swapped” for an increased state excise tax. The same legislation raises the sales tax rate on diesel fuel, while simultaneously lowering the state excise tax on diesel fuel. Cal-B/C was adjusted to accommodate differential rates for the two types of fuel.

The State Board of Equalization (BOE) is required to adjust the excise tax rates for gasoline and diesel fuel annually so that the total revenue generated is equal to what would have been generated under the old rates. In this way, the Fuel Tax Swap is revenue neutral. Effective July 1, 2010, the gasoline excise tax increased by 17.3¢ per gallon. As a result, the State of California currently collects 18¢ per gallon excise tax on gasoline plus an additional 17.3¢ per gallon for a combined rate of 35.3¢ per gallon on gasoline.

The Fuel Tax Swap lowered the excise tax on diesel to roughly 13¢ per gallon. This rate will change over the next few years, but the expected change in the excise tax is considerably less than the variation in the price of diesel fuel. Cal-B/C uses the 13¢ per gallon to calculate the fuel costs for trucks.

The Fuel Tax Swap also charged sales tax on gasoline and diesel fuels. On July 1, 2011, sales taxes on diesel fuel increased by 1.87 percent and the excise tax decreased – to ensure local transit operators received State Transit Assistance funding. The current sales tax rate on diesel is the basic 7.25 percent sales tax plus the 1.87 percent surcharge as part of the gas tax swap.

For gasoline, the Fuel Tax Swap lowered the sales tax. The basic California sales tax includes a 5-percent allocation to the State Retail Sales Tax Fund, a 2-percent allocation to local general funds, and a 0.25-percent allocation to Local Transportation Funds (LTF). The gas tax swap eliminated the 5-percent retail sales tax on gasoline, but the other 2.25 percent remains.

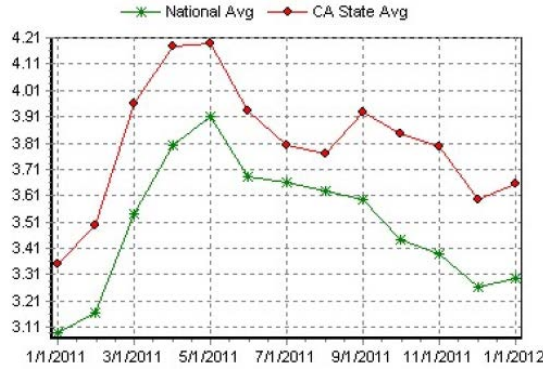
In addition to these taxes, a number of counties have imposed county transportation sales tax measures, which include both transit districts and general transportation measures (“self help”). *Transportation Funding in California* provides a list of the current county transportation sales tax measures. County sales taxes are generally 0.5 percent, but Los Angeles imposes a 1.5-percent tax (1-percent permanent plus 0.5 percent temporary).

Roughly 75 percent of the state (based on population) is subject to these additional county sales tax measures. The combination of transit and “self help” taxes means that county sales taxes can range from 0.5 percent to 1.5 percent. Although a detailed analysis of sales taxes and payments by counties could be conducted using data from the California State Controller’s Office, the Cal-B/C development team decided to simplify the calculation and assume a uniform 0.5 percent county sale tax measure. As with the excise tax rates, the potential error in this assumption is much less than the annual variation in fuel prices.

The Cal-B/C development team used the American Automobile Association (AAA) Daily Fuel Gauge Report (<[fuelgaugereport.opisnet.com/CAavg.asp](http://fuelgaugereport.opisnet.com/CAavg.asp)>) as the source for fuel cost data. The Daily Fuel Gauge Report is AAA’s media website for retail gasoline prices. The report is updated daily using information from credit card transactions at more than 85,000 stations around the country. The data is provided by Oil Price Information Service (OPIS) in cooperation with Wright Express. According to the AAA website, OPIS wholesale rack prices are the industry benchmark.

The Cal-B/C development team gathered fuel prices from the AAA website on January 5, 2012. Exhibit III-25 shows how fuel prices have varied and generally increased over the previous year. Consistent with prior Cal-B/C updates, the Cal-B/C development team is used the average of two days (January 5, 2011 and January 5, 2012) to estimate fuel costs. However, as illustrated in Exhibit III-25, the price of unleaded gasoline was higher than the price on these two days for much of the year.

**Exhibit III-25: Twelve-Month Average of Unleaded Gasoline Prices**



Source: American Automobile Association, Daily Fuel Gauge Report, [www.fuelgauge.com/caavg.asp](http://www.fuelgauge.com/caavg.asp), accessed on January 5, 2012.

To account for the various tax changes associated with the Fuel Tax Swap, the Cal-B/C development team modified the model to include separate excise tax and sales tax parameters for gasoline and diesel fuel. For automobile fuel costs, the development team used the average of prices for regular unleaded gasoline (\$3.335 on January 5, 2011 and \$3.666 on January 5, 2012). For truck fuel costs, the Cal-B/C development team used the average of prices for diesel fuel (\$3.562 on January 5, 2011 and \$4.125 on January 5, 2012). The equations below show the calculation of fuel costs including the changes in applicable excise and sales taxes:

$$Fuel\ Cost = \left[ \frac{Two\ Day\ Average\ Price}{(1 + State\ Sales\ Tax + Average\ Local\ Sales\ Tax)} \right] - Federal\ Fuel\ Excise\ Tax - State\ Fuel\ Excise\ Tax$$

$$Automobile\ Fuel\ Cost = \left[ \frac{Average(\$3.335, \$3.666)}{1 + 2.25\% + 0.5\%} \right] - \$0.184 - (\$0.18 - \$0.173) = \$2.87\ per\ gallon$$

$$Truck\ Fuel\ Cost = \left[ \frac{Average(\$3.562, \$4.125)}{1 + (7.25\% + 1.87\%) + 0.5\%} \right] - \$0.244 - \$0.13 = \$3.13\ per\ gallon$$

Cal-B/C rounds these figures to \$2.85 and \$3.15, respectively. The model assumes that the gasoline fuel cost is applicable to automobiles and the diesel fuel cost is applicable to trucks.

Revision Made to Cal-B/C: included separate fuel costs for automobiles (\$2.85 per gallon) and trucks (\$3.15 per gallon)

### 4.3 Non-Fuel Costs

Cal-B/C estimates non-fuel costs as a fixed per-mile cost that includes oil, tires, maintenance and repair, and vehicle depreciation. Other costs, such as insurance and registration, are not included because their costs do not vary (or at least are not very sensitive) with vehicle mileage. Cal-B/C separates non-fuel costs from fuel costs to give users the ability to change fuel prices without having to re-estimate consumption rates.

As shown in Volume 1 of the Cal-B/C technical documentation, the research conducted for the initial version of Cal-B/C revealed that most benefit cost models use non-fuel costs based on a single report to the FHWA:

J.P. Zaniewski, et al., Vehicle Operating Costs, Fuel Consumption, and Pavement Type and Condition Factors, Texas Research and Development Foundation, June 1982.

As described further in Volume 1, the Cal-B/C development team found research suggesting that the Zaniewski et al. study did not provide accurate non-fuel cost estimates and decided to use STEAM's non-fuel cost estimates plus separate estimates of depreciation. The original automobile depreciation estimates were derived from a 1991 FHWA study by Jack Faucett Associates. The truck depreciation estimates were the result of personal communication with Paccar Inc., a very large truck manufacturer.

As part of the 2009 revision, the Cal-B/C development team conducted a brief review of documentation for other benefit-cost models. For example, Li (2006) provided a literature review on highway benefit-cost and tradeoff analyses for asset management investment decisions under risk and uncertainty. In a section on vehicle operating costs, Li documented the estimation methods for five models (including Cal-B/C), and shows that HERS and StratBENCOST are based on Zaniewski et al., while STEAM and Cal-B/C are based on a 1992 USDOT publication "Characteristics of Urban Transportation Systems." The review revealed that most models continue to base their estimates of non-fuel costs on the Zaniewski et al. This study is now over 25 years out of date.

STEAM has been updated since the original Cal-B/C model was developed. Appendix A of the user's manual for STEAM 2.0 provides documentation for the sources of the default values used in the new model. Unfortunately, the documentation is incomplete and does not list the source for non-fuel costs.

A review of the technical report for the Highway Economic Requirements System-State Version (HERS-ST v2.0), confirms that the non-fuel costs are still based on the Zaniewski et al. estimates. Exhibit III-26 reproduces the table of vehicle operating cost components in HERS-ST v2.0. As can be seen in the exhibit, the component prices are in 1997 dollars - over a decade old. The values for oil, tires, maintenance, and repair were estimated by updating the Zaniewski et al. estimates using the appropriate components

of the consumer price index (CPI). Depreciation was derived using data from the 1997 Federal Highway Cost Allocation Study, the Truck Blue Book, and the American Automobile Manufacturers Association's "Motor Vehicles Facts and Figures."

**Exhibit III-26: Component Prices for Estimating  
Vehicle Operating Costs in HERS-ST v2.0 (in 1997 dollars)**

Vehicle Type	Fuel (\$/gallon)	Oil (\$/quart) <sup>a</sup>	Tires (\$/tire)	Maintenance and Repair (\$/1,000 miles)	Depreciable Value (\$/vehicle)
Automobiles					
Small	\$0.871	\$3.573	\$45.2	\$84.1	\$18,117
Medium/Large	0.871	3.573	71.5	102.1	21,369
Trucks					
Single Units					
4 Tires	0.871	3.573	78.8	129.8	23,028
6 Tires	0.871	1.429	190.1	242.9	34,410
3+ Axles	0.762	1.429	470.7	343.5	75,702
Combination					
3-4 Axles	0.762	1.429	470.7	355.8	87,690
5+ Axles	0.762	1.429	470.7	355.8	95,349

a. The unit cost for oil includes the labor charge for changing the oil.

Source: Federal Highway Administration, *Highway Economic Requirements System - State Version: Technical Report*, US Department of Transportation, August 2005.

*Automobile Costs.* This review suggests that Cal-B/C could continue to use the original STEAM non-fuel cost estimates plus separate estimates of depreciation. However, a more current source is available. As shown in Volume 1 of the Cal-B/C technical documentation, the 1992 USDOT study (used as the source of non-fuel vehicle operating costs for the original STEAM model and Cal-B/C) is based on the American Automobile Association's (AAA's) publication "Your Driving Costs." AAA has published this pamphlet annually since 1950.

Runzheimer International currently collects the data for AAA. The methodology is proprietary and designed to model the average AAA member's use of a vehicle over five years of ownership and 75,000 miles of driving. While the pamphlet provides summary data, it also provides detailed driving cost estimates useful for Cal-B/C. The Cal-B/C development team used the 2011 AAA figures to be consistent with the other economic values in Cal-B/C.

Consistent with previous editions, the 2011 edition of "Your Driving Costs" includes the following costs:



- Operating Costs that are calculated on a per mile basis
  - Gas - Fuel costs are based on the AAA Fuel Gauge Report, the same source that Cal-B/C uses for its per-gallon fuel cost estimate. AAA estimates fuel mileage based on US Environmental Protection Agency (EPA) fuel economy ratings weighted 60 percent city and 40 percent highway driving.
  - Maintenance - Costs include retail parts and labor for routine maintenance, the price of a comprehensive extended warranty with one warranty deductible claim of \$100 and other wear-and-tear to be expected during the first five years of ownership. This cost estimate may underestimate costs for the overall vehicle fleet in California, because the average age of vehicles on the road is older than 2.5 years. The AAA maintenance costs also include sales tax on a national average basis. This component overestimates costs slightly, because some portion of sales taxes (as in the California self-help counties) is transfer payments for road repairs.
  - Tires - AAA bases the cost of tires on purchasing a replacement set of the same quality, size, and rating as the original tires. The cost includes mounting, balancing, and sales tax.
- Ownership Costs that are estimated on an annual basis (and, with the exception of depreciation, not applicable to Cal-B/C)
  - Full-coverage insurance - AAA estimated the costs of a full-coverage policy for a married 47-year old male with a good driving record, living in a small city, and commuting three to ten miles daily to work. This estimate is likely too low for urban California drivers who commute longer distances and face higher insurance premiums. Cal-B/C does not include these insurance costs, because they are not likely to vary with small mileage changes.
  - License, registration, and taxes - These costs include all government taxes and fees payable at the time of purchase as well as annual license and registration fees. Since the fees are not based on mileage, they are not applicable to Cal-B/C.
  - Depreciation - AAA bases its estimate of depreciation on the difference between purchase price and trade-in after five years of ownership. AAA uses typical driving of 15,000 miles for its

base estimate. However, AAA also provides estimates of the change in depreciation for 10,000 and 20,000 miles.

- Finance charges - These estimates are based on a five-year loan at six percent interest and a ten-percent down payment. These charges are not mileage-based and not applicable to Cal-B/C.

AAA was the original source for the automobile maintenance, repair, and tire costs in STEAM and Cal-B/C, so it makes sense to use estimates from the current publication. The original source of automobile depreciation (the Jack Faucett Associates estimates) is from 1991. Since AAA has more updated mileage-based depreciation estimates, the Cal-B/C development team now uses the AAA depreciation estimates for Cal-B/C.

AAA estimates driving costs for three categories of sedans (small, medium, and large) and an average of the sedan categories. AAA provides separate driving cost estimates for Sport Utility Vehicles (SUVs) and minivans, but these classes of vehicles are not included in the sedan average. The estimate for each category is a composite of the five top selling models. "Your Driving Costs" publication lists the five models used for each category. These models have not changed for several years.

The non-fuel costs in the latest update of Cal-B/C are based on the average of the three sedan categories:

- Maintenance - 4.44 cents per mile
- Tires - 0.96 cents per mile.

AAA does not provide an estimate of depreciation by mile. However, the change in depreciation can be estimated by comparing the 10,000 and 20,000 total miles per year to the 15,000 standard mileage:

- Decreased depreciation from 15,000 to 10,000 miles per year = \$257 annually or 5.14 cents per additional mile (\$257/5000 miles)
- Increased depreciation from 15,000 to 20,000 miles per year = \$196 annually or 3.92 cents per additional mile (\$196/5000 miles).

These two figures average to a depreciation of 4.53 cents per mile. This mileage-based depreciation is much lower than the depreciation estimated using the same methodology in 2007 (i.e., 18.3 cents per mile in 2007). Despite efforts to contact AAA, the Cal-B/C development team is unable to determine what caused this drop in rates.

As a result, the Cal-B/C development team has decided to adopt a simpler and more consistent method - dividing the depreciation at the 15,000 standard mileage by the mileage (\$3,728/15,000). This calculation results in depreciation of 24.85 cents per mile.

A review of “Your Driving Costs” from previous years suggests that this estimate is consistent over the years. The Cal-B/C development team plan to use this methodology in future years.

As a point of comparison, the Cal-B/C development team also reviewed the Internal Revenue Service (IRS) standard mileage rates. The IRS estimates these costs annually for taxpayers to calculate the deductible costs of operating an automobile for business. The standard mileage rate for business is based on an annual study of the fixed and variable costs of operating an automobile conducted by Runzheimer International for the IRS. The same contractor conducts the AAA study.

The 2012 IRS reimbursement rate is 55.5 cents per mile for business miles driven. This rate includes fuel costs in addition to the vehicle operating costs. For calculating the reduction in asset basis, the IRS estimates the portion of the business standard mileage rate treated as depreciation (i.e., 21 cents per mile for 2008, and 2009, 23 cents per mile for 2010, 22 cents per mile for 2011, and 23 cents per mile for 2012). These values are very similar to the 24.85 cents estimated from AAA.

Added to the earlier maintenance (4.44 cents) and tires estimates (0.96 cents), the new depreciation cost (24.85 cents) results in a non-fuel cost per mile of 30.3 cents per mile. This estimate includes only costs that vary by mile. Other fixed costs, such as insurance, license, taxes, and finance charges are excluded.

*Truck Costs.* AAA does not estimate the non-fuel costs incurred by light-duty and heavy-duty trucks. In addition, the Paccar estimates used in the original Cal-B/C model are not easily reproduced. So, a new source is needed for truck costs.

For the 2009 revision, the Cal-B/C development team updated truck costs using the values from an FHWA spreadsheet tool. These costs are based ultimately on the 1982 Zaniewski et al. estimates. Since the 2009 revision, the American Transportation Research Institute (ATRI - the research arm of the American Trucking Associations Federation) has conducted an analysis of the operational costs of trucking. The study uses costs derived directly from motor vehicle fleet operations. While higher than the estimates using the FHWA tool, the ATRI figures are direct from the trucking industry and better reflect current operating costs. While the ATRI figures will be used going forward, the section below described both the FHWA and ATRI methodologies.

The FHWA Office of Freight Management and Operations conducted a study of the benefits and costs associated with freight operations (FHWA 2008). Details of the study can be found on the FHWA website located at <[www.ops.fhwa.dot.gov/freight/freight\\_analysis/econ\\_methods](http://www.ops.fhwa.dot.gov/freight/freight_analysis/econ_methods)>. As part of the study, HDR | HLB Decision Economics Inc. developed a spreadsheet tool, called the “Highway Freight Logistics Reorganization Benefits Estimation Tool.” Most benefit-cost models (Cal-B/C included) focus on the first-order impacts, such as the immediate cost reductions to carriers and shippers as well as the gains to shippers from reduced transit times and increased

reliability. The new FHWA freight benefit-cost analysis (BCA) tool is intended to capture the second-order impacts in terms of reorganization-effect gains from improvements in logistics (assuming the quantity and quality of firms' outputs do not change).

The Cal-B/C development team decided not to add second-order benefits to Cal-B/C. However, the documentation for the freight BCA tool notes that the benefits may be added to benefit-cost analyses (as in Cal-B/C) that do not account independently for the value of improved freight management. The freight BCA tool does not appear to contain a feedback loop showing the impact of increased freight demand on the traffic operations (i.e., decreased speeds for other vehicles on the freight corridor), so it may overestimate the logistic benefits in the final equilibrium. This is unlikely to be a major factor for most corridors, except those with heavy truck traffic.

The assumptions used to estimate the first-order effects are directly relevant to updating the Cal-B/C economic parameters. The freight BCA tool relies primarily on unit estimates in HERS-ST, which are based on the 1982 study by Zaniewski et al. Since the FHWA Office of Freight Management and Operations recently looked at these values, the Cal-B/C development team decided to consider the values in the FHWA tool. The freight tool documentation refers to the 2002 HERS-ST documentation (FHWA, 2002). The Cal-B/C development team reviewed that documentation as well as the 2005 final documentation (FHWA, 2005).

As described in the technical documentation for the tool (HDR|HLB Decision Economics, 2008), the freight BCA tool simplifies the vehicle operating cost methodology for HERS-ST. The HERS-ST model estimates vehicle operating costs for constant speeds by vehicle type and applies adjustments to account for highway grade, highway curvature, and pavement condition. The freight BCA tool eliminates the adjustments for grade, curvature, and pavement condition to estimate vehicle operating costs on flat, straight sections of roadway with good pavement condition. This underestimates vehicle operating costs in "real-world" conditions.

The freight BCA tool has the ability to calculate aggregate vehicle operating cost (VOC) values and VOC by component. The Cal-B/C development team used these two functions to modify the VOC by component and calculate an aggregate value. The Cal-B/C development team also estimated vehicle operating costs externally to ensure that the values were consistent.

Consistent with HERS-ST, the freight BCA estimates vehicle operating costs for four separate cost categories (or components):

- Fuel
- Repair and Maintenance
- Tire Wear
- Mileage-Related Depreciation.

The Cal-B/C development team ignored fuel costs (i.e., set the value of fuel to \$0 in the freight BCA tool) to estimate non-fuel costs for Cal-B/C. The Cal-B/C development team provides detailed estimates for the remaining three components below.

The freight BCA tool uses the HERS-ST values (in 1997 dollars) for the average repair and maintenance costs. These values are multiplied by percentages to adjust for highway geometrics. The freight BCA tool calculates the percentage adjustments using the HERS-ST equations (documented in Appendix D of the HERS-ST technical documentation). Since the freight BCA tool assumes flat, straight roadway sections, the repair and operating costs are lower than average. The percentages in the freight BCA tool range from 62.2 to 68.1 percent. The Cal-B/C development team adjusted these to 100 percent (to account for average conditions) as shown in Exhibit III-27.

**Exhibit III-27: Truck and Maintenance Cost Estimate  
in Freight BCA Tool (in 1997 dollars)**

Ctrl+Shift+S for Single State Ctrl+Shift+M for Multiple States Select: <input checked="" type="radio"/> Single State <input type="radio"/> Multiple States		Clear ALL Inputs Ctrl+Shift+C to Clear All Inputs	Predefined Values	User Input	Value In Use
<b>2. Repair and Maintenance (\$ per 1000 miles)</b>					
Average Repair and Maintenance Cost per 1000 Miles					
4-Tire Truck	\$129.80		\$129.80	\$129.80	
6-Tire Truck	\$242.90		\$242.90	\$242.90	
3-4 Axle Truck	\$343.50		\$343.50	\$343.50	
4-Axle Comb.	\$355.80		\$355.80	\$355.80	
5-Axle Comb.	\$355.80		\$355.80	\$355.80	
Percent of Average Repair and Maintenance Cost per 1000 Miles					
4-Tire Truck	67.0%		\$1.000	100.0%	
6-Tire Truck	67.4%		\$1.000	100.0%	
3-4 Axle Truck	62.2%		\$1.000	100.0%	
4-Axle Comb.	62.2%		\$1.000	100.0%	
5-Axle Comb.	68.1%		\$1.000	100.0%	

Tire wear is a function of speed, grade, curvature, and pavement quality. The freight BCA tool uses a starting speed of 45 mph, which can be modified for specific projects. The Cal-B/C development team decided to use the 45 mph speed because this is a compromise between typical freeway speeds (55 mph) and arterial speeds (35 mph and less). The Cal-B/C development team tested the sensitivity of tire wear to speed and found that overall non-fuel VOC (tire wear plus the other components) varies less than 0.2 cents per mile between 45 mph and 65 mph. Tire wear increases for 35 mph (by 0.6 cents per mile) and 25 mph (by 1.8 cents per mile).

The freight BCA tool uses tire wear costs that are 1.1057 times greater than the base values in HERS-ST. The HERS-ST pavement adjustment equations show that this

corresponds to a “perfect” pavement rating (PSR = 5). The values used in HERS-ST correspond to an “average” pavement rating of PSR 4. Since the HERS-ST average is probably more reflective of less-than-perfect pavement in real world conditions, the Cal-B/C development team reset the tire wear values to the HERS-ST averages as shown in Exhibit III-28. The percent worn per 1000 miles values correspond to the HERS-ST figures for travel at 45 mph.

**Exhibit III-28: Tire Wear Cost Estimate  
in Freight BCA Tool (in 1997 dollars)**

	Predefined Values	User Input	Value In Use
<div style="display: flex; justify-content: space-between; align-items: flex-start;"> <div style="font-size: small;">                     Ctrl+Shift+S for Single State                      Ctrl+Shift+M for Multiple States                      Select:  <input checked="" type="radio"/> Single State  <input type="radio"/> Multiple States                 </div> <div style="border: 1px solid gray; padding: 2px; text-align: center; color: red; font-weight: bold;">                     Clear ALL Inputs                 </div> <div style="font-size: small;">                     Ctrl+Shift+C to Clear All Inputs                 </div> </div>			
<b>3. Tires Usage Cost (\$ per 1000 miles)</b>			
Cost per Tire (\$ per tire)			
4-Tire Truck	\$87.13	\$78.80	\$78.80
6-Tire Truck	\$210.20	\$190.10	\$190.10
3-4 Axle Truck	\$520.46	\$470.70	\$470.70
4-Axle Comb.	\$520.46	\$470.70	\$470.70
5-Axle Comb.	\$520.46	\$470.70	\$470.70
Tire Wear (% worn per 1000 miles)			
4-Tire Truck	0.40%		0.40%
6-Tire Truck	0.55%		0.55%
3-4 Axle Truck	0.35%		0.35%
4-Axle Comb.	0.33%		0.33%
5-Axle Comb.	0.26%		0.26%

Mileage-related depreciation is also a function of speed. As with tire wear, the Cal-B/C development team estimated the depreciation costs using the 45-mph average speed. The freight BCA tool uses values for mileage-related depreciation at 0.93625 times the HERS-ST values. This difference is due to the assumptions of straight, flat roadway with perfect pavement. As with tire wear, the Cal-B/C development team reset the values to the HERS-ST averages, as shown in Exhibit III-29.

The sum of the three non-fuel VOC components results in separate estimates for each of the five truck classifications shown in Exhibit III-30. The freight BCA tool provides defaults for the truck vehicle mix. These percentages are derived from the US Census Bureau’s 2002 Vehicle Inventory and Use Survey and are consistent with the values in HERS. The 2002 US Census Bureau data can be found at: <[www.census.gov/svsd/www/vius/products.htm](http://www.census.gov/svsd/www/vius/products.htm)>. The US Census Bureau has stopped collecting the vehicle inventory data.

### Exhibit III-29: Mileage-Related Depreciation Estimate in Freight BCA Tool (in 1997 dollars)

	Predefined Values	User Input	Value In Use
<div style="display: flex; justify-content: space-between; align-items: flex-start;"> <div style="width: 30%;"> <p>Ctrl+Shift+S for Single State Ctrl+Shift+M for Multiple States</p> <p>Select:</p> <p><input checked="" type="radio"/> Single State <input type="radio"/> Multiple States</p> </div> <div style="width: 20%; text-align: center;"> <p style="border: 1px solid gray; padding: 2px; background-color: #f0f0f0;"><b>Clear ALL Inputs</b></p> <p>Ctrl+Shift+C to Clear <b>A</b>ll Inputs</p> </div> </div>			
<b>4. Mileage-Related Depreciation (\$ per mile)</b>			
Depreciable Value (\$ per vehicle)			
4-Tire Truck	\$21,560	\$23,028	\$23,028
6-Tire Truck	\$32,217	\$34,410	\$34,410
3-4 Axle Truck	\$70,877	\$75,702	\$75,702
4-Axle Comb.	\$82,101	\$87,690	\$87,690
5-Axle Comb.	\$89,272	\$95,349	\$95,349
Depreciation Rate (% of price depreciation per 1000 miles)			
4-Tire Truck	0.27%		0.27%
6-Tire Truck	0.31%		0.31%
3-4 Axle Truck	0.09%		0.09%
4-Axle Comb.	0.09%		0.09%
5-Axle Comb.	0.09%		0.09%

### Exhibit III-30: Mileage-Related Depreciation Estimate in Freight BCA Tool (in 1997 dollars)

	Predefined Values	User Input	Value In Use
<div style="display: flex; justify-content: space-between; align-items: flex-start;"> <div style="width: 30%;"> <p>Ctrl+Shift+S for Single State Ctrl+Shift+M for Multiple States</p> <p>Select:</p> <p><input checked="" type="radio"/> Single State <input type="radio"/> Multiple States</p> </div> <div style="width: 20%; text-align: center;"> <p style="border: 1px solid gray; padding: 2px; background-color: #f0f0f0;"><b>Clear ALL Inputs</b></p> <p>Ctrl+Shift+C to Clear <b>A</b>ll Inputs</p> </div> </div>			
<b>Vehicle Operating Costs (VOC):</b> Ctrl+Shift+G for Aggregate VOC / Ctrl+Shift+H for VOC by Component			
<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="width: 30%;"> <p><input checked="" type="radio"/> Aggregate VOC <input type="radio"/> VOC by Component</p> </div> <div style="width: 20%; text-align: center;"> <p style="border: 1px solid gray; padding: 2px; background-color: #ffffe0;">California</p> </div> </div>			
<b>Aggregate VOC Per Mile (\$ per mile)</b>			
4-Tire Truck	\$0.193		\$0.193
6-Tire Truck	\$0.356		\$0.356
3-4 Axle Truck	\$0.432		\$0.432
4-Axle Comb.	\$0.457		\$0.457
5-Axle Comb.	\$0.467		\$0.467

The Cal-B/C development team tried comparing the 2002 vehicle inventory data with current truck counts from the Traffic Census Program. However, the comparison could not be made because the truck counts are listed by segment. The 2002 vehicle inventory data found in the Freight BCA tool are shown in Exhibit III-31.

### Exhibit III-31: Vehicle Mix Defaults in Freight BCA Tool (in 1997 dollars)

Ctrl+Shift+S for Single State Ctrl+Shift+M for Multiple States Select: <input checked="" type="radio"/> Single State <input type="radio"/> Multiple States		<b>Predefined Values</b> Clear ALL Inputs Ctrl+Shift+C to Clear All Inputs	<b>User Input</b>	<b>Value In Use</b>
<b>Specify Vehicle Mix on Segment (% of total truck traffic)</b>				
4-Tire Truck	60.8%			60.8%
6-Tire Truck	10.6%			10.6%
3-4 Axle Truck	2.2%			2.2%
4-Axle Comb.	4.9%			4.9%
5-Axle Comb.	21.5%			21.5%
<b>Average Effective Speed on Segment (mph)</b>	45.0 mph			45.0 mph

The Cal-B/C development team used the default data on vehicle mix from the freight BCA tool and the GDP deflator to calculate non-fuel truck operating costs in 2011 dollars. Although HERS-ST used detailed CPI data to update the economic values to 1997 dollars, the Cal-B/C development team chose the GDP deflator to update the values to 2011 dollars for consistency with the other economic values in Cal-B/C. The resulting non-fuel truck operating cost is 38.2 cents per mile in 2007 dollars. Exhibit III-32 summarizes the values and sources used to calculate the non-fuel truck operating costs using the FHWA tool.

### Exhibit III-32: Calculation of Non-Fuel Truck Operating Costs from FHWA Tool

Value	Maint. & Repair (\$/1000 miles)		Tire Wear @ 45 mph (% worn/ 1000 miles)				Depreciable Value (\$/vehicle)			Non-Fuel VOC Per Mile (\$/mile)	
	Maint. & Repair (\$/mile)	Tires (\$/tire)	HERS-ST	BCA Tool	Number of Tires	Tires (\$/mile)	HERS-ST	BCA Tool	Dep. Rate (% dep./ 1000 miles)	Depreciation (\$/mile)	Vehicle Mix
Source	HERS-ST		HERS-ST	BCA Tool	BCA Tool		HERS-ST	BCA Tool			BCA Tool
Single Unit Trucks											
4 Tires	\$ 129.80	\$ 0.130	\$ 78.80	0.401%	4	\$ 0.001	\$ 23,028	0.271%	\$ 0.062	\$ 0.193	60.8%
6 Tires	\$ 242.90	\$ 0.243	\$ 190.10	0.551%	6	\$ 0.006	\$ 34,410	0.312%	\$ 0.107	\$ 0.357	10.6%
3+ Axles	\$ 343.50	\$ 0.344	\$ 470.70	0.354%	12	\$ 0.020	\$ 75,702	0.091%	\$ 0.069	\$ 0.432	2.2%
Combination Trucks											
3-4 Axles	\$ 355.80	\$ 0.356	\$ 470.70	0.325%	14	\$ 0.021	\$ 87,690	0.091%	\$ 0.080	\$ 0.457	4.9%
5+ Axles	\$ 355.80	\$ 0.356	\$ 470.70	0.257%	20	\$ 0.024	\$ 95,349	0.091%	\$ 0.087	\$ 0.467	21.5%
TOTAL (in 1997\$)										\$0.288	
1997 GDP Deflator										0.8495	
2011 GDP Deflator										1.1275	
TOTAL (in 2011\$)										\$0.382	

Since the 2009 Cal-B/C revision, ATRI has published two reports in an effort to provide more accurate average cost data for motor vehicle operations. ATRI published the first report, *An Analysis of the Operational Costs of Trucking*, in late 2008 (too late for the 2009 Cal-B/C revision). In the report, ATRI noted that industry stakeholders considered the costs estimated in several previous studies to be unreasonably high or low. ATRI conducted a survey to document the key marginal costs of for-hire motor carrier operations. ATRI sent a survey to financial officers representing truckload, less-than



truckload, and specialized carriers. Using the costs reported in the survey, ATRI calculated average marginal costs on a per-hour and per-mileage basis.

ATRI revised the 2008 study and published the results in *An Analysis of the Operational Costs of Trucking: A 2011 Update*. The 2011 report generally follows the methodology of the previous report with a few minor updates. The report includes results from a survey distributed in late 2010, which collected operating costs for 2009 and Q1 2010.

The operating costs reported include a number of categories associated with travel time and fuel operating costs in addition to non-fuel operating costs. As a result, it is important to select the appropriate categories when estimating operating costs for Cal-B/C. ATRI uses the following classification:

- Vehicle-Based Marginal Expenses
  - Fuel and Oil Costs
  - Truck/Trailer Lease or Purchase Payments
  - Repair and Maintenance
  - Truck Insurance Premiums
  - Permits and Licenses
  - Tires
  - Tolls
- Driver-Based Marginal Expenses
  - Driver Wages
  - Driver Benefits.

The driver-based marginal expenses reflect the costs covered under the value of time for trucks. Including these costs as vehicle operating costs in Cal-B/C would be double counting. Likewise, the fuel and oil costs are already covered under the fuel operating costs estimated from the AAA Daily Fuel Gauge Report. The remaining costs can potentially be included in non-fuel truck operating costs, with the exception of tolls (a transfer payment) and permits and licenses (which are associated with specialized carriers and loads).

Although ATRI tried to include only marginal costs, the Institute noted that the definitions of fixed and marginal costs could be difficult to classify in the trucking industry. Some fixed costs decline with increases in VMT. In addition, fixed costs can vary through the year. ATRI defined marginal costs as “incurred while operating a truck for either one mile or one hour under average operating conditions” (ATRI 2011).

ATRI included some quasi-operational costs, such as truck and trailer payments and truck insurance premiums. ATRI chose to include truck and trailer payments because carriers may purchase additional trucks and trailers in response to capacity constraints

during high demand. These payments may also reflect vehicle depreciation. Insurance premiums include both fixed (property and liability insurance) and marginal (property damage coverage) costs. Since ATRI did not attempt to separate these costs, the Cal-B/C development team did not include these costs in the non-fuel truck operating costs.

The Cal-B/C development team chose to use the ATRI figures for 2009, since they represent costs for a complete year. The Cal-B/C development team updated these figures to 2011 dollars using the GDP deflator (1.1275/1.1043). Exhibit III-33 shows the original ATRI values and the final 2011 values used in Cal-B/C.

### Exhibit III-33: Calculation of Non-Fuel Truck Operating Costs from ATRI

Category	Original ATRI (2009\$)	Final Cal-B/C (2011\$)
Repair and Maintenance	\$0.123	\$0.126
Tires	\$0.029	\$0.030
Truck/Trailer Payments	\$0.257	\$0.262
<b>Total Non-Fuel Costs</b>	<b>\$0.409</b>	<b>\$0.418</b>

*Estimated from ATRI, An Analysis of the Operational Costs of Trucking: 2011 Update.*

*Revision Made to Cal-B/C: used 30.3 cents per mile for non-fuel automobile operating costs and 41.8 cents per mile for non-fuel truck operating costs*

## 5.0 ACCIDENT COST PARAMETERS

Over the last few years, transportation agencies have adopted new terminology regarding safety. What USDOT now calls “crashes,” the Department calls “collisions.” Transit agencies continue to refer to these as “accidents.” Given the disparity in terminology, Cal-B/C continues to refer to user costs due to safety issues as “accident costs.”

In updating the accident cost parameters, the most important distinction is the difference between accidents and events. Events refer to each impact of an accident, which can include deaths, injuries, or property damage. A single accident can include multiple events. For example, a fatality accident may include one fatality, two injuries, and significant property damage. An event, however, belongs to only one accident.

The Department reports highway collision data in terms of both accidents and events. Transit agencies report event data only. For this reason, Cal-B/C must use costs applicable to events rather than accidents. Cal-B/C also needs information on the severity or typical composition of the three accident types (fatality, injury, and property damage only). This composition data answers questions such as how many fatalities

occur in the typical fatality accident and the average relative severity of injuries in an injury accident.

## 5.1 Accident Costs

There are several approaches for estimating accident costs, which in order of comprehensiveness are:

- Direct costs – includes only easily measured, out-of-pocket costs
- Human capital – includes all direct costs plus lost work and housework
- Comprehensive (or willingness-to-pay) – equals the human capital cost plus the amount people are willing to pay to avoid injury.

Cal-B/C uses the comprehensive (willingness-to-pay) methodology to estimate accident costs. This is also the methodology recommended by USDOT in the January 8, 1993 memorandum “Treatment of the Value of Life and Injuries in Preparing Economic Evaluations.” In a revised memorandum dated January 29, 2002, USDOT continues to recommend using the comprehensive approach. The FHWA also weighed in on the issue in its technical advisory on motor vehicle accident costs published in 1994 (FHWA 1994). The FHWA concurred with the prior USDOT guidance that the comprehensive method be used for estimating accident costs in benefit-cost analysis.

In February 2008, USDOT revised its guidance to estimating the value of statistical life (USDOT 2008). While USDOT continues to recommend using the comprehensive or willingness-to-pay methodology for estimating the value of statistical life, the guidance points to more recent economic studies. These studies substantially raise the value of life estimates. A July 2011 interim adjustment (USDOT 2011) continues to recommend a willingness-to-pay methodology and suggests a higher value of statistical life. This issue is explored further later in this section.

Paul Hanley of the Public Policy Center at the University of Iowa conducted a review of guidance documents and practices at state departments of transportation (DOTs) in applying economic costs to highway accidents (Hanley 2004). Hanley concluded that the human capital approach is the best approach for estimating the past economic losses and ranking high accident locations based on economic loss. Hanley agrees with USDOT and FHWA guidance and concludes that comprehensive costs are the most appropriate for benefit-cost analysis.

## 5.2 Values by Event

There are two primary sources of comprehensive cost data: the National Highway Traffic Safety Administration (NHTSA) and the National Safety Council (NSC). Hanley provides a comprehensive review of these sources, USDOT and FHWA guidance, state DOT practices, and methods for updating economic values. That review is paraphrased

in this technical documentation, but a more comprehensive treatment can be found in Hanley (2004).

The biggest differences between NHTSA and NSC are the frequency of updates and the scale used to capture the severity of highway injuries. The NHTSA data are updated very occasionally, but the summary of economic costs is very comprehensive. The last NHTSA estimate reported 2000 data and was published in 2002, while the previous estimate reported 1994 data and was published in 1996.

The Cal-B/C development team contacted Larry Blincoe, the author of the NHTSA report, who indicated that the next report would be published in Summer 2012. The next NHTSA report will follow the USDOT value of statistical life guidance and adopt a value close to \$6.2 million. This value is considerably higher than the value in the previous NHTSA report and current NSC estimates.

NHTSA estimates costs from actual accident histories and report severity using the Abbreviated Injury Scale (AIS) of the Association for the Advancement of Automotive Medicine. On a per person (injury) basis, the average comprehensive costs for 2000 are:

- Fatal (AIS 6) - \$3,366,388
- Critical (AIS 5) - \$2,402,997
- Severe (AIS 4) - \$731,580
- Serious (AIS 3) - \$314,204
- Moderate (AIS 2) - \$157,017
- Minor (AIS 1) - \$15,017
- Property Damage Only (PDO) - \$2,532.

Cal-B/C relies on NSC data. This information is updated annually by adjusting benchmark costs. In some cases, the benchmark costs are components of the NHTSA estimates. NSC classifies injuries using severity definitions from Sections 2.3.4 through 2.3.6 of the Manual on the Classification of Motor Vehicle Traffic Accidents (Sixth Edition) ANSI Standard D16.1-1996. The latest comprehensive data available are for 2009. These are online ([www.nsc.org/NEWS\\_RESOURCES/INJURY\\_AND\\_DEATH\\_STATISTICS/Pages/EstimatingtheCostsofUnintentionalInjuries.aspx](http://www.nsc.org/NEWS_RESOURCES/INJURY_AND_DEATH_STATISTICS/Pages/EstimatingtheCostsofUnintentionalInjuries.aspx)) or available in the 2011 annual report. On a per person (injury) basis and in 2009 dollars, the average comprehensive costs are:

- Death - \$4,300,000
- Incapacitating Injury (A) - \$216,800
- Non-Incapacitating Event Injury (B) - \$55,300
- Possible Injury (C) - \$26,300
- No Injury - \$2,400.

Hanley (2004) finds that after updating the data to the same economic years, the differences in the two sources are not very large (about 10 percent for the value of a

death). Hanley suggests that the best source is the one that corresponds to the injury severity scale used in the state. This equivalence between the sources will disappear once NHTSA adopts the USDOT guidance unless NSC updates its estimates as well.

The Cal-B/C development team contacted Ken Kolosh of the National Safety Council, who indicated that NSC is not planning any immediate changes to its value of statistical life estimate, but is closely watching the values being considered by USDOT and the United States Environmental Protection Agency (USEPA). The USEPA value is currently \$7.4 million. NSC is considering a revision to its calculation methodology to be consistent with the Center for Disease Control (CDC) but this is still in the future. NSC indicated that a trend toward consistency among the agencies is desirable and the NSC value is likely to rise.

In the interim, Cal-B/C continues to use the NSC accident cost estimates for consistency and because the California Highway Patrol (CHP) and other California police forces use the ABC injury scale. Updating the latest NSC values to 2011 dollars using the GDP deflator (i.e., multiplying by  $1.0210 = 1.1275 / 1.1043$ ) results in the following values rounded to the nearest hundred (hundred thousand for death):

- Death - \$4,400,000
- Incapacitating Injury (A) - \$221,400
- Non-Incapacitating Event Injury (B) - \$56,500
- Possible Injury (C) - \$26,900
- No Injury - \$2,500.

The Cal-B/C development team cannot calculate the average injury severity from Traffic Accident Surveillance and Analysis System (TASAS) data. The injury (A through C) categories have already been summarized as “injuries” in the data that CHP sends the Department. The detailed data is available in the California Statewide Integrated Traffic Incident Reporting System (SWITRS), but this would require a special request from CHP. Rather than try to obtain custom SWITRS data, the Cal-B/C development team decided to rely on the data available in the annual safety summary produced by CHP. The latest version is the 2009 Annual Report of Fatal and Injury Motor Vehicle Traffic Collisions.

Table 8C of the 2009 Annual Report estimates the cost of collision by victim severity and collision type. CHP uses the values found in the 1994 FHWA guidance updated by the GDP deflator. The Cal-B/C development team believes that relying on NSC data is a better approach. The FHWA guidance is over ten years old and is based on twenty-year data. At the time of the FHWA guidance, NSC did not estimate comprehensive accident costs using the willingness-to-pay method. NSC now does on an annual basis.

According to Table 7C, injury severities occur with the following frequencies:

- Severe Injury (A) - 10,931 out of 232,777 injuries or 4.70 percent

- Other Visible Injury (B) - 61,175 out of 232,777 injuries or 26.28 percent
- Complaint of Pain (C) - 160,671 out of 232,777 injuries or 69.02 percent.

As indicated in Table 7Q, there were 3,076 people killed in 2,805 fatal accidents for 1.097 deaths per fatal accident in 2009. Since more detailed injury severity data are not available, Cal-B/C uses the same frequencies for urban, suburban, and rural accidents. The separate calculations for urban, suburban, and rural have been included in Cal-B/C for consistency with Traffic Safety Index (SI) calculations made by the Office of Traffic Safety. However, Cal-B/C uses only the rural and urban values. The calculations and other modifications made for consistency with the Division of Traffic Operations are described in Chapter IV of this technical documentation.

The Office of Traffic Safety provided detailed information on the number of people killed, the number of people injured, the number of vehicles involved as well as severity by the type of accident for 2007 through 2009. Cal-B/C includes the final accident values. Data are also available for urban and rural areas for consistency with the Traffic Safety Index (SI) calculation.

*Revision Made to Cal-B/C:* used 2009 NSC values updated to 2011 by the GDP deflator as well as injury severity and accident event data from TASAS, added separate values for rural and urban accidents

### 5.3 Statewide Accident Rates

Cal-B/C includes average statewide accident rates from the Departmental publication "Collision Data on California State Highway." The latest data are found on page 11 of the 2009 report:

- Fatal accident rate: 1,159 fatal accidents / 176,460.8 million vehicle-miles (MVM) = 0.0066 per MVM
- Injury accident rate: 47,673 injury accidents / 176,460.8 MVM = 0.2702 per MVM
- PDO accident rate: 93,389 PDO accidents / 176,460.8 MVM = 0.5292 per MVM
- Non-freeway accident rate: 1.05 accidents per MVM (from the page 7 summary).

These figures have been rounded to 0.007, 0.27, 0.53, and 1.05, respectively, in Cal-B/C.

*Revision Made to Cal-B/C:* adopted statewide accident rates from 2009 data

## 6.0 EMISSIONS COSTS

Cal-B/C calculates emissions costs as functions of the emissions rates and the costs per pollutant. The sections below describe the development of updated values for rates and cost per pollutant. The latest Cal-B/C revision also includes a new calculation of greenhouse gas emissions. The distinction between the emissions (described in this section) and greenhouse gas emissions (described in Section 7.0) is that emissions affect local air quality with an immediate health impact, while greenhouse gases have a long-term global impact not directly tied to human health.

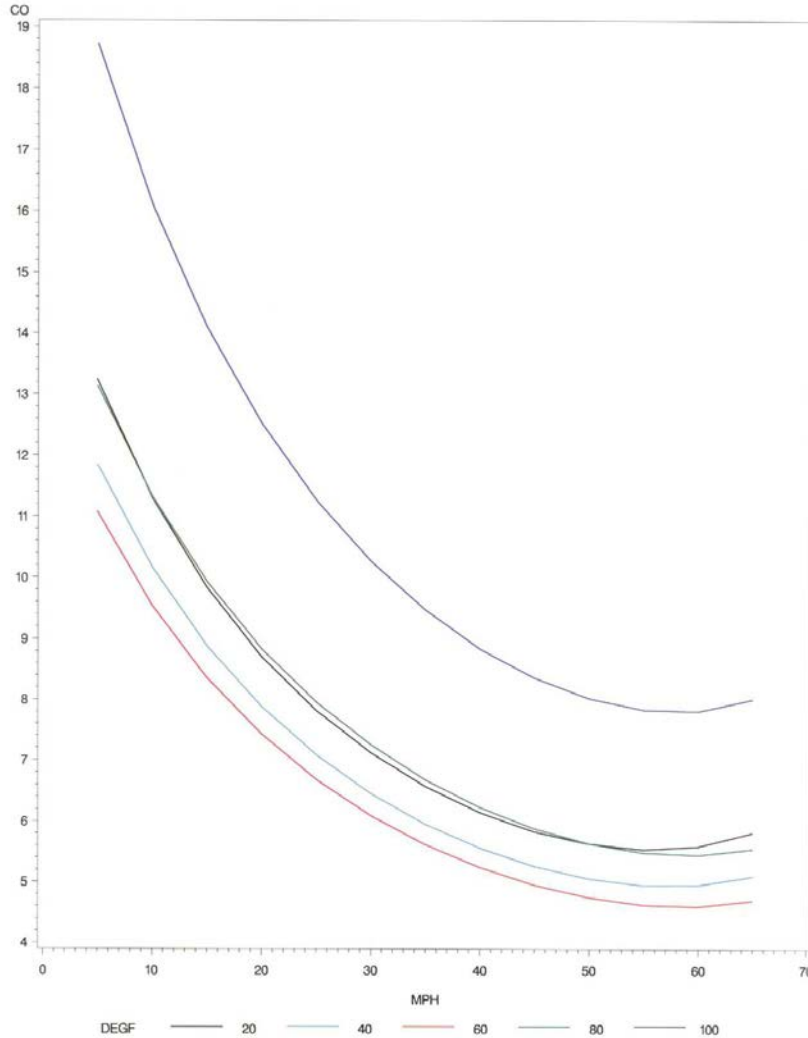
### 6.1 Emission Rates

The Cal-B/C development team updated the emissions factors in Cal-B/C using the latest California Air Resources Board (CARB) model, EMFAC2011. As described earlier in this chapter, EMFAC2011 includes a series of models to estimate automobile and truck emissions factors. The Cal-B/C development team estimated emissions rates for Cal-B/C using data from EMFAC2011-LDV running in Burden mode, the emissions and emissions rates available on CARB's website as well as discussions with CARB staff.

Prior to the 2009 revision, the Cal-B/C development team pulled preliminary data from EMFAC2007 to determine the major factors affecting emission rates. This analysis helped to determine how to summarize emissions rates and interpolate rates across years. The development team did not repeat this analysis using EMFAC2011. The original EMFAC2007 results are reported on the next few pages.

As shown in Exhibit III-34, the emission rates in EMFAC2007 exhibit non-linear relationships to speed. However, the specific shape of the curve varies by pollutant. An analysis conducted with EMFAC2011 data indicates that similar non-linear relationships still exist in the latest data.

If ambient temperature is taken into account, the shapes of the functions become more complicated. For example, carbon monoxide (CO) takes a saddle shape with the highest emission rates occurring at low and high temperatures, while the lowest emission rates occur at moderate temperatures. This suggests that ambient temperature, or at least some indication of the range of temperatures by region, might need to be considered in benefit-cost modeling.

**Exhibit III-34: Carbon Monoxide (CO) Emissions per Mile**

To test this idea, the Cal-B/C development team looked at pollutants by air basin to see if any patterns emerged. Emissions were calculated by adding all sources of each item (e.g., tons of CO<sub>2</sub>, NO<sub>x</sub>, etc.) in the area and dividing by the total miles driven for that area. This calculation distorts actual driving emissions, because it lumps running emissions together with those created per engine start and running or resting hour, but it is an easy way to see trends caused by the full set of EMFAC drivers in the base model.

Exhibits III-35 through III-40 show the results for the 69 sub-areas included in EMFAC2007. As can be seen in the exhibits, emissions levels vary by sub-area. Emissions appear to be higher for rural areas, but it is hard to identify a pattern for simplifying the data. Higher emission in rural areas may be due to the age of vehicles, presences of farm and industrial factors, average temperature or other factors. Given this uncertainty, Cal-B/C continues to use statewide averages. If detailed analysis is





Exhibit III-37: NOx Emissions per Mile

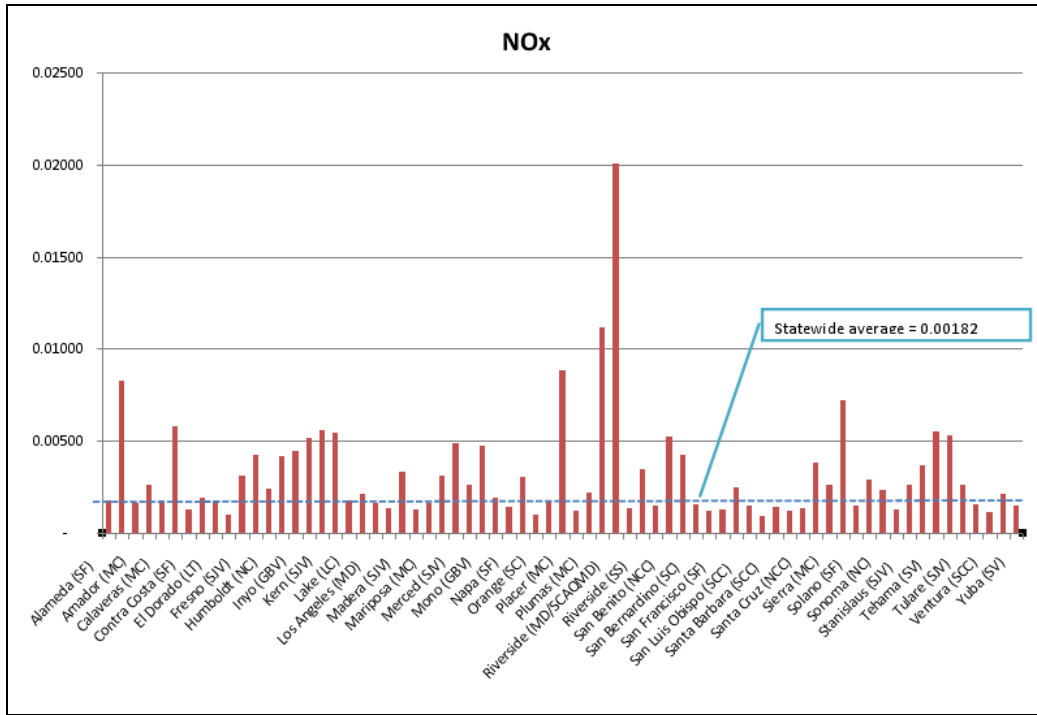
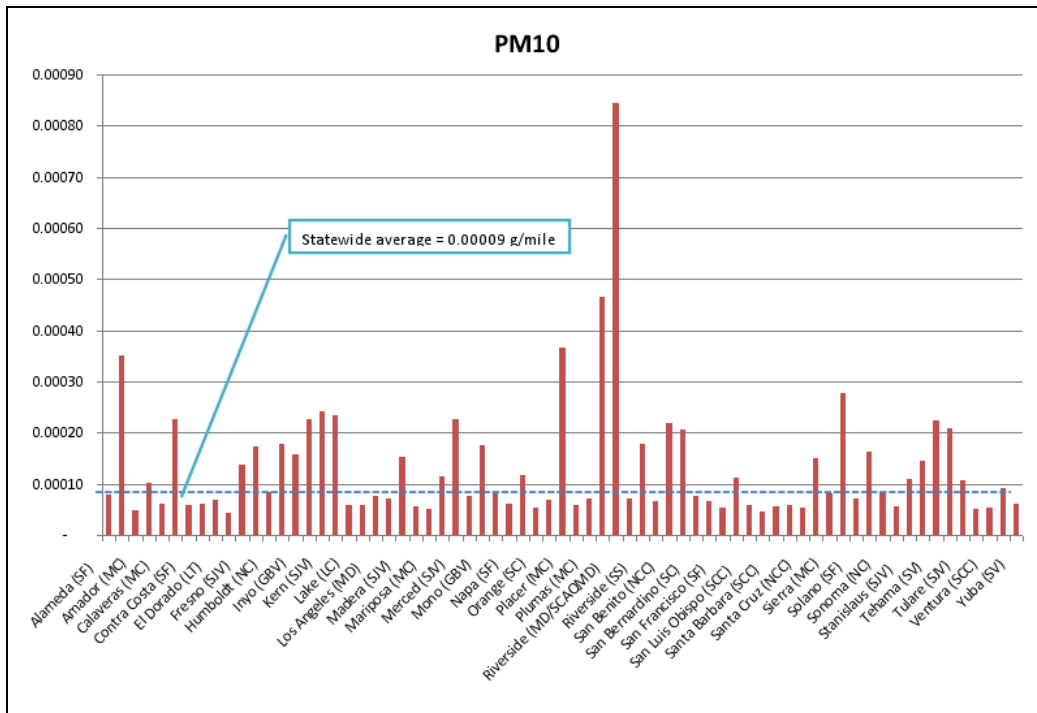


Exhibit III-38: PM10 Emissions per Mile



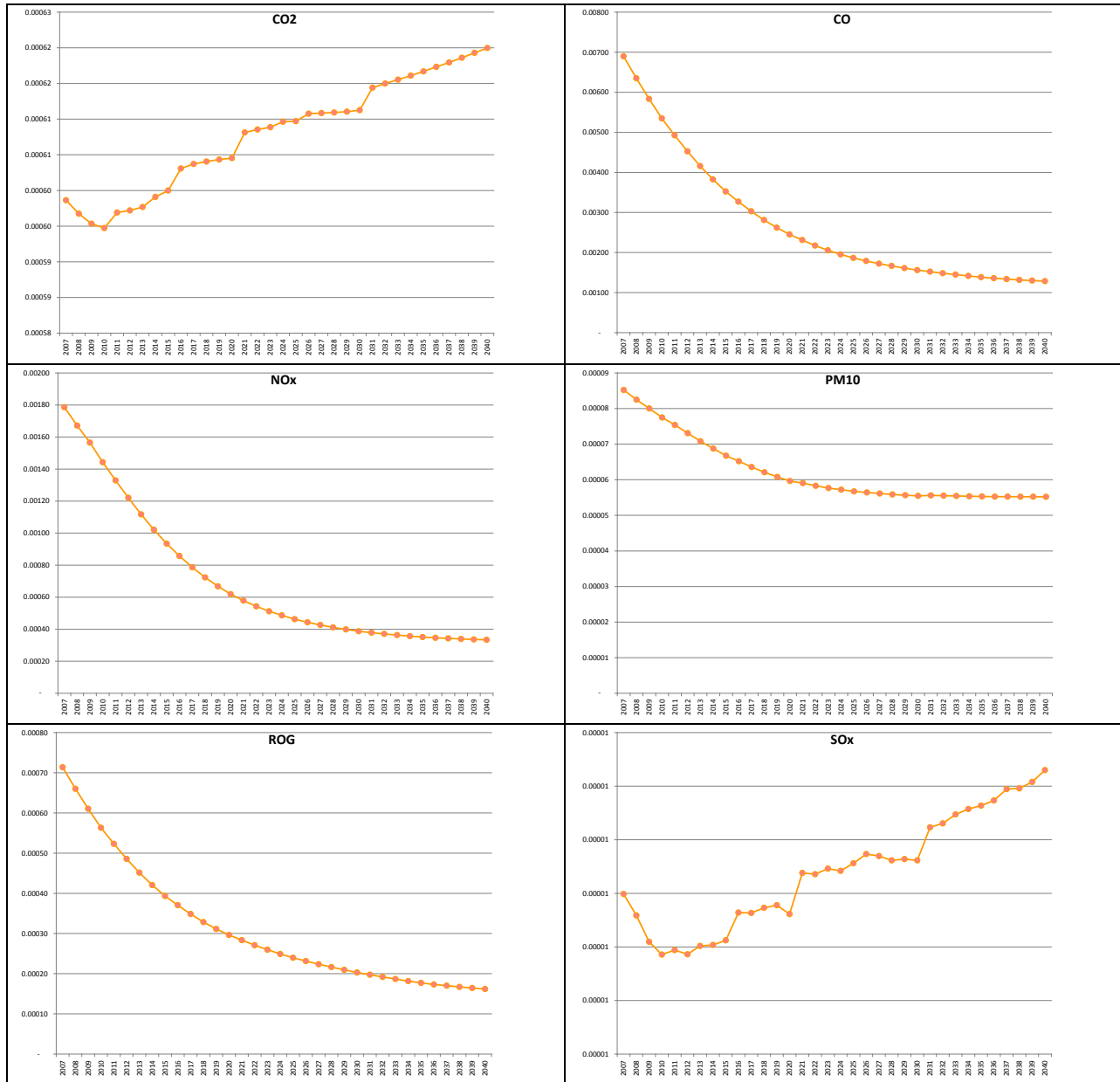


The Cal-B/C development team also spoke with representatives of the Mobile Source Analysis Section at the California Air Resources Board (CARB), who described how emission data are estimated. Researchers at the University of California, Los Angeles (UCLA), conducted the most comprehensive, recent data collection. In that study, engineers collected a sample of real-world driving conditions by following cars in Southern California. They measured the distance between the floating car and the car being followed using a laser. These distances were used to adjust the floating car tachometer and estimate the speed profile of the car being followed. There have been discussions about whether driver behavior varies by region, but this has not yet been tested or captured in the EMFAC factors.

Older versions of Cal-B/C used emissions rates for a base year and a future year. The base year values were used for the first ten years of benefit-cost analysis, while the future values were used for the last ten years. This approach included an implicit assumption that emissions rates change linearly over time. To test this assumption during the 2007 revision, the Cal-B/C development team plotted average emission rates from EMFAC2007 for each pollutant by year.

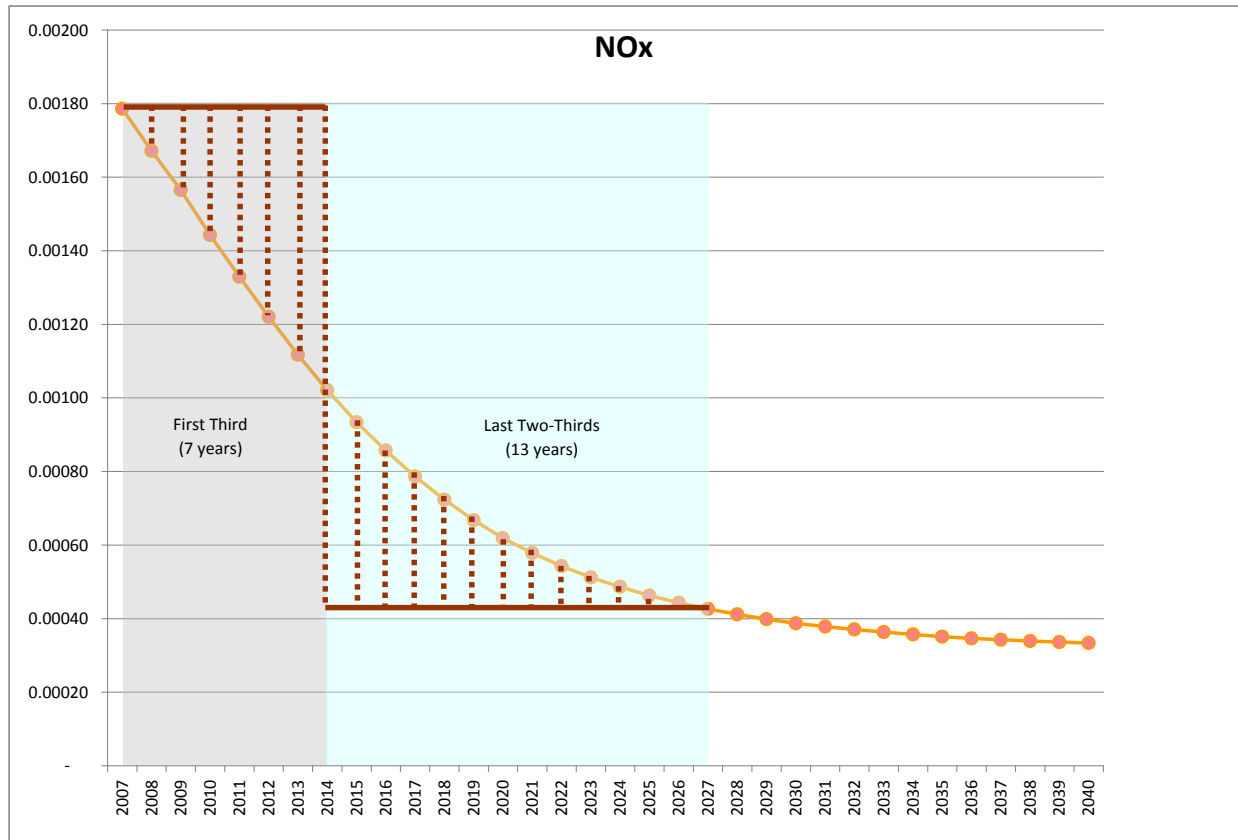
These rates are shown in Exhibit III-41. Four pollutants (CO, NO<sub>x</sub>, PM<sub>10</sub>, and ROG) follow smooth exponentially declining curves rather than straight lines. The other two pollutants (CO<sub>2</sub> and SO<sub>x</sub>) show increasing values over time and follow much more jagged lines, potentially because of policy milestones.

### Exhibit III-41: Changes in Emission Rates over Time



The CO<sub>2</sub> and SO<sub>x</sub> data series are more amenable than the other pollutants to straight-line approximation. However, the straight-line approximation can be preserved for the other pollutants by using the first-year emissions rates for the first third (seven years) and future-year emissions rates for the last two-thirds (13 years) of the benefit-cost analysis. Exhibit III-42 illustrates the concept. By balancing the overestimation in the first few years with the underestimation in the last few years, the Cal-B/C approximates emissions for the entire 20 years while under- or overestimating emissions for individual years.

### Exhibit III-42: Approximation of Emissions using Two Years



For the current version of Cal-B/C, the Cal-B/C development team used EMFAC2011 to generate emissions factors for 2011 and 2031 EMFAC estimates. Cal-B/C uses the 2011 rates first seven years of benefit-cost analysis and the 2031 rates for the last 13 years of analysis for all pollutants. Although an even ten year split would be more appropriate for estimating CO<sub>2</sub> and SO<sub>x</sub> emissions, the uneven split was chosen for consistency across pollutants. A rough calculation using the update emissions costs suggest that the difference in interpolation affects the final benefit-cost calculations by no more than one percent for most projects.

The final emissions factors can be found in the revised Cal-B/C model. Cal-B/C separates starting emissions (starting evaporation and hot soak) from other emissions (running exhaust and running loss). These are listed as emissions at “0 mph” in the model and help capture the increase in emissions due to new trips. The model assumes that each new trip results in a start, which may overestimate emissions if trip chaining occurs. The other emissions factors include idling emissions, but exclude diurnal and resting loss emissions because they are not impacted by the transportation projects evaluated in Cal-B/C. Because idling factors could not be separated in the emission factor calculations, Cal-B/C uses five mph for estimating idling emissions in highway-rail grade separation projects.

Separate emissions curves were generated for automobiles, trucks, and buses. The emissions factors were calculated in EMFAC2011 at five-mph intervals. The five-mph results were interpolated to generate one-mph intervals for use in the model lookup table.

*Revision Made to Cal-B/C: Separated starting emissions from other emission rates, estimated new rates for 2011 and 2031 from EMFAC2011*

## 6.2 Emissions Costs

Cal-B/C continues to use emissions costs based on the 1996 study by Delucchi and McCubin (1996) at the University of California, Davis. During the 2009 revision to Cal-B/C, the Cal-B/C development team contacted CARB staff involved in economic analysis to learn what economic values they use, if any, for emissions. The Cal-B/C development team also contacted Dr. Mark Delucchi, one of the original authors of the Delucchi and McCubin study. Dr. Delucchi indicated that the emissions values estimated in the 1996 study were still the most current and comprehensive estimates available.

The original emissions values (Table 5-1 in Volume 1 of the Cal-B/C technical documentation) come from page 236 (Table 11.7-7A) of Delucchi and McCubin (2006). These values are the cost of direct motor-vehicle emissions. Cal-B/C includes values updated from the original 2000 Cal-B/C values to 2011 dollars using the GDP deflator (an adjustment factor of 1.2684). Exhibit III-43 shows the resulting values rounded for use in Cal-B/C. The Cal-B/C development team calculated separate values for greenhouse gas emission using other sources, which the next section describes.

**Exhibit III-43: Health Cost of Transportation Emissions (in 2011 dollars per ton)**

Area	CO	NO <sub>x</sub>	PM <sub>10</sub>	SO <sub>x</sub>	VOC
LA/South Coast	\$145	\$59,100	\$484,300	\$182,000	\$3,675
CA Urban Area	\$75	\$17,300	\$139,900	\$69,800	\$1,210
CA Rural Area	\$70	\$12,900	\$99,700	\$50,400	\$950

*Adapted from Delucchi and McCubin (1996).*

As part of the 2009 revision, the Cal-B/C development team also met with representatives of the FHWA Office of Asset Management, which maintains transportation benefit-cost tools at the federal level, to determine if they use any particular economic values. At the time, FHWA did not place monetary values on emissions. In addition, the Federal Economic Analysis Primer did not discuss emissions values.

In 2009, USDOT began offering Transportation Investment Generating Economic Recovery (TIGER) grants. In order to qualify for these discretionary grants, applicants

must conduct benefit-cost analyses. For each round of applications, USDOT has issued increasingly detailed guidance for preparing the benefit-cost analyses.

For the 2012 TIGER IV program, USDOT prepared a TIGER Benefit-Cost Analysis (BCA) Resource Guide (USDOT 2012). The guide references emissions values from the 2010 NHTSA Final Regulatory Impact Analysis for Model Year (MY) 2010 – MY 2016 Corporate Average Fuel Economy (CAFE) standards. The CAFE impact analysis notes that these values came from recent USEPA estimates, but does not provide details (NHTSA 2010). Exhibit III-44 shows the values provided in the TIGER BCA Resource Guide. The Cal-B/C development team will continue to research these values and consider adopting them in future updates.

**Exhibit III-44: USDOT TIGER Value of Emissions (in 2007 dollars per ton)**

Emission	Value per Long Ton	Value per Metric Ton
Volatile Organic Compounds (VOC)	\$1,300	\$1,280
Nitrogen oxides (NO <sub>x</sub> )	\$5,300	\$5,217
Particulate matter (PM)	\$290,000	\$285,469
Sulfur dioxide (SO <sub>x</sub> )	\$31,000	\$30,516

*Source: USDOT, TIGER Benefit-Cost Analysis (BCA) Resource Guide, February 2012.*

*Revision Made to Cal-B/C: updated original emission costs to 2011 dollars*

## 7.0 GREENHOUSE GAS EMISSIONS

Cal-B/C includes the value of greenhouse gas emissions in its monetization of emissions benefits. It also reports the total tons of CO<sub>2</sub> emissions saved because of transportation improvements. Practical experience using Cal-B/C suggests that projects that moderately improve speeds may have a negative greenhouse gas impact. However, many projects, particularly those with large speed improvements, have a positive impact. The sections below describe the research and methodologies adopted for estimating emissions rates and valuing greenhouse gas emissions. This methodology will evolve as CARB improves its estimation of CO<sub>2</sub> in EMFAC and as the State's Climate Action Program develops strategies for the future.

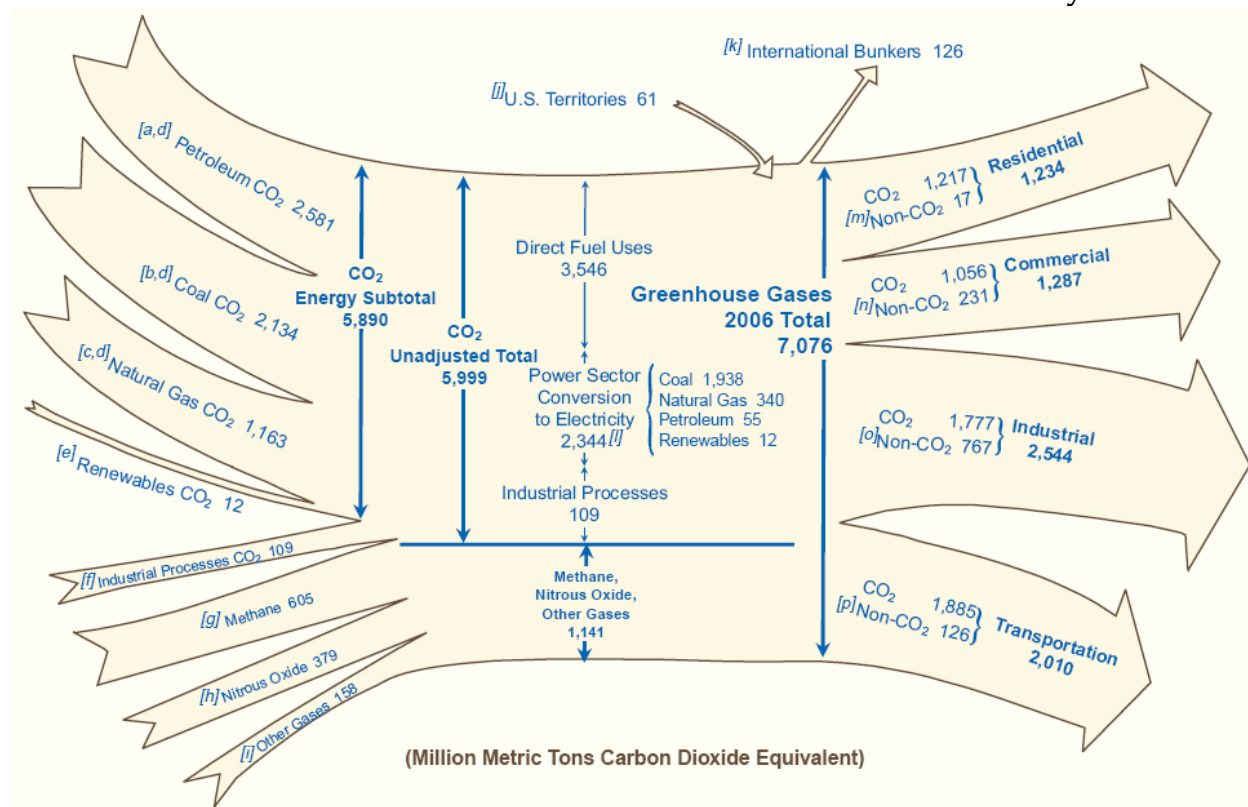
### 7.1 Emissions Rates

The latest version of Cal-B/C reports greenhouse gas emissions in terms of the amount of CO<sub>2</sub> emissions saved because of project construction. This section describes the process of estimating those rates.



The US Department of Energy releases its annual greenhouse gas emissions report each November. Exhibit III-45, taken from the 2007 report, shows that the majority of greenhouse emissions produced by vehicles are in the form of CO<sub>2</sub>. Non-CO<sub>2</sub> emissions include methane and nitrous oxide emissions from mobile source combustion and hydrofluorocarbon (HFC-134a) emissions from vehicle air-conditioning units. The report notes that the transportation sector has led all sectors in the emission of CO<sub>2</sub> since 1999. A general diagram of greenhouse gas emissions in the US economy is shown in Exhibit III-45.

**Exhibit III-45: Greenhouse Gas Emissions in the US Economy**



Source: Energy Information Administration, Office of Integrated Analysis and Forecasting, US Department of Energy, Emissions of Greenhouse Gases in the United States 2006, November 2007.

California leads the nation in adopting strategies to reduce greenhouse gases. In 2006, Governor Arnold Schwarzenegger signed Assembly Bill 32 (AB 32), the Global Warming Solutions Act, which establishes a comprehensive program of regulatory and market mechanisms to achieve quantifiable and cost-effective reductions of greenhouse gases. AB 32 requires that the State’s greenhouse gas emissions be reduced to 1990 levels by 2020, which is about a 25-percent reduction under business-as-usual estimates. CARB is charged with monitoring and regulating greenhouse gas emission sources under AB 32.

As mandated by AB 32, CARB identified 44 early action measures to reduce greenhouse gas emissions. These measures are to be developed into regulatory proposals, adopted by the CARB Board, and made enforceable by January 1, 2010. CARB identified eight early action measures for the transportation sector:

1. Automobile Regulation (Assembly Bill 1493, Pavley) - the regulation will reduce greenhouse gases from new passenger vehicles starting in 2009. The regulations are on hold due to automaker lawsuits and US EPA's refusal to grant California an implementation waiver. California is suing the federal government over the failure to grant the waiver.
2. Cool Automobile Paints - the strategy will be in place by January 1, 2010, and promotes the use of cool automobile paints to reduce the solar heat gain in a vehicle parked in the sun. A cooler interior would make drivers less likely to activate the air conditioner, which increases carbon dioxide emissions.
3. Smartway Truck Efficiency (Heavy-Duty Vehicle Greenhouse Gas Emission Reduction Measure) - the proposed regulation requires the use of technologies that improve the efficiency of heavy-duty tractors and trailers operating in California based on the US EPA's Smartway Program.
4. Tire Inflation Program - ARB is considering options to ensure that tire pressure in older vehicles is properly maintained in order to maximize vehicle fuel efficiency.
5. Anti-Idling Enforcement - these new engine requirements require 2008 and newer model year heavy-duty diesel engines to be equipped with a non-programmable engine shutdown system that automatically shuts down the engine after five minutes of idling or meet a stringent oxides of nitrogen idling emission standard.
6. Strengthen Light-Duty Vehicle Standards
7. Privately Owned On-Road Trucks - regulation is being developed to reduce diesel particulate matter (PM) and other emissions from in-use heavy-duty diesel powered vehicles operating in California.
8. Hybridization of Medium and Heavy-Duty Diesel Vehicles

CARB is responsible for maintaining and updating California's Greenhouse Gas (GHG) Inventory per AB 1803. The GHG Inventory provides estimates of GHGs caused by human activities. In 2009, CARB released a query tool for assessing the inventory values. That GHG Inventory covered the years 1990 to 2004, and included estimates for carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), sulfur hexafluoride (SF<sub>6</sub>), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs) (the "six Kyoto gases"). The

GHG inventory provided the basis for developing the 1990 statewide emissions level and 2020 emissions limit required by AB 32.

EMFAC2011 can produce CO<sub>2</sub> and CH<sub>4</sub> emission estimates and is a tool for assessing alternative growth scenarios associated with regional transportation planning for greenhouse gas reductions (SB375). The EMFAC2011-SG module can estimate the benefits of Pavley and Low Carbon Fuel Standard regulations, but this is achieved by post-processing results from EMFAC2011-LDV and EMFAC2011-HD. In the next iteration of EMFAC, CARB plans to reflect planned GHG emissions standards and their impact on future year fleet mix. In the meantime, Cal-B/C uses the Pavley adjusted CO<sub>2</sub> estimates from EMFAC2011 as its basic rates.

The Results page of Cal-B/C reports the tons of CO<sub>2</sub> saved because of project construction. This represents the difference in CO<sub>2</sub> emissions between the build and the no-build cases. The estimates are based on the EMFAC factors for CO<sub>2</sub> only.

*Revision Made to Cal-B/C: added new CO<sub>2</sub> rates and report CO<sub>2</sub> saved on the results page*

## 7.2 Emissions Costs

The 2009 revision to Cal-B/C added the capability to place a value on greenhouse gas emissions. At the time, the United States had not yet developed a social cost of CO<sub>2</sub> emissions and research in the United Kingdom (UK) provided the most promising values. In February 2010, the United States Interagency Working Group on Social Cost of Carbon released its final guidance on the value of greenhouse gas emissions. Although the values in the United States estimates vary somewhat from the UK estimates, the methodology for monetizing greenhouse gas emissions is consistent. Cal-B/C now uses a social cost of carbon consistent with the United States Interagency Working Group guidance. The discussion below describes the United Kingdom method first and then the United States guidance.

The UK government has required a Carbon Impact Assessment to be included in economic appraisals since 2003 as documented in the UK Treasury's Appraisal and Evaluation in Central Government (or "Green Book"). In 2005, the UK Treasury sponsored an extensive review of the economics of climate change (the "Stern Review"), which is available at <[www.hm-treasury.gov.uk/independent\\_reviews/stern\\_review\\_economics\\_climate\\_change/stern\\_review\\_report.cfm](http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm)>.

The UK Department for Environment Food and Rural Affairs (DEFRA) is tasked with valuing greenhouse gas emissions. With the help of AEA Technology, DEFRA initially developed an interim value using a social cost of carbon methodology (AEA Technology 2005). In December 2007, DEFRA adopted a more expansive approach based on the shadow price of carbon. The valuation reflects the full global cost of an incremental ton of CO<sub>2</sub> equivalent (CO<sub>2</sub>e) emissions from the time of production to the

damage it imposes over the whole of its time in the atmosphere. DEFRA estimated future values, subjected the values to academic peer review, and published guidelines on the differences in the social cost and shadow prices as well as how to use the shadow price of carbon in policy appraisals (DEFRA 2007). DEFRA also maintains a website documenting all of its efforts to value greenhouse gas emissions <[www.defra.gov.uk/environment/climatechange/research/carboncost/index.htm](http://www.defra.gov.uk/environment/climatechange/research/carboncost/index.htm)>.

The Cal-B/C methodology follows the DEFRA approach for valuing greenhouse gas emissions. The DEFRA approach relies on a shadow price per metric ton of CO<sub>2e</sub> emitted in the Year 2000 and valued in 2000 dollars. Box 13.3 of the Stern Review shows that this price is \$30 per metric ton of CO<sub>2e</sub>. This value is increased or “uprated” by two percent per year to reflect the increasing cumulative damage to the world environment each year. The value also increases due to inflation.

Further information on the DEFRA approach can be found in the publication “How to use the Shadow Price of Carbon in policy appraisal,” which is available on the DEFRA website. The publication also provides global warming potential factors for converting greenhouse gases into carbon dioxide equivalents. These factors can be used if methane or other greenhouse gas emissions need to be included in a benefit-cost analysis.

In 2010, the US Interagency Working Group on Social Cost of Carbon issued its guidance on “Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866.” This guidance provides values under four scenarios (average social carbon costs with discount rates of 5 percent, 3 percent, and 2.5 percent as well as 95<sup>th</sup> percentile social carbon costs at a 3-percent discount rate) for every five years between 2010 and 2050 in 2007 dollars as shown in Exhibit III-46.

**Exhibit III-46: Social Cost of CO<sub>2</sub>, 2010 to 2050 (in 2007 dollars)**

Discount Rate	5%	3%	2.5%	3%
Year	Avg	Avg	Avg	95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

*Source: Interagency Working Group on Social Cost of Carbon, United States Government, Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, February 2010.*

As a moderate estimate of the benefits associated with CO<sub>2</sub> emission reductions, the Cal-B/C development team chose to use average values from the Interagency Working

Group Guidance at a 3-percent discount rate (\$21.40 in 2007 dollars for 2010 emissions). This value was grown by a 1.6 percent uprater to 2011 emissions and updated to 2011 dollars using the GDP deflator. The resulting value was rounded to \$23 per US ton of CO<sub>2</sub>e. Consistent with guidance from the US Interagency Working Group, Cal-B/C uses a value of CO<sub>2</sub>e that increases with each year of analysis. The values for subsequent years are estimated using an uprater (or growth factor) of 1.6 percent per year. This uprater is consistent with the growth shown in Exhibit III-46 for the average cost in the 3-percent discount rate scenario.

To make sure that all projects are evaluated using comparable values, Cal-B/C uses the \$23 estimate for the first year of project benefits. The model includes the 1.6-percent “uprating” factor, so that subsequent years reflect increasing values. Since Cal-B/C evaluates all projects with starting values based on 2011 emissions, the approach underestimates the value of greenhouse gas emissions with project openings delayed substantially into the future.

*Revision Made to Cal-B/C:* added estimation of greenhouse gas emissions to Cal-B/C using EMFAC2011 emission rates for CO<sub>2</sub> and the US Interagency Working Group values for greenhouse emissions

## 8.0 TRANSIT PARAMETERS

The next two sections describe updates to the parameters for transit accidents and emissions. In the Cal-B/C framework, transit refers to a range of modes:

- Passenger trains, including heavy rail and commuter rail
- Light rail transit (LRT)
- Buses, which exclude intercity and school buses.

### 8.1 Transit Accident Cost Parameters

*Transit Accident Rates.* Cal-B/C uses default accident rates based on USDOT national averages because users are unlikely to know accident rates for particular transit facilities. The original rates reflected an average of 1994, 1995, and 1996 annual figures from the USDOT publication “National Transportation Statistics.” That publication is no longer printed, but is available in electronic form for 2009.

USDOT produces two reports that summarize transportation statistics. The “Transportation Statistics Annual Report” has been prepared since 1994 and summarizes transportation statistics for the President and US Congress in response to 49 U.S.C. 111 (1). This report is shorter than “National Transportation Statistics” and omits transit mode details that are needed for Cal-B/C. As a result, the Cal-B/C development team relied on 2007 edition of National Transportation Statistics to develop the transit accident rates for Cal-B/C. A state-specific report is available, but

the Cal-B/C development team chose to use national statistics because they are more robust (i.e., larger sample of transit accidents per year).

The Cal-B/C development team used data from Table 2-32, which provides transit safety data by mode for all reported accidents. Accidents include collisions with vehicles, objects, people (except suicides), as well as derailments or vehicles going off road. A more comprehensive definition of “incidents” includes personal casualties, fires, and property damage associated with transit agency revenue vehicles and all transit facilities. Incidents are reported in Table 2-33a. The Cal-B/C development team decided to use data from Table 2-32 (consistent with the original Cal-B/C) because the non-accident incidents are not directly related to the amount of service provided (number of revenue vehicle-miles traveled).

Exhibit III-47 shows the updated transit accident rates for Cal-B/C. The Cal-B/C development team used the average of safety statistics for 2002 through 2008. Ideally, these statistics would cover a ten-year period. However, the Federal Transit Administration (FTA) changed the definitions for reportable accidents in 2002. Future updates to Cal-B/C should include ten-years of accident data.

**Exhibit III-47: Average of Transit Accident Rates for 2002-2008  
(events per million vehicle-miles)**

Event	Passenger Train	Light Rail	Bus
Fatality	0.0428	0.1897	0.0351
Injury	0.2517	3.6283	3.8909
All Accidents	0.2519	7.4952	3.8924

*Source: US Department of Transportation, Transportation Statistics Annual Report, 2009.*

The passenger train category reflects the sum of accidents for heavy rail and commuter rail transit. Non-transit passenger and freight rail statistics are reported separately and excluded from these statistics. The rates for non-transit rail are comparable to (but lower than) the rates for transit rail. Heavy rail accident rates are lower than commuter rail rates due to the use of exclusive right-of-way. The bus accident statistics do not include intercity or school buses. The base data for these statistics is FTA “Transit Safety & Security Statistics & Analysis Annual Report,” which is available online.

The accident rates in Exhibit III-47 are much lower than the accident rates used in earlier versions of Cal-B/C. As noted in National Transportation Statistics, transit accident rates have dropped considerably over the last decade. Another factor is that the reporting thresholds for injury and property damage only accidents have changed, resulting in fewer accidents being reported.

Cal-B/C also incorporates accident rates and costs for accidents at highway-rail grade crossings. Details on these additions are in Chapter VI, which has a discussion on highway-rail grade crossing accidents.

*Cost of Transit Accident Events.* Cal-B/C uses the same cost for a transit fatality as it does for a highway fatality to ensure that the cost evaluation is the same for both modes.

The distribution of injuries by severity type is necessary to estimate the cost of transit injuries. Since this information is not readily available, Cal-B/C assumes that transit accidents have the same injury distribution as the California statewide average for highway accidents. The requirements for reporting transit accidents in the National Transit Database (NTD) changed in 2002 to coincide with other transportation modes. Prior to 2002, any report injury or incident was reported to the NTD. Since 2002, only incidents requiring immediate medical treatment away from the scene qualify as reportable injuries (e.g., similar to injury types A and B for highway accidents). This new reporting is more consistent with accident reporting for highway accidents. Transit accidents are much less frequent than highway accidents, so the assumption about injury distribution is unlikely to have a major impact on Cal-B/C model results.

Property damage must be estimated separately by transit mode because buses and trains have different replacement values. In the original Cal-B/C model, property damage costs for passenger trains and buses were estimated from a 1994 Journal of Safety Research article by the National Safety Council. The National Safety Council data has not been updated. The value for light rail vehicles came from the California Public Utility Commission (CPUC) Annual Report of Railroad Accidents Occurring in California. The 1999 report is the latest edition available electronically on the internet. Notes from a CPUC meeting reference a 2000 report, but the Cal-B/C development team was unable to find a copy online. The CPUC railway accident report appears to have been discontinued.

The FTA "Transit Safety & Security Statistics & Analysis Annual Report" was the primary source for the transit accident rates. It also provides annual estimates of transit property damage due to accidents (available at <[transit-safety.volpe.dot.gov/Data/Samis.asp](http://transit-safety.volpe.dot.gov/Data/Samis.asp)>). The reportable property damage threshold increased in 2002. Accidents that involve property damage exceeding \$7,500 are reportable to the NTD. The previous threshold for property damage accidents was \$1,000, but included transit property damage only. These reporting limits mean that the dollar estimate of property damage and the accident rate statistics exclude lower-value property damages.

Exhibit III-48 provides updated property damage values for Cal-B/C. The values in the chart are calculated by dividing the property damage totals by the number of vehicle miles reported in the FTA database for 2002 through 2007 and rounded for use in Cal-B/C. The transit mode definitions are the same as those used for the accident rates.

**Exhibit III-48: Cost of Transit Accident Events**

Value	Passenger Train	Light Rail	Bus
Total Property Damage Cost	\$19,686,581	\$3,392,946	\$22,513,626
Total Number of Accidents	240	581	8,055
Property Damage (\$/event)*	\$82,000	\$5,800	\$2,800

\* Rounded

Source: Federal Transit Administration, *Transit Safety & Security Statistics & Analysis Annual Report*, available at <[transit-safety.volpe.dot.gov/Data/Samis.asp](http://transit-safety.volpe.dot.gov/Data/Samis.asp)>

*Revision Made to Cal-B/C: updated transit accident cost factors in Cal-B/C*

## 8.2 Transit Emissions Factors

*Buses.* EMFAC includes emissions factors for buses. The latest version of Cal-B/C includes updated bus emissions factors consistent with other emissions. The development of these factors is described earlier in the section on automobile and truck emissions factors.

*Passenger Rail and Light Rail.* The original Cal-B/C emissions factors for passenger rail and light rail came from the 1991 CARB Locomotive Emissions Study. The Cal-B/C development team was unable to find an updated source for locomotive emissions.

Light rail vehicles generally operate on electric power generated from remote sources, so no exhaust or evaporative emissions are emitted directly by the trains. In order to estimate the emissions associated with these vehicles, Cal-B/C captures the contribution to environmental effects of the power plants that generate electricity, in terms of their emissions. For the original version of Cal-B/C, power plant emissions were converted to emissions per LRT vehicle-mile based on LRT traction power, energy consumption, the mix of power generation methods in California, and their respective emissions per mega-watt hour. This methodology is based on work completed by the California Air Resources Board, the California Energy Commission, and the South Coast Air Quality Management District. The Cal-B/C development team was unable to find updated California sources for the factors.

The Cal-B/C development team also researched potential federal sources. USEPA issued a Final Rule on Tier 3-4 locomotives and smaller (i.e., less than 30 liters per cylinder) marine diesel emissions in May 2008. The phase-in for these regulations begins around 2015 for new locomotives and later for rebuilds. In May 2009, USEPA published Emission Factors for Locomotives consistent with the final Tier 4 standards. These standards are codified at 40 CFR part 1033 and their applicability depends on the date a locomotive is first manufactured. USEPA estimated locomotive emission rates by tier, but applying these requires knowing the locomotive manufacturing date.



USEPA also estimates emissions factors in grams per gallon. However, applying these would require fuel consumption figures to be known. In addition, USEPA estimated factors for only oxides of nitrogen (NO<sub>x</sub>), particulate matter (PM<sub>10</sub>), and hydrocarbons (HC).

*Revision Made to Cal-B/C: updated bus emission factors, other transit emissions factors unchanged*

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**IV. TRAFFIC OPERATIONS  
CONSISTENCY**



#### IV. TRAFFIC OPERATIONS CONSISTENCY

This chapter describes the issues in making Cal-B/C consistent with established procedures to assess safety and mobility projects in the State Highway Operations and Preservation Program (SHOPP). It also describes the 2009 revisions made to address these issues. The resulting benefit-cost model balances the need for common procedures and different levels of analysis in the Divisions of Transportation Planning and Traffic Operations.

Although the rest of this section refers to Cal-B/C v4.0, the current version of Cal-B/C (v5.0) continues to include these modifications. Some of the values found in this chapter reference the prior version of the model (v4.0), but the basic structure remains the same. Chapter III provides the current economic values used in Cal-B/C from the 2012 update.

For the 2009 revision, the Cal-B/C development team worked the Division of Traffic Operations to establish consistency in the following five areas:

- Traffic Safety Index (SI)
- Collision Values
- Priority Index Number (PIN)
- Highway Congestion Monitoring Program (HICOMP)
- Delay Definition.

As a result of the collaboration, the development team modified the safety calculations in Cal-B/C to be more consistent with the SI and the terminology used in the Traffic Safety Program. The revised model can also handle the collision reduction factors used for SI calculations. A list of the current collision reduction factors is available in the Highway Safety Improvement Program (HSIP) Guidelines. The Cal-B/C development team also worked with the Traffic Safety Program to establish common collision values and a procedure for updating these values annually.

The Operations System Branch helped the Cal-B/C development team review the procedures for selecting mobility projects. The Cal-B/C methodology is similar to the PIN calculations and can be adopted for evaluating operations mobility projects. The review of HICOMP data and delay definitions revealed the complexity of reporting congestion monitoring and reporting mobility benefits. On the basis of this review, Cal-B/C v4.0 has a refined nomenclature that refers to travel time savings rather than delay savings.

More details on these changes can be found in the rest of this chapter, which is organized around the five collaboration areas.

## 1.0 TRAFFIC SAFETY INDEX (SI)

Traffic Operations calculates a traffic safety index (SI) for projects proposed for funding in the 010 Collision Reduction Program, which is part of the State Highway Operations and Preservation Program (SHOPP). The SI is essentially a benefit-cost calculation that compares the safety benefits of a project to its construction costs. The benefits are not discounted in the SI calculation, but the Department uses a threshold SI score of 200 when considering projects for funding. This threshold corresponds to a benefit-cost ratio of 1.0 with 8.0 percent real discounting over 20 years. If the Traffic Safety Program were to use a lower discount rate, the corresponding SI threshold would be lower. The Department has a customized Filemaker Pro program for calculating SI.

To learn more about the SI, the Cal-B/C development team met with appropriate staff in the Traffic Safety Program. The development team received a copy of Draft 2004 HSIP Guidelines and examples of SI calculations for two projects. This chapter describes calculation of the traffic safety index (which the HSIP Guidelines abbreviate as TSI, but other documents refer to as SI). The Cal-B/C development team also spoke with Departmental staff in Transportation Programming to understand how SI and Cal-B/C are used in SHOPP programming decisions.

The SI is a benefit-cost calculation. Users provide recent collision data for a facility by the type of collision. This information is compared to the statewide average for similar facilities (by rate group) to determine whether the differences are statistically significant (according to a Poisson distribution). The HSIP Guidelines have a table of collision reduction factors. Along with current and average collision rates, the reduction factors are used to determine the “after” collision rates. The SI calculation allows three different methods to estimate the after rates:

- Method I – use of the reduction factor, as long as it does not result in a collision rate lower than the base rate for the collision rate group.
- Method II – assumption that collisions will be reduced (or increased) to the base rate, if no reduction factor is available or Method I is negative
- Method III – analysis of actual collisions to determine which can be removed by the improvement, only for segments greater than 0.5 miles.

The table of collision reduction factors also lists typical lifecycles for safety improvements. These range from 10 to 20 years depending on the type of project. The SI calculation estimates the difference in accident costs over the lifecycle and compares them to the benefits. In the past, future traffic volumes (AADT) were available from “Printout SHS004-7,” which was distributed annually. The Department has stopped using these standardized future volumes. The estimation of future traffic is now left to

discretion of the Department's district staff. Traffic volumes are interpolated linearly for intervening years using a volume correction factor (VCF). The VCF allows benefits to be calculated for the "average" year over the lifecycle and compared to the costs.

The SI is calculated as an index, which is the benefit-cost ratio multiplied by 100. The SI uses different values for collisions depending on whether the improvement is on an urban, suburban, or rural segment. Rather than estimate changes in collision rates separately for fatality, injury, and property damage only (PDO) collisions, the SI methodology calculates all benefits using a single accident cost. This cost is adjusted to account for statistically significant changes in accident severity. The approach ensures that only statistically significant changes are included and does not require the Department to estimate the number of future collisions by type.

The specific calculations depend on whether the improvement is a spot improvement or a correction of a wet pavement problem. The only major difference is that the wet pavement calculations include only collisions under wet conditions.

### **1.1 Comparisons with the Prior Version of Cal-B/C**

Both SI and the prior version of Cal-B/C (before v4.0) produce benefit-cost ratios for safety improvements, but some differences and similarities are worth noting:

- Both estimate changes in base average collision rates using the published collision rate groups.
- Cal-B/C calculates benefits using a method similar to the SI Method II, but allows users to change the reduction factor.
- The SI does not discount future benefits (although the SI threshold makes discounting implicit), while Cal-B/C uses a real discount rate to account for the time value of resources.
- The project lifecycle can vary from 10 to 20 years in an SI calculation, while it is fixed at 20 years for Cal-B/C.
- The SI calculation includes a test for statistical significance in estimating differences from statewide averages.
- Cal-B/C uses a single set of collision costs for the state, while the SI differentiates between, urban, suburban, and rural roadways.
- The HSIP Guidelines include collision reduction factors for highway safety projects.

- Cal-B/C is unable to estimate the safety benefits of improving wet pavement, while the SI includes wet pavement factors.

## 1.2 Consistency in Methods

The SI is calculated to justify investments in highway safety projects. The method was implemented in Filemaker Pro, approved by many stakeholders, and passed legal requirements. In order to make changes to SI calculations, the Cal-B/C development team would need to document why the changes result in a better SI calculation and demonstrate how the elimination or addition of projects under the new method is justified. For example, lowering the SI threshold to account for a lower discount rate would lower the funding bar and add projects. Removing statistical significance testing would add and eliminate projects, but it would also lower confidence in the results.

Given these considerations, the Cal-B/C development team did not try to change existing SI calculations as part of the Cal-B/C update. Instead, the Cal-B/C development team tried to make the Cal-B/C calculations as consistent as possible with the SI procedures. However, the Cal-B/C development team did not try to mimic the entire SI calculation. The Department already has one tool that produces a definitive SI calculation and creating a second tool would simply duplicate efforts. The new version of Cal-B/C incorporates a number of features from the SI calculation that provide greater consistency for State Transportation Improvement Projects (STIP):

- Terms consistent with SI, such as rate group and reduction factor
- User-specified rate groups on the Cal-B/C input sheets
- Modified calculations to handle the collision reduction factors in the HSIP Guidelines (see Chapter 5, Figure 5-C, Table 1 of the guidelines)
- Consistent collision values (which are discussed in Section 2.0)
- Accident rates for intersections estimated as a function of million vehicles (MV).

## 2.0 COLLISION VALUES

The Traffic Operations calculations use collision values as part of its SI calculation. The calculation produces different values for rural, urban, and suburban travel to take into account the variation in the average number of fatalities and injuries in different driving situations. For example, rural fatal accidents tend to involve more total fatalities and injuries on average than do urban fatal accidents.

Exhibit IV-1 compares the values shown in Chapter 5 of the Draft 2004 Highway Safety Improvement Program (HSIP) guidelines with those used in the previous version of Cal-B/C. As can be seen in the exhibit, the values were inconsistent. Although the comparison suggests a large difference in methodologies, this gap is mostly due to different severity and cost escalation data – the underlying methodologies were the same.

#### Exhibit IV-1: Previous HSIP and Cal-B/C Collision Values

Value	Fatal	Injury	PDO	Average
Rural	\$4,521.9	\$89.7	\$4.6	\$161.6
Urban	\$4,058.1	\$60.5	\$4.6	\$46.8
Suburban	\$4,174.1	\$72.4	\$4.6	\$68.3
Average	\$4,290.0	\$68.1	\$4.6	\$69.7
Cal-B/C	\$3,262.5	\$85.7	\$7.2	\$61.5

The Cal-B/C development team worked with the Traffic Safety Program to develop consistent values for Cal-B/C and SI calculations. Cal-B/C calculates separate accident values for rural, urban, and suburban travel that can be used for SI calculations. This maintains consistency with previous SI calculations and adds accuracy to the Cal-B/C safety calculations. Cal-B/C uses only the rural and urban values, because these are the two area types reported on Cal-B/C input sheets. After the user selects the location of a project (rural or urban), Cal-B/C calculates the appropriate values for fatal, injury, and PDO accidents. Cal-B/C has the suburban values available and could use these values, if needed, in the future.

The calculations of accident rates were made explicit in the new version of Cal-B/C, so the values and assumptions are documented in the model. Several new tables were added to the Cal-B/C Parameters page to support these calculations. The Office of Traffic Safety provided detailed Traffic Accident Surveillance and Analysis System (TASAS) information on the number of people killed, the number of people injured, the number of vehicles involved as well as severity by the type of accident for 2004 through 2006. As the new tables show, rural accidents tend to involve fewer vehicles, but are more severe in terms of fatalities and injuries than are urban accidents. The new accident values reflect these differences.

Cal-B/C also needed information on the severity distribution of highway injuries in order to estimate appropriate accident values. Exhibit IV-2 shows the distribution table used in Cal-B/C. The percentages are reported according to the KABC severity scale used in the National Safety Council (NSC) cost estimates. Another injury scale, the Abbreviated Injury Scale (AIS), is used by the National Highway Traffic Safety Administration (NHTSA) for cost estimates. The Cal-B/C team chose the KABC scale because it is readily available in California and needed for NSC cost estimates (the

standard for Cal-B/C). The differences in these two scales are described further in the Chapter III discussion on economic values for safety.

TASAS does not contain injury severity information, so the California Highway Patrol (CHP) Statewide Integrated Traffic Incident Reporting System (SWITRS) is the only source for this information. Injury severity is likely to vary by location in the state just as the event frequency does. However, SWITRS does not have detailed highway information and TASAS does not have injury severity information. The only way to collect this information is to request a special run of SWITRS data and match it to the highway tables in TASAS. That could not be done within the timeframe of the Cal-B/C update, but as Exhibit IV-2 shows, Cal-B/C contains placeholders for different severity data by location if this information were available in the future.

### Exhibit IV-2: Highway Injury Severity Frequency in Cal-B/C

Event	Urban	Suburban	Rural	Average
Severe Injury (A)	4.70%	4.70%	4.70%	4.70%
Other Visible Injury (B)	26.28%	26.28%	26.28%	26.28%
Complaint of Pain (C)	69.02%	69.02%	69.02%	69.02%

Source: 2009 SWITRS Annual Report, Table 8C

### 3.0 PRIORITY INDEX NUMBER (PIN)

The 310 Operational Improvement program is a part of the SHOPP that targets mobility issues. Another program, 315 Transportation Management Systems, was addressed in earlier Cal-B/C updates. The goal of the 310 program is to reduce traffic congestion and associated traffic collisions through improvements addressing operational deficiencies related to the flow and movement of traffic without expanding the design capacity. According to the program guidelines adopted by the California Transportation Commission on December 11, 2003, examples of 310 program improvements include:

- Interchange modifications (not to accommodate larger traffic volumes)
- Ramp modifications
- Auxiliary lanes for merging or weaving between adjacent interchanges
- Curve corrections or alignment improvements
- Signals or intersection improvements
- Two-way left turn lanes
- Channelization
- Turnouts
- Shoulder widening.

Capacity-increasing operational improvements are not eligible for SHOPP funding and must be programmed through the STIP. According to the STIP program guidelines, the following operational improvements are capacity increasing:

- HOV lanes and HOV interchanges
- Interchange design modifications and upgrades to accommodate traffic volumes significantly larger than the existing facility design
- Truck or slow vehicle lanes on freeways of six or more mixed lanes.

The PIN is a benefit-cost evaluation of operational improvement projects considered for SHOPP funding. It is used to prioritize eligible and qualifying SHOPP 310 projects and is one of the key parameters in assigning SHOPP funds to statewide operational improvement projects. To be considered for programming, a 310 project must have a benefit-cost ratio greater than 1.0 (i.e., a PIN greater than 100).

The current PIN methodology computes the ratio of a project's benefits to its cost. Traffic Operations developed an Excel spreadsheet that automates the calculation. The PIN is comprised of two parts: 1) *Delay Index (DI)*, which is similar in concept to the travel time savings estimated in Cal-B/C; and 2) *Discounted Safety Index (SI)*, which is a modified version of the safety index used by the Traffic Safety Program and similar in concept to the safety benefits calculated in Cal-B/C. The PIN is calculated according to the following formulas:

$$PIN = Delay Index + Discounted Safety Index$$

OR

$$PIN = \left( \frac{\text{discounted delay benefits}}{\text{cost}} \right) \times 100 + \left( \frac{\text{discounted safety benefits}}{\text{cost}} \right) \times 100$$

### 3.1 Delay Index (DI)

The delay index is simply the discounted delay benefits divided by the cost and indexed to 100. As in Cal-B/C, the delay benefits are calculated by multiplying the daily delay savings (B) by the value of time (A) and the number of days in the year (D) that the traffic problem causes delays. This annual delay benefit is turned into a life-cycle benefit by multiplying by a present work factor ( $P_L$ ) based on the life of the project in years (L) and a discount rate.

The daily delay savings (B) is calculated as the total daily delay in vehicle-minutes before project implementation minus the total daily delay after project implementation using the following formula:

$$B = \left( \frac{L_1}{S_1} - \frac{L_2}{S_2} \right) \times \left( \frac{60 \text{ minutes}}{\text{hour}} \right) \times AveAADT_{Ben}$$

where,

- $L_1$  = length of highway segment at  $S_1$  before improvement (in miles)
- $L_2$  = length of highway segment at  $S_2$  after improvement (in miles)
- $S_1$  = average operation speed before improvement (in miles per hour)
- $S_2$  = average operation speed after improvement (in miles per hour)
- $AveAADT_{Ben}$  = average of the Annual Average Daily Traffic benefited by the improvement (in vehicles per day)

The most critical values influencing the PIN calculation are the before and after speeds ( $S_1$  and  $S_2$ ). The PIN value can be changed significantly by changing the before and after speeds in the spreadsheet. A similar issue motivated the incorporation of Bureau of Public Roads (BPR) curves and speed estimation into the original version of Cal-B/C.

$S_1$  may vary significantly according to season (e.g., ski season and summer recreational travel) and time of day (e.g., AM Peak period, PM peak period, and other time periods). The extent to which these variations are included in the calculations depends on the availability of data and resources.

$S_2$  cannot exceed the lesser of the design speed (i.e., the geometric speed), the posted speed limit, or the speed limit specified in Vehicle Code, Chapter 7, beginning with Section 22348. Traffic Operations provides guidance that  $S_2$  should be estimated only after a sufficient period of time elapsed for the traffic to adjust to the operational improvement. The PIN calculation does not allow the  $S_1$  or  $S_2$  to vary over the life of the project even though the AADT is expected to change.

In the PIN calculation,  $AveAADT_{Ben}$  is the sum of the existing AADT benefit and the AADT benefit at the end of the life of the improvement divided by two.  $AveAADT_{Ben}$  should include only the portion of AADT that receives a delay reduction due to the operational improvement. This is similar in concept to the “peak period” travel volume used in Cal-B/C. Only travel under congested conditions receives a congestion reduction benefit. Traffic Operations does not provide guidance on how to calculate the portion of AADT that receives a delay reduction. The Cal-B/C development team researched methods for estimating the proportion of AADT in congested conditions for Cal-B/C. The method decided upon is described in Chapter III on updated economic values and model parameters.

The daily delay savings (B) is converted to a total delay savings by multiplying by an annual conversion factor, a weighted average time value of trucks and autos, and a present worth factor corresponding to the life of the project. It is left to each district to



determine whether a project benefits all year or weekdays only. Traffic Operations provides the following guidelines for the annual conversion factor (D):

- Weekend traffic = 115 days
- Recurrent weekday traffic = 250 days
- All year traffic = 365 days.

Cal-B/C uses a 365-day annualizing factor. In the prior version of Cal-B/C, the annualizing factor was buried in the benefit calculations. In the latest version, the factor was converted into a model parameter. Although the factor can be changed, it is located in the Parameters page and, therefore, less likely to be changed by the user. In the PIN calculation, the annual conversion factor is a direct user input as shown in Exhibit IV-3.

**Exhibit IV-3: Annual Conversion Factor in PIN Spreadsheet**

DELAY INDEX						
DAILY		COST		DAYS		PRESENT
DELAY		PER VEH MIN		PER YEAR		WORTH
SAYINGS				APPLIED		FACTOR
(VEH-MIN. PER DAY)		(\$ PER VEH. MIN.)		(DAYS PER YEAR)		
B	X	A	X	D	X	P <sub>L</sub>
10731		0.204		365		12.6

According to the latest PIN guidelines and a March 3, 2006 memorandum from the Division Chief of Traffic Operations, the following time values (A) should be used for PIN calculations:

- Automobiles 19 cents per minute (\$11.51 per hour)
- Trucks 46 cents per minute (\$27.83 per hour).

These values are comparable to those found in the prior version of Cal-B/C. The automobile value for PIN calculations is adjusted by an average occupancy of 1.1 persons per vehicle, which is the same value that the older version of Cal-B/C uses for peak period travel. The updated version used 1.15 persons per vehicle. Cal-B/C uses a higher value for non-peak travel. The PIN calculation estimates a weighted average of the time values based upon the percentage trucks as shown in Exhibit IV-4. Cal-B/C estimates the benefits separately for automobiles and trucks based on the percentage trucks. However, the concept and results are similar.

**Exhibit IV-4: Estimation of Weighted Value of Time in PIN Spreadsheet**

WEIGHTED AVERAGE COST PER VEHICLE MINUTE (TRUCKS & AUTOS)												
		TRUCK		CONVERT				AUTO		CONVERT		COST PER
		TIME VALUE		TO				TIME VALUE		TO		VEH. MIN.
		(\$ PER		DECIMAL				(\$ PER		DECIMAL		(\$ PER
Σ		VEH. MIN.)			Σ			VEH. MIN.)				VEH. MIN.)
TRUCKS	X	0.4	/	100	+	AUTOS	X	0.15	/	100	=	A
5.0		0.46		100		95.0		0.19		100	=	0.204
		(new)						(new)				

The present worth factor (P<sub>L</sub>) is estimated based on the estimated life of the project. The PIN guidelines use the same number of years as used in the SI calculations. The project life varies by type of improvement (as shown in Exhibit IV-5), but most are around 20 years, which is the standard life-cycle in Cal-B/C.

**Exhibit IV-5: Project Life Table for PIN Calculations**

Type of Improvement	Life (in years)
New and Modified Signals	15
Left Turn Channelization	20/10*
Curve Correction	20
Shoulder Widening	20/10*
Truck Climbing Lane	20/10*
Other Geometric Improvements	20/10*

\* Shorter life for non-standard geometrics

The present worth factor is provided for five-year increments and the analyst is required to interpolate for in-between project lives. The factors assume even traffic growth and discounting and correspond to an annual discount rate of 4.9 percent (compared to five percent in the prior version of Cal-B/C and four percent in the latest versions). The source of the PIN discount rate is the Wharton Economy Forecasting Association (WEFA) Fourth Quarter Report for 1988 titled "Present Worth Factor for Uniform Annual Series." The WEFA forecast assumed moderate growth to estimate a discount rate for 1988 through 2008. Adoption of the prior Cal-B/C discount rate would yield slightly lower benefits, but the difference would be marginal. The discount rate in Cal-B/C v4.0 would yield higher project benefits. As described earlier, the Safety Program uses a higher implied discount rate by using an SI cutoff of 200.

For the PIN calculation, the benefits are divided by the total capital costs, which includes construction and right-of-way costs, to yield the delay index (DI). Operating and maintenance costs are not included in the PIN calculation as they are in Cal-B/C. However, these costs are often ignored in Cal-B/C project evaluations as well.

Since the SI can be calculated with the Filemaker Pro program to evaluate collision reduction projects, the PIN spreadsheet focuses on estimating daily delay savings. The safety index data are estimated externally following the HSIP Guidelines issued by the Traffic Safety Program and entered into the spreadsheet. A discounted safety index is computed as a product of the project's safety index and the present worth factor divided by the life of the project. This calculation uses the same 4.9 percent discount rate as does the DI. The resulting discounted safety index is added to the delay index (DI) to arrive at the PIN.

### **3.2 Verifying Input Data**

The programming document for a 310 project is an approved project study report (PSR). The Project Development Procedures Manual issued by Design and Local Programs defines the content of a PSR. Headquarters Traffic Operations works with the districts to ensure consistency in the PIN calculations statewide. Traffic Operations reviews the following input parameters for each project:

- Length of the project - compared against the information in the programming document
- Capital cost - compared against the information in the programming document
- Current AADT - compared to the traffic volumes reported by the Traffic Data Branch in the Traffic Census Program.
- Future AADT - compared to forecasts from regional travel demand models
- Benefited AADT - verified through discussions with district representatives.

Headquarters does not currently review before and after speeds. An internal methodology review suggests that the speeds could be verified using the Freeway Performance Measurement System (PeMS). PeMS could provide information for before speeds, but speeds vary considerably over the course of the day, week, and year. The Department would need guidelines on how to use PeMS data to verify speed data provided by the district. PeMS is unable to predict how a particular project influences speeds.

### **3.3 Consistency in Methods**

Cal-B/C can assess proposed projects in the 310 Operational Improvements program. The calculations in Cal-B/C model are more comparable to the SI calculations in the Traffic Safety Program, and Cal-B/C incorporates the discounting of the SI needed for

the PIN calculations. The new Cal-B/C discount rate (four percent) is lower than the existing PIN calculation. The adoption of Cal-B/C for the 310 program would provide more consistency between STIP and SHOPP project evaluations. It would also provide a check on the speeds estimated for individual project. Cal-B/C does not normally support the modification of the annualization factor, but the parameter could be adjusted as needed.

The only remaining difference is the estimates for the length of project lifecycles. As Exhibit IV-5 shows, the Traffic Operations calculation assumes that the lifecycle for some projects is less than 20 years. However, the PIN guidelines support a 20-year lifecycle for most projects with standard geometrics. Traffic Operations could use Cal-B/C for projects with non-standard geometrics by including the incremental lifecycle cost for the second ten years.

#### 4.0 HIGHWAY CONGESTION MONITORING PROGRAM (HICOMP)

The Highway Congestion Monitoring Program (HICOMP) is an ongoing effort by Traffic Operations to measure congestion on California urban freeways. The Department has prepared an annual HICOMP report since 1987. Beginning in September 2002, this congestion information is required by statute:

*“The Department shall, within existing resources, collect, analyze, and summarize highway congestion data and make it available upon request to California regional transportation planning agencies, congestion management agencies and transit agencies.” (California government Code Section 14032.6)*

HICOMP focuses on urban freeways. It does not include congestion on other State Highways or local surface streets. The program also reports only recurrent congestion (i.e., excludes non-recurrent congestion due to collisions, holidays, maintenance, or special events). The measurements are intended to reflect typical weekday travel conditions.

HICOMP defines recurrent congestion as “a condition lasting for 15 minutes or longer where travel demand exceeds freeway capacity and vehicular speeds are 35 miles per hour (mph) or less during peak commute periods on a typical incident-free weekday” (2007 HICOMP report). The Department uses three measures to describe recurrent congestion:

- *Magnitude:* The difference between the time to travel a segment at the congested speed and the travel time at 35 miles per hour (mph). Magnitude is measured in daily vehicle-hours of delay (DVHD).
- *Extent:* The length of freeway segment that experiences speeds below 35 mph for 15 minutes or more. Extent is expressed in terms of congested

directional miles (CDM). One-mile stretch of roadway contains two directional miles (one mile for each direction of travel).

- *Duration:* The length of time expressed in hours that the directional segment remains congested.

As these definitions illustrate, the HICOMP concept of delay is more restrictive than the travel time savings measured in Cal-B/C. In HICOMP, congestion is not considered to be a detriment to the traveling public until it is measured for 15 minutes or more and the average speed must be below 35 mph. In Cal-B/C, all reductions in travel times are monetized, regardless of the initial (no-build) travel speeds.

Traffic Operations calculates daily vehicle-hours of delay for the HICOMP report using the following formula:

$$\text{Daily Vehicle Hours of Delay} = V \times D \times T$$

where,

- V = volume in vehicles per hour = vehicles per hour per lane (vphpl) × number of lanes
- D = duration of congestion in hours
- T = travel time (in hours) to cover a given distance under congested conditions (speeds less than 35 mph) minus the travel time at 35 mph

The formula illustrates another difference between the vehicle hours of delay measured in HICOMP and the travel time savings estimated in Cal-B/C. HICOMP compares the travel time at the measured speed, which is below 35 mph, to the travel time at a fixed 35 mph. Cal-B/C compares the no-build speeds to the build speed. The build speed could be higher than 35 mph and as high as free-flow speeds.

The Department is developing a more comprehensive freeway performance assessment report to be used in future HICOMP reporting. The new report is expected to include new performance measures and address shortcomings of the current approach. The new performance report will include a number of new measures for outcomes including:

- Mobility
- Reliability
- Productivity
- Safety.

The new delay measure uses a measurement closer to the Cal-B/C definition. Travel at measured speeds is compared to 60 mph (which approximates free-flow conditions in most cases). The delay associated with speeds below 35 mph is called “severe delay,”

while the delay associated with speeds above 35 mph is called “other delay.” This measure still differs from the Cal-B/C calculation of travel time savings in that the comparison is set at 60 mph in HICOMP, while Cal-B/C uses the estimated build speed. However, the build speed is likely to be much closer to the 60 mph comparison in the comprehensive report than the 35 mph currently used in HICOMP.

The other measures are unlikely to have comparable measures in Cal-B/C:

- *Reliability* measures the variability in travel time. Reliability can not be predicted, so Cal-B/C would be unable to estimate reliability. However, Cal-B/C could estimate unexpected or non-recurrent delays if an agreed-upon methodology were developed. So far, there is no consensus on how to estimate non-recurrent delays. Cal-B/C includes a placeholder value for unexpected travel time if a methodology is developed.
- *Productivity* measures the degree to which the transportation system performs during peak demand conditions. The productivity indicator is defined as the percent utilization during peak demand conditions. As an example, freeways are typically designed to carry 2,000 vehicles per hour per lane. The carrying capacity of a freeway lane can drop by as much as 50 percent, allowing only 1,000 vehicles per hour to pass. In effect, the system “loses” capacity, which can be estimated in terms of equivalent lost lane-miles. This requires field measurement in addition to the calculations available in Cal-B/C.
- *Safety* is measured in terms of the number of collisions or accidents. While this data can be summarized in Cal-B/C, it could be reported more easily using the Department’s safety database.

## 5.0 DELAY DEFINITION

As described below, the PIN calculation and Cal-B/C use similar definitions of delay. The 310 program uses a combination of PIN delay estimates and measured delay from HICOMP. These definitions vary considerably, so the estimated benefits of a project (calculated in PIN or Cal-B/C) cannot be counted against measured delay (HICOMP). The Department needs to distinguish between these two concepts by calling the first “travel time savings” and the second “delay.”

*Revised Cal-B/C Definition.* As shown in Exhibit IV-6, the results page of Cal-B/C was updated to report the person-hours of travel time saved. Subsequent versions of Cal-B/C use a similar page. Since this term implies that the travel time improved for existing trips, the value calculated for the results page shows travel time savings only for trips in the build and no-build case. Induced demand is included for the calculation

of build scenario speeds, but it is excluded when estimating aggregated travel time savings.

**Exhibit IV-6: Performance Measures on Cal-B/C Results Page**

INVESTMENT ANALYSIS SUMMARY RESULTS		
3		
<b>Life-Cycle Costs (mil. \$)</b>	\$0.0	
<b>Life-Cycle Benefits (mil. \$)</b>	\$0.0	
<b>Net Present Value (mil. \$)</b>	\$0.0	
<b>Benefit / Cost Ratio:</b>	N/A	
<b>Rate of Return on Investment:</b>	N/A	
<b>Payback Period:</b>	N/A	
		Average Annual      Total Over 20 Years
<b>ITEMIZED BENEFITS (mil. \$)</b>		
<b>Travel Time Savings</b>	\$0.0	\$0.0
<b>Veh. Op. Cost Savings</b>	\$0.0	\$0.0
<b>Accident Cost Savings</b>	\$0.0	\$0.0
<b>Emission Cost Savings</b>	\$0.0	\$0.0
<b>TOTAL BENEFITS</b>	\$0.0	\$0.0
<b>Person-Hours of Time Saved</b>	0	0
<b>CO<sub>2</sub> Emissions Saved (tons)</b>	0	0
<b>CO<sub>2</sub> Emissions Saved (mil. \$)</b>	\$0.0	\$0.0

The person-hours of time saved are estimated using the following formula:

$$\text{Person Hours of Delay Saved} = \min(\text{No Build Volume, Build Volume}) \times (\text{No Build Travel Time} - \text{Build Travel Time}) \times \text{Average Vehicle Occupancy}$$

*SHOPP Ten-Year Plan.* Traffic Operations lists its statewide goal for the 310 Program to “reduce 30,000 daily vehicle hours of recurring delay from 2008/09 through 2017/18.” The information page does not have a definition for daily vehicle hours, but presumably, recurring delay is measured as in the HICOMP report.

A project qualifies for 310 SHOPP funding by achieving a benefit-cost ratio of at least 1.0 (as measured by a PIN greater than 100). This suggests that delay is defined in terms of changes in travel time and may not be limited to recurrent congestion. Priorities, however, are assigned by vehicle-hours of delay per mile for corridors with HICOMP data. For corridors without HICOMP data, priorities are ranked by PIN.

*PIN Calculation.* The measure used to assess the performance of 310 projects is a by-product of the PIN calculations. Calculating a project’s reduction in Daily Vehicle-Hours of Delay (DVHD) is a simple conversion of the daily delay savings from vehicle-minutes per day to vehicle-hours per day. This performance measure quantifies benefits for the 310 program in the SHOPP Ten-Year Plan and is used in the SHOPP Investment Analysis Tool.

The DVHD reported in the PIN calculation is the same as the person-hours of travel time saved reported in Cal-B/C v4.0, except that the Cal-B/C measure adjusts the travel

time savings by the average vehicle occupancy. In this way, Cal-B/C reports the travel time savings by people rather than vehicles.

*Congestion Monitoring.* As described in the earlier section, HICOMP estimates delay by comparing measured speeds to a 35-mph threshold. The HICOMP concept of delay differs from the Cal-B/C and PIN calculations.

## 6.0 REFERENCES

Balji, Kris, 2006 Travel Time Values for Automobiles and Trucks, California Department of Transportation, Traffic Operations, memorandum dated March 3, 2006.

California Department of Transportation, 1992 Project Candidate Development Manual (for 1992 STIP and HSOPP Projects), Office of Transportation Programming, HB4N and HB4C Operational Improvements, revised April 5, 1991.

California Department of Transportation, Draft 2004 Highway Safety Improvement Program (HSIP) Guidelines, Division of Traffic Operations, Office of Traffic Safety, Chapter 5 Traffic Safety Index.

California Department of Transportation, Operational Improvements: Priority Index Number (PIN) Instructions, June 30, 2006.

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California Department of Transportation, 2007 State Highway Congestion Monitoring Program (HICOMP), annual data compilation, May 2007.

California Transportation Commission, State Transportation Improvement Guidelines, adopted December 11, 2003.



**V. HIGH OCCUPANCY TOLL (HOT)  
LANES**

## V. HIGH OCCUPANCY TOLL (HOT) LANES

This chapter describes the effort to incorporate the evaluation of High Occupancy Toll (HOT) lanes in the Cal-B/C model as part of the 2009 update. The focus on HOT lanes gave the Cal-B/C development team an opportunity to review the assumptions used in Cal-B/C for High Occupancy Vehicle (HOV) lanes. Like HOT lanes, these lanes involve a separate facility dedicated to a group of highway users and higher average vehicle occupancy (AVO).

The 2009 review resulted in a Bureau of Public Roads (BPR) curve specific to the estimation of speeds on HOV and HOT lanes as well as a slightly modified induced demand calculation. These changes allow Cal-B/C to estimate user benefits for HOT lanes. They also enable assessments of HOV-to-HOT lane conversions and changes in HOV occupancy requirements. The latest version of Cal-B/C retains these improvements.

This chapter describes the research conducted by the Cal-B/C development team and modifications made to Cal-B/C for incorporating HOT lanes and updating the HOV methodology. After this introduction, the chapter is organized as follows:

- *Description of High Occupancy Toll (HOT) Lanes* – provides a brief description of HOT lanes and identifies factors to be considered in evaluating their cost effectiveness
- *Relevant Departmental Guidelines and Procedures* – reviews Department resources on HOV and HOT lanes, including guidelines, performance evaluation reports, and safety data
- *Benefit-Cost Models and Other Methodologies* – describes how other benefit-cost models handle HOT lanes, if at all
- *Recent Research and Findings* – discusses findings from recent theoretical research with particular emphasis on the benefits and impacts of HOV and HOT lanes
- *Updated Cal-B/C Methodology* – explains how Cal-B/C evaluates HOT lanes and better captures the benefits of HOV lanes.

This chapter was written as part of the 2009 Cal-B/C update, so references to prior versions of Cal-B/C indicate versions before Cal-B/C v4.0. Since this chapter was first written, the application of HOT and managed lanes has expanded in California with several agencies considering their adoption. These lanes may also be called “express

lanes.” This chapter retains the original HOT lane nomenclature, although the HOT lane capabilities in Cal-B/C may be used for HOT lanes, managed lanes, or express lanes.

## 1.0 DESCRIPTION OF HIGH OCCUPANCY TOLL (HOT) LANES

HOT lanes or managed lanes are like HOV lanes in that they provide limited access and free-flow travel for their users. Unlike HOV lanes, they allow non-HOVs to use the facility for a toll. While HOT lanes alleviate highway congestion for users, they also have the potential to improve travel conditions in other lanes and provide toll revenues. HOT lanes draw users from adjacent general purpose lanes, which could lessen the volume or duration of congestion. The effects depend on demand elasticity, the potential for latent demand, and congestion levels.

Federal statutes restrict the charging of tolls on interstate highways, except where tolls previously existed or where exceptions have been made for pilot projects under 23 U.S.C § 301. The latest federal transportation funding act (Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, or SAFETEA-LU), provides states with increased flexibility to use tolling to manage congestion and to finance infrastructure improvements on a pilot or demonstration basis (USDOT, 2008).

California is involved in a pilot project under Assembly Bill (AB) 1467, passed in May 2006. AB 1467 authorizes the Department and regional transportation agencies “to develop and operate high-occupancy toll lanes, including the administration and operation of a value pricing program and exclusive or preferential lane facilities for public transit, as specified” (CTC, 2008). Under AB 1467, the California Transportation Commission is responsible for administering the project, while the California State Legislature determines project selections. The Legislature may select up to four projects: two in Northern California and two in Southern California.

Exhibit V-1 shows an example of a HOT lane system with variable tolls in Washington State. The Express Lanes on SR-91 in Orange County use a similar concept except that the variable tolls are published rather than dynamically priced. HOT lanes often have variable tolling to ensure that the lanes remain free flowing and that performance for HOV does not degrade below a certain threshold. Variable tolls can be a fixed time-of-day schedule based on historical traffic patterns, changed administratively, or set dynamically according to traffic in the HOT lane.

## Exhibit V-1: Washington State Route 167 HOT Lanes



Source: Seattle Times (May 5, 2008)

HOT lanes can result from new construction or the conversion of existing HOV lanes to HOT lanes. The construction of new lanes can be costly and difficult to implement. As a comparison, recent HOV projects often required Districts to acquire property in built-out areas for lane additions. HOV-to-HOT lane conversions are likely to be less costly, requiring the installation of toll enforcement equipment and access controls.

The type of HOT lane project impacts how benefits are calculated for the project. The construction of a new HOT lane facility is similar to the construction of an HOV facility, except that the AVO is different. A HOV-to-HOT lane conversion is more difficult to evaluate, because it requires information about toll elasticities and AVO changes on the facility and in the general purpose lanes.

## 2.0 RELEVANT DEPARTMENTAL GUIDELINES AND PROCEDURES

This section summarizes Department guidelines, procedures, and data sources relevant to HOT lanes. More detailed information is available in the source documentation.

### 2.1 Departmental HOV Guidelines

The Departmental HOV Operations Guidelines provide planners, designers, and operators with policies, design standards, and practices for the deployment of mainline HOV facilities. The guidelines are intended to be advisory and used only when every effort to conform to established standards has been exhausted. The guidelines were last updated in August 2003 and include six sections: planning, operations, geometric design, ingress/egress, signing and delineation, and enforcement. The appendices

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provide an overview of the statutes and policies relevant to HOV facilities as well as the requirements for district HOV reports.

According to the HOV guidelines, districts should consider changing the HOV occupancy requirement when the level of service (LOS) on an HOV facility drops to LOS C. The Department considers LOS C to occur at approximately 1,650 vehicles per hour per lane (vphpl).

Changing the occupancy requirement is intended to reduce demand on the facility. According to the HOV guidelines, increasing the occupancy requirement from two to three could reduce vehicular demand by 75 percent to 85 percent. This implies that many California HOV users are in two-person rather than three-person vehicles. These rules of thumb can be used to help estimate the impacts of changing HOV requirements when implementing HOT lanes.

HOV violation rates are a related issue. According to the HOV guidelines, a violation rate below ten percent is preferable. But a ten-percent violation rate on a HOT lane means considerable revenue loss. It is likely that minimizing HOT lane violation rates will be included in the HOT lane design, so violation rates could be ignored in the benefit-cost analysis.

Another consideration for HOV and HOT lanes is how the special lanes are separated from the general purpose lanes. Currently, HOV lanes are barrier-free and allow unimpeded access from the adjacent general purpose lanes in Northern California. In Southern California, most HOV and HOT lanes are separated from general purpose lanes by physical barriers or buffers.

Departmental HOV Guidelines state:

“When right space and cost considerations are not major concerns, a physical barrier separating the HOV lanes from the mixed-flow lanes generally offers a higher level of service than other geometric configurations. They offer operational advantages such as (1) ease of enforcement; (2) ease of incident management; (3) unimpeded HOV operation without interference from mixed-flow lanes; (4) lower violation rates; (5) high level of driver comfort” (Caltrans, 2003).

The Guidelines note that for a buffer-separated facility, a minimum of 400 meters of dashed white line should be offered on the right to provide consistency of appearance with ingress and egress areas.

## 2.2 District HOV Reports

Appendix B of the HOV Guidelines describes the requirement for districts to develop HOV reports. Department districts are supposed to collect vehicle occupancy data twice a year, although data may be collected less often.

Exhibit V-2 summarizes the vehicle occupancy data based on the HOV Reports from District 3 (Sacramento), District 4 (San Francisco), and District 7 (Los Angeles). More detailed information can be found in Chapter II, which provides information on updating the economic values in Cal-B/C.

**Exhibit V-2: Average Vehicle Occupancy (AVO) Summary  
Based on 2004 District HOV Reports**

	HOV Lane-Miles	2+ Restriction				3+ Restriction			
		Peak Period HOV Occupancy Range*	Most Frequently Observed Peak Period HOV Occupancy*	Peak Period Mixed Flow Occupancy Range*	Most Frequently Observed Peak Period Mixed Flow Occupancy*	Peak Period HOV Occupancy Range*	Most Frequently Observed Peak Period HOV Occupancy*	Peak Period Mixed Flow Occupancy Range*	Most Frequently Observed Peak Period Mixed Flow Occupancy*
District 3 - Sacramento	71	2.04 - 2.36	-	1.05 - 1.32	-	N/A	N/A	N/A	N/A
District 4 - San Francisco Bay	323	1.9 - 2.9	2.1	1.0 - 1.3	1.1	2.9 - 3.8	3.1	1.1 - 1.3	1.2
District 7 - Los Angeles	440	2.05 - 2.88	2.2	1.04 - 1.16	1.1	4.14 - 4.22 <sup>1</sup> 3.21 - 3.71 <sup>2</sup>	-	1.08 - 1.12	-

\* persons per vehicle

<sup>1</sup> accounts for buses on the El Monte Busway

<sup>2</sup> carpools

N/A Not Applicable

Comparing the vehicle occupancy data in Exhibit V-2 with Exhibit V-3 suggests that the average vehicle occupancy figures are too low in the prior version of Cal-B/C. As documented in Chapter III, these AVO figures were raised in the 2009 revision to Cal-B/C and are more comparable to those in Exhibit V-2.

**Exhibit V-3: Average Vehicle Occupancy (AVO)  
Estimates Used in the Prior Version of Cal-B/C**

Type of Travel	AVO
Non-Peak General Traffic	1.15
Peak General Traffic	1.10
HOV 3+ Restriction	3.0
HOV 2+ Restriction	2.05

### 2.3 Traffic Accident Surveillance and Analysis System (TASAS)

As part of its annual publication “Collision Data on California State Highways,” the TASAS Branch estimates basic average accident rate tables for state highways using linear regression. The tables provide equations for estimating statewide accident rates for different facility types, called rate groups. Separate equations are provided for 67 highway rate groups, 30 interchange rate groups, and 80 ramp rate groups. Exhibit V-4 shows an example of the accident rate group tables.

**Exhibit V-4: Example of a TASAS Accident Rate Group Table**

03-28-07 BASIC AVERAGE ACCIDENT RATE TABLE FOR HIGHWAYS												
RATE GROUP	BASE RATE	+ ADT FACTOR	PCT FAT	PCT INJ	PCT F+I	HIGHWAY TYPE	TERRAIN OR ADT	DESIGN SPEED	AREA	ACC COSTS (\$1000)		
										F+I	ALL	
H 32	1.95	0.0000	0.4	45.1	45.6	UNDIVIDED 5-6 LANES		>45	URBAN	95.4	46.0	
H 33	0.90	0.0000	2.9	43.9	46.8	DIVIDED 4 LANES	FLAT		RURAL	364.3	173.0	
H 34	1.65	0.0000	1.0	35.5	38.5	DIVIDED 4 LANES	ROLL/MTN		RURAL	211.1	80.0	
H 35	1.85	0.0000	0.7	43.1	43.8	DIVIDED 4 LANES		≤65	SUBURBAN	138.0	63.0	
H 36	1.70	0.0000	1.8	40.4	42.2	DIVIDED 4 LANES		>55	SUBURBAN	247.4	107.0	
H 37	3.35	0.0000	0.5	42.3	42.8	DIVIDED 4 LANES		<45	URBAN	107.2	48.5	
H 38	2.10	0.0000	0.7	43.8	44.4	DIVIDED 4 LANES		>45	URBAN	123.7	57.5	
H 39	1.05	0.0000	2.4	30.0	32.4	DIVIDED 5 LANES OR MORE	FLAT		RURAL	418.0	138.5	
H 40	1.50	0.0000	1.6	50.0	51.6	DIVIDED 5 LANES OR MORE	ROLL/MTN		RURAL	227.1	119.4	
H 41	2.75	0.0000	1.2	43.1	44.4	DIVIDED 5 LANES OR MORE		≤55	SUBURBAN	183.1	83.9	
H 42	2.10	0.0000	0.9	33.3	34.3	DIVIDED 5 LANES OR MORE		>55	SUBURBAN	179.8	64.7	
H 43	2.40	0.0000	0.7	56.8	57.5	DIVIDED 5 LANES OR MORE		<45	URBAN	109.2	64.7	
H 44	2.40	0.0000	0.7	46.1	46.8	DIVIDED 5 LANES OR MORE		≥45	URBAN	120.3	58.7	
H 45	0.50	0.0070	2.6	42.6	45.2	DIV. EXPRESSWAY 4 LNS OR MORE		≤65	RURAL	344.6	158.3	
H 46	0.50	0.0070	3.0	44.7	47.6	DIV. EXPRESSWAY 4 LNS OR MORE		>65	RURAL	369.2	178.2	
H 47	0.90	0.0170	1.5	43.2	44.8	DIV. EXPRESSWAY 4 LNS OR MORE		≤65	SUBURBAN	209.6	96.4	
H 48	0.75	0.0100	0.8	40.8	41.5	DIV. EXPRESSWAY 4 LNS OR MORE		>65	SUBURBAN	151.6	65.6	
H 49	1.75	0.0000	0.5	40.7	41.2	DIV. EXPRESSWAY 4 LNS OR MORE		≤55	URBAN	109.0	47.6	
H 50	1.35	0.0000	1.3	44.5	45.9	DIV. EXPRESSWAY 4 LNS OR MORE		>55	URBAN	173.6	82.2	
H 51	0.45	0.5000 /	2.4	40.2	42.6	FREEWAY 4 LANES OR LESS	≤15000	≤65	RURAL	339.4	147.2	
H 52	0.45	0.6500 /	4.0	44.9	48.8	FREEWAY 4 LANES OR LESS	≤15000	>65	RURAL	453.2	223.5	
H 53	0.45	0.0035	3.4	40.1	43.4	FREEWAY 4 LANES OR LESS	>15000	≤65	RURAL	437.1	192.3	
H 54	0.40	0.0035	3.1	40.3	43.4	FREEWAY 4 LANES OR LESS	>15000	>65	RURAL	406.3	178.9	
H 55	0.25	0.0050	2.2	40.1	42.3	FREEWAY 5-6 LANES			RURAL	320.2	138.1	
H 56	0.20	0.0035	1.5	36.7	38.2	FREEWAY 7 LANES OR MORE			RURAL	263.7	103.6	
H 57	0.50	0.5000 /	3.6	43.6	47.2	FREEWAY 4 LANES OR LESS	≤15000	≤65	SUBURBAN	365.2	184.3	
H 58	0.45	0.5500 /	2.7	39.0	41.7	FREEWAY 4 LANES OR LESS	≤15000	>65	SUBURBAN	338.0	143.6	
H 59	0.75	0.0050	1.2	36.8	38.0	FREEWAY 4 LANES OR LESS	>15000	≤65	SUBURBAN	201.9	79.6	
H 60	0.50	0.0035	1.3	35.7	37.0	FREEWAY 4 LANES OR LESS	>15000	>65	SUBURBAN	216.5	83.0	
H 61	0.20	0.0060	1.5	33.8	35.3	FREEWAY 5-6 LANES			SUBURBAN	246.7	90.1	

Source: California Department of Transportation, 2006 Collision Data on California State Highways, Division of Traffic Operations, 2006.

HOV facilities do not have separate rate groups. Presumably, a four-lane facility with an additional HOV or HOT lane would have different accident rates due to the weaving of HOV or HOT lane traffic and merging maneuvers. The presence of median barriers may also be a factor, but these are not included in the rate tables. In this example, the four-lane facility with an HOV lane would be treated as a five-lane facility. Since the TASAS rate tables make no distinction between HOV and general purpose lanes, the conversion of a general purpose lane to a HOT lane (or an HOV lane to a HOT lane) would have no impact on accident rates.

### 3.0 BENEFIT-COST MODELS AND OTHER METHODOLOGIES

The Texas Department of Transportation (TxDOT) developed an analytical tool to evaluate the major issues associated with converting a HOV lane to a HOT lane. Referred to as the High-Occupancy Toll Strategic Analysis Rating Tool (HOT START), the software considers broad categories of issues: (1) facility considerations, such as design, operations, and enforcement; (2) performance considerations, or goals, such as increasing carpools, reducing congesting, generating revenue; and (3) institutional considerations, including public acceptance, revenue use, interagency cooperation, and media relations.

HOT START allows public agencies to evaluate the tradeoffs within and among identified project objectives. The tool asks users to assign a numerical weight to each of the factors from the three categories and forces users to make relative judgments of each factor while maintaining a maximum summed weight of 100. The tool then scores each factor using a decision-tree method, which is a series of questions related to each factor. HOT START is a structured decision-making tool and does not value user benefits directly. However, the decision categories address some of the major impacts of HOV-to-HOT lane conversion.

Researchers at the Texas Transportation Institute (TTI) identified a potential methodology to determine the incremental societal costs and benefits from a variable pricing project. Burriss and Sullivan (2006) applied it to the QuickRide HOT lanes in Texas. The QuickRide lanes allow two-person carpools to use the 3+ HOV lanes during peak periods by paying a toll. Burriss and Sullivan note that the incremental societal benefits of QuickRide exceeded the incremental societal costs over a ten-year period.

Burriss and Sullivan wrote a companion paper that used the same methodology to examine the benefits and costs of the SR-91 Express Lanes. While the SR-91 Express lanes benefit tens of thousands of travelers per day (compared to approximately 400 on the QuickRide HOT lanes), Burriss and Sullivan found that the benefit-cost ratios of the two projects were similar (between 1.5 and 1.7). The majority of benefits were derived from travel time savings, underscoring the importance of determining accurate values for time and vehicle occupancy. Burriss and Sullivan also note that transfers of wealth among different groups were excluded (the so-called “Lexus lane” effect). This exclusion is appropriate because transfer payments do not affect total user benefits.

The quantified benefits used in the methodology include travel time savings, vehicle operating and ownership costs, and emissions. The costs associated with the project include the agency’s start-up costs and annual operation and maintenance costs. The toll and monthly enrollment fee were not included, because they were considered to be transfers from the driver to the QuickRide Agency.



The FHWA developed three sketch-level benefit-cost models that incorporate the analysis of tolling projects. The IMPACTS spreadsheet software was developed for a 1996 National Highway Institute Course (DeCorla-Souza, 1999). It contains seven Excel worksheets that cover different urban transportation alternatives, including the conversion of an existing facility to a toll facility. The spreadsheet is not structured to analyze a HOT lane, since it assumes that the entire roadway is converted to the tollway. IMPACTS does not address issues important for HOT lanes, such as the speed and safety impacts on general purpose lanes and the accompanying shifts in demand and vehicle occupancy.

Another FHWA model, Tool for Rush-hour User Charge Evaluation (TRUCE), helps metropolitan areas evaluate the applicability of the high-performance highway concept. This concept involves converting all lanes on an existing highway to premium service lanes reserved for buses and toll-paying private vehicles during peak hours. The high performance highway concept represents an alternative form of congestion pricing. Like IMPACTS, TRUCE is not intended to consider the detailed user benefits involved in HOT lane projects.

The Sketch Planning for Road Use Charge Evaluation (SPRUCE) model is an Excel spreadsheet that compares HOT lanes with a concept called a “Fast and Intertwined Regular (FAIR) network.” The emphasis is on presenting the relative benefits of these alternative concepts rather than a detailed analysis of a specific HOT lane project. The alternatives are presented at the network level using summary hourly data for freeways and arterials in two directions on cross-town and radial routes. Freeway speeds are evaluated simply as 30 mph or 60 mph, depending on whether demand exceeds capacity in each hourly time period.

The SPRUCE model calculates benefit-cost ratios by comparing total societal benefits to project costs. The total societal benefits include total traveler benefits, net toll revenues, and the change in external costs (calculated as six percent of the reduction in vehicle-miles traveled) minus the reduction in fuel taxes. The Cal-B/C development team believes the inclusion of fuel taxes and toll revenues are transfer payments and should not be included in the evaluation (see the discussion on the FHWA Economic Analysis Primer in a later section of this chapter).

FHWA maintains an internet forum called “Community of Practice” (CoP) at: <[knowledge.fhwa.dot.gov/cops/hcx.nsf/home](http://knowledge.fhwa.dot.gov/cops/hcx.nsf/home)>. The website allows members of the transportation community to share and exchange important information. In the congestion pricing forum, users can find existing documents for a number of value pricing pilot projects, including HOT lane projects in California. There is also a discussion area where participants can post a question or start a dialogue with others in the community, and a “works in progress” area where participants are encouraged to comment on draft documents. The forum is updated as new documents are posted and may provide information for the assessment of HOT lane projects. This is particularly useful given the short history, but large interest in HOT lanes.

A similar source is the congestion pricing forum hosted by the University of Minnesota. This website can be accessed at: <[lists.umn.edu/cgi-bin/wa?A0=CON-PRIC](http://lists.umn.edu/cgi-bin/wa?A0=CON-PRIC)>. The Transportation Research Board's Congestion Pricing Committee (ABE 25) also presents relevant information and presentations on its website: <[www.trb-pricing.org](http://www.trb-pricing.org)>

#### **4.0 RECENT RESEARCH AND FINDINGS**

This section discusses recent research related to the evaluation of the benefits of HOV and HOT lanes. The Cal-B/C development team found that five issues impact the benefit-cost assessment of the projects:

- **Enforcement** – Effective enforcement of HOV and HOT lanes is essential to maintain optimal speeds and ensure a stable revenue stream.
- **Travel Time** – The travel time benefits are a function of vehicle speed and the number of people in each vehicle. Both speed and average vehicle occupancies in HOV and HOT lanes differ from those found on general purpose lanes.
- **Safety** – The configurations of HOV and HOT lanes (barrier versus buffer-separated and limited versus continuous access) affect driving patterns and can create safety issues. The shifting traffic from general purpose lanes to HOT lanes may also affect the number or severity of collisions.
- **Vehicle Operating Costs and Emissions** – These user benefits are a function of vehicle speed and are impacted by the method chosen to estimate speed.
- **Project Costs and Revenues** – The costs of projects should include enforcement mechanisms. A related issue is whether to include toll revenues in benefit-cost analyses.

#### **4.1 Enforcement**

HOV and HOT lanes perform optimally when drivers do the following reliably:

- Carrying at least the minimum number of people required to use the lanes (i.e., the minimum occupancy requirement)
- Entering and exiting at proper locations
- Paying the toll (in the case of HOT lanes).

Drivers who violate occupancy requirements undermine the system by using lane capacity that is intended solely for HOV and toll-paying motorists (in the case of HOT lanes). Similarly, drivers who improperly enter and exit HOV and HOT lanes outside designated locations cause other drivers on the HOV and HOT lanes to slow. This impact weakens the predictability of traffic flow in the lanes, resulting in a significant decrease in the operational efficiency of the lanes.

While not a factor in benefit-cost analysis, vehicles that fail to pay tolls weaken the revenue streams generated and the financial viability of proposed projects. The Departmental HOV Guidelines set an acceptable violation rate below ten percent and recommends a combination of routine and heightened enforcement to keep violations within that range.

For example, Vu, et al. (2007) propose a system called Gantry Controlled Access (GCA), which has the capability to identify vehicles that enter and exit the managed lanes improperly. The system includes monitoring stations placed at strategic locations along HOV and HOT lanes to record the presence of vehicles at each station. By monitoring vehicle locations, the system can automatically determine when vehicles cross the electronic barrier illegally. The system records the license plates of violators and issues citations.

There are also various electronic technologies that can determine if tolls are paid. These technologies require vehicles to register and carry electronic transponders. HOVs are not charged a toll, while others are charged the appropriate toll. More complex enforcement schemes are required if tolls are further varied by the number of occupants. Accompanying electronic technologies include:

- Gantry lights - Lights are placed at each enforcement zone and flash when vehicles with valid transponders enter.
- Notification transponders - The device allows officers to determine whether low occupancy vehicles have valid accounts.
- Mobile Enforcement Transponders (MER) - These devices allow officers to ensure that drivers do not turn off their transponders as they pass under tolling gantries.

When considering the costs of HOT lane conversion, the enforcement costs must be included to ensure that the managed lanes function safely and at optimal capacity. It is possible that the greater scrutiny tolling places on vehicle occupancy (due to the potential revenue impact) may lower violation rates over the existing HOV lanes. However, benefit-cost analyses in Cal-B/C must be based on the assumption that the planners and engineers proposing the projects have correctly included violation rates in their projects of traffic volumes on the lanes.

## 4.2 Travel Time

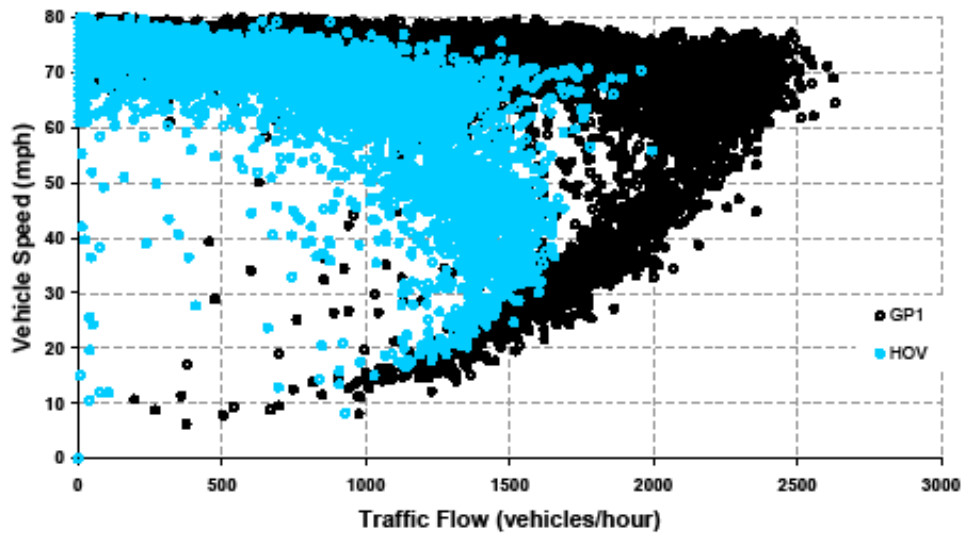
HOV and HOT lanes are designed to provide a greater level of service than general purpose lanes by imposing requirements on vehicles utilizing these lanes. These requirements may include minimum occupancy (number of people in vehicle), toll payment, limited ingress and egress points, or limited hours of operation. HOV and HOT lanes are configured differently from general purpose lanes. Most HOV or HOT lanes operate as a single-lane facility, but there are some double-lane facilities in California. These unique qualities cause HOV and HOT lanes to function quite differently than general purpose lanes. The most notable difference is speed.

The BPR curve found in the prior version of Cal-B/C model is calibrated to approximate the speed-volume relationship found in the 2000 Highway Capacity Manual (HCM) for urban freeways. It does not consider the conditions characteristic of HOV and HOT lanes. Cal-B/C needs to calculate speed based on a BPR curve that applies specifically to HOV and HOT lane facilities.

In the current version of Cal-B/C, the standard BPR curve sets the “a” coefficient, which determines the ratio of the free-flow speed to the speed at capacity, at 0.20. For HOV and HOT lanes, the “a” coefficient of the BPR curve will be significantly higher because the maximum throughput occurs at a much lower speed relative to the free-flow speed on HOV lanes than on the adjacent general purpose lane, as observed on Atlanta’s I-85 HOV lane between October 2006 and February 2007 (Guin, Hunter, and Guensler, 2007). As illustrated in Exhibit V-5, flow in the HOV lane breaks down around 1,500 vehicles per hour (vph) at a speed of 40 mph, whereas the adjacent general purpose lane shows the flow breakdown at 2,400 vph at a speed of 65 mph.

Similarly, the “b” exponent, which determines how abruptly speeds drop from free-flow speed, needs to be adjusted in a BPR curve for HOV and HOT lanes. The standard BPR curve sets the “b” exponent at 10. As shown in Exhibit V-5, Guin, Hunter and Guensler, found that speeds in HOV lanes decline more gradually than those on general purpose lanes. As a result, the “b” exponent should be lower for HOV and HOT lanes.

### Exhibit V-5: Speed versus Flow Plot for HOV Lane and General Purpose Lane 1

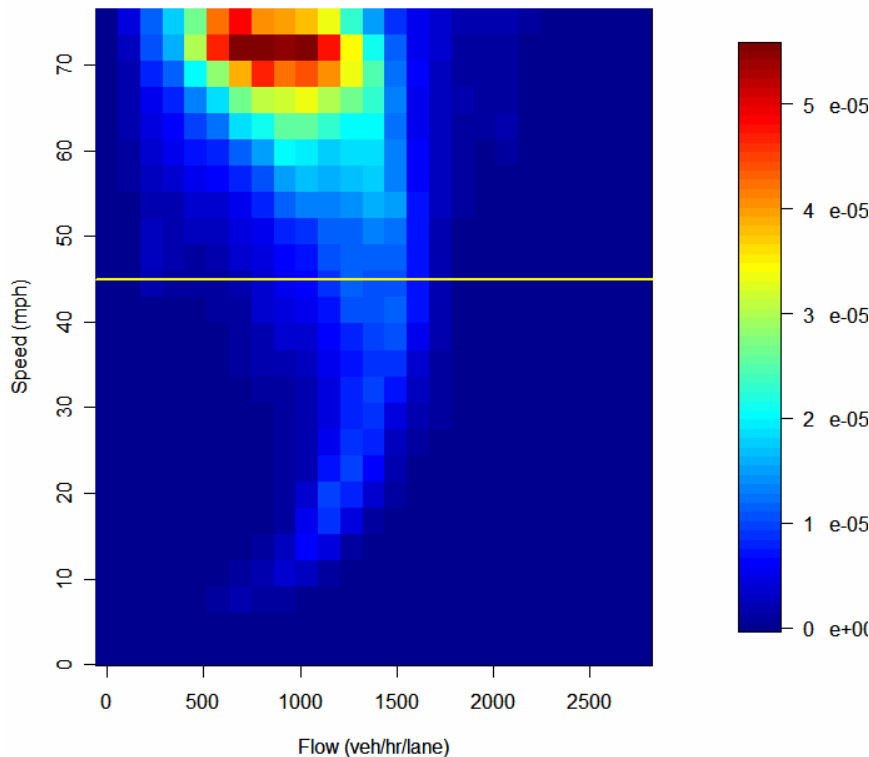


Source: Guin, Hunter and Guensler (2007)

While these are findings for only a single HOV facility, they are confirmed by a much larger study of HOV lanes in California. In a Partners for Advanced Transit and Highways (PATH) research project, Varaiya (2007) used data from the Performance Measurement System (PeMS) to examine operating characteristics for HOV lanes. PeMS provides archived intelligent transportation system (ITS) data for 1,700 inductive loop-based vehicle detector stations (VDS) that monitor 780 out of the 1,171 lane-miles in California's HOV system. From this very large sample, Varaiya collected speed and flow measurements from more than 700 stations during the 5 to 6 PM peak hour on 128 weekdays between January and June, 2005. Varaiya used only data that the PeMS system determined to be reliable (hence the drop from 1,700 to more than 700 VDS).

As shown in Exhibit V-6, Varaiya plotted a speed-flow curve that is remarkably similar to the one produced by Guin, Hunter, and Guensler. Varaiya uses a histogram-style graph that also illustrates that the majority of HOV lane travel occurs under free-flow conditions. From this graph, Varaiya notes that HOV lanes suffer a 20-percent capacity penalty compared to general purpose lanes. Varaiya finds that HOV lanes achieve a maximum flow of 1,600 vehicles per hour per lane (vphp1) at 45 mph, which is less than posted speed limits. In contrast, general purpose lanes record maximum flows above 2,000 vphp1 at 60 mph. The histogram also shows that most HOV lanes are underutilized – 81 percent of HOV detectors measure flows below 1,400 vphp1 during the PM peak hour.

### Exhibit V-6: Probability Histogram of Speed and Flow at California HOV Detector Stations, January - June, 2005, 5 - 6PM

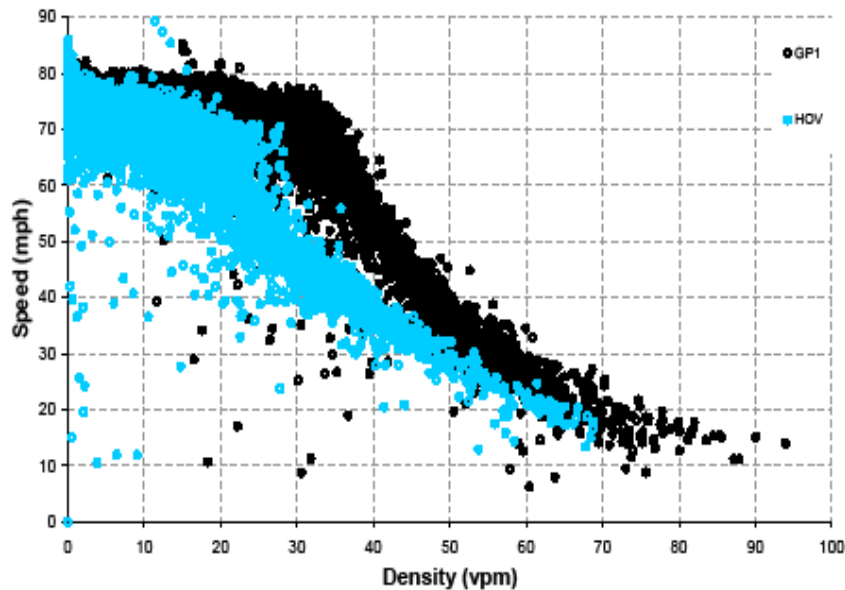


Source: Varaiya (2007)

The HOV capacity penalty and different speed flow curve can be explained partly by what Varaiya (2007) refers to as “snails,” or slower-moving-vehicles that set the speed in the HOV lane. Since HOV lanes are typically one lane, faster-moving HOV vehicles cannot pass the slower snails in front of them. As HOV volume increases, the number of snails also increases, resulting in a decline in speeds and capacity.

There are several potential reasons for the “snail” effect on HOV lanes. Guin, Hunter and Guensler (2007) suggest that the decline of speeds on HOV lanes with increased congestion on the general purpose lanes may be the result of HOV drivers who are cautious of vehicles entering from the general purpose lane, or who are looking for a gap to merge out of the HOV lane to access an approaching exit ramp. Varaiya (2007) adds that as congestion in the adjacent general purpose lane worsens, violators may dart into and out of the HOV for short time intervals with increasing frequency, forcing HOV drivers to slow down.

The existence of the “snail” effect is supported by Guin, Hunter, and Guensler (2007), who developed a density plot (Exhibit V-7) that reveals that density on the HOV lane is not as high as the general purpose lanes, suggesting that vehicles are not following as closely on the HOV lane.

**Exhibit V-7: Speed versus Density Plot for HOV Lane and General Purpose Lane 1**

Source: Guin, Hunter and Guensler (2007)

The “snails” found on HOV lanes lead to a decrease in the lanes’ operational efficiency. Varaiya (2007) finds that many HOV lanes suffer degraded operations and that travel time savings do not provide a statistically significant carpooling incentive. In comparing 10-mile routes randomly generated from reliable loop data, Varaiya noted that the mean savings on an HOV lane versus a general purpose left-hand lane (lane 1) is 1.7 minutes, while the median is 0.7 minutes. However, Varaiya found that HOV lanes have more reliable travel times.

Chung (2007) offers a potential solution to improving conditions in an HOV facility. In a case study involving the I-405 in Orange County, Chung found that expanding the HOV facility from one to two lanes by converting a general purpose lane would make the HOV reasonably competitive in vehicle travel times. However, converting a general purpose lane into an HOV lane may not be politically feasible as described earlier in this chapter.

Many vehicles attempt to pass the slow-moving “snails.” While observing the maneuvering of vehicles at HOV access openings, Fitzpatrick, Brewer, and Park (2007) found that over seven percent of maneuvers involved passing actions.

Although speeds on HOV and general purpose lanes differ, it is important to compare them in order to measure the performance of HOV lanes, particularly the travel-time savings. As the Departmental HOV Guidelines note, the performance of HOV lanes must be isolated from the rest of the system, because HOV facilities are designed to operate at higher levels of service than adjacent general purpose lanes. Therefore, it is essential that discrete HOV performance data is collected and analyzed, such as speeds,

volumes, and lane occupancies so that adjustments to the system can be made to maintain a desirable level of service.

While speeds on HOV/HOT lanes and general purpose lanes are important for measuring travel-time savings, it is also important to consider the vehicle occupancy requirement.

The research suggests that benefit-cost analyses of HOT lanes should incorporate speed estimation appropriate to HOV and HOT lane facilities. It also suggests that vehicle occupancy estimates and HOT lane elasticity are important, but no guidance was found for either factor.

### 4.3 Safety

Preventing death and injury is a key goal for transportation investments. The safety of HOV and HOT lanes differ from general purpose lanes for two main reasons:

- Many HOV lanes and most (if not all) HOT lanes have limited access points, requiring vehicles to merge swiftly in and out of the lane at these specific points.
- There is typically a large speed differential between vehicles traveling on the HOV or HOT lanes and those on general purpose lanes during congestion periods.

A 2005 Wall Street Journal article (Gold, 2005) reports increasing evidence that adding a HOV lane could lead to more accidents. It cites an example in Maryland, where accident rates were twice as high on the I-270 HOV lanes as the statewide average. Similarly, a study by the Texas Transportation Institute (2005) found that injury crash rates increased significantly after the addition of buffer-separated HOV lanes on several highways. IH-635 experienced a 41-percent increase and IH-35E North experienced a 56-percent increase (Cothron, Ranft, Walters, and Fenno, 2005).

Although these examples suggest that HOV lanes are less safe than general purpose lanes, an earlier study published by Sullivan (1992) observed no difference in accident rates, and many studies have yielded inconclusive results on the safety of HOV projects. It is important to note that the results of one study cannot be applied to other regions given the vast differences in traffic patterns and corridor configurations.

The configurations of California's HOV facilities have been examined to determine whether one design exhibits safety advantages over another. Departmental HOV Guidelines discuss the HOV facility configurations in three categories:

- Barrier-separated facility - HOV lanes separated from the general purpose lane by a solid barrier. These facilities are designed to provide



unimpeded HOV operation without interference from the general purpose lanes, and improve incidence management.

- Buffer-separated facility – HOV lanes separated from the general purpose lane by buffers, typically double white lines on the pavement with varying width amounts and generally less than 1.2 meters.
- Contiguous (continuous access) facility – these facilities allow vehicles to enter or exit the lane at any point from the adjacent general purpose lane on the freeway, unlike buffer and barrier-separated lanes that have designated access points.

The Department operates continuous-access, barrier-separated, and buffer-separated HOV lanes. Future HOT lanes are likely to have similar configurations. Barrier-separated facilities are typically regarded as a safety precaution by isolating accidents to either HOV or general purpose lanes and by preventing frequent weaving into and out of the facility. Barrier-separated HOV facilities also protect against the large speed differential that often exists between HOV traffic and traffic in general purpose lanes. However, barriers pose a problem when incidents occur in the facility without sufficient shoulder width for the disabled vehicle to wait. This interferes with the flow of traffic and makes it difficult for vehicles to safely bypass the disabled vehicle.

A number of studies look at the effect that HOV lane configurations have on accident rates. Results from these studies do not provide consensus on the relative safety of these configurations. Skowronek, Ranft, Cothron (2002) conducted a study on IH-30 in Texas and found no significant difference in corridor crash rates before and after the construction of barriers. This implies that barrier-separated facilities offer no safety benefits over buffer-separated facilities and that the type of facility does not play a significant role in safety analysis. Similarly, an assessment of eight California freeways by Jang et al. (2008) revealed that limited access HOV lanes appear to offer no safety advantages over continuous access HOV lanes.

However, Fitzpatrick, Brewer, and Park (2007) assert that crash rates are higher on buffer-separated, managed lanes than barrier-separated managed lanes because many of the crashes relate to the access openings.

These studies suggest that one HOV configuration is not decisively safer than another. Nevertheless, precautionary steps can be taken to avoid accidents. Fitzpatrick, Brewer, and Park (2007) observed the maneuvering of vehicles at designated HOV access points, and made several observations. These observations are relevant to the configuration and potential safety of HOV lanes.

- About nine percent of the vehicles moving into HOV lanes and eight percent of those moving out of HOV lanes crossed the solid white markings, suggesting that drivers may have difficulties entering the

HOV lane within the available access opening. This finding may prompt agencies to lengthen access openings to prevent collisions.

- Over seven percent of all maneuvers involved a passing action either beginning at the HOV lane or from the general purpose lane, suggesting that passing lanes within HOV facilities could improve service.

However, these are design considerations. Benefit-cost analyses of HOT lane projects must be based on the assumption that the appropriate operational analyses were conducted and incorporated into proposed designs. As a result, the research suggests that benefit-cost analysis should not incorporate different safety factors for different design types.

#### **4.4 Vehicle Operating Costs and Emissions**

For benefit-cost modeling, both vehicle operating costs and emissions are a function of speed. Cal-B/C estimates speeds using a standard BPR curve. The previous section shows why the BPR curves in previous versions of Cal-B/C needed to be modified to capture the specific speed characteristics of HOV and HOT lanes. This section shows how vehicle speeds and hybrid vehicles traveling on the lanes affect vehicle operating costs and emissions.

The configuration of HOV lanes impacts not only safety, but also fuel consumption and emissions. Boriboonsomsin and Barth (2007) found that limited access HOV lanes contribute to a higher level of emissions due to more frequent and aggressive acceleration and deceleration maneuvers at the dedicated ingress/egress sections than continuous access HOV lanes. They also found that vehicles in the limited access HOV lanes tended to exceed posted speed limits more often than vehicles in continuous access HOV lanes. Higher speeds create higher emissions and are likely due to the avoidance of merge-related delays.

Although Boriboonsomsin and Barth do not address fuel consumption, it would be impacted by the same higher speeds and aggressive speed cycling. Since the California emissions rates used in Cal-B/C assume a standard speed cycling pattern and commensurate acceleration and deceleration factors are not readily available, the project team did not pursue the impacts on vehicle operating costs and emissions further. Benefit-cost analyses need to consider the impact of HOT lanes on speed limit adherence and speed cycling.

Hybrid vehicles have become increasingly popular among motorists concerned about fuel consumption and air quality. The 2005 Federal Transportation Bill allowed California to implement Assembly Bill 2628, which provided for the use of HOV lanes by clean and efficient vehicles with single occupants. This policy intends to reduce automobile emissions by encouraging motorists to drive cleaner vehicles, while

attempting to maximize corridor efficiency by allowing these vehicles to access underutilized HOV lanes.

Nesamani, Chu, and Recker (2007) examined the impact of the policy on air quality and corridor-level performance in Orange County, and found that the policy reduces emission. However, they recommended limiting the exemptions to 50,000 vehicles and noted that the policy should not be applied to HOV lanes lacking capacity reserves. The study illustrates the delicate balance between promoting cleaner, fuel-efficient vehicles, and managing congestion on the corridors. A similar balance needs to be maintained in HOT lanes.

#### **4.5 Project Costs and Revenues**

As described earlier, HOT lanes require toll collection equipment and enforcement mechanisms, which increase the capital cost of HOT lane projects relative to HOV lanes. However, toll and enforcement equipment are among the few capital costs incurred in HOV-to-HOT lane conversion projects. Other capital costs include operations improvements, signing, striping, and enforcement zones. HOT lanes are likely to have incrementally higher operating and maintenance costs. These should be captured in the project input sheet.

It may be tempting to include toll collection as a project benefit (and revenue generation is the motivation for some HOT lane projects). However, tolls should be excluded from benefit-cost analyses. According to the FHWA Economic Analysis Primer, toll receipts and other user fees are transfer payments from users to the agency operating the project. The benefits still exist, but they are paid back to the agency in the form of toll revenue to be used for other public purposes. Consistent with this approach is the benefit-cost analysis performed on Houston's QuickRide HOT lane program, which excluded toll revenues and monthly enrollment fees in calculating project costs. Burriss and Sullivan (2006) noted that tolls serve as transfer payments.

Revenue generation is a major component of HOT lane projects and the estimation of toll revenues is likely to be included in the financial analysis of these projects. While revenues should be excluded from benefit-cost analyses, a less obvious problem is that the traffic evaluations supporting the financial analyses may alter benefits estimated in the benefit-cost assessments.

The tolls charged on the HOT lanes are functions of the toll elasticities and determine the traffic volumes on these facilities. Some agencies and their consultants may be tempted to estimate the revenue generation of HOT lane projects conservatively to demonstrate financial feasibility even in worst-case scenarios. However, estimating lower toll revenues also implies few vehicles shifting from adjacent general purpose lanes to the HOT lanes. While this would result in higher speeds on HOT lanes, it also means that there are fewer HOT lane users to receive a benefit and the general purpose lanes may realize a smaller benefit.

Alternatively, analyses of HOT lane projects may estimate that the number of vehicles using the HOT lanes to be close to capacity (about 1,600 according to the above research), but underestimate the tolls required or not determine the exact composition of vehicles by number of occupants. If the toll amounts are underestimated, benefit-cost analyses will not be affected due to the transfer payment issue. However, if the composition of vehicles is inadequately considered, there will be poor information for conducting benefit-cost analyses.

## 5.0 UPDATED CAL-B/C METHODOLOGY

Since HOT lanes are an emerging strategy, there is little guidance for assessing the benefits of these projects. Despite the limited number of existing HOT lanes, the research provides some useful information for incorporating HOT lanes (and improving the HOV methodology) in Cal-B/C. The rest of this section describes the changes made to Cal-B/C in the 2009 revision.

*Project Types.* Prior to the 2009 update, Cal-B/C had a category for assessing HOV lane additions. As part of the 2009 update, project types were added for HOT lane additions and HOV-to-HOT lane conversions. The HOT lane addition project type is similar to the HOV lane addition project type and simply requires the user to verify the AVO on the HOT lanes and input the HOV AVO.

However, the addition of the HOT lane conversion project type required significant revisions to Cal-B/C. As a side benefit of these revisions, Cal-B/C can now handle HOV-2-to-HOV-3 conversions. A separate project type was added for these projects in a manner similar to the HOV-to-HOT lane project type.

*Average Vehicle Occupancy.* The Cal-B/C model needs good estimates of vehicle occupancies on general purpose, HOV, and HOT lanes. Although districts survey existing HOV lanes, these data are inadequate to predict the impact of an HOV-to-HOT lane conversion or the addition of a HOT lane on vehicle occupancy. Since there are no comprehensive sources of AVO data, the Cal-B/C development team was unable to incorporate rules of thumb for HOV-to-HOT lane conversions.

Cal-B/C continues to require AVO data on the project input page. It is expected that this information will be provided on project input sheets and that the model user will verify that the inputted AVO results in the appropriate number of trips made in the build and no-build cases. This input data should be checked carefully to make sure they are not inflated to produce higher project benefits. For HOV-2-to-HOV-3 conversions, Cal-B/C solves for the peak period general traffic AVO that ensures the number of trips remains unchanged.

*Travel Demand Elasticity.* Analyses of HOV and HOT lanes need to incorporate the demand response of how users choose high-occupancy lanes over general purpose lanes. This elasticity issue is particularly important for HOT lanes. The Cal-B/C development team found no research to help estimate the demand elasticities among the various user groups involved in HOT lane projects.

The current Cal-B/C approach to benefit-cost modeling for any project assumes that the elasticity is estimated correctly outside the model. Since the demand elasticity is particular to each HOT lane configuration and other factors, Cal-B/C operates on the assumption that demand elasticities for HOT lane projects continue to be estimated outside Cal-B/C. Recent experience in evaluating benefits for HOT projects suggests that the data submitted for Cal-B/C needs to be reviewed carefully to ensure that the same (implied) demand elasticities are used to forecast revenues and estimate project benefits.

*Toll-Paying Users.* For most project types, Cal-B/C estimates benefits on the basis of user groups rather than where the vehicles are located. As an example, Cal-B/C expects users to input an HOV volume in the no-build case for an HOV lane addition project even if no HOV lane exists in the no-build case. This HOV volume represents the number of vehicles that would have qualified as HOVs if a lane existed. In this manner, the travel conditions in the build and no-build conditions are compared for each user group correctly.

However, as Exhibit V-8 demonstrates, there are four to five user groups for an HOV-to-HOT lane conversion project.

#### **Exhibit V-8: User Groups Involved in HOV-to-HOT Lane Conversions**

<b>User Group</b>	<b>No-build Location</b>	<b>Build Location</b>	<b>Potential for Induced Trips</b>
1. SOV → SOV	GP	GP	Possible
2. SOV → Toll Paying	GP	HOV	Possible
3. HOV-3 → HOV-3 HOV-2 → Toll Paying	HOV HOV	HOV HOV	Unlikely Unlikely
4. HOV-2 → General Purpose	HOV	GP	Unlikely

GP = General Purpose Lanes  
HOV = HOV Lanes

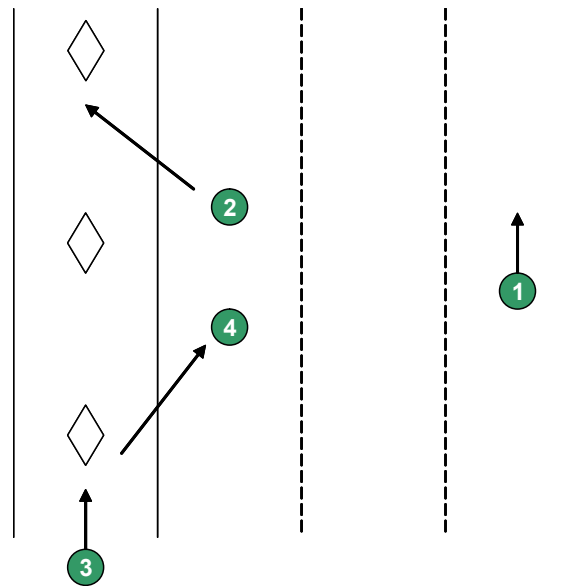
There are single occupancy vehicles (SOVs) that currently use the general purpose lanes and continue to use these lanes after the HOT lane conversion occurs. There are also some SOVs that choose to pay tolls and use the HOT lanes. These users experience different build conditions than the SOVs that remain in the HOT lanes. HOV-3s

(including vehicles with more than 3 people) continue to qualify for HOT lane use in a HOT lane conversion.

Depending on whether there is an HOV requirement change, HOV-2s may not qualify for HOT lane use. If HOV-2s are required to pay tolls, some may choose to remain in the HOT lanes, while others choose to use the general purpose lanes and pay no toll. Like the HOV-3s, the HOV-2s that choose to pay tolls remain in the HOT lanes and experience travel conditions in the HOT lanes in the build and no-build cases. Since the HOV-3s and toll-paying HOV-2 experience the same travel conditions, they can be collapsed into a single user group indicated by Group 3 in Exhibit V-8. With this consolidation, there are only four user groups.

Exhibit V-9 provides a graphical illustration of how these users change their physical locations from no-build to build conditions. The numbers in the exhibit correspond to those used in Exhibit V-8. As Exhibit V-9 shows, Groups 1 and 3 correspond to groups modeled in the prior version of Cal-B/C- non-HOV (and truck) and HOV. Groups 2 and 4 are new user groups. The latest Cal-B/C model uses a simple approach that assesses benefits where they occur, which is described further below.

**Exhibit V-9: Illustration of How User Groups Change Travel Locations from No-Build to Build Cases**



*Consumer Surplus.* The most challenging calculation is to make sure that Cal-B/C correctly assigns the consumer surplus calculation when induced demand occurs. (The standard consumer surplus calculation is described in Volume 1.) As indicated in the final column of Exhibit V-8, HOT lanes can induce additional demand among SOVs. The prospect of free-flow conditions on HOT lanes may encourage additional SOVs to pay a toll and use the corridor. It may also encourage some SOVs to be occasional HOT lane users. In this case, a proportion of these additional users will use the general

purpose lanes on a given day, so the induced travel appears in both the HOT lanes and the general purpose lanes.

The other user groups are unlikely to have induced demand, because they previously had the option of using HOV lanes. Additional HOV-2s would not be encouraged to pay for HOT lane use - a privilege that was previously free. If the HOT lane provides more free-flow conditions on the HOT lane, there may be a few induced HOV-3s (new trips, not HOV-2s that decide to form HOV-3 carpools). Cal-B/C ignores this induced travel because it is likely to be small.

The estimation of consumer surplus requires Cal-B/C to calculate changes in trips between the no-build and build cases. In prior versions, Cal-B/C made the calculation on the number of vehicles and multiplied the results by the appropriate AVO:

$$\begin{aligned} \text{Travel Time Benefit} &= [\min (\text{Vol}_{\text{NB}}, \text{Vol}_{\text{B}}) \times \text{AVO}_{\text{NB}}] \times [\text{TT}_{\text{NB}} - \text{TT}_{\text{B}}] \\ \text{Induced Travel Benefit} &= \frac{1}{2} [\text{Vol}_{\text{B}} \times \text{AVO}_{\text{B}} - \text{Vol}_{\text{B}} \times \text{AVO}_{\text{NB}}] \times [\text{TT}_{\text{NB}} - \text{TT}_{\text{B}}] \end{aligned}$$

where,

- Vol = volume
- AVO = average vehicle occupancy
- TT = travel time
  
- NB = no-build
- B = build

These formulas worked because the definition of user groups ensured that the AVO was the same in the build and no-build cases. With the change to location-based user groups for HOV-to-HOT lane conversions and HOV-2-to-HOV-3 conversions, the AVO changes from the no-build to the build case. To accommodate this, Cal-B/C explicitly calculates the number of trips in the travel time benefit page before estimating the travel time and induced travel benefits. These benefits are now estimated using the following formulas:

$$\begin{aligned} \text{Travel Time Benefit} &= [\min (\text{Vol}_{\text{NB}} \times \text{AVO}_{\text{NB}}, \text{Vol}_{\text{B}} \times \text{AVO}_{\text{B}})] \times [\text{TT}_{\text{NB}} - \text{TT}_{\text{B}}] \\ \text{Induced Travel Benefit} &= \frac{1}{2} [\text{Vol}_{\text{B}} \times \text{AVO}_{\text{NB}} - \text{Vol}_{\text{B}} \times \text{AVO}_{\text{NB}}] \times [\text{TT}_{\text{NB}} - \text{TT}_{\text{B}}] \end{aligned}$$

Cal-B/C also has a new table in the model inputs page, so users can verify that the values of AVO, average daily traffic (ADT), hourly HOV volume, and percent trucks produce the expected annual number of person-trips. Exhibit V-10 provides an example of this table.

**Exhibit V-10: New Table for Verifying Annual Person-Trips in Cal-B/C**

2D <b>ANNUAL PERSON-TRIPS</b> (for HOV and HOT lane projects that affect average vehicle occupancy)			
	No Build	Build	Induced
<b>Year 1</b>			
<b>Peak Period</b>			
HOV Trips	0	0	
Non-HOV Trips	0	0	0
Truck Trips	0	0	0
<b>Non-Peak Period</b>			
Non-HOV Trips	0	0	0
Truck Trips	0	0	0
<b>Total Trips</b>	0	0	0
<b>Year 20</b>			
<b>Peak Period</b>			
HOV Trips	0	0	
Non-HOV Trips	0	0	0
Truck Trips	0	0	0
<b>Non-Peak Period</b>			
Non-HOV Trips	0	0	0
Truck Trips	0	0	0
<b>Total Trips</b>	0	0	0

Since induced trips can occur on the general purpose lanes or the HOT lanes, Cal-B/C asks the user to input the percent of induced trips occurring on the HOT lanes. The model assumes that 100 percent of the trips occur on the HOT lanes, but the user can change this percentage. The adjustment for where the induce travel occurs is made in the non-HOV and truck induced benefit calculations, which subtract the entire benefit when induced demand is excluded and half of the benefit when induced demand is included. The full and half benefits are excluded because the entire travel time benefit was included in the travel time calculation and this needs to be adjusted by the “rule of 0.5” (i.e., consumer surplus is half the travel time benefit).

*BPR parameters.* While the Highway Capacity Manual and other sources provide “a” and “b” parameters for freeways and conventional highways, there are no recommendations for BPR parameters for HOV and HOT lanes. The recent research by Varaiya, as well as Guin, Hunter and Guensler, suggests that separate BPR parameters are needed for HOV and HOT lanes.

The Cal-B/C development team used data from the curves presented in these two research papers to estimate an “a” parameter of 0.55 and a “b” parameter of 8. This curve is an approximation, because the project team did not have access to the underlying data. The parameters make HOV and HOT lane speeds more sensitive to



traffic volumes, particularly as the approach and surpass 1500 vphpl. These parameters can be adjusted as more up-to-date research and guidance becomes available.

*Lane Capacity.* The revised Cal-B/C model includes a separate lane capacity to use in the BPR curves for HOV and HOT lanes. This capacity is set at 1600 vphpl, using the data in Varaiya, as well as Guin, Hunter and Guensler. This capacity may vary by the number of lanes in the HOV facility (i.e., the “snail” effect is less pronounced in two-lane facilities), but the Cal-B/C development team did not find enough research to support having different capacities for one and two-lane facilities.

*Free-Flow Speed.* Cal-B/C uses a single free-flow speed for the general purpose lane and the HOV and HOT lane speed calculations. As with lane capacity, the Cal-B/C development team did not find research to support having different free-flow speeds for one and two-lane facilities.

*Safety Impact.* The Cal-B/C development team was unable to find research showing incremental collision rates associated with HOV or HOT lanes compared to general purpose only facilities. The literature provides ambivalent guidance on how barrier separation and the frequency of lane access influence collision rates. The effects appear to be project-specific and more relevant to project design than benefit-cost analysis.

*Vehicle Operating Costs and Emissions.* Beyond the typical fuel consumption and emissions parameters associated with fixed speeds, HOV and HOT lanes have the potential to influence vehicle operating costs and emissions through speed cycling as a result of merging. However, the Cal-B/C development team was unable to find research on these speed cycling effects and a typical speed cycling pattern is assumed in the standard fuel consumption and emission curves. Cal-B/C ignores any effects due to changes in speed cycling.

*Toll Revenues.* Cal-B/C excludes toll revenues from the benefit-cost evaluation because they are transfers from users to the operating agency.

*Violation Rates.* Departmental guidance suggests HOV lanes should target less than 10 percent violation rates. The violation rates for HOT lanes are likely to be even lower. Although violation rates impact operational performance and the estimation of benefits for individual user groups, Cal-B/C does not adjust any input data for potential violation rates. It is assumed that these are correctly included in the forecasted traffic volumes.

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**VI. GRADE-SEPARATED RAIL  
CROSSINGS**

## VI. GRADE-SEPARATED RAIL CROSSINGS

The 2009 update of the Cal-B/C model added the ability to assess the benefits of grade separations at rail crossings. The scope of these projects is expected to be similar to those funded under the Federal Railroad-Highway Grade Crossing Program (Section 130 Program). Cal-B/C is unable to assess other types of rail crossing projects, such as improved signals or gates. The methodology incorporated in Cal-B/C is limited. It assumes that the queues on highways clear completely between times that warning gates are down. However, this limited methodology is more comprehensive than the hazard indices typically used to assess grade crossing projects.

The Cal-B/C methodology is intended for use with single grade crossings, but grade-separations are frequently planned as part of a network of grade separations. Cal-B/C can approximate benefits for multiple grade separations by entering the data for all crossings (rail movements and traffic data) as if they occurred at one large crossing. The resulting benefits are an approximation that includes several simplifying assumptions. Some of the assumptions include: traffic distributions are the same at all crossings, and the operations of each crossing is independent of the others. To conduct a more detailed analysis, users should run a separate rail operations model and monetize the resulting benefits.

This chapter provides an overview of the benefits associated with grade separation improvements, relevant Departmental guidelines and procedures, other relevant methodologies, findings from a review of recent theoretical literature, and a description of the methodology for incorporating grade separation projects into Cal-B/C. After this introduction, the chapter is organized as follows:

- *Factors Affecting Grade-Separated Rail Crossings* – provides a detailed description of at-grade highway-rail grade crossings, the purpose for building grade-separated crossings, and critical factors to be considered in evaluating their cost effectiveness
- *Relevant Departmental Guidelines and Procedures* – describes Departmental resources on rail grade separations
- *Other Methodologies* – discusses non-Departmental guidance, and reviews the ways other benefit-cost models and tools analyze grade-separation projects
- *Recent Research and Findings* – discusses findings from recent theoretical research with particular emphasis on the benefits and impacts of rail grade-separation projects

- *Cal-B/C Methodology* – explains the revisions made to Cal-B/C to accommodate the evaluation of grade-separated rail crossings.

This chapter was written as part of the 2009 Cal-B/C update, so references to prior versions of Cal-B/C indicate versions before Cal-B/C v4.0. Since the 2009 update, the Cal-B/C development team has identified grade crossing methodologies used in other states (i.e., Iowa and Florida). Descriptions of these methodologies have been added to the chapter. However, the newly found methodologies continue to support the approach taken in Cal-B/C.

Cal-B/C and the Iowa methodologies appear to be among the few approaches that monetize the value of accidents at grade crossings. Both methodologies use highway accident values for grade crossing accidents. However, grade crossing accidents are likely to be more severe and involve higher costs than typical highway accidents. A National Highway Cooperative Research Project (NCHRP 08-85) is currently investigating the comprehensive costs of grade crossing accidents. These costs should be incorporated into Cal-B/C when they are available.

## **1.0 FACTORS AFFECTING GRADE-SEPARATED RAIL CROSSINGS**

A highway-rail grade crossing constitutes the intersection of two transportation modes that differ in their physical characteristics and operations (FHWA, 2007). Trains operate on a fixed schedule along guided tracks. Trains are unable to swerve and stopping to avoid unexpected objects is very difficult. In contrast, automobiles and trucks are more maneuverable and possess the ability to change lanes and travel at unscheduled times. These operational differences highlight the need for careful planning in areas where trains and automobiles closely interact, particularly at highway-rail grade crossings.

Highway-rail grade crossings can be “at-grade,” indicating that the intersection is on a shared level and is controlled by gates. They may also be “grade-separated,” meaning the trains and automobiles are separated by infrastructure. There are various users of highway-rail grade crossings, including automobiles, trucks, passenger rail, and freight rail. Each of these users needs to be considered in the benefit-cost analysis of grade crossing projects.

### **1.1 Section 130 Grade Crossing Program**

Title 23, United States Code, Section 130 (23 USC 130) authorizes the Railroad-Highway Grade Crossing Program, a categorical funding program established as part of the Highway Safety Act of 1973. The program provides funding for at-grade crossing improvement projects that reduce the number and severity of highway crashes by eliminating hazards to vehicles and pedestrians at existing railroad crossings. Under the program, railroad-highway safety projects are federally financed up to 90 percent of

total project costs when state or local funds match at least 10 percent of costs. Activities eligible for Section 130 safety funds include: separation or protection of grades at crossings, reconstruction of existing railroad grade crossing structures, relocation of highways to eliminate grade crossings, elimination of hazards and the installation of protective devices at highway-rail crossings, permanent closure of at-grade crossings, and projects to address bicycle safety.

States are free to develop their own methods for measuring safety hazards and selecting grade crossings and projects to include on their statewide lists. As a result, a number of different formulas are in use nationally to assist in prioritizing highway-rail grade crossings. In general, the methods fall into two categories – hazard indices and crash prediction formulas. While hazard indices rank crossings relative to other crossings using scales of expected crashes or casualties, crash prediction formulas estimate the absolute number of crashes or casualties for each crossing. Most methods do not consider the costs of grade crossing crashes explicitly. However, there have been some attempts to include these costs in Illinois and Iowa.

## 1.2 California Public Utilities Commission Guidelines

The California Public Utilities Commission (CPUC) establishes grade crossing guidelines for the Section 130 Grade Crossing Program. The guidelines describe improvement types acceptable for Section 130 funding. These include converting at-grade crossing to grade-separated crossings (referred to as “grade crossing elimination projects”), advanced warning devices, medians, and preemption.

Although Cal-B/C can handle only grade crossing elimination projects, other alternative improvements can improve safety and mobility at crossings. Alternatives may include: traffic intersection lighting, flashing lights, median barriers, four-quadrant gate system, and long arm gates. Additional information on highway-rail crossings can be found in the Federal Highway Administration’s (FHWA) Railroad-Highway Grade Crossing Handbook - Revised Second Edition August 2007.

Grade crossing elimination projects offer major benefits, including reductions in collisions, highway vehicle delay, rail traffic delay, as well as savings in the maintenance costs of crossing surfaces and traffic control devices. Both private rail operators and road users gain from these benefits. However, there are also large costs related to the construction of a grade separation project.

The CPUC guidelines identify two types of grade crossing elimination projects:

- Closure occurs when vehicular traffic is removed from conflict with railroad traffic by closing the road. This includes: removal of warning devices, removal of the surfacing and approaches, construction of barriers and/or fencing, signage, and other measures as deemed necessary during the diagnostic review.



- Abandonment occurs when railroad traffic is removed from conflict with at-grade vehicular traffic through the cessation of all railroad operation or the removal of tracks from the crossing. Abandoned crossings are not eligible to receive Section 130 funds for their removal. (CPUC, 2005)

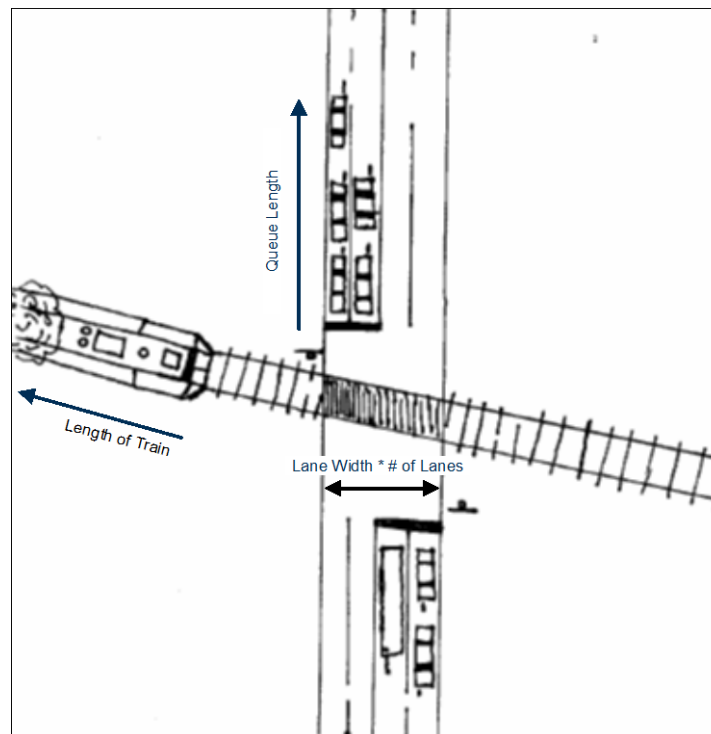
### 1.3 Common Factors

The accident prediction or hazard index formulas used in all states involve the same basic elements that are selected in combinations based on the needs of each particular state. These elements include: vehicular traffic volume, train volume, a protection factor for crossing controls, frequency of trains, speeds of vehicular and train traffic, number of tracks, type of highway surface, and the number of highway travel lanes.

Exhibit VI-1 illustrates a typical at-grade crossing and highlights some of the key attributes involved in assessing the benefits of eliminating a highway grade crossing:

- Length of train
- Queue length
- Lane width
- Number of lanes.

**Exhibit VI-1: Typical At-Grade Rail-Highway Crossing**



Safety is an important motivation for separating grade crossings. There are 147,805 at-grade rail crossings in the U.S. Of these, 90,274 crossings are located in rural areas, while the remaining 57,531 crossings are located in urban areas. In 2004, there were 2,623 collisions at grade crossings, resulting in 331 fatalities and 931 injuries (FHWA, 2007). Approximately 77 percent of California's 10,140 rail crossings occur at grade (CPUC, 2008). These fatalities occur almost exclusively among motor vehicle occupants or pedestrians. Rail passengers are rarely affected. In addition to collisions involving a train, other motor vehicle collisions can occur due to abrupt stops at crossings resulting in rear-end collisions.

As with any at-grade crossing of transportation facilities, delays are expected. Due to the "character" and "momentum" of trains, an 1895 United States Supreme Court ruling granted trains the right-of-way at grade crossings (*Baltimore & O R Co. v. Griffith*, 159 U.S. 603, 1895). As a result, automobiles generally experience greater delay near grade crossings than trains. However in urban communities, restrictions are commonly placed on train speeds for various reasons, including noise reduction, safety concerns, and the abundance of grade crossings.

According to the FHWA Railroad-Highway Grade Crossing Handbook (2007), grade crossings impose four types of delay on highway traffic:

- Trains occupying crossings – Highway traffic should slow down to look for trains, particularly at crossings with passive traffic control devices. Vehicles must stop and wait for trains to clear crossings. Furthermore, there may be some delay to vehicles that arrive at crossings before queued vehicles have cleared the crossing.
- Special vehicles – Certain vehicles can be required to stop at all crossings. These include commercial buses, passenger-carrying vehicles, and vehicles carrying hazardous materials. In addition to the delay incurred by these special vehicles, their stopping may also impose delay on vehicles following them.
- Crossing surface – The railroad crossing surface may cause vehicles to slowdown (e.g., 15 mph). The time needed for a vehicle to slow down and cross should be taken into account.
- Presence of crossing – This delay occurs regardless of whether a train is approaching or occupying the crossing. Motorists usually slow down before crossings so that they can stop safely if a train is approaching. This is a required safe driving practice in conformance with the Uniform Vehicle Code, which states "...vehicles must stop within 15 to 50 feet from the crossing when a train is in such proximity so as to constitute an immediate hazard." Therefore, the existence of a crossing may cause some delays to motorists who slow to look for a train.

The Institute of Transportation Engineers (ITE) recommends the implementation of grade separation crossings when their cost can be economically justified based on fully allocated life-cycle costs beyond the societal benefits, and where one or more of the following conditions exist (Light Rail Transit Grade Separation Guidelines, 1992):

- The highway is a part of the designated National Highway System.
- The highway is otherwise designed to have partial controlled access.
- The posted highway speed exceeds 88 km per hour (55 mph).
- AADT exceeds 50,000 in urban areas or 25,000 in rural areas.
- Maximum authorized train speed exceeds 161 km per hour (100 mph).<sup>1</sup>
- An average of 75 or more trains per day or 150 million gross tons per year use the crossing.
- An average of 50 or more passenger trains per day in urban areas or 12 or more passenger trains per day in rural areas use the crossing.
- Crossing exposure (the product of the number of trains per day and AADT) exceeds 500,000 in urban areas or 125,000 in rural areas; or passenger train crossing exposure (the product of the number of passenger trains per day and AADT) exceeds 400,000 in urban areas or 100,000 in rural areas.
- The expected accident frequency for active devices with gates as calculated by the United States Department of Transportation (USDOT) Accident Prediction Formula, including five-year accident history, exceeds 0.2.
- Vehicle delay exceeds 30 vehicle hours per day.
- An engineering study indicates that the absence of a grade separation structure would result in the highway facility performing at a level of service below its intended minimum design level 10 percent or more of the time.

There are several formulas related to the USDOT Accident Prediction Formula that predict accident rates at rail-highway crossings. The National Cooperative Highway

<sup>1</sup> *Maximum speed limit for Amtrak is 79 mph.*

Research Program (NCHRP) Report 50 Accident Prediction Formula uses a hazard index when calculating both the expected number of accidents and the number of non-train-involved accidents per year. Similarly, the Peabody-Dimmick Formula, published in 1941, uses five years of accident data from rural crossings to determine the expected number of accidents in five years. Lastly, the Florida Department of Transportation Accident Prediction Model uses stepwise regression analysis to predict the number of accidents in a four-year period at crossings with either passive or active traffic control devices.

Since the ITE guidelines require grade separation projects to satisfy one of the above conditions in addition to being cost-effective (societal benefits exceeding life-cycle costs), it is possible for a project to be cost-effective, but “unjustified.”

## **2.0 RELEVANT DEPARTMENTAL GUIDELINES AND PROCEDURES**

This section summarizes Department guidelines and procedures relevant to rail grade separation projects. More detailed information is available in the source documentation.

### **2.1 Highway Design Manual (HDM)**

The Highway Design Manual establishes uniform policies and procedures for highway design in California. The manual is organized into 25 chapters. Each chapter takes into account new design considerations. The manual contains design standards for rail crossings, including sightline distances and control device distances from the crossing.

While this document does not include methods for analyzing rail grade separation projects, it does discuss horizontal and vertical clearances and grade lines. The Highway Design Manual notes that it is more desirable to construct highways overhead. Advantages include less damage in a derailment, the facilitation of design and maintenance agreements, ease in widening overheads, fewer drainage issues, and generally lower initial costs.

### **2.2 California Manual on Uniform Traffic Control Devices**

The California Traffic Manual provides guidance on signs, pavement markings, and traffic controls for all types of roadway situations. The Department adopted the California Manual on Uniform Traffic Control Devices (FHWA’s MUTCD 2003 Revision 1, as amended for use in California), also called the California MUTCD, on September 26, 2006 to prescribe uniform standards and specifications for all official traffic control devices in California. The California MUTCD replaces the previously adopted MUTCD 2003 Edition (May 20, 2004); the MUTCD 2003 California Supplement; Chapters 4, 5, 6, 8, 10, 11, 12 and the traffic signals portion of Chapter 9 of the 1996 California Traffic Manual, as amended; and all previous editions.

Part 8 of the California MUTCD discusses traffic controls for highway-rail grade crossings and offers two points of guidance:

- Since at-grade rail crossings are a potential source of accidents and congestion, agencies should conduct engineering studies to determine the cost and benefits of eliminating these crossings.
- Any highway-rail grade crossing that cannot be justified should be eliminated.

This guidance assumes a default scenario of eliminating grade crossings compared to a more onerous scenario that involves maintaining an at-grade crossing. This logic is the reverse of the ITE guidelines, which require a proposed grade crossing project to meet certain operational criteria and pass a benefit-cost test. Otherwise, an at-grade crossing should be kept under the ITE guidelines.

The California Traffic Manual further specifies that “when a highway-rail grade crossing is eliminated, the traffic control devices for the crossing shall be removed” (Caltrans, 2002).

### **2.3 Transportation Management Systems (TMS) Master Plan**

The Transportation Management Systems (TMS) Master Plan lays out the blueprint for safer and more effective operations of the state transportation system through system management enabled by intelligent infrastructure. The focus of the TMS Master Plan is on freeway mobility improvements. Although grade separation can impact highway facility performance (as highlighted in the ITE guidelines), they occur on conventional highways. As a result, the TMS Master Plan does not cover rail grade separation projects.

### **2.4 California Intermodal Transportation Management System (ITMS)**

The Intermodal Transportation Management System (ITMS) is a computer tool to evaluate the performance of California’s transportation network and support planning decisions. The ITMS is used to identify system deficiencies, develop actions to mitigate these deficiencies, and evaluate effectiveness using performance measures. The tool contains a database of current and forecast future person and freight demand by corridor, facility, and mode, includes a mode shift-model, and uses geographic information system (GIS) capabilities. ITMS does not estimate the benefits of rail grade separations, but it may provide useful information for evaluating projects in Cal-B/C.

The person movement demand forecasts found in ITMS come from regional travel demand models maintained by metropolitan planning organizations (MPOs) throughout California. The forecasts are standardized and updated in the ITMS every

few years. Since most rail grade crossings involve travel on conventional highways, the ITMS data is useful only if the regional travel demand models and the ITMS basic network include the conventional highways that cross rail rights-of-way.

The freight forecasts are developed from freight waybill information compiled by Reebie Associates. While the freight forecasts may include rail movements and be useful for rail grade separation project evaluations, they are unlikely to be consistent with rail databases or with the current train movement data at the private railroad companies.

### **3.0 OTHER METHODOLOGIES**

The next few sections discuss non-Departmental guidance and other methods for analyzing rail grade separation projects. Additional methods found since the 2009 revision have been added to Section 4 of this chapter.

#### **3.1 FHWA Railroad-Highway Grade Crossing Handbook Guidance**

The FHWA Handbook (2007) provides a stepwise technique for calculating the benefit-cost ratio for a highway-rail grade crossing:

- Determine the initial cost of implementation of the crossing improvement being studied
- Determine the net annual operating and maintenance costs
- Determine the annual safety benefits derived from the project
- Assign a dollar value to each safety benefit unit (National Safety Council, National Highway Traffic Safety Administration, or other methodology)
- Estimate the service life of the project based on patterns of historic depreciation of similar types of projects
- Estimate the salvage value of the project or improvement after its primary service life has ended
- Determine the interest rate by taking into account the time value of money
- Calculate the B/C ratio using equivalent uniform annual costs (EUAC) and equivalent uniform annual benefits (EUAB)

- Calculate the B/C ratio using PWOC and present worth of benefits (PWOB).

The handbook also provides a sample worksheet with hypothetical values for the B/C analysis as shown in Exhibit VI-2.

**Exhibit VI-2: Sample Feature of Benefit-Cost Worksheet**

Sample Benefit-to-Cost Analysis Worksheet	
Evaluation No.:	_____ Project No.:
_____ Date:	
Evaluator:	
_____	
1.	Initial implementation cost, I: \$ 100,000
2.	Annual operating and maintenance costs before project implementation: \$ 100
3.	Annual operating and maintenance costs after project implementation: \$ 1,000
4.	Net annual operating and maintenance costs, K (#3 - #2): \$ 900
5.	Annual safety benefits in number of accidents prevented:
	Severity Actual – Expected = Annual Benefit
a)	Fatal accidents (fatalities) 0 – 0 = 0
b)	Injury accidents (injuries) 4 – 2 = 2
c)	PDO accidents (involvements) 5 – 3 = 2
6.	Accident cost values (Source Department )
	Severity Cost
a)	Fatal accident (fatality) \$ 500,000
b)	Injury accident (injury) \$ 50,000
c)	PDO accident (involvement) \$ 2,000
7.	Annual safety benefits in dollars saved, B:
(5a) x (6a)	= 500,000 x 0 = 0
(5b) x (6b)	= 50,000 x 2 = 100,000
(5c) x (6c)	= 2,000 x 2 = 4,000
	Total = \$104,000
8.	Service life, n: 20 yrs 10. Interest rate: 10% = .10
9.	Salvage value, T: \$5,000 (Annual compounding interest)
11.	EUAC Calculation:
	Capital recovery factor, CR = 0.1175
	Sinking fund factor, SF = 0.0175
	EUAC = I (CR) + K - T (SF)
	= 100,000 (0.1175) + 900 - 5,000 (0.0175) = 12,562
12.	EUAB Calculation: EUAB = B = 104,000
13.	B/C = EUAB/EUAC = 104,000 / 12,562 = 8.3
14.	PWOC Calculation:
	Present worth factor, PW = 8.5136
	Single payment present worth factor, SPW = 0.1486
	PWOC = I + K (SPW) - T (PW)
	= 100,000 + 900 (8.5136) - 5,000 (0.1486) = 106,919
15.	PWOB Calculation:
	PWOB = B (SPW) = 104,000 (8.5136) = 885,414
16.	B/C = PWOB/PWOC = 885,414 / 106,919 = 8.3
Source: Railroad-Highway Grade Crossing Handbook, Second Edition. Washington, DC: U.S. Department of Transportation, Federal Highway Administration, 1986.	

This method requires an estimate of collision severity in dollar terms, which can greatly affect the outcome. The method is relatively easy to apply and is generally accepted in engineering and financial studies. The process can be performed for alternative improvements at a single crossing and arrayed for all projects to determine priorities for funding.

The FHWA Handbook also describes several of the accident prediction or hazard index formulas used in other states. Some of the more prominent indices include the New Hampshire Index, the USDOT Accident Prediction Model, and the NCHRP Report 50 Accident Prediction Formula. Some of these methods are described more fully in Section 4.

### **3.2 Highway Capacity Manual (HCM)**

The Highway Capacity Manual (HCM) provides techniques for estimating the capacity and level of service for transportation facilities. Although not a software tool, the document includes worksheets for determining the quality of service and analytical procedures for several other performance measures. The methodologies are generally for traditional roadway, bicycle, pedestrian, and transit projects, but some operational improvements are available as well.

The HCM does not estimate the benefits of rail grade separation projects, but it can be used to analyze the benefits of signal improvements even though they are not specific to rail crossing signal improvements. These methods may be used in combination with the Cal-B/C methods to yield a comprehensive benefit-cost assessment. For example, the construction of a grade-separated crossing may allow traffic engineers to optimize the neighboring traffic signals and further reduce traffic delays in the vicinity of the grade crossing. Cal-B/C can be used to estimate the elimination of the queuing delays, while HCM methods (or other methods) can be used to estimate additional delay savings at neighboring signals.

### **3.3 RailDec**

RailDec was developed for the Federal Railroad Administration (FRA) to provide decision support for state and local transportation agencies engaged in strategic planning and budgeting for rail and rail-related intermodal projects. RailDec adopts standard cost-benefit and financial analysis techniques to evaluate investment alternatives. RailDec provides users with:

- Forecasted values of financial and economic benefits of intermodal rail and rail-related investments. By calculating both public and private rates of return on rail and rail-related investment, RailDec provides data to promote public/private partnerships and innovative financing.



- Project-level analysis to develop evidence that allows decision-makers to screen investment alternatives in a cost-effective and timely manner.
- Risk analysis framework to account for model input uncertainty and provide decision makers with a probability range of cost-benefit and financial analysis results.

RailDec calculates the financial rate of return and can demonstrate how a project will generate net income from investment as well as the economic rate of return, to capture a wider range of benefits. RailDec incorporates a risk analysis framework to give decision-makers cost-benefit and financial analysis results to account for uncertainty in model input. Model outputs are also reported in probabilistic terms.

This tool does not estimate the benefits of rail grade separation projects, but a similar tool (GradeDec.NET) specifically estimates rail grade crossings.

### 3.4 GradeDec.NET

The FRA GradeDec.NET tool is a newer, web-based application to analyze rail-highway grade improvements. The tool provides information on safety benefits, time savings, vehicle operating costs, emissions, network benefits, and local benefits. GradeDec.NET calculates the rate of return on investment by comparing the streams of benefits against the streams of maintenance and other life-cycle costs. According to GradeDec.NET documentation, the model uses benefit-cost assumptions consistent with USDOT guidance. Results can be provided for individual grade crossings and the entire corridor.

GradeDec.NET applies input-output techniques from recent research to calculate time in queue and highway delays.<sup>2</sup> GradeDec.NET uses the following series of equations to estimate travel time savings that result from eliminating delays due to queuing:

- Average crossing closure time (minute)

$$CCT_i = \frac{cl_i \cdot nc_i + el}{spd_i \cdot cf} + \frac{36}{60}$$

$$ACCT = \frac{\sum_i \delta_i \cdot CCT_i}{\sum_i \delta_i}$$

where,

<sup>2</sup> Lawson, Tim, David J. Lovell, and Carlos F. Daganzo. *Using Input-Output Diagram to Determine Spatial and Temporal Extents of Queue Upstream of a Bottleneck*, *Transportation Research Record* 1972, pp. 140-147.

- $i$  = Index indicating the type of train: passenger, freight, or switch
  - $CCT_i$  = Crossing closure time for train of type  $i$ , minutes
  - $cl_i$  = Average car length for train of type  $i$ , feet
  - $nc_i$  = Average number of cars for train of type  $i$
  - $el$  = Engine length (set at 50 feet)
  - $cf$  = Factor for converting mph to feet per minute, equal to  $5,280/60$
  - $spd_i$  = Average speed at the crossing of train of type  $i$ , mph
  - $\delta_i$  = Trains per day of type  $i$
  - $ACCT$  = Average crossing closure time, minutes
- 36 seconds (0.6 minutes) is assumed for gate closing and opening time

- Affected highway vehicles at closure

$$N_K = \frac{\lambda \cdot \mu \cdot ACCT}{60 \cdot (\mu - \lambda)}$$

where,

- $\lambda$  = Arrival rate of vehicles, vehicles per second
- $\mu$  = Dispersal rate of vehicles, vehicles per second (constant value of 0.5).

- Total vehicle delay per closure (vehicle-seconds)

$$w = N_K \cdot \left[ \frac{ACCT}{60} + \left( \frac{1}{\mu} - \frac{1}{\lambda} \right) \cdot \left\{ \frac{N_K + 1}{2} \right\} \right]$$

where,

- $\mu$  = Dispersal rate of vehicles, vehicles per second (constant value of 0.5)
- $N_K$  = Number of affected vehicles at closure.

- Time-in-queue per closure (vehicle-seconds)

$$t_q = N_K \cdot \left[ \frac{ACCT}{60} + \left( \frac{1}{\mu} - \frac{1}{z} \right) \cdot \left\{ \frac{N_K + 1}{2} \right\} \right]$$

where,

- $z$  = Slope of the back-of-queue equation

- Back-of-queue

$$z = \frac{\lambda \bullet v_f \bullet k_j}{v_f \bullet k_j - \lambda}$$

where,

- $v_f$  = Free-flow speed of highway vehicles (constant value of 45 mph converted to feet per second)
- $k_j$  = Traffic density in vehicles per feet at speed 0 (set to constant 0.05).

The model uses the total vehicle delay time to calculate the travel time impact of a grade crossing and the time-in-queue to calculate the idling time for emissions and operating costs.

### 3.5 Transportation Economic Development Impact System (TREDIS)

The Transportation Economic Development Impact System (TREDIS) is a web-based transportation analysis and impact tool. The tool is intended to help users evaluate economic impacts and benefit-cost tradeoffs for transportation investments. TREDIS focuses on freight projects and has the capability to:

- Estimate economic impacts of constructing terminals or facilities
- Examine strategies for managing transportation corridors
- Evaluate freight performance
- Weigh benefits and costs of alternative transportation investments
- Estimate impact of congestion on households and industries by sector
- Evaluate economic benefit of improved access to consumer, producer, and labor markets.

TREDIS has four modules to determine the full economic impact of transportation projects and modules may be used independently. The ones most relevant to Cal-B/C are:

- Travel Cost Module (TC) - translates changes in traffic volumes, travel times, and accidents into direct cost savings that accrue to households and businesses.
- Benefit-Cost Module (BC) - calculates the net present value of project benefits and costs from federal, state, and local agencies perspectives.

TREDIS requires user impacts, such as travel time, to be estimated outside the tool, and TREDIS computes dollar values. Despite its focus on goods movement strategies and

economic impacts, TREDIS does not consider or estimate the benefits of rail grade separation projects.

### **3.6 Surface Transportation Efficiency Analysis Model (STEAM) and Sketch Planning Analysis Spreadsheet Model (SPASM)**

STEAM is a transportation/economic impact analysis tool developed by the FHWA. It is used for detailed, system-wide analyses of alternative transportation investments. When introduced in 1997, it was the first FHWA impact analysis product to use outputs directly from the four-step travel demand modeling process. SPASM was a precursor to STEAM and is superseded in sophistication and functionality by STEAM. Neither STEAM nor SPASM estimates the benefits of rail grade separation projects directly.

### **3.7 Highway Economic Requirements System (HERS)**

The Highway Economic Requirements System (HERS) is a computer model designed to estimate the costs, benefits, and national economic implications associated with various highway investments at the national level. USDOT uses the HERS model to estimate the transportation funding needed as part of the federal Condition and Performance Report. This report is produced biennially and presented to Congress. HERS estimates the benefits to highway users (travel time, operating costs, and safety), to highway agencies (maintenance costs and the residual value of an improvement at the end of the analysis period), and reduction in vehicle emissions. A benefit-cost analysis compares potential improvements

HERS uses four sets of delay equations (by road types) that were developed by fitting curves to data generated by repeated runs of queuing models (e.g., FRESIM and NETSIM). Although a queuing analysis underlies the HERS delay equations, HERS does not perform queuing analyses at run time. An independent Operations Preprocessor provides adjustment factors that are applied within the HERS model. Neither HERS nor the Operations Preprocessor can estimate the benefits for rail grade separation projects, but they can analyze the benefits of rail grade warning improvements.

### **3.8 IMPACTS**

The IMPACTS spreadsheet software was developed in 1996 in tandem with workshop exercises for a National Highway Institute (NHI) course, “Estimating the Impacts of Urban Transportation Alternatives.” It contains seven Excel worksheets that encompass different alternatives: highway expansion, bus system expansion, light-rail transit investment, HOV lanes, and conversion of an existing facility to a toll facility, employer-based travel demand management, and bicycle lanes. Although this method does not estimate the benefits of rail grade separation projects, it can analyze the benefits of rail grade warning improvements.

Analysis can be conducted over a single facility or a corridor (provided that the analysis is repeated for each affected facility), and for different markets and travel segments. Separate analyses are needed by mode if the user wishes to evaluate multimodal improvements.

The estimated impacts of the alternatives include the following:

- Costs of implementation (including capital, operation, and maintenance)
- Benefits including trip time and out-of-pocket
- Induced demand
- Congestion savings to highway users
- Changes in other highway user costs, such as accidents and parking
- Revenue transfers due to tolls, fares or parking fees
- Changes in fuel consumption
- Changes in emissions.

### 3.9 ITS Deployment Analysis System (IDAS)

The Federal Highway Administration (FHWA) sponsored the development of IDAS to assist public agencies, particularly MPOs and other regional agencies in integrating ITS into the transportation planning process. Regional agencies have had trouble mainstreaming ITS because four-step models are geared towards capacity expansion, and are not sensitive to many of the benefits derived from ITS technologies, such as increasing the effective capacity of roadways. While IDAS does not estimate the benefits of rail grade separation projects, it includes a module for assessing the effectiveness of grade crossing monitors (i.e., warning improvements).

To estimate the safety benefits of rail grade crossing monitors, the module asks for accident rates associated with specific grade crossings. If the accident rates are not available, users can use default rates. IDAS uses the following default rates derived from a 1997 Federal Railroad Administration bulletin on the Highway-Rail Crossing Accident/Incident Inventory:

- 0.0028 annual fatalities per crossing
- 0.0091 annual injuries per crossing
- 0.0114 annual property damage only (PDO) accidents per crossing.

IDAS assumes that the grade warnings reduce accidents by 43 percent. The IDAS user's guide notes that, according to a 1997 Mitretek report on ITS benefits, the actual accident rate reductions range from 8.7 percent to 78 percent (based on experiences in Los Angeles, Maryland, and San Antonio). The guide also notes that previous studies have shown a reduction in grade crossing violations between 50 and 92 percent after implementation of photo surveillance and enforcement.

### 3.10 Screening for ITS (SCRITS)

Screening for ITS (SCRITS) is a spreadsheet analysis tool to estimate the user benefits of Intelligent Transportation Systems (ITS). It is intended as a sketch-level or screening-level analysis tool to allow practitioners to obtain an initial indication of the possible benefits of various ITS applications. Although this tool does not estimate the benefits of rail grade separation projects, it can analyze the benefits of rail grade warning improvements.

SCRITS is an Excel workbook. Baseline data are housed in a single worksheet, while the analyses of ITS applications are performed on other worksheets. The analysis of each ITS application typically requires user inputs in addition to the data in the baseline worksheet. Additional worksheets serve as lookup tables for analyzing ITS applications. The primary measures of effectiveness calculated by SCRITS vary by individual application and include the following:

- Vehicle-hours traveled
- Vehicle-miles traveled
- Emissions (CO, NO<sub>x</sub>, HC)
- Vehicle operating costs
- Energy consumption
- Number of accidents
- Economic benefit and benefit/cost ratio.

### 3.11 MicroBENCOST

MicroBENCOST was developed in the early 1990s through an NCHRP project as a comprehensive framework for conducting highway user benefit-cost analysis. MicroBENCOST is designed to analyze different types of highway improvement projects along a corridor. Benefits are calculated for existing and induced traffic, as well as for diverted traffic in the presence of a competing parallel route or when a bypass project is evaluated. The program incorporates:

- Speed versus volume-capacity (v/c) ratio relationships for rural highways based on the 1985 Highway Capacity Manual
- Interchange and intersection delay relationships derived from off-line TRANSYT-7F simulations
- Railroad grade crossing delays using the deterministic queuing concepts found in the HCM
- Incident and work zone delays also based on simple queuing concepts.

## 4.0 RECENT RESEARCH AND FINDINGS

This section provides an overview of key research related to rail grade separation projects. Along with the previous discussion on benefit-cost models, this research provides three primary “methods” for analyzing queuing on highways caused by at-grade rail crossings:

- GradeDec.NET, which is based on the research by Lawson, Lovell, and Deganzo and used by the FRA
- Bayport Loop Build-Out, which illustrates a method used by the Surface Transportation Board (STB)
- Inland Empire Railroad Main Line Study and the Riverside County Rail Crossing Priority Analysis, which use delay equations developed for the 1984 Southern California Association of Governments (SCAG) San Pedro Bay Ports Access Study and used extensively throughout Southern California.

Although these methods appear different, careful examination of the equations and assumptions reveals that they are very similar. All are functions of gate down times, arrival rates, and departure rates. The largest difference is between using the sum of impacted vehicles (STB and SCAG methods) compared to using the sum + 1 in the FRA method. Even though these methods make different assumptions about gate down times (e.g., 0.5 minutes versus 0.6 minutes, direct consideration of the time to traverse the highway, etc.), the net impact is minor. Other differences among these methods are superficial and are related to variable definitions and the units used.

Since the 2009 update, the Cal-B/C development team has found additional methods for assessing grade crossing projects. These methods are consistent with the three primary methods described above and the method ultimately adopted for Cal-B/C. The text in this section is revised to include descriptions of the following methods: New Hampshire Index, Iowa Benefit-Cost Calculations, the Florida Freight Rail Investment Software, and the USDOT Accident Prediction Model. The Iowa methods were developed at roughly the same time as the Cal-B/C methods and are nearly identical. Along with Cal-B/C, the Iowa approach is one of the few available that monetizes the costs of grade crossing accidents.

### 4.1 Bayport Loop Build-Out

As part of an Environmental Impact Statement, the Surface Transportation Board’s Section of Environmental Analysis reported on the level of service (LOS) at grade crossings. The LOS was based on vehicle delay, blocked crossing time, average daily traffic, and departure and arrival rates. A value of 0.5 minutes (or 30 seconds) was assumed for gate closing and opening time, which is very similar to the 0.6 minutes (or

36 seconds) used in GradeDEC.NET. Vehicle arrival rates were calculated by dividing the average daily traffic by 24 hours. This method assumes that vehicle arrival rates are uniform (without peaking) throughout the day. While highway travel demand is known to have peak periods, this simplifying assumption is reasonable given the difficulty in obtaining traffic data (let alone peaking characteristics) on conventional highways. Vehicle departure rates were assumed to be 1,800 vehicles per hour for highways, 1,400 vehicles per hour for arterials, 900 vehicles per hour for collectors, and 700 vehicles per hour for local roads.

The following equations were used in determining the LOS:

- Blocked crossing time (minutes):

$$(D_c) = \frac{L}{V \times 88} + 0.5$$

where,

- L = Length of the train, in feet
- V = Train speed in miles per hour
- 88 = Conversion factor from miles per hour to feet per minute (1 mile per hour is 88 feet per minute)
- 0.5 = Time required, in minutes, for gate closing and operating before and after train passage

- Crossing delay (minutes) per stopped vehicle:

$$D_A = \frac{D_c \times (S_c / (S_c - S_Q))}{2}$$

where,

- S<sub>c</sub> = Vehicle departure rate, vehicles per hour per lane
- S<sub>Q</sub> = Average arrival rate, average daily traffic in vehicles per hour per lane
- 2 = Denominator to reflect that vehicles do not experience delay for the entire time that the train blocks the grade crossing, but arrive on average at the midpoint of the train crossing period

- Number of vehicles delayed per day:

$$T_D = \frac{D_c}{1,440} \times N \times ADT$$



where,

1,440 = Minutes per day  
 N = Number of trains per day  
 ADT = Average daily traffic volume

- Average delay per vehicle (in a 24-hour period):

$$Delay = \frac{D_c}{1,440} \times N \times D_A \times 60$$

where,

$D_C$  = Blocked crossing time, minutes  
 $D_A$  = Crossing delay per stopped vehicle  
 60 = Conversion factor for minutes to seconds

## 4.2 Inland Empire Railroad Main Line Study

Leachman and Associates LLC prepared the Inland Empire Railroad Main Line Study for SCAG in June 2005. The study examines railroad infrastructure needs and operations for both freight and passenger trains in Southern California. Future freight and passenger traffic routing alternatives are analyzed based on capital costs, locomotive emissions, and vehicular delay at grade crossings as well as public exposure (in residential neighborhoods) to mainline freight train operations and access to passenger train operations. The analysis of grade crossings is relevant to the Cal-B/C updates included in the study.

The delay equations are identical to those used in SCAG's San Pedro Bay Ports Access Study published in 1984. According to the Leachman study, these equations are consistently used in grade crossing delay studies throughout the SCAG Region, and in several Environmental Impact Reports (EIRs) for major projects, such as the Riverside County Rail Crossing Priority Analysis (April 2001). The equations were originally developed by James Powell in a paper submitted to the Transportation Research Board (TRB) in 1982. Internet searches by the Cal-B/C development team were unable to find a copy of Powell's paper, although records do exist on the TRB website.

Important inputs to the analysis include:

- Average Daily Traffic (ADT) at the crossing and distribution of traffic volumes over four time periods: morning peak period, midday, afternoon peak period and night (determines vehicular arrival rate)
- Number of lanes at the crossing (affects queue storage)
- Speed of the train (affects gate down time)

- Vehicular departure rate (depends on number of trucks in the queue)
- Number of trains by length and distribution of trains by time of day (determines the number of queues formed).

The CPUC provided ADT estimates and the number of lanes for each highway crossed. Train speeds were taken from railroad track charts. Leachman and Associates assumed the estimates of freight train volumes by type and length and these are documented in Appendix B of the study report. Freight train volumes were assumed to be evenly distributed over 24 hours. Passenger train volumes by time period came from published schedules.

The gate-down time depends on train length and speed, lead time and lag time (time the gate goes down before the train arrives and when it goes up after the train clears the crossing) as well as the width of the intersection.

Vehicular delay is a function of the square of the gate-down time:

$$Delay\ in\ vehicle\ -\ hours = \left(\frac{1}{2}\right) \frac{aT_G^2}{\left(1 - \frac{a}{d}\right)} \left(\frac{1}{60}\right)$$

where,

- T<sub>G</sub> = Gate-down time expressed in minutes
- a = Vehicular arrival rate expressed in vehicles per minute
- d = Vehicular departure rate expressed in vehicles per minute
- 2 = Denominator to reflect the average delay, vehicles arrive at the midpoint of the TG
- 60 = Conversion factor for minutes to hours

The estimation of the gate-down time is explained further in the Riverside County Rail Crossing Priority Analysis, which uses a similar methodology.

### 4.3 Riverside County Rail Crossing Priority Analysis

In response to population growth and the development of the Alameda Corridor (freight line), Riverside County conducted a study to identify its rail-highway improvement priorities as an input to the Alameda Corridor East study. The Riverside County study used total gate down time and vehicle-hours of delay as its principal measures of effectiveness. The gate down time includes a value of 0.603 minutes for the gate closing and opening time plus an additional calculation for the amount of time necessary for the train to cross all lanes of the highway. The gate opening and closing time of 0.603 minutes is essentially the same as the 0.6 minutes used in GradeDEC.NET. The following equations were used to calculate the measures of effectiveness:

- Gate down time (minutes per train):

$$0.603 + \left( \frac{\text{Train Length} + 50 + 12 * \# \text{ Lanes}}{\text{Train Speed}} \right)$$

where,

The width of a traffic lane is assumed to be 12 feet and gates are assumed to go down when the train is 50 feet from the crossing.

- Vehicle delay (hours per train):

$$\frac{GDT^2}{2 * 60} + \left( \frac{VQ}{1 - \frac{VQ}{VDR}} \right) * \text{Lanes}$$

where,

- GDT = Gate down time
- V<sub>Q</sub> = Vehicle queue per lane
- VDR = Vehicle departure rate
- 2 = Denominator to reflect the average delay, vehicles arrive at the midpoint of the GDT
- 60 = Conversion factor for minutes to hours

#### 4.4 Grade Separation Program: Rail Crossing Engineering Section, California Public Utilities Commission

The Grade Separation Program provides state funding to grade-separated highway-rail crossings. The optimal safety improvement to a grade crossing is the complete separation of the railroad from the roadway. Grade separation eliminates fatalities and injuries that occur between train and highway users. They also eliminate blocking delays, train horn and automatic warning device noises, and improve emergency response times.

The CPUC uses two formulas to rank projects, depending on the type of improvement being proposed. The first formula allows the CPUC to analyze crossings that need improvements, but will remain at-grade. The second (shown below) evaluates crossings nominated for separation or elimination:

$$\text{Project Rank} = \frac{V * (T + 0.1 * LRT) * (AH + 1)}{C} + SCF$$

where,

V	=	Average daily vehicle traffic
T	=	Traffic average daily freight and commuter train traffic
LRT	=	Average daily light-rail train traffic
C	=	Project cost share to be allocated from Grade Separation Fund
AH	=	Accident history (number of accidents at crossing)
SCF	=	Special conditions factor

This second CPUC formula is a type of hazard index that ranks crossings relative to other crossings using a scale of accidents. The formula includes a number of critical factors: cost, number of affected vehicles, and accident history. However, it does not explicitly estimate the benefits of grade-separated rail crossings.

#### 4.5 Traffic Signal Operations near Highway-Rail Grade Crossings

TRB prepared guidance for traffic signal operations near highway-rail grade crossings. The document discusses the details of highway-rail grade crossing warning devices and how they may be integrated into the surrounding traffic signals. The discussion on train detection systems is particularly relevant. Although too detailed to be included in this chapter, the report provides important documentation of the different train detection systems that can be used near at-grade rail crossings.

Some detection systems can measure the speed of the train and time the warning device activation appropriately. Others cannot and may activate the warning devices prematurely due to trains moving at slower speeds. Premature gate activation would cause the standard gate down time factor in a queuing formula to underestimate delays at the crossing. Trains may also activate warning devices during maneuvers, such as changing tracks, unrelated to crossing the roadway. As a result, highway delays may actually be longer than estimates due to early and false warnings. In order to develop accurate benefit-cost analyses, the gate down times used in Cal-B/C should be verified by field observations rather than collected through the traffic warning devices.

#### 4.6 New Hampshire Index

The New Hampshire Index is a commonly used hazard index. The index is calculated using the annual average vehicular traffic, the average daily train traffic, and a protection factor based on the traffic control devices used at the crossing. The index is not a full benefit-cost analysis and does not attempt to place a value on accident costs. The New Hampshire Index is indicative of the standard practice for ranking crossings and calculating exposure in most states. The index is used by New Hampshire, Michigan, and Kansas among others.

#### **4.7 Illinois Department of Transportation**

The Illinois Department of Transportation (DOT) provides a methodology for evaluating the safety impact of grade crossing improvements. When assessing the benefits of grade separation projects, Illinois DOT assumes a 100 percent reduction in accidents. Illinois DOT relies on the accident reporting in the Federal Highway-Rail Grade Crossing Accident/Incident Database and expects grade separations to eliminate accidents associated with trains. The methodology also assumes that the highway-only accidents occurring in the vicinity of at-grade crossings (but reported in the highway collision database) are no more frequent than on the rest of the roadway.

The Illinois Expected Accident Frequency Formula uses a non-linear regression analysis procedure. Estimates are based upon a ten-year crash history, average daily traffic, the number of trains per day, the maximum timetable speed, the number of main and other tracks, the number of highway lanes, the average number of crashes per year, and a warning devices factor to compute the expected crash frequency. Illinois also estimates benefit-cost ratios for the installation of warning devices at railroad crossings. The user benefits are calculated using National Safety Council (NSC) estimates of the value of fatalities and injuries per crash, while the cost reflects the device installation and maintenance cost. The Illinois Bureau of Design and Environmental Manual does not cite which NSC estimates are used, but they are likely to be the same as those used for highway projects.

#### **4.8 Iowa Department of Transportation**

In 2006, Iowa DOT began a review of its procedure for selecting Section 130 projects. At the time, Iowa DOT gave priority to projects with a predicted accident calculation above a certain threshold and ranked projects by an exposure index. Iowa DOT decided to replace this procedure with a benefit-cost calculation. Iowa DOT began to use the Iowa Benefit-Cost Calculations in 2006 for projects constructed starting in 2008. Iowa DOT favored the benefit-cost approach because it distinguished projects by the cost of improvements and the severity of crashes at the crossing.

The benefit-cost calculation starts by predicting the number of crashes at a crossing using procedures adapted from GradeDec. The procedure takes into account train traffic, annual average daily traffic counts, time-of-day factors, train-movement factors, roadway and crossing characteristics, and the type of crossing protection. Once the number of crashes is predicted, the severity of crashes (i.e., the breakdown by number of fatalities, injuries, and property damage) is estimated using procedures adapted from GradeDec.

The societal cost of crashes is estimated using separate costs for fatalities, injuries and property damage. These costs are adapted from the methodology used by Iowa DOT for highway crashes. The net societal benefit is estimated after applying an effectiveness factor that estimates the reduction in crashes due to the improvement.

To adapt the highway crash costs to highway-grade crossings, Iowa DOT estimates the numbers of fatal and injury events per type of accidents using FRA safety data for Iowa from 1977 to 2004 and calculates a total societal cost for each type of crash. The grade crossing methodology uses the same value for a fatality event (\$1.0 million per fatality) as does the highway methodology. Iowa DOT assumes that highway-rail crashes are more severe than typical highway crashes and uses twice the typical rate for highway injuries (2 x \$160,000 per injury = \$320,000 per injury). Property damage in a highway-rail crash is assumed to involve only a single highway vehicle (compared to multiple vehicles in a highway crash), but is expected to be more severe. Iowa DOT assumes these two factors balance, and uses the same property damage as it does for a highway intersection crash (\$26,000 per crash).

#### **4.9 Florida Department of Transportation**

The Freight Rail Investment Software is part of a framework Florida DOT recently developed for evaluating how private freight investments generate public benefits. Florida DOT developed an Excel-based model called the Capital Budget Model Decision Support System. The software can calculate a benefit-cost ratio that includes the following benefits:

- Avoided highway maintenance costs
- Shipper logistics costs
- Highway delay at rail-highway grade crossings
- New or retained jobs
- Tax increases from industrial development
- Highway safety improvements
- Environmental quality improvements.

The highway safety benefits are valued using a standard cost per vehicle-mile traveled (\$0.091 in 2006 dollars). This cost was derived from National Highway Traffic Safety Administration (NHTSA) statistics.

#### **4.10 Federal Condition and Performance Report**

The Federal Condition and Performance Report may help provide guidance on the appropriate assumption to use in determining when highway and rail traffic peaks. Highway and rail travel could conceivably have different peaking characteristics due to different trip purposes, origins, and destinations.

As part of its 2002 report, USDOT included an analysis of Federal-aid highway-rail grade crossings. It described the assumptions used for the analysis and reported its findings in the section titled "Supplemental Analysis of System Components." USDOT addressed the difficulty in obtaining travel peaking data by analyzing two scenarios: peak traffic and uniform traffic. The peak scenario in the supplemental analysis

assumes 48 percent of the total daily traffic occurs during the six peak hours to a maximum of eight percent of the daily traffic in any one hour, 37 percent are distributed over the next 12 hours, and the remaining 15 percent are distributed evenly for the final six hours.

Using this information, the Cal-B/C development team decided to adjust the hourly traffic calculation to assume that most traffic impacted by rail crossings occurs during the day (i.e., divide ADT by 12). This methodology is described further in Section 5.

#### 4.11 Highway-Rail Grade Crossing Accident/Incident Database

The FRA Office of Safety Analysis manages a website that allows the public to access railroad safety information, such as accidents and incidents, inspections, and highway-rail crossing data. From this site, users can run dynamic queries, download a variety of safety database files, publications and forms, and view current statistical information on railroad safety. Under the page entitled “Highway-Rail Crossing Accidents,” visitors can find historical grade crossing data from 1975 through the current year, including reported cases of impacts between on-track equipment and any user of a public or private highway-rail intersection.

Comparing the number of incidents on highway-rail crossings in California between the years 1987 (see Exhibit VI-3) and 2007 (see Exhibit VI-4) reveals that total accidents decreased from 269 to 162 (a decline of 66 percent). However, the number of fatalities during this period increased from 24 to 47, and the number of injuries remained consistent at roughly 72 per year. Other years reveal different results, indicating that this comparison does not necessarily signal a trend in accident rates.

**Exhibit VI-3: Highway-Rail Incidents by Type Highway User from Form FRA F6180.57 (2007)**

Selections: Railroad - ALL  
 State - CALIFORNIA, County - ALL  
 Time Frame - Jan 2007 to Dec 2007

Type & Highway User		Totals			At Public Crossing						At Private Crossing		
					Motor Vehicle			Other			Motor Vehicle		
		Accs	Kld	Inj	Accs	Kld	Inj	Accs	Kld	Inj	Accs	Kld	Inj
Train struck highway user	Car	58	11	14	54	10	14	-	-	-	4	1	-
	Trucks	28	12	40	22	11	37	-	-	-	6	1	3
	Trk& Trail	25	-	2	14	-	1	-	-	-	11	-	1
	Van	7	2	1	4	1	1	-	-	-	3	1	-
	Oth Mtr V.	4	-	4	3	-	4	-	-	-	1	-	-
	Pedestrian	20	15	6	-	-	-	20	15	6	-	-	-
	Other	3	2	1	-	-	-	3	2	1	-	-	-
---- Total	145	42	68	97	22	57	23	17	7	25	3	4	
Train struck BY highway user	Car	7	1	1	7	1	1	-	-	-	-	-	-
	Trucks	5	1	1	5	1	1	-	-	-	-	-	-
	Trk& Trail	1	-	-	1	-	-	-	-	-	-	-	-
	Van	1	-	1	1	-	1	-	-	-	-	-	-
	Oth Mtr V.	3	3	1	3	3	1	-	-	-	-	-	-
---- Total	17	5	4	17	5	4	-	-	-	-	-	-	
---- Total		162	47	72	114	27	61	23	17	7	25	3	4

**Exhibit VI-4: Highway-Rail Incidents by Type Highway User from Form FRA F6180.57 (1987)**

Selections: Railroad - ALL  
 State - CALIFORNIA, County - ALL  
 Time Frame - Jan 1987 to Dec 1987

Type & Highway User		Totals			At Public Crossing						At Private Crossing					
					Motor Vehicle			Other			Motor Vehicle			Other		
		Accs	Kld	Inj	Accs	Kld	Inj	Accs	Kld	Inj	Accs	Kld	Inj	Accs	Kld	Inj
Train struck highway user	Car	144	12	38	133	12	36	-	-	-	11	-	2	-	-	-
	Trucks	39	3	10	36	3	10	-	-	-	3	-	-	-	-	-
	Trk& Trail	21	-	2	12	-	-	-	-	-	9	-	2	-	-	-
	Buses	1	-	8	1	-	8	-	-	-	-	-	-	-	-	-
	Oth Mtr V.	2	-	-	1	-	-	-	-	-	1	-	-	-	-	-
	Pedestrian	5	6	-	-	-	-	5	6	-	-	-	-	-	-	-
	Other	5	1	-	-	-	-	4	1	-	-	-	-	1	-	-
	---- Total	217	22	58	183	15	54	9	7	-	24	-	4	1	-	-
Train struck BY highway user	Car	35	2	12	34	1	11	-	-	-	1	1	1	-	-	-
	Trucks	12	-	1	10	-	1	-	-	-	2	-	-	-	-	-
	Trk& Trail	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-
	Oth Mtr V.	3	-	2	3	-	2	-	-	-	-	-	-	-	-	-
	Other	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-
	---- Total	52	2	15	48	1	14	1	-	-	3	1	1	-	-	-
---- Total		269	24	73	231	16	68	10	7	-	27	1	5	1	-	-

**4.12 Web Accident Prediction System (WBAPS)**

The FRA Web Accident Prediction System (WBAPS) is a web-based model accessible through the FRA website. WBAPS is intended to alert law enforcement and local officials of the need to improve safety at particular highway-rail crossings. The WBAPS crash prediction formula is based upon two independent variables which include: 1) basic data about a crossing’s physical and operating characteristics, and 2) five years of accident history data at the crossing. The data for WBAPS comes from the FRA safety database.

While WBAPS is not intended to be used to predict collisions at the most dangerous crossings, the system can provide an indication of where a crossing may be more hazardous than others based on data available. FRA intends for WBAPS to be one of many tools (including accident prediction or hazard index formulas) that assist states, railroads and local highway authorities in determining where to focus attention for improving safety. The Cal-B/C methodology can use 10-year accident data from the FRA highway-rail grade crossing database or the WBAPS estimates when evaluating the safety impact of grade separation projects.

**4.13 USDOT Accident Prediction Model**

The US Department of Transportation (USDOT) Accident Prediction Model adds components to the WBAPS estimate to calculate a collision prediction value that can be used for the more detailed, diagnostic phase of project selection. The basic formula



provides an initial hazard ranking based on a crossing's characteristics, similar to the New Hampshire Index. The second calculation estimates future annual collisions and uses the actual collision history at a crossing over a number of years, usually five years or less, to produce a collision prediction value.

These first two components of the USDOT Accident model use the same or similar data in calculating hazard potentials as the WBAPS. A third equation adds a normalizing constant (the ratio of the actual number of accidents to the predicted number of accidents) that is adjusted periodically to keep the procedure matched with current collision trends. These constants are obtained from WBAPS.

The USDOT model has additional equations to predict accident severity for fatalities and injuries. The probability of a fatal accident given an accident is dependent upon factors such as the maximum timetable train speed, through trains per day, switch trains per day, urban or rural crossing, and a formula constant. The probability of an injury accident given an accident is dependent upon the maximum timetable trains speed, the number of tracks, urban or rural crossing, and a formula constant.

According to the New York State Rail Plan, at least 20 states (including New Mexico, North Carolina, and Virginia) use the USDOT Accident Prediction Model as part of an in-depth review to prioritize crossing improvements for the Section 130 program. Diagnostic reviews are more detailed with additional rail-highway crossing data from the field and other available sources to help prioritize the projects.

## **5.0 CAL-B/C METHODOLOGY**

The Cal-B/C development team considered developing a separate methodology or relying on an existing model, such as GradeDEC.NET. However, the final decision was to incorporate rail grade separation projects directly in Cal-B/C to ensure consistency with other project types. While this approach complicated the existing model, it added queuing features that could be expanded upon for use in assessing highway bottleneck projects. The highway queuing methodology is described further in Chapter VII.

### **5.1 Model Inputs**

The Cal-B/C uses the following inputs to estimate the benefits of grade-separated crossings:

- **Project Location** – As with other project types, Cal-B/C uses the location of the project (by area of the state) to estimate emissions values correctly. This input already existed on the project information page, so Cal-B/C needed no modification.

- Length of Construction Period - Cal-B/C needs the length of the construction period to apply correct discounting to the estimated user benefits. This input was already in Cal-B/C, so no modification was made to accommodate grade separation projections.
- Number of Traffic Lanes (No Build) - This input already exists on the project information page of Cal-B/C. While the model uses this to calculate speeds using a Bureau of Public Roads (BPR) curve for most project types, it is used to estimate the queue departure rate for rail grade separation projects. The parameters page has a standard per lane departure rate. This rate is multiplied by the number of lanes to determine the overall departure rate for a project.
- Highway Posted Speed Limit (in mph) - This input is needed to calculate vehicle operating and emissions costs in the build case. Cal-B/C already requires this input to estimate speeds in the BPR curves.
- Annual Number of Trains - This input was added to the project information page. It is used to calculate the number of times that queues form. Since the number of train movements is easier to collect by operator, the Cal-B/C input sheets ask for separate freight and passenger rail operations information. Cal-B/C users are expected to combine the information before entering it in the model.
- Average Gate Down Time (in minutes) - The gate down time determines the length of time that queues form and delays occur. This data could be an input or estimated from the average train length and speed. Track charts provide information to calculate average speeds, but average train length is more difficult to estimate. Since average gate down time can be observed directly, Cal-B/C asks for this variable as an input. As with the annual number of trains, the gate down time varies dramatically between passenger and freight trains. Passenger trains tend to be much shorter and pass crossings more quickly than freight trains. The Cal-B/C input sheets ask for the information separately by freight and passenger rail operations. Cal-B/C should be run separately for freight and passenger trains. These results should be combined to obtain the overall benefit-cost ratio.
- Number of Highway-Grade Crossing Accidents - Rail grade crossing accident data are collected and reported separately from normal highway accident data, so this information is not available in TASAS. The FRA collects rail grade crossing accident data for the area immediately around the intersection of the rail right-of-way and the highway. Actual 10-year historical data can be obtained from the FRA Highway-Rail Crossing Accident Database. Alternatively, the FRA has

a Web Accident Prediction System (WBAPS) that uses site specific data and a computer model to predict grade crossing accident levels. Cal-B/C can use either data to estimate highway grade crossing safety benefits. If WBAPS data are used, Cal-B/C multiplies the predicted collisions by statewide average numbers of fatalities and injuries per collision. These averages were calculated from ten years of FRA accident data for California grade crossings. If 10-year historical data are used, Cal-B/C divides the figures by 10 to annualize the data.

- Number of Highway Accidents - The highway-grade crossing accident rates capture the accidents due to the intersection of the highway and the railway, which the grade separation project eliminates. A less likely benefit is that the grade crossing changes the basic configuration of the highway and lowers the accident rate for the overall highway. This benefit can be reflected in a change in the TASAS rate group for the roadway. Cal-B/C allows the TASAS accident reduction to be captured by entering the TASAS data on the project information page. After the highway accident rate information on the model inputs page is entered as "changed by user," the TASAS data can be replaced by highway-grade crossing accident data. In this manner, both sets of safety benefits are included in the analysis. It is not expected that the highway (TASAS) data will often be used to assess project benefits.
- Annual Average Daily Traffic (ADT) - Cal-B/C already asks for this input to estimate highway volumes and calculate speeds using BPR curves. For rail grade separation projects, ADT is needed to estimate the arrival rate for automobiles and trucks at the grade crossing. The arrival rate determines how quickly the queue grows.
- Percent Trucks - Cal-B/C needs this percentage to separate truck and automobile benefits. This information was already collected on the project information page, so no change was made in Cal-B/C.

The Cal-B/C development team also added two parameters to the Cal-B/C model:

- Vehicle Departure Rate - Cal-B/C incorporates the vehicle departure rates used by STB (shown in the Bayport Loop Build-Out report) as a lookup table in the parameters page: 1,800 vehicles per hour for highways and 1,400 vehicles per hour for arterials. These values were chosen because they are facility-specific and comparable to the 1,800 vehicles per hour assumption in GradeDEC.NET. Cal-B/C is rarely used to assess collectors and local roads, but STB provides values that can be used: 900 vehicles per hour for collectors and 700 vehicles per hour for local roads. They have not been incorporated in Cal-B/C and must be changed manually.

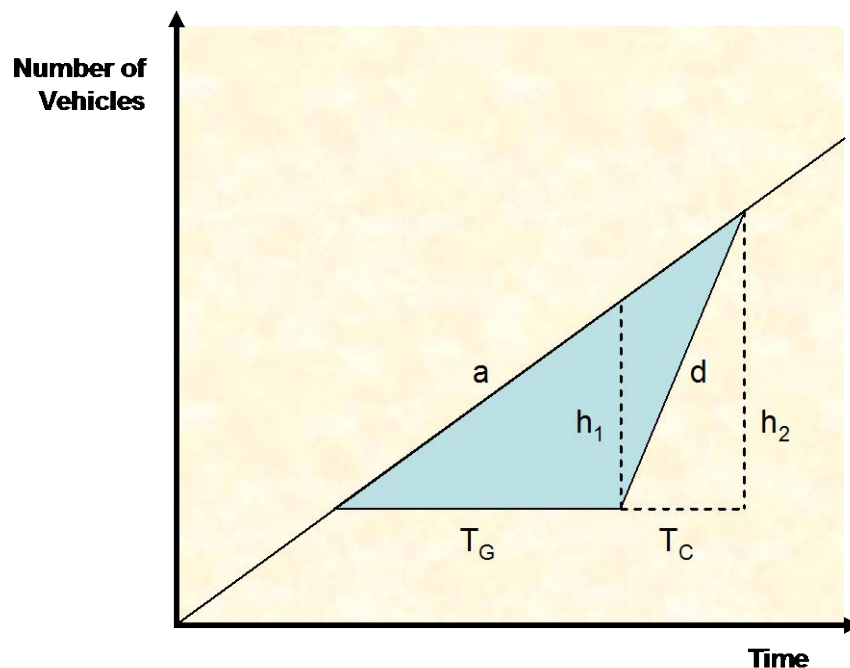
- Idling Speed (in mph) - Cal-B/C needs a speed to estimate vehicle operating costs and emissions for time spent in queues at rail grade crossings. As described more fully in Chapter III, this has been set at 5 MPH to produce the best estimate of idling emissions using EMFAC data.

## 5.2 Delay Estimation

The Federal Railroad-Highway Grade Crossing Handbook categorizes vehicle delays and costs at rail grade crossings into four kinds due to: trains occupying crossings, special vehicles, crossing surfaces, and the presence of crossings. Cal-B/C considers only delays to queued vehicles due to trains occupying crossings. It would be difficult to incorporate special vehicle delays in Cal-B/C, since this would require estimating the number of special vehicles. This information is not readily available and the benefits are likely to be small. The benefits due to elimination of crossing surfaces and the presence of crossing are primarily the result of reductions in vehicle operating costs for automobiles and trucks that are not actually delayed in queues. The Cal-B/C development team decided not to add these delays because information on the wear and tear costs is not available and the benefits are likely to be small.

The Cal-B/C methodology focuses on just one of the benefits identified in the Federal handbook - delays due to queued automobiles and trucks. To estimate these delays, Cal-B/C uses a standard queuing analysis based on the input-output diagram shown in Exhibit VI-5.

**Exhibit VI-5: Input-Output Diagram for Grade Crossing Queuing Analysis**



where,

a	=	automobile or truck arrival rate
d	=	automobile or truck departure rate
h <sub>1</sub>	=	maximum number of vehicles in the queue
h <sub>2</sub>	=	total number of vehicles in the queue
T <sub>G</sub>	=	gate down time
T <sub>C</sub>	=	time to clear the queue.

Cal-B/C estimates the queuing delays for automobiles and trucks using the following formulas, which are consistent with the SCAG and GradeDEC.NET approaches (except for the issue of Sum versus Sum + 1):

$$\text{Total Delay per Train} = \frac{\frac{1}{2}aT_G^2}{1 - \frac{a}{d}}$$

$$\text{Number of Vehicles Queued per Train (h}_2\text{)} = \frac{aT_G}{1 - \frac{a}{d}}$$

$$\text{Average Delay per Vehicle} = \frac{1}{2}T_G$$

This approach assumes that queues clear completely between trains. Cal-B/C also assumes that motor vehicle arrivals are uniform and calculates the hourly arrival rate from the ADT figures. Originally, the hourly arrival rate was calculated by dividing ADT by 24 hours. More recently, this formula was changed to divide by 12 hours. This change reflects the fact that the impacted traffic is more likely to occur during the day and is based on the non-uniform analysis conducted for the Federal Condition and Performance Report.

Cal-B/C does not estimate separate delays for the peak and non-peak periods. Schedules with train frequencies are difficult to obtain (particularly for freight trains). It does not make sense to separate motor vehicle travel into peak and non-peak periods when Cal-B/C must assume train movements are uniform throughout the day.

The model asks users to provide the average gate down time per train. Ideally, this information is obtained from direct field observations. However, these observations are complicated by the fact that freight trains may not be regularly scheduled and substantial variation can occur throughout a week, month, or year. Passenger trains may also have schedules that vary, but the number of passenger trains is not likely to impact substantially the overall benefit-cost calculation.

The gate down time is a primary determinant of the benefit-cost ratio for grade crossing projects. The impact of the gate down time is geometric, so doubling the gate down time more than doubles the delays at a grade crossing. In choosing appropriate gate down times, Cal-B/C users should consider the variations over a year and select gate down times that approximate the average delays experienced. This can be determined by testing different, reasonable gate down times and selecting the one that produces average delays. The gate down times should be supported by field observations.

If field observations are unavailable, reasonable gate down times may be calculated using the following equation, which is derived from the Riverside County Rail Crossing Priority Analysis and GradeDec.NET:

$$T_G = \frac{\text{Average Train Length} + 12 \text{ feet} \times \text{Lanes}}{\text{Average Train Speed}} + 0.6 \text{ minutes}$$

This calculation assumes lane widths of 12 feet and a warning time of 0.6 minutes to account for the time before and after the train passes when vehicles are unable to cross.

### 5.3 Other User Benefits

Cal-B/C estimates fuel consumption and emissions costs for the delayed vehicles using standard lookup tables. Fuel consumption and emissions at crossings involve a combination of idling and acceleration from a stop. Cal-B/C does not have detailed idling and acceleration factors. Likewise, rates for acceleration from a stop are not included in the latest version of EMFAC.

Cal-B/C estimates fuel consumption and emissions using travel at 5 mph for an “implied” distance. The implied distance equals the distance one would travel at 5 mph for the delayed time. In this manner, fuel consumption and idling emissions are estimated for the same amount of time as the delay occurs. This methodology is intended to capture the combination of idling and acceleration, but it is likely to overestimate fuel consumption and emissions. However, the error occurs for both the build and the no-build so the overestimation is somewhat mitigated.

Cal-B/C estimates accident cost savings by comparing the number of automobiles and trucks involved in grade crossing accidents (as reported in the FRA Highway-Rail Crossing Accident Database) in the no-build case to the number of accidents in the build case. Cal-B/C uses the same assumption as Illinois DOT that the grade separation eliminates all accidents at the rail crossing.

Cal-B/C does not estimate any benefits due to eliminating delays associated with grade crossing accidents. Accidents at rail grade crossings typically close the railway and the highway, which causes large delays on both. The cost of the delay to freight railroads varies considerably and depends on the type of freight transported along the rail

corridor. Since information on the type of freight and average accident duration is difficult to obtain, Cal-B/C ignores these benefits.

In addition, the comprehensive costs of rail accidents is likely to be much higher than typical highway accidents due to investigation costs, the potential presence of hazardous materials, and disruptions to the freight rail network. NCHRP 08-85 is currently investigating the comprehensive of costs of accidents at highway-rail grade crossings. Cal-B/C should incorporate these comprehensive costs if the NCHRP project produces a practical value.

### 5.4 Using the Grade Crossing Procedures

To using the grade crossing procedures in Cal-B/C, users need to enter only a limited set of data. However, unlike typical highway projects, Cal-B/C requires information about the crossing roadway and the rail network. In addition, users need to obtain information on gate down times and grade crossing accidents.

The following inputs are typically entered for a grade-crossing project:

- Standard project data in Box 1A
- Roadway type, number of general traffic lanes, highway free-flow speed, and average daily traffic in Box 1B
- Grade crossing accident data in Box 1C
- Annual number of trains and average gate down time in Box 1D.

The next few snapshots (Exhibits VI-6 to VI-9) show an example of data entered into Cal-B/C for a grade-crossing project. Cal-B/C estimates the queue formation in Box 1B (not shown in Exhibit VI-7). This information is rarely modified by the user. Cal-B/C automatically changes the label in Box 1C (see Exhibit VI-8) to indicate grade crossing accident data should be entered. These data can come from the Highway-Rail Crossing Accident Database or WBAPS. If no data are entered in the detailed accident boxes, Cal-B/C assumes that the accident data comes from WBAPS. If historical data are entered in the detailed accident boxes, they should represent the 10-year totals.

**Exhibit VI-6: Box 1A Project Data**

<b>Type of Project</b>	Put hwy design in 1B, safety in 1C & crossing in 1D	
Select project type from list	Hwy-Rail Grade Crossing	
<b>Project Location</b> (enter 1 for So. Cal., 2 for No. Cal., or 3 for rural)	1	
Length of Construction Period	3	years
One- or Two-Way Data	2	enter 1 or 2
	Current	
<b>Length of Peak Period(s)</b> (up to 24 hrs)	5	hours

**Exhibit VI-7: Box 1B Highway Design and Traffic Data**

<b>Highway Design</b>		No Build	Build
Roadway Type (Fwy, Exp, Conv Hwy)		C	C
Number of General Traffic Lanes		6	6
Number of HOV/HOT Lanes			
HOV Restriction (2 or 3)			
Exclusive ROW for Buses (y/n)		N	
Highway Free-Flow Speed		35	35
Ramp Design Speed (if aux. lane/off-ramp proj.)		35	35
Length (in miles) Highway Segment			0.0
Impacted Length		0.0	0.0

<b>Average Daily Traffic</b>		No Build	Build
Current		42,680	
Base (Year 1)		47,728	47,728
Forecast (Year 20)		79,700	79,700

<b>Average Hourly HOV/HOT Lane Traffic</b>		No Build	Build
Percent of Induced Trips in HOV (if HOT or 2-to-3 conv.)			0
<b>Percent Traffic in Weave</b>			0.0%
<b>Percent Trucks</b> (include RVs, if applicable)		9%	9%
<b>Truck Speed</b>			

**Exhibit VI-8: Box 1C Grade Crossing Accident Data**

<b>Actual 10-Year Fat &amp; Inj Data or WBAPS Prediction (from FRA)</b>		
	Count (No.)	Rate
Total Accidents (Tot)	0.377257	0.00
Fatal Accidents (Fat)		0.075
Injury Accidents (Inj)		0.13
Property Damage Only (PDO) Accidents		0.00

**Exhibit VI-9: Box 1D Rail and Transit Data**

<b>Highway Grade Crossing</b>	Current	Year 1	Year 20
Annual Number of Trains	14,600	16,541	28,835
Avg. Gate Down Time (in min.)	2.0	2.0	2.0

Grade crossing benefits should be estimated separately for passenger and freight trains and combined at the end of the analysis. In practice, the gate down times are short for passenger trains and the schedules are infrequent. As a result, the benefits associated with passenger trains are minimal. Users can ignore passenger trains and capture most of the benefits by simply modeling the freight trains. However, passenger trains should be included if they are an important factor at a crossing.



Cal-B/C can approximate the benefits of consolidating crossings. Consolidation occurs when some crossings are closed, while others are grade separated. To estimate these benefits, users should input the total number of lanes for all crossings and the total traffic for all crossings as if they were a single crossing. This approach ignores any additional travel time associated detours, but it would be difficult to obtain this information (and equilibrium travel patterns) without additional detailed analysis.

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## VII. QUEUES AND QUEUING ANALYSIS

## VII. QUEUES AND QUEUING ANALYSIS

As part of the 2009 revision, Cal-B/C was updated to include the ability to conduct a simple queuing analysis. Queuing analysis is relevant to many Cal-B/C project types, including: general highway expansion, interchanges, auxiliary lanes, freeway connectors, high-occupancy vehicle (HOV) connectors, HOV drop ramps, as well as on and off ramp widening. However, the queuing capabilities in Cal-B/C are intended to be used only for special cases with no other analysis methods available (e.g., a lane drop that creates a bottleneck). The usual speed and travel time benefit estimations found in Cal-B/C should be used for other types of projects.

This chapter provides an overview of how queues form, Departmental guidelines and procedures relevant to queuing analysis, relevant methodologies, findings from a review of recent literature, and a description of the queuing methodology incorporated into Cal-B/C. This chapter was written as part of the 2009 Cal-B/C update, so references to prior versions of Cal-B/C indicate versions before Cal-B/C v4.0.

### 1.0 QUEUE FORMATION

Traffic queues form when vehicle volume is greater than the capacity of the roadway. This can occur as a result of a lane reduction or merger. Queues may also occur where a roadway configuration changes, such as a tight corner or lane width reduction. In addition, weaving traffic can cause queuing. Vehicles changing lanes require space in both lanes, effectively doubling their demand for space on the facility.

According to a Federal Highway Administration (FHWA) report on bottlenecks (U.S. DOT FHWA, 2007), the following situations are likely to cause queues:

- Weaving sections
- Short, steep multiple acceleration lanes
- Closely placed interchanges
- Exit ramp geometry
- Lane drops
- Steep highway grades.

Exhibit VII-1 provides an example of a queues forming at an interchange with closely spaced ramps. Since the configuration of roadways effects queue formation, a thorough queuing analysis can predict and address potential queuing situations within a transportation project. Queues lengthen as more vehicles arrive than leave bottlenecks. The difference between the arrival and departure rates is an important element in determining the user costs that result from queuing.

## Exhibit VII-1: Queuing on a California Freeway



Source: System Metrics Group, Inc.

There are three main costs associated with queuing – travel time delay, emissions, and fuel consumption. The time vehicles spend idling has an impact on the calculation of emissions and fuel consumption. In addition, queue lengths are important because they have the potential to spread to ramps and other surface facilities.

## 2.0 RELEVANT DEPARTMENTAL GUIDELINES AND PROCEDURES

This section summarizes the Department's guidelines and procedures for queuing analysis. More detailed information is available in the source documentation.

### 2.1 Highway Design Manual

The Highway Design Manual establishes uniform policies and procedures for highway design in California. The manual is organized into 25 chapters. Each chapter is updated to take into account new design considerations. Although the need to design for adequate storage to hold queues is discussed, the Highway Design Manual does not consider or estimate the benefits of queue reduction.

### 2.2 Ramp Meter Design Manual

This manual gives Department designers, as well as consulting engineers hired by the Department, cities, or counties to perform design work on State Highways, a comprehensive document covering the design and operation of ramp meters. Although, queuing is discussed in the section on storage length, this manual does not consider or estimate the benefits of queue reduction.

### **2.3 Transportation Management Systems (TMS) Master Plan Efforts**

The Transportation Management System (TMS) Master Plan lays out a blueprint for safer and more effective operations of the state transportation system through system management enabled by intelligent infrastructure. The TMS Master Plan emphasizes physical and managed operational improvements.

Recently, the Department has built upon the system management strategies laid out in the TMS Master Plan by conducting Corridor System Management Plans (CSMPs) for corridors throughout the state. As part of the first-round CSMPs, the Department has started identifying bottlenecks and conducting micro-simulations of traffic along the corridors. Micro-simulation analysis is more detailed than queue analysis and replaces the need for this type of analysis. The benefits of queue reductions are estimated through the considerations of highway demand, route choices, and operational performance.

### **2.4 California Manual on Uniform Traffic Control Devices**

The California Traffic Manual provides guidance on signs and traffic controls for all types of roadway situations. The traffic manual discusses the problems caused by queues as well as statewide standards for traffic control devices, but it does not provide methodologies for estimating the benefits of queue reduction. For example, the manual provides guidance that a ramp control signal study should include an evaluation of the impact of queued traffic on the local street intersection, but it does not state how this evaluation should be conducted.

### **2.5 Traffic Bulletins**

The Office of Traffic Safety maintains an archive of traffic safety analysis documents, including traffic bulletins written by Department traffic engineers in the early 1960s. While these bulletins are decades old, the analysis techniques are still relevant. Two bulletins in particular highlight the use of queuing analysis:

- Traffic Bulletin No. 7 summarizes the results of “Statewide Delay Studies” relevant to delays associated with resurfacing projects. The bulletin shows the application of a classical queuing analysis including an input-output diagram.
- Traffic Bulletin No. 2 describes queuing analysis in relation to analyzing the affects of roadway grade on capacity.

Both of these bulletins are summarized below.

State of California Department of Public Works Division of Highways: Traffic Bulletin No. 7 Delay to Traffic due to Future Resurfacing Operations

Step 1 develops a process to determine the presence of delay caused by queuing. Step 2 explains how to apply that procedure to calculate delay due to a lane closure. This delay is separated into delay due to reduced speed and delay due to queuing. Step 3 presents an example of delay calculation.

According to Traffic Bulletin No. 7, delay caused by queuing should be calculated according to the following procedure:

1. The first step is to determine if a queue will form. This occurs when the estimated input rate exceeds the output rate shown in Exhibit VII-2.

**Exhibit VII-2: Capacity Table\***

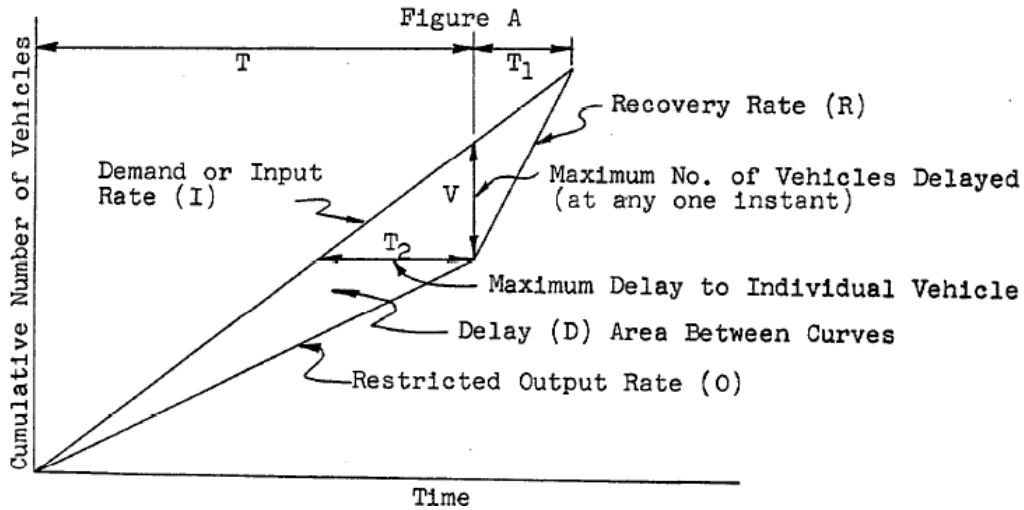
Percent trucks	No. of Lanes One Direction (Normal Operations)	2	3	4
	No. of Lanes One Direction (Restricted Operations)	1	2	3
0 - 10	Output Rate O	1,400	2,800	4,500
	Recovery Rate R	3,000	4,700	6,400
Over 10	Output Rate O	1,350	2,700	4,350
	Recovery Rate R	3,000	4,500	6,200

*\*Input rates greater than the output rates listed will normally result in the formation of queue.  
Note: The rates as listed above are vehicle per hour in one direction.*

2. If a queue is likely to form, the second step is to select a delay-estimation formula. The total delay is estimated using the duration of the incident (T) and the input rate (i) for the entire scenario using relationships derived from the input-output diagram shown in Exhibit VII-3. The example shown in the exhibit assumes a constant input rate. A variable flow rate can still be graphed, but will require some integration to complete the calculation.
3. Once the duration of the delay is calculated, the bulletin provides standard cost factors to estimate the monetary cost of the delay.



**Exhibit VII-3: Queuing Delay for Lane Closures**



- I = Demand or input rate in vehicles per hour
- O = Restricted output rate in vehicles per hour
- H = Recovery rate in vehicles per hour
- T = Length of time of lane restriction in hours
- T<sub>1</sub> = Length of time to recover to normal in hours
- V = Maximum number of vehicles delayed (just before lane restriction is removed)
- T<sub>2</sub> = Maximum delay to an individual vehicle in hours
- D = Delay in vehicle-hours

Exhibit VII-3 shows that V, the maximum number of vehicles delayed, can be expressed as follows:

$$V = IT - OT = T(I - O)$$

The time required for traffic to return to normal conditions (T<sub>1</sub>) is:

$$RT_1 = V + IT_1$$

Substituting the equivalency  $V = T(I - O)$  into the above equation results in:

$$RT_1 = T(I - O) + IT_1$$

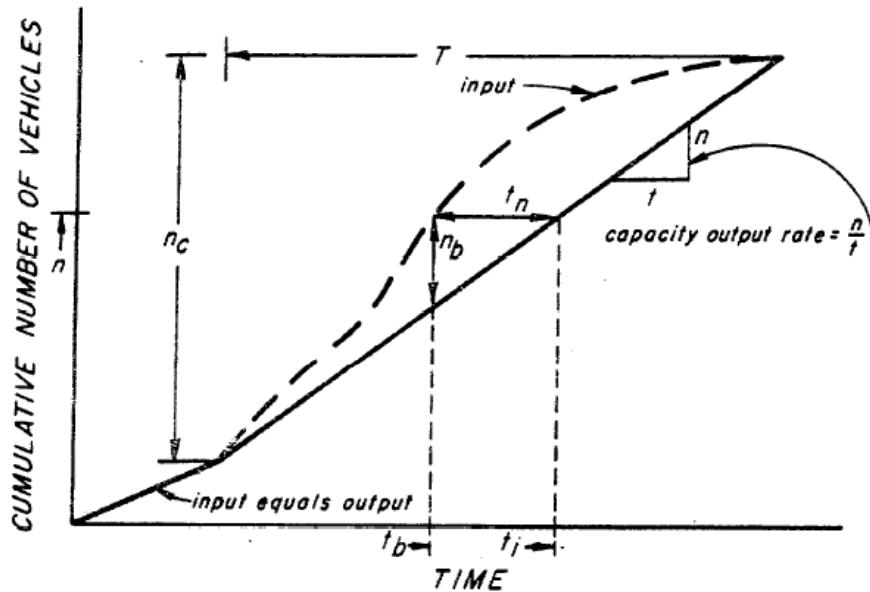
$$T_1 = (R - I) = T(I - O)$$

and 
$$T_1 = \frac{T(I - O)}{R - I}$$

State of California Department of Public Works Division of Highways: Traffic Bulletin  
No. 4 Notes on Freeway Capacity

According to this traffic bulletin, minor incline grades (e.g., two or three percent) will form brief, moving queues. Higher grades can create congestion conditions. An input-output diagram illustrating this situation is presented in Exhibit VII-4.

**Exhibit VII-4: Queuing Delay for Roadway Grades**



where:

- $n_b$  = Number of cars delayed at time  $t_b$   
 $T_n$  = Delay suffered by the  $n$ th car  
 $n_c$  = Number of cars delayed during the entire period that queue exists  
 $T$  = Total length of time that congestion lasts  
 Area between curves = Total delay in vehicle-miles.

### 3.0 OTHER METHODOLOGIES

Queue analysis has a long history and wealth of associated literature. Rather than provide a lengthy review of queuing analysis, this section discusses how several other benefit-cost tools handle queuing analysis and summarizes some of the methods available.

#### 3.1 Highway Capacity Manual (HCM)

The Highway Capacity Manual (HCM) provides techniques for estimating the capacity and level of service for transportation facilities. The document includes worksheets for determining the quality of service and analytical procedures for several other

performance measures. The methodologies are generally for traditional roadway, bicycle, pedestrian, and transit projects, but some operational improvements are available as well. Speed and delay are the primary performance measures produced for individual system elements. These can be used to estimate impacts for system analysis (by converting to travel times and aggregating the values).

The 2000 HCM analytical procedures are based on estimates of travel time and delays along segments and at particular points. (Note: 2010 HCM has been released since this chapter of the technical supplement was written.) A segment is a facility (freeway, urban street, or rural highway) with consistent demand and capacity over its length. A point is a very short portion of the facility where demand or capacity changes abruptly. Segment and point travel times and delays are converted to person-hours and aggregated to estimate the total impact. Most of the procedures require estimates of hourly demand in each direction and some can be quite complex.

Queues due to facility constraints and traffic control devices are calculated differently. For queues caused by traffic control devices, the HCM provides the following equation for the delay associated with queuing:

$$d_3 = \frac{1800 \cdot Q_b(1+u)t}{cT}$$

where:

- Q<sub>b</sub> = Initial queue at the start period T (vehicles)
- c = Adjusted lane group capacity (vehicles per hour)
- T = Duration of analysis period (hours)
- t = Duration of unmet demand in T (hours)
- u = Delay parameter.

$$t = 0 \text{ if } Q_b = 0, \text{ else } t = \min \left\{ T, \frac{Q_b}{c[1 - \min(1, X)]} \right\}$$

where:

- x = Lane group degree of saturation, v/c
- $u = 0 \text{ if } t < T, \text{ else } u = 1 - \frac{cT}{Q_b[1 - \min(1, X)]}$

Delay associated with a congested corridor is given by the following equation:

$$DQ(d,l,h) = \frac{T}{2} * Q(d,l,h-1) + [v(d,l,h) - c(d,l,h)] * \frac{T^2}{2}$$

where:

DQ(d,l,h)	=	Total delay due to excess demand (vehicle-hours) for direction (d), segment (l), and time period (h)
T	=	Duration of time subperiod (hours)
Q(d,l,h - 1)	=	Queue left over at end of previous time period (vehicles)
v(d,l,h)	=	Demand rate for current time period (vehicles per hour)
c(d,l,h)	=	Capacity of segment in subject direction (vehicles per hour)

The back of a queue can be found using the following equations:

$$Q_1 = PF_2 \frac{\frac{v_L C}{3600} \left(1 - \frac{g}{C}\right)}{1 - \left[ \min(1.0, X_L) \frac{g}{C} \right]}$$

where:

Q <sub>1</sub>	=	First-term queued vehicles (vehicles)
PF <sub>2</sub>	=	Adjustment factor for effects of progression
v <sub>L</sub>	=	Lane group flow rate per lane (vehicles per hour)
C	=	Cycle length (s)
g	=	Effective green time (s)
X <sub>L</sub>	=	Ratio of flow rate to capacity (v <sub>L</sub> /c <sub>L</sub> ratio)

$$PF_2 = \frac{\left(1 - R_p \frac{g}{C}\right) \left(1 - \frac{v_L}{s_L}\right)}{\left(1 - \frac{g}{C}\right) \left[1 - R_p \left(\frac{v_L}{s_L}\right)\right]}$$

where:

PF <sub>2</sub>	=	Adjustment factor for effects of progression
v <sub>L</sub>	=	Lane group flow rate per lane (vehicles per hour)
s <sub>L</sub>	=	Lane group saturation flow rate per lane (vehicles per hour)
g	=	Effective green time (s)
C	=	Cycle length (s)
R <sub>P</sub>	=	Platoon ratio [P(C/g)]

### 3.2 CA4PRS

CA4PRS is a schedule and traffic analysis tool that helps planners and designers select effective, economical rehabilitation strategies. Funded through an FHWA (Federal Highway Administration) pooled-fund, multistate consortium (California, Minnesota, Texas, and Washington), CA4PRS was developed by the University of California Pavement Research Center (UCPRC) through the UC Berkeley Institute of

Transportation Studies. FHWA formally endorsed CA4PRS as a “Priority, Market-Ready Technologies and Innovations” product in 2008 for nationwide deployment. The Department recently added CA4PRS to its standard software list for statewide implementation.

The software’s scheduling module estimates highway project duration (total number of closures) and incorporates alternative strategies for pavement designs, lane-closure tactics, and contractor logistics. CA4PRS’s traffic module (using the Highway Capacity Manual demand capacity model) quantifies the impact of construction work zone closures on the traveling public in terms of road user cost and time spent in queue.

CA4PRS is especially beneficial when it is implemented during the planning and design stages of project development to balance schedule (construction production) with inconvenience (traffic delay) and affordability (agency budget).

### **3.3 Surface Transportation Efficiency Analysis Model (STEAM)**

STEAM is an economic impact analysis tool developed by the FHWA to be used for detailed, systemwide analyses of alternative transportation investments. When STEAM was introduced in 1997, it was the first FHWA impact analysis product to use outputs directly from the four-step travel demand modeling process. STEAM post-processes the traffic assignment volumes that are generated by the four-step models and derives highway travel speeds that are sensitive to congestion and queuing impacts. STEAM applies consumer surplus theory to estimated user benefits of alternative programs and policies.

The latest version of the model, STEAM 2.0, can perform monetized impact estimates for a wide range of transportation investments and policies, including major capital projects, pricing, and travel demand management (TDM). STEAM provides flexibility in transportation modes, trip purposes, and time periods analyzed. The model has default analysis parameters for seven modes: auto, truck, carpool, local bus, express bus, light rail, and heavy rail. Users can specify different values of time for different travel markets. They are asked to provide “base case” and “improvement case” trip tables for different trip purposes. STEAM can be applied to average weekday traffic or to peak and off-peak traffic with different definitions of the peak periods.

STEAM can estimate the following:

- Benefits and costs to transportation users
- Annualized costs to public agencies
- Effects on total transportation cost
- Changes in accessibility to jobs for residents of defined districts
- Changes in emissions for particulate matter, hydrocarbons, carbon monoxide, and nitrogen oxides
- Changes in energy use

- Changes in noise and other external costs
- Changes in fatal, injury, and property damage only accidents
- Revenue transfers due to toll or fare changes.

The new speed models were developed for STEAM 2.0 by conducting hourly simulation of traffic volumes and queuing for facilities with different levels of congestion. The simulation tracked vehicle arrivals and departures in the queue, and queuing was assumed to occur if the volume of a facility exceeded its capacity. The results of these queuing simulations were used to produce a new set of delay curves for a six-hour peak period and an 18-hour off-peak period. The STEAM estimates speed using the following equations (with D as delay estimated from the delay curves):

$$S = \frac{1}{\frac{1}{F} + D}$$

$$D = c_1 x^{c_2} e^{c_3 x} \quad \text{for } x \leq c_0$$

$$D = c_4 (1 - c_5 x^{c_6} e^{c_7 x}) \quad \text{for } x > c_0$$

where,

- S = average speed in miles per hour
- F = free-flow speed in miles per hour
- D = congestion delay in hours per vehicle mile
- x = the ratio of average weekday traffic to hourly capacity for the section (AWDT/C)
- c0 to c7 = are constants given in Exhibit VII-5.

**Exhibit VII-5: Parameter Lookup Table for Speed Calculations in STEAM Model**

	Freeways			Signalized Arterials		
	Daily	Peak	Off-Peak	Daily	Peak	Off-Peak
C0	1.05E+01	1.21E+01	1.11E+01	9.74E+00	9.62E+00	1.26E+01
C1	2.39E-08	2.35E-07	1.13E-07	5.62E-04	8.44E-04	4.35E-04
C2	3.75E+00	3.29E+00	2.52E+00	8.62E-01	6.15E-01	9.37E-01
C3	2.87E-01	2.35E-01	2.59E-01	7.39E-02	1.24E-01	5.16E-02
C4	5.00E-02	5.00E-02	5.00E-02	1.66E-01	1.66E-01	1.66E-01
C5	1.494E-02	2.865E-04	1.058E-03	1.313E-01	8.591E-03	1.177E-02
C6	3.42E+00	7.00E+00	4.91E+00	1.61E+00	3.80E+00	2.91E+00
C7	-3.72E-01	-7.97E-01	-4.49E-01	-1.73E-01	-4.07E-01	-2.37E-01

STEAM does not estimate the benefits of queue reduction. The user is responsible for estimating the demand, capacity, or travel cost impacts prior to using the tool. STEAM uses 1994 HCM queue departure rates that range from 1,500 to 2,000 vphpl.

### 3.4 Highway Economic Requirements System (HERS)

The Highway Economic Requirements System (HERS) is a computer model designed to estimate the costs, benefits, and economic implications associated with various highway investments at the national level. The HERS model is used in the US Department of Transportation's biennial Status of the Nation's Surface Transportation System Condition and Performance Report to Congress (C&P Report). HERS estimates the benefits to highway users (travel time, operating costs, and safety), to highway agencies (maintenance costs and the residual value of an improvement at the end of the analysis period), and reduction in vehicle emissions.

A benefit-cost analysis compares potential improvements. For each funding period, HERS forecasts the condition of each sample section and determines which improvements should be made. The current version of the HERS model considers highway improvements to the pavement (resurfacing and reconstruction) and geometrics (lane widening and additions, shoulder improvements, curve and grade improvements, access control, and median improvements for urban freeways).

HERS uses four sets of delay equations (by road types) developed by fitting curves to data generated by repeated runs of queuing models (e.g., FRESIM and NETSIM). Although a queuing analysis underlies the HERS delay equations, HERS does not analyze queues during calculations because it would be time consuming.

An independent Operations Preprocessor was developed for a division of the ITS Joint Program Office. This Preprocessor is used in limited fashion by the Joint Program Office to provide information outside the reach of HERS, but it has not been validated or implemented as a tool within HERS in its own right. The Preprocessor uses a more basic strategy than HERS, which includes scheduling operational improvements and keeping track of deployment costs. The Preprocessor estimates user impact by updating the base conditions on the FHWA's Highway Performance Monitoring System (HPMS) segments, and modifies the HPMS dataset. The Operations Preprocessor provides adjustment factors that are applied within the HERS model instead of estimating user impacts directly.

### 3.5 Other Benefit-Cost Models

Many of the other economic models that the Cal-B/C development team examined do not include queuing analysis. These include:

- **IMPACTS** – This Excel spreadsheet was developed as part of a National Highway Institute (NHI) course to estimate benefits for seven different types of transportation projects. IMPACTS estimates travel time benefits by comparing volume-to-capacity ratios with a lookup table. The focus is on mode shifts and determining equilibrium conditions rather than on queuing.

- ITS Deployment Analysis System (IDAS) – The FHWA sponsored the development of IDAS to integrate ITS evaluation with the transportation planning processes. IDAS uses observed data to adjust regional travel demand models. Queuing analysis is not included in the evaluation.
- MicroBENCOST – This model was developed in the early 1990s through the National Cooperative Research Program (NCHRP) to support in-depth economic analysis of detailed project options. The methodologies for estimating travel time benefits vary by type of project and include Highway Capacity Manual derived volume-to-capacity (v/c) methods, delay relationships derived from simulations, and queuing analysis (for railroad grade crossings only).
- NET\_BC – The model post-processes traffic assignment networks and regional travel demand model trip tables. NET\_BC computes system-wide user benefits directly from the model results and does not include any queuing analysis.
- Screening for ITS (SCRITS) – The FHWA sponsored the development of this sketch-planning tool for the early analysis of ITS benefits. SCRITS estimates travel time changes by comparing volume-to-capacity ratios to a lookup table derived from the same source as the table in IMPACTS. SCRITS is largely made obsolete by IDAS’s more detailed analysis. (STEAM also used this data prior to the STEAM 2.0 update.)
- StratBENCOST – This model was developed for the NCHRP to assess multiple projects at the strategic level and is a companion tool to MicroBENCOST.
- Washington State Mobility Programming – Washington State Department of Transportation (WSDOT) uses a series of benefit-cost spreadsheets to prioritize roadway capacity improvements. The travel time benefit estimation methodologies vary by improvement type, but all are calculated using v/c ratios rather than queuing analysis.

#### 4.0 RECENT RESEARCH AND FINDINGS

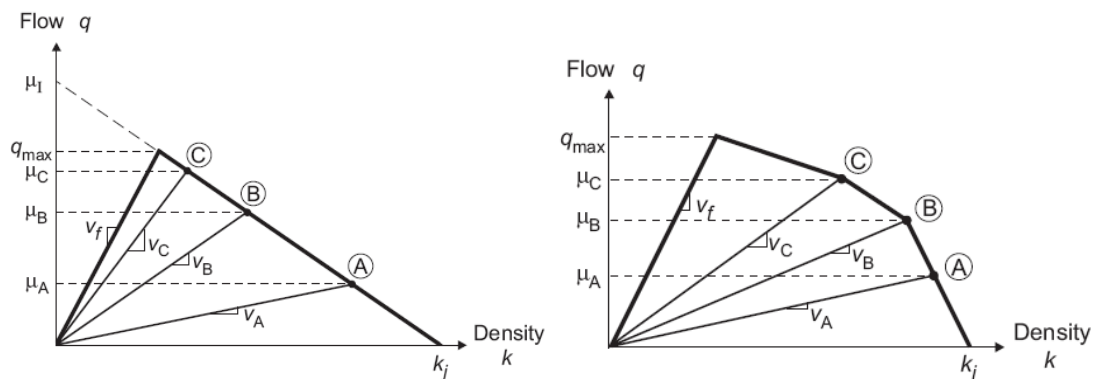
This section provides an overview of key research related to queuing analysis.



#### 4.1 A Simple, Generalized Method for Analysis of a Traffic Queue Upstream of a Bottleneck (Erera, 1998)

This paper generalizes an approach for enhancing the standard calculation of the amount of time vehicles spend queued upstream of a bottleneck. The paper relaxes the original assumption of a triangular flow-density relation in favor of a relationship that is piecewise-linear concave, as illustrated in Exhibit VII-6. The application of this new approach is simpler for complex problems, because it allows the estimation of several measures, including: the accurate number of vehicles in queue at any time, the time that individual and aggregate vehicles spend in each queued state, and the distance individual and aggregate vehicles travel while in queue. Knowing the time a vehicle spends in each queue is important for calculating the emissions and energy usage of bottlenecks and queues.

**Exhibit VII-6: Two Approaches to Modeling Flow-Density Relationships - Triangular and Piecewise-Linear Concave**



#### 4.2 Simulation Model Performance Evaluation for Congested Freeway Operations (Middleton and Cooner, 2003)

On behalf of the Texas Department of Transportation, Middleton and Cooner and the Texas Transportation Institute (TTI) launched a study to identify the models that best estimate the benefits of removing bottlenecks under different conditions. Middleton and Cooner began with a review of previous research focused on:

- Speed-flow relationships for uncongested and congested conditions on freeways
- Freeway simulation model documentation
- Studies of freeway simulation model applications.

The researchers selected the three most promising models (FREQ, INTEGRATION, and CORSIM) and tested them using three study sites in Dallas, Texas. The tests found that the models performed fairly well for uncongested conditions, but were mostly unreliable for congested conditions. The results suggested that people drive differently in congested conditions than in uncongested conditions.

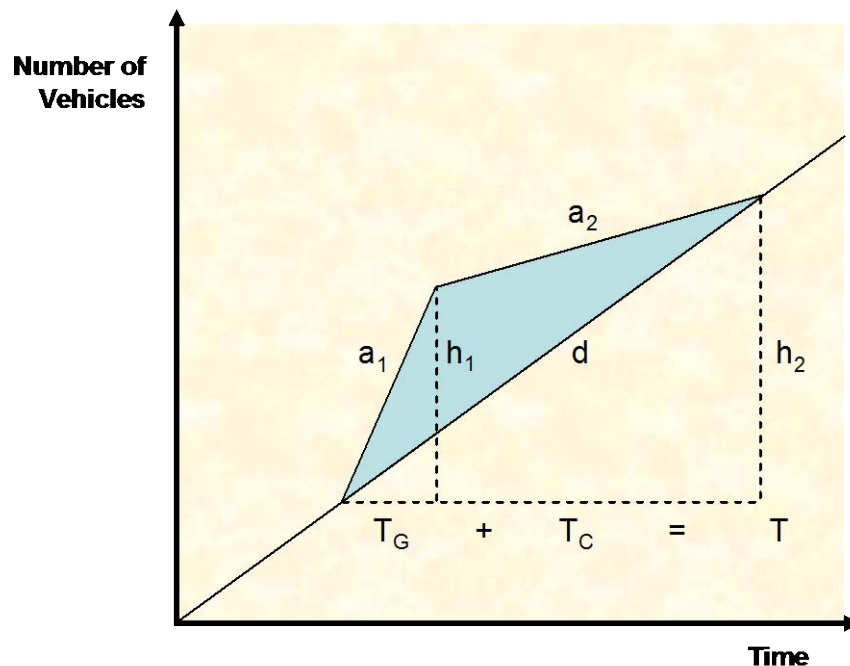
## 5.0 CAL-B/C METHODOLOGY

Cal-B/C calculates the benefits of relieving bottlenecks by applying a deterministic queuing model to estimate the time spent in queue and speed traveled in the no-build case. The model assumes that the proposed project removes the bottleneck completely and estimates speeds in the build case using a standard Bureau of Public Roads (BPR) model. Planners and engineers should use traffic models and other design techniques to determine the best configuration that removes a queue prior to running Cal-B/C. If a proposed project does not fully remove a queue, the methodology in Cal-B/C overestimates the benefits of the project.

Cal-B/C applies a deterministic model because it is easier to implement and explain than a stochastic model. (Detailed explanations of the differences between deterministic and stochastic models are available on the internet.) One could argue that upstream bottlenecks meter traffic to the next queue in a way that is actually deterministic. However, this would not apply in all cases. Extensive queuing analysis is beyond the scope of the Cal-B/C model, which is intended to be simple sketch planning tool. The existing queuing literature could be consulted for developing a complex queuing analysis tool that considers stochastic arrivals or departures and varying conditions, such as on-ramps along a corridor.

Cal-B/C uses an approach to highway queuing analysis similar to the one it uses for assessing the benefits of grade-separated rail crossings (see Chapter VI). Exhibit VII-7 shows the standard deterministic queuing analysis included in Cal-B/C.

**Exhibit VII-7: Input-Output Diagram for Highway Queuing Analysis**



where,

$a_1$	=	vehicle arrival rate during queue formation
$a_2$	=	vehicle arrival rate during queue dissipation
$d$	=	vehicle departure rate
$h_1$	=	cumulative vehicles delayed at time of maximum queue
$h_2$	=	cumulative vehicle delayed by queue
$T_G$	=	time queue grows
$T_C$	=	time to clear the queue

Comparing Exhibit VII-7 with Exhibit VI-5 in the previous chapter illustrates the key differences between eliminating queues due to highway bottlenecks and queues at rail crossings. As discussed in Chapter VI, queues at rail crossings dissipate when the gate is lifted and the departure rate is no longer zero. As shown in Exhibit VII-7, highway queues dissipate only when the arrival rate drops below the departure rate, so that the queue stops growing and begins to dissipate.

Several formulas can be derived from Exhibit VII-7, depending on whether  $T_G$  (the amount of time the arrival rate is larger than the departure rate and the queue grows) or  $T$  (the amount of time that the queue persists) is known. The Cal-B/C development team decided that basing the formulas on  $T_G$  is more consistent with requiring  $a_1$  as an input for Cal-B/C. However,  $T$  is a bit more intuitive since it corresponds to the definition of the peak (or congested) period used in Cal-B/C. Both values can be obtained from the freeway Performance Measurement System (PeMS).

Cal-B/C estimates the queuing delays for automobiles and trucks using the following formulas, which assume that  $T$  is known:

$$\text{Total Delay in Bottleneck} = \frac{1}{2} T^2 \frac{(a_1 - d)(d - a_2)}{(a_1 - a_2)}$$

$$\text{Number of Vehicles Affected by Bottleneck } (h_2) = dT$$

$$\text{Average Delay per Vehicle} = \frac{1}{2} \times \frac{T}{d} \times \frac{(a_1 - d)(d - a_2)}{(a_1 - a_2)}$$

The Department is likely to build experience using queuing analysis as a result of the emphasis on bottleneck identification in the CSMPs. If  $T_G$  proves to be more readily available, the following formulas could be used in place of the earlier formulas:

$$\text{Total Delay in Bottleneck} = \frac{1}{2} T_G^2 \frac{(a_1 - d)(a_1 - a_2)}{(d - a_2)}$$

$$\text{Number of Vehicles Affected by Bottleneck (h}_2\text{)} = d \times T_G \times \frac{(a_1 - a_2)}{(d - a_2)}$$

$$\text{Average Delay per Vehicle} = \frac{1}{2} T_G \frac{a_1 - d}{d}$$

Cal-B/C estimates travel time, vehicle operating cost, and emissions benefits by comparing the speeds in the build and no-build cases. The no-build speeds are calculated by estimating the average delay per vehicle. This delay is added to the travel time at free-flow speeds and divided by the length of highway impacted by queues to derive the no-build free-flow travel times. Cal-B/C estimates the speeds in the build case using the standard BPR formulas. The number of vehicles affected by the bottleneck is estimated using the formula provided above.

This methodology requires several key inputs:

- Highway Posted Speed Limit (in mph) – This input is used to estimate the travel time in the no-build case at free-flow speed. This travel time is added to the delay calculated using the queuing formula to estimate the no-build speed. Cal-B/C also requires this input to estimate speeds in the BPR curves, which are used in the build case.
- Arrival Rate (in vehicles per hour) – This is the arrival rate during queue formation and corresponds to the variable  $a_1$  in the queuing equations. Cal-B/C automatically calculates the arrival rate during queuing dissipation ( $a_2$ ) by assuming it is equal to the arrival rate during the non-peak period. This is estimated by dividing the non-peak ADT by the number of hours in the non-peak period.
- Departure Rate – This is the rate at which the queue dissipates. Cal-B/C uses the same departure rate lookup table for this value as it does for rail grade-separation projects (see Chapter VI for details). The following vehicle departure rates are included in Cal-B/C: 1,800 vehicles per hour for highways and 1,400 vehicles per hour for arterials. If Cal-B/C is used to assess queuing on collectors or local roads, the projects must be entered as arterials and the departure rates changed manually in the model parameters. The following values should be used: 900 vehicles per hour for collectors and 700 vehicles per hour for local roads.

The arrival rates and departure rates are needed for both Year 1 and Year 20. The speed and volume calculations for Year 20 are more complicated than those for Year 1 due to implicit peak spreading. Cal-B/C assumes that the arrival rates grow between Year 1 and Year 20 by the same percentage that ADT grows. This assumption can be overridden by the user. The larger arrival rate causes the area of the triangle in Exhibit VII-7 to grow considerably. As a result, the number of vehicles affected and the average

delay per vehicle for Year 20 must be calculated using modifications of the earlier formulas that take into account the peak spreading:

$$\text{Number of Vehicles Affected (in Year 20)} = \frac{DT(d - a_2)}{\frac{ADT_1}{ADT_{20}}(D - a_2)}$$

$$\text{Average Delay per Vehicle} = \frac{1}{2} \frac{T(A_1 - D)(d - a_2)}{D(a_1 - a_2)}$$

where most variables equal their Year 1 values and,

$A_1$  = vehicle arrival rate during queue formation in Year 20

$D$  = vehicle departure rate in Year 20

Unlike rail crossings, highway bottlenecks tend to involve moving queues. As a result, Cal-B/C estimates the vehicle operating costs and emissions in the no-build case using the estimated speeds rather than an idling speed (as described in Chapter VI for rail grade-separation projects).

Cal-B/C calculates safety benefits for projects that eliminate queues using the usual procedures. Such projects may lower accident rates due to reductions in weaving or raise accident rates due to increased speeds. However, the Cal-B/C development team was unable to find support for either assumption in the research literature. As a result, safety benefits are based on changes in the accident rate group or user-supplied accident reductions as described in other parts of the technical documentation.

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**VIII. NETWORK AND  
CORRIDOR ANALYSIS**



## VIII. NETWORK AND CORRIDOR ANALYSIS

Over the last several years, the Department and its partners have embraced corridor planning and system management. During the 2009 revision to Cal-B/C, the development team recognized that the model needed to be ready to support corridor analyses and the potential range of resulting projects. This recognition was prompted in part by the experience of conducting benefit-cost analyses for the Corridor Mobility Improvement Account (CMIA) established under Proposition 1B.

The proposed CMIA projects often involved corridor improvements through combinations of traditional solutions. These combinations and corridor-focus complicated the analysis and led to questions of how the original Cal-B/C sketch planning tool could handle multiple projects and lengthy corridors. As described in Volume 1 of the technical supplement, the Cal-B/C development team had explicitly ruled out network analysis when developing the original tool. The 2009 revision provided a reevaluation of network and corridor analysis and resulted in a suite of Cal-B/C tools.

This chapter identifies the role of Cal-B/C in conducting corridor analyses. It also describes the modifications made to Cal-B/C as part of the 2009 update to support these analyses, namely the development of the Cal-B/C framework. The changes described in this chapter continue in the latest versions of Cal-B/C and other models in the Cal-B/C framework. Since the 2009 revision, a number of additional activities have reinforced the importance of having the ability to conduct network and corridor analyses in the Cal-B/C framework:

- Corridor System Management Plans (CSMPs) - The Department and its partners have conducted detailed micro-simulations for nearly 20 corridors statewide. Processing the results and conducting the benefit-cost analyses would have been impossible without the addition of Cal-B/C Corridor to the Cal-B/C framework.
- Integrated Corridor Management (ICM) - The Federal Highway Administration (FHWA) has recently advocated the concept of coordinating across multiple transportation networks, making cross-network connections comprising a corridor, and facilitating integrating across institutions responsible for corridor mobility. Two of the pioneer ICM sites are located in California and the concept is being considered for other corridors as well.
- TIGER Discretionary Grants - In 2009, the United States Department of Transportation (USDOT) began offering Transportation Investment Generating Economic Recovery (TIGER) grants. In order to qualify for

these discretionary grants, applicants must demonstrate a benefit-cost ratio above 1.0. While the original Cal-B/C model was designed for sketch planning, these analyses frequently require the use of detailed model data that captures network or corridor impacts.

The 2009 update to Cal-B/C expanded the analysis framework from a single model to a suite of tools supporting benefit-cost analysis. This suite of tools is called the Cal-B/C framework. The three tools in the Cal-B/C framework use the same assumptions and parameters. While the original Cal-B/C model focused on sketch planning, the other two tools in the Cal-B/C framework support corridor and network analysis:

- *Cal-B/C Corridor* facilitates the analysis of summary-level results from regional travel demand models and micro-simulation models. This tool provides a more tailored “Model Inputs” page than Cal-B/C and allows multiple segments to be calculated at once. Cal-B/C Corridor can be used when aggregate model data are available.
- *Cal-NET\_BC* is built upon the NET\_BC model, which has been customized for California to ensure compatibility with Cal-B/C. Cal-NET\_BC uses the same parameters page as Cal-B/C, but allows detailed link-level benefit evaluation. Cal-NET\_BC can be used when detailed regional travel demand model or micro-simulation model data are available.

Since the 2009 update, the Department’s experience in applying Cal-B/C Corridor has demonstrated that the model is easier to use than Cal-NET\_BC and appropriate for many of applications envisioned for Cal-NET\_BC. Chapter IX provides a more detailed description of Cal-B/C Corridor. Separate technical documentation is available for the Cal-NET\_BC model.

The rest of this chapter is organized as follows:

- Corridor System Management Plans (CSMPs)
- Corridor Planning Process
- Examples of CSMP Analysis
- Application of Cal-B/C for CMIA Funding
- Options and Implications.

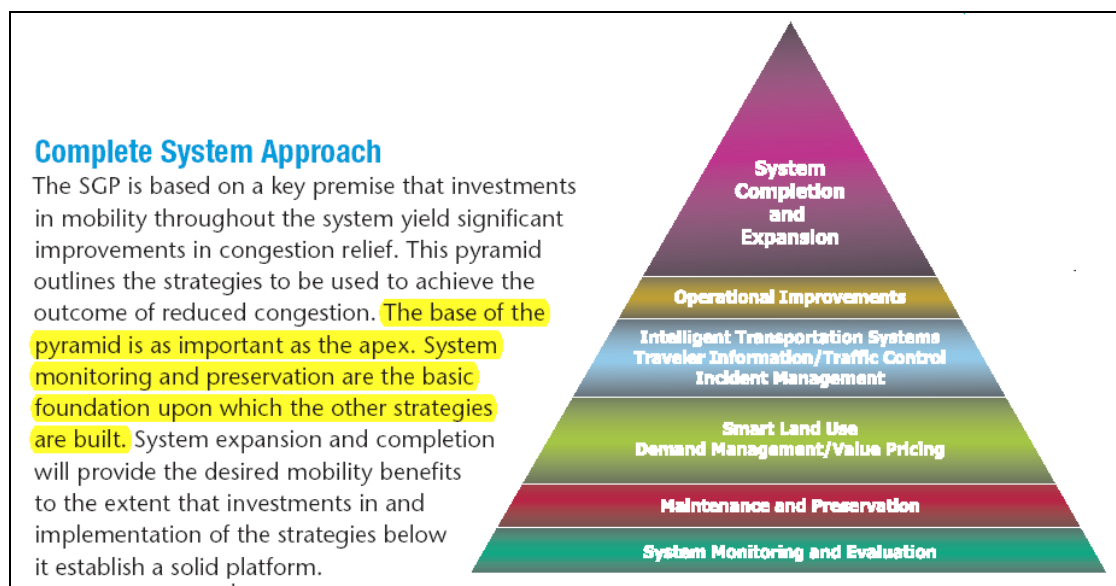
Since this chapter was original developed for the 2009 revision, the language reflects the state of the practice at the time of that revision. The basic concepts and motivations continue to be applicable to the Cal-B/C framework.

## 1.0 CORRIDOR SYSTEM MANAGEMENT PLANS (CSMPs)

The Department is putting in practice a new approach to system and operations planning by developing Corridor System Management Plans (CSMPs) for congested urban corridors. System management is intended to help maximize the productivity of existing transportation resources, determine investment value, and prioritize projects, strategies, and actions. The immediate effort is to develop CSMPs for corridors with capital projects funded by the CMIA. While the role of CSMPs within the context of traditional planning at the Department and its stakeholder agencies is still being defined, the Department anticipates that CSMPs or a similar planning document will be prepared for all congested urban corridors. Ultimately, these documents and a system planning approach may replace Transportation Concept Reports (TCRs) for these corridors.

The system management principles in CSMPs are based on the Transportation Management System (TMS) Master Plan framework. As shown in Exhibit VIII-1, Governor Schwarzenegger's Strategic Growth Plan (SGP) describes the system management approach as a pyramid. While system completion and expansion continue to serve a role, they can be successful only if the operational strategies establish a solid foundation. The ideas presented in the SGP build on the Transportation Management Systems (TMS) Master Plan, which provides an action plan for the business processes, associated tools, field elements, and communication systems that maximize the productivity of the transportation system.

### Exhibit VIII-1: System Management Approach



Source: Governor Arnold Schwarzenegger's Strategic Growth Plan: Transportation Investments for Mobility, September 2006.

CSMPs are critical for establishing a baseline of current corridor conditions, identifying potential solutions, and assessing potential outcomes of implementing these solutions.

This is the system monitoring and evaluation shown at the base of the pyramid. The system approach is intended to maximize the efficiency and effectiveness of the existing transportation infrastructure through proven methods and technologies. These usually involve relatively low-cost capital activities, such as ramp metering, high occupancy vehicle lanes, traffic information collection and dissemination, incident management, increased use of local parallel arterial roadways, and demand management strategies.

The system management approach can be successful only if the right solutions are matched to each corridor. This is often done through detailed modeling, such as micro-simulation analysis. As a result, corridor studies have richer set of build and no-build data than is typically available in Cal-B/C sketch planning applications.

In addition, corridor planning requires the testing of multiple scenarios with multiple projects. These projects potentially have different phasing and certainly extend along lengthy corridors in sections with different geometry. For example, the I-405 corridor in Los Angeles County extends 36 miles from the I-110 junction to the I-5 junction. While Cal-B/C assumes that highway sections are uniform, this assumption is not very accurate for a 36-mile corridor.

## 2.0 CORRIDOR PLANNING PROCESS

CSMPs are intended to lay the groundwork for system management by assessing current corridor conditions, identifying potential solutions, and identifying the appropriate outcomes. There are currently 45 corridor studies underway from CMIA funding or SR-99 infrastructure bonds. Of these, 26 corridors involve the development of micro-simulation models to test potential solutions, while the remaining 19 corridors have adopted some form of modified TCR. The specific planning process varies by corridor study with the analysis evolving by trial and error. The planning involves a combination of Department staff, local agency involvement, and consultants.

Despite these differences, the Department developed a “cookbook” that lays out a general process to help districts and local stakeholders prepare effective CSMPs. In addition, a recent corridor management planning demonstration provides an example of how a comprehensive corridor study should be conducted. Corridor planning and the development of CSMPs require several common steps:

- Defining the corridor transportation network, including State Highways, major local streets and roads, intercity rail service, regional rail service, primary regional transit service, and key regional bicycle facilities
- Involving key stakeholders and gathering a knowledge base for the corridor

- Determining and summarizing existing travel conditions from measures of mobility, reliability, productivity, and safety to establish a baseline
- Evaluating corridor existing system management practices
- Forecasting future travel conditions using computer simulation tools calibrated to existing performance baseline
- Preparing and analyzing corridor management strategies for the future
- Preparing final CSMP recommendations and a ten-year implementation plan acceptable to the Department and corridor stakeholders.

Developing effective CSMPs requires the involvement of Department planning and operations staff, local and regional partner agency staff, and management. Unlike the traditional system planning approach, CSMPs require advanced analysis including: corridor performance assessment (using data intensive tools such as the Freeway Performance Measurement System or PeMS); operational analysis to identify and determine the cause of major, minor, and hidden bottleneck locations; identification and assessment of improvement options and strategies; review of constructability; and testing of improvement scenarios using computer simulation tools, such as micro-simulation models.

The timeframe for forecasting corridor conditions varies, but most CSMP study teams have adopted 15-year to 20-year horizons. This is comparable to the standard 20-year life-cycle framework in Cal-B/C, but having forecasts not exactly 20 years from the base year complicates the analysis.

A lot of information will be available to assess the benefit-cost of proposed solutions. In fact, more will be available than is needed for a typical analysis using Cal-B/C. The corridor studies are expected to provide a very rich set of micro-simulation modeling data along each corridor that shows the no-build and build impacts of various bundles of projects along the corridor.

### **3.0 EXAMPLES OF CSMP ANALYSIS**

CSMP analysis requires a comprehensive performance assessment that describes the baseline conditions on the corridor. This is analogous to current year data in the no-build case for Cal-B/C. The performance measures are intended to provide a technical basis for describing potential problems along the corridor. The performance measures focus on four key areas:

- Mobility describes how well the corridor moves people and freight.

- Reliability captures the relative predictability of the public's travel time.
- Safety conveys the likelihood of collisions occurring along the corridor and encountering fatality, injury, or property damage.
- Productivity is a general efficiency measure defined in terms of lost lane-miles.

Improvements in the mobility and safety measures are similar to the travel time and safety user benefits calculated in Cal-B/C. Improvements to the productivity measure may indicate shifts in travel patterns or induced demand. The reliability performance measure captures variations in travel time. Improvements would indicate greater travel time reliability. Cal-B/C does not directly measure the user benefits associated with improvements in travel time reliability, but the model does have a factor to increase the value of time associated with incident-related travel. This could be considered similar to reliability (although not all reliability issues are due to highway incidents). The CSMPs do not report on vehicle operating costs or air quality under current corridor conditions, which are user benefits included in Cal-B/C. (Note: the issue of incorporating travel time reliability was explored, but ultimately rejected in a later update of Cal-B/C).

The specific outputs vary by CSMP corridor. Exhibit VIII-2 presents an example of the mobility measure for the I-5 South Corridor in Los Angeles County. The exhibit shows how travel time along the corridor varies by time of day for 2005 through 2008. The data comes from the freeway Performance Measurement System (PeMS) and it highlights how travel times (and underlying speeds) are different in different times of the day. This paints a more complicated picture of congestion than the standard Cal-B/C assumption of travel occurring in uniform peak and non-peak periods.

### Exhibit VIII-2: Example of Travel Time Performance Measure

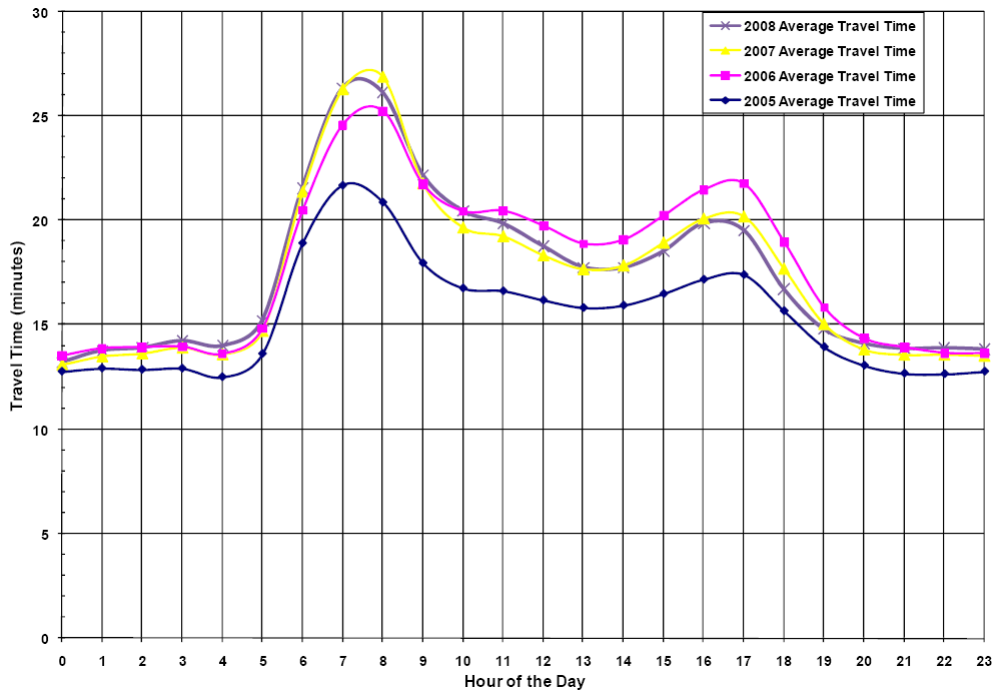
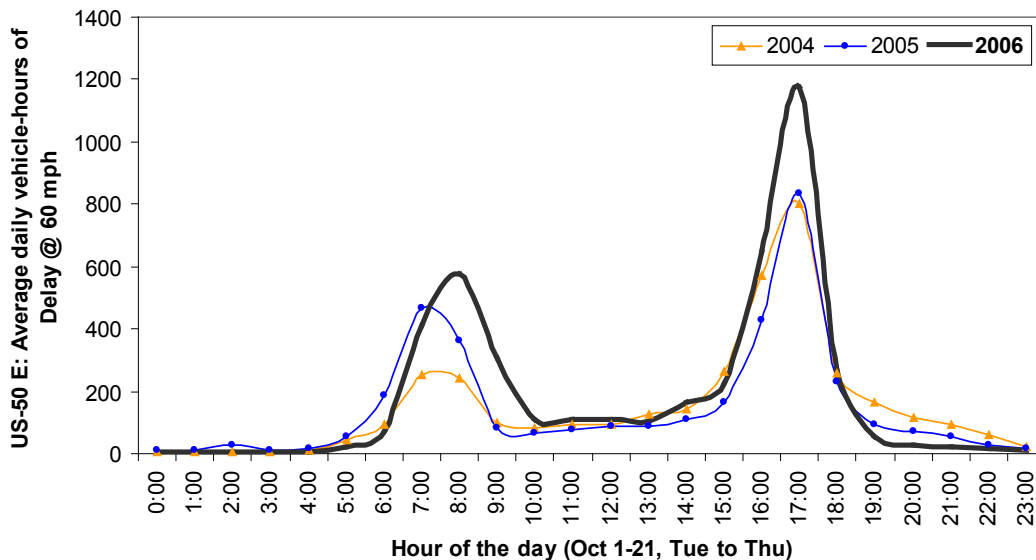


Exhibit VIII-3 presents another example of a mobility measure for the US 50 corridor in Sacramento County. This exhibit shows average weekday vehicle-hours of delay by hour for the eastbound direction. For this exhibit, delay has been defined as travel less than 60 miles per hour and is comparable to the types of definitions found in the Highway Congestion Monitoring (HICOMP) report.

### Exhibit VIII-3: Example of Delay Performance Measure





The CSMPs also break the corridor into smaller segments by bottleneck area. Exhibit VIII-4 provides an example of how bottleneck areas vary by time of day and direction along the I-5 South Corridor in Los Angeles.

**Exhibit VIII-4: Example of a Bottleneck Area**

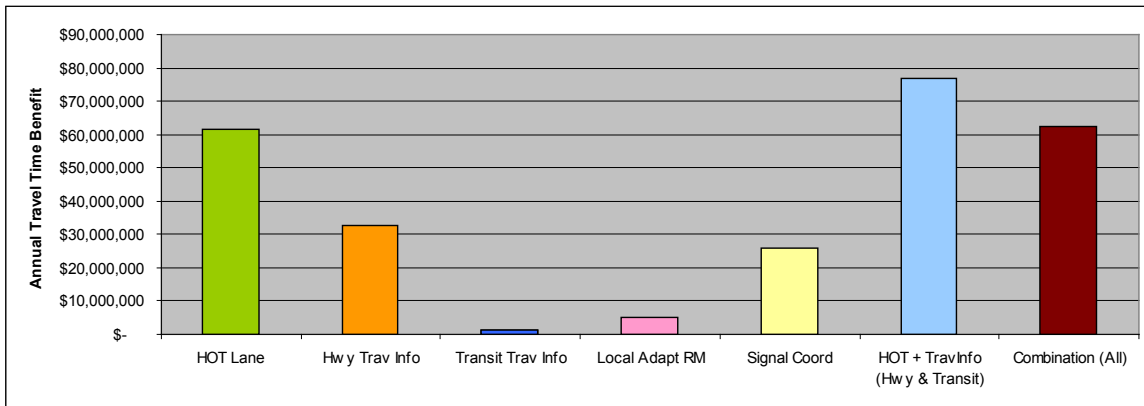
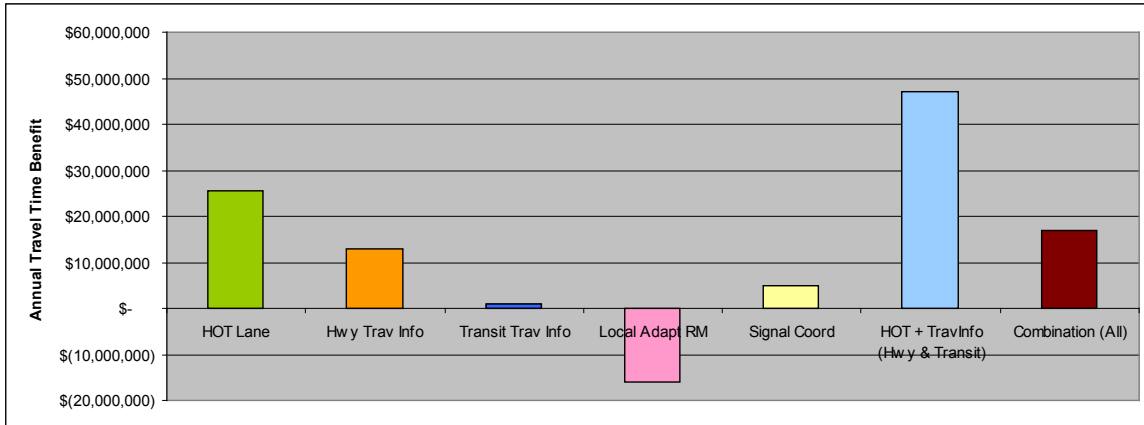


While there is no specific guidance or requirement for benefit-cost analysis in the CSMPs, several corridors may include benefit-cost or benefits valuation to estimate and compare the benefits, and prioritize the improvement strategies.

Exhibit VIII-5 provides an example of how the travel time measure could be used to compare improvements using monetized mobility benefits. The figures were generated using analysis results from a simulation model. The first figure is representative of the annual travel time benefits from an analysis assuming medium levels of demand and major incidents, while the second figure represents benefits under high demand and major incident conditions. The third figure combines the performance measures and compares the resulting benefit-cost.

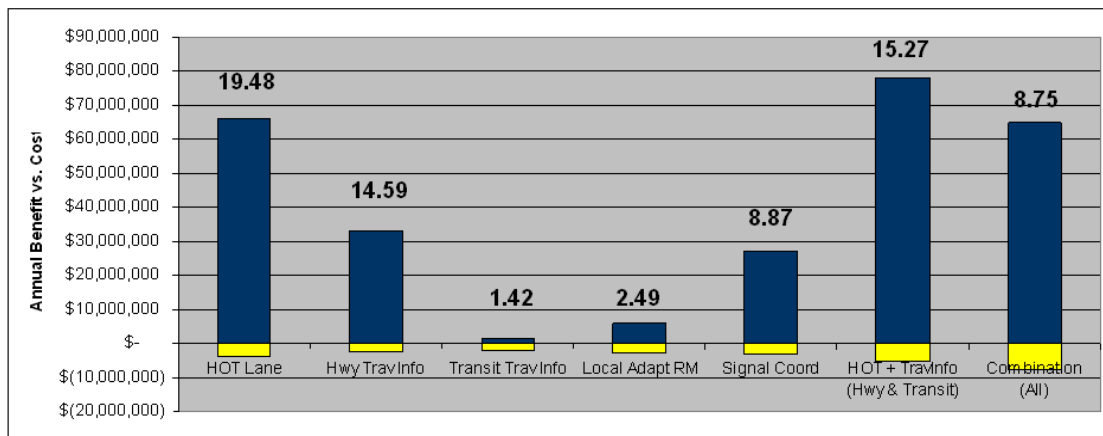


### Exhibit VIII-5: Examples of Benefit-Cost Evaluation Using Micro-Simulation



## Summary of Benefits vs. Costs

### High Demand with Major Incident



## 4.0 APPLICATION OF CAL-B/C FOR CMIA FUNDING

The California Transportation Commission (CTC) adopted CMIA Program Guidelines (November 8, 2006) for the selection of CMIA projects, and included an evaluation of benefits for each nominated project. The CTC gave priority to projects expected to provide the greatest benefits in relationship to costs. The CMIA Program Guidelines called for the use of the Cal-B/C model to help quantify these benefits. The Cal-B/C results were just one measure of the benefits and the CTC also considered other assessments of time savings, safety benefits, emissions benefits, and other benefits identified in the project nominations.

Cal-B/C provided a consistent approach and a good screening tool to compare projects submitted under the CMIA program, particularly within a very short timeframe. However, the model had several limitations. Some of these included:

- The inability to analyze improvements not included in Cal-B/C
- An inconsistency with the analysis of long corridors, particularly those with variations in the number of lanes and volumes (e.g., most agencies used an average or the worst location instead of submitting multiple input sheets)
- The need to capture bottlenecks and the queue delay impacts associated with reducing them
- The desire by the submitting agencies to use analysis results from more sophisticated analysis tools to estimate the benefits (e.g., travel demand model, simulation tools, and operational analyses)
- The inability of Cal-B/C to capture the link-level, corridor-level, and network-level analyses (Cal-B/C uses averages and aggregates)
- The inability to capture route diversion (network-level analyses) and other traveler responses
- The potential for Cal-B/C to show projects as beneficial when they shift problems to other locations
- The inability of Cal-B/C to analyze possible synergistic impacts (e.g., ramp metering with auxiliary lane improvements)
- A lack of guidance on parameters, adjustments to defaults, and key sources of data.

## 5.0 OPTIONS AND IMPLICATIONS

Some form of benefit-cost analysis or benefit valuation is expected to be part of the CSMP analysis to compare, phase, and prioritize improvements. In addition, the overall shift to greater performance measurement means that the Department will have more detailed data available for future benefit-cost analysis even in the State Transportation Improvement Program. The most promising place to begin testing the use of this data is the current CSMP assessments.

Since many corridor studies are using simulation models to capture bottlenecks, queue lengths and durations, speed variations, and traveler responses, the results from these analyses must be considered in calculating the benefits of corridor improvements in benefit-cost analyses. Simulation models have the potential to eliminate many Cal-B/C limitations cited in the context of the CMIA analysis. For example, simulation models may help the Department capture network effects and model combinations of projects.

In the 2009 update to Cal-B/C, the development team explored four primary options for changes to Cal-B/C that support current and future corridor analysis:

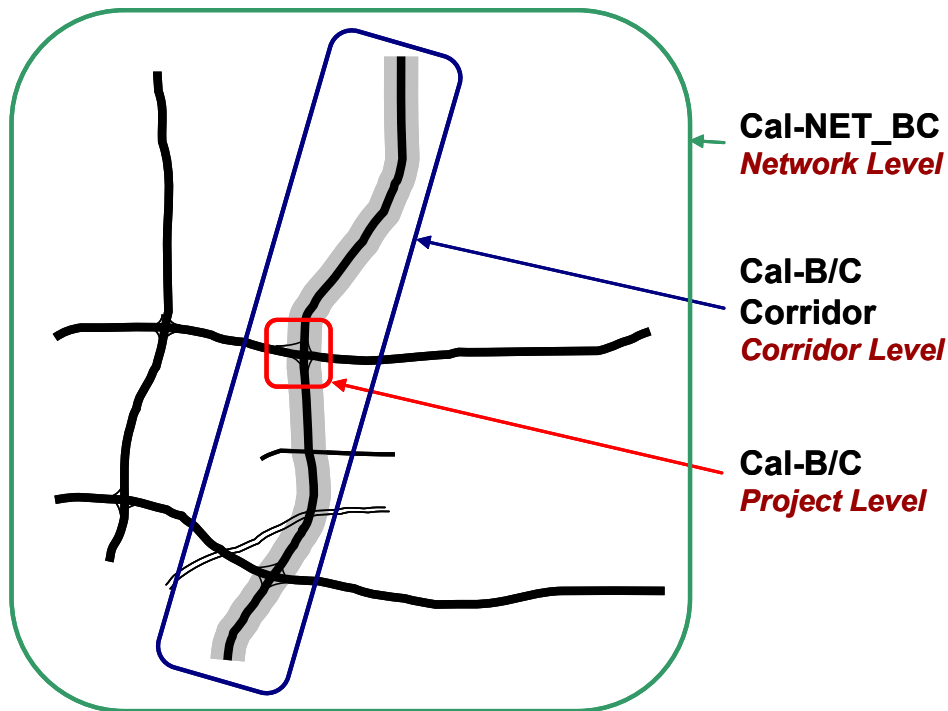
- Modifications to Cal-B/C
- Monetizing Aggregate Benefits
- Network Level Analysis
- Standard Factors for Custom Analysis.

These options and the actions taken to address them are discussed further in the next sections. However, the ultimate result of the 2009 revision and efforts to address network and corridor analysis is the Cal-B/C framework.

The 2009 update to Cal-B/C expanded the analysis framework from a single sketch planning model to a suite of tools, called the Cal-B/C framework. While the original Cal-B/C model focused on sketch planning, the other two companion tools support corridor and network analysis. These two tools, called Cal-B/C Corridor and Cal-NET\_BC, use methods consistent with Cal-B/C and produce comparable results.

Exhibit VIII-6 illustrates the three tools in the Cal-B/C Framework. Expansion of the Cal-B/C framework is part of the Department's commitment to the system management approach. It also supports scenario analysis for CSMPs, which are the embodiment of system management. The rest of this chapter explores the four options considered that resulted in the Cal-B/C framework.

### Exhibit VIII-6: Cal-B/C Framework



#### Area 1 - Modifications to Cal-B/C

As part of the 2009 update, the Cal-B/C development team made two modifications to Cal-B/C to support corridor analysis: support for multiple improvements, and incorporation of queuing analysis.

*Multiple Improvements.* Cal-B/C could be modified to handle multiple improvements types. However, it did not make sense to turn Cal-B/C into a tradeoff tool because micro-simulation analysis and travel demand models can estimate the results of these tradeoffs in a much more comprehensive manner. In developing the Cal-B/C v4.0, the development team tried to make sure that multiple improvement types did not conflict. However, the development team recommends running the model for one project type at a time. This general setup has not been modified in subsequent versions of Cal-B/C.

*Queuing Analysis.* The CSMP studies identify bottlenecks along their respective corridors. Many of these bottlenecks create congestion through queuing. In the 2009 update, Cal-B/C was updated to include queuing analysis. These methodologies are fully described in Chapter VII.

#### Area 2 - Monetizing Aggregate Benefits

*Monetizing Aggregate Benefits.* The second page (Model Inputs) of the Cal-B/C model is intended to handle more detailed data than the first page (Project Information). If an

analysis were limited to peak versus non-peak travel, the Cal-B/C can handle data from micro-simulation models and travel demand models (with some external manipulation of the data). Cal-B/C could be modified to incorporate the simulation analysis results into a benefit-cost calculation.

Such a modification would use the performance measures directly from the model results (vehicle-miles traveled, vehicle-hours traveled, and number of trips) for the various time periods of analysis and by vehicle type. In order to accommodate the findings from the MPO model survey, a modified Model Inputs page would need to handle five time periods.

The Cal-B/C development team decided to develop a corridor-level spreadsheet based on Cal-B/C. This spreadsheet, Cal-B/C Corridor, is tailored to accommodate the output of micro-simulation models and regional travel demand models. It also provides flexibility in defining user groups, so Cal-B/C Corridor can be used with a wide range of model outputs.

Since the 2009 update, the Department's experience with Cal-B/C Corridor has shown that Cal-B/C should be used for sketch planning, while Cal-B/C Corridor should be used for monetizing transportation impacts estimated by detailed travel demand or micro-simulation model analysis.

### **Area 3 - Network Level Analysis**

As part of the 2009 update, the Cal-B/C development team built a California version of NET\_BC with parameters and an analysis approach consistent with Cal-B/C. This program, called Cal-NET\_BC, provides the ability to conduct a network-level analysis using link-by link data. Cal-NET\_BC builds on earlier Departmental efforts to develop a network benefit-cost tool suitable for California. This effort started with a prototype interface between the NET\_BC model and the Association of Monterey Bay Area Government (AMBAG) TransCAD travel demand model.

Cal-NET\_BC is a software package written in Visual Basic. Cal-NET\_BC reads travel demand and network data files outputted by transportation planning models. From this information, the model computes benefits associated with reduced travel times, fewer accidents, better air quality, and reduced vehicle operating costs. Detailed information about the benefits can be generated (e.g., the number and type of accident reductions). The monetized benefits are discounted over the economic life of the project to their present value. Cal-NET\_BC reads user-provided capital, operating and maintenance (O&M) costs and discounts these costs to their present value.

Cal-NET\_BC is best suited for projects that are sufficiently large to divert traffic from other competing streets and modes. However, planners and engineers can also use Cal-NET\_BC to capture corridor-level analyses. Separate technical documentation is available for the Cal-NET\_BC model. This documentation describes how travel

demand model outputs are used in Cal-NET\_BC. It also provides guidance on how output from other analysis tools, such as micro-simulation models, might be aggregated and put in a format consistent with Cal-NET\_BC.

As described earlier, practical experience with Cal-B/C Corridor over the last several years has demonstrated that it is easier to use and appropriate for many of the types of analyzes envisioned for Cal-NET\_BC. A big limitation of Cal-NET\_BC is the need to reformat travel demand model outputs into a specific format. The Cal-B/C development team had to adopt a generic format to accommodate the range of travel demand model outputs used in California.

Cal-B/C Corridor is flexible in the inputs it uses, so model outputs can be more readily format to input into Cal-B/C Corridor. For example, travel demand and micro-simulation model data can be summarized in one mile per hour (1-mph) speed bins. In this way, Cal-B/C Corridor is capable of analyzing an entire network, not just a specific corridor.

#### **Area 4 - Standard Factors for Custom Analysis**

Staff involved in the preparation of corridor analyses for the CSMPs may choose to develop customized benefit-cost assessments by “post processing” the results of their simulation analyses. This means calculating benefit assessments directly from the simulation results using their own spreadsheets, programs, or databases. To support these types of analyses, the Department has begun providing guidance on its website in terms of the standard economic values for benefit-cost analysis. These values are updated roughly annually and recommended to be used for all modes, including highway, rail and transit projects. The values on the website are consistent with the parameters page of the Cal-B/C models.

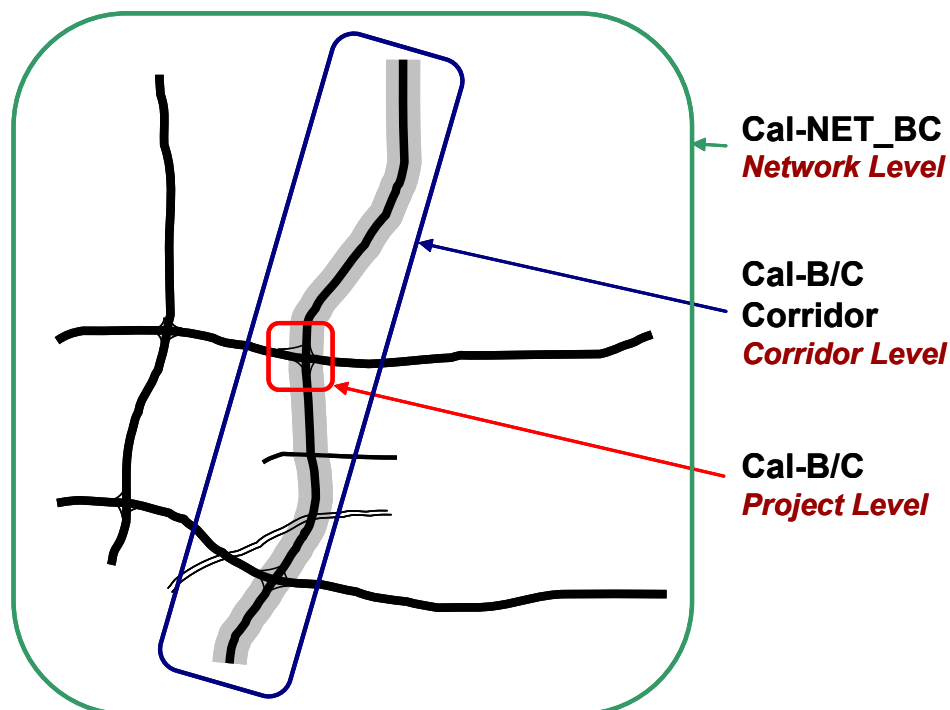
**IX. CAL-B/C CORRIDOR**

## IX. CAL-B/C CORRIDOR

As part of the 2009 Cal-B/C revision, the development team developed a suite of tools for conducting benefit-cost analysis. This suite includes the original Cal-B/C model, Cal-B/C Corridor, and Cal-NET\_BC. While the original model retains its sketch planning format, the other two tools support benefit-cost analysis after a project's transportation user impacts are modeled in an engineering or planning tool. Examples of such tools include travel demand models, micro-simulation models, and Highway Capacity Manual (HCM) methods. All Cal-B/C tools use consistent analysis methods and produce comparable results. In fact, each model relies on the same Cal-B/C parameters page.

Exhibit IX-1 shows the focus of the three tools in the Cal-B/C framework. The Cal-B/C model supports project-level analysis, particularly during the sketch planning stage when detailed project modeling is unavailable. Cal-B/C Corridor and Cal-NET\_BC support detailed project analysis as well as corridor and network analysis. These companion tools calculate scenario benefits using travel impacts estimated in regional travel demand or simulation models. In doing so, they provide better estimates of the complimentary or duplicative benefits of combination projects. Unlike Cal-B/C, they rely completely on other models to estimate impacts and simply monetize the benefits.

**Exhibit IX-1: Cal-B/C Framework**





Cal-NET\_BC is built upon the NET\_BC model and is customized for California to ensure compatibility with Cal-B/C. Cal-NET\_BC uses the same Parameters page as Cal-B/C, but allows detailed, link-level benefit evaluation as well as induced demand estimation using travel time skims from the travel demand matrices. Since California Metropolitan Planning Organizations (MPOs) use different travel demand models with different output formats, Cal-NET\_BC uses a standardized set of inputs. This requires outputs from travel demand models (or other models, such as micro-simulation models) to be converted into the appropriate format before Cal-NET\_BC can be run. Separate technical documentation is available for the Cal-NET\_BC model.

The Cal-B/C development team originally intended Cal-NET\_BC to be used whenever detailed regional travel demand model or micro-simulation model data were available. However, the conversion of travel demand data into the appropriate format is time consuming. Over the last several years, experience with Cal-B/C Corridor has demonstrated that the model is easier to use and can handle most of the analyses envisioned for Cal-NET\_BC. As a result, the development of Cal-B/C Corridor has continued since the 2009 revision. The model can now handle more model groups and has other added features to make the model more user-friendly.

The Department and its partners are expected to use Cal-B/C and Cal-B/C Corridor as their primary benefit-cost tools going forward. Cal-B/C serves as a sketch planning tool that supports benefit-cost analyses when potential project impacts are not yet fully known. Cal-B/C Corridor conducts benefit-cost analyses using the changes in vehicle-miles traveled (VMT) and vehicle-hours traveled (VHT) estimated in planning and simulation models. The model has a flexible design that supports a variety of input data.

The rest of Chapter IX provides more detailed documentation on Cal-B/C Corridor. The chapter provides an overview of the model and its design, describes the fundamental sections of the model, and presents an example illustrating its use. The chapter is organized into the following sections:

- Model Design
- Project Information
- Model Inputs
- Benefit Calculations
- Interchange Example.

## 1.0 MODEL DESIGN

Cal-B/C Corridor is derived directly from Cal-B/C, so it produces results fully comparable with those from the original model. Cal-B/C Corridor uses the same assumptions and parameters, but it facilitates the analysis of travel impacts estimated in regional travel demand models and micro-simulation models. Cal-B/C looks very similar to Cal-B/C and the model interface should be familiar for Cal-B/C users.

As in Cal-B/C, the corridor version of the model has three main pages for entering information about the project and its travel impacts as well as for reviewing benefit-cost results:

- 1) Project Information
- 2) Model Inputs
- 3) Results.

The detailed benefit calculations occur on subsequent pages. There is also a Parameters page, identical to the one found in Cal-B/C. Since Cal-B/C requires more operational parameters for its sketch planning rules-of-thumb, several of the values found on the Cal-B/C Corridor parameters page are not used in Cal-B/C Corridor. This design is intentional, so the same parameters page can be used in both models. Specific model pages are described in detail in the next few sections.

The biggest difference between Cal-B/C and Cal-B/C Corridor is on the Model Inputs page. While Cal-B/C estimates model inputs from simple project data using rules-of-thumb and Bureau of Public Roads (BPR) curves, Cal-B/C Corridor has a Model Inputs page tailored to accept summarized results from regional travel demand models and micro-simulation models.

The Model Input page in Cal-B/C Corridor has a very flexible design that allows users to define how data are entered through generic user groups. Exhibit IX-2 provides a high-level snapshot of the Model Inputs page. This graphic is small, but each box is described in detail in a subsequent section. At the top of the Model Inputs page, users are able to define each model group (or record) that Cal-B/C Corridor processes. Exhibit IX-2 shows user groups defined by time-of-day and vehicle type classifications. However, the groups could represent different trip purposes, sections of roadway, roadway classifications, or speed bins. This flexibility allows Cal-B/C Corridor to be used with many kinds of model output.

On its benefits pages, Cal-B/C Corridor calculates benefits separately for each model group and adds them for the total user benefits. Cal-B/C Corridor allows users to define 100 model groups at a time. Once these benefits are estimated, users can define new sets of model groups up to four times. In this manner, Cal-B/C Corridor can process up to 400 model groups. For most applications, 100 to 200 model groups will be adequate. For example, defining data by speed bin would require about 70 model groups. If these are defined separately for automobiles and trucks, then about 140 model groups are needed.

The way that Cal-B/C Corridor calculates user benefits is part of its flexibility. For each model group, Cal-B/C Corridor estimates benefits assuming that both automobiles and trucks are part of the model group. The average vehicle occupancy (AVO) and percent trucks inputs allow the model to proportion and sum the benefits correctly. If

automobile and truck data are combined, the appropriate percent trucks can be entered for each model group. If automobile and truck data are entered separately, the percent trucks can be set to 0 percent and 100 percent as appropriate. The AVO input allows facility-specific analyses, such as the evaluation of High Occupancy Vehicle (HOV) or High Occupancy Toll (HOT) lanes.

Cal-B/C Corridor estimates user benefits in three main categories:

- Travel time savings
- Vehicle operating cost savings
- Emission cost savings.

The model does not estimate accident cost savings, because these benefits cannot be estimated simply from the model group data. However, Cal-B/C Corridor retains the accident cost parameters and includes accident cost savings on the Final Calculations page. Users can estimate these safety benefits outside of Cal-B/C Corridor or include customized pages in the Cal-B/C Corridor workbook. If the discounted user benefits are added to the Final Calculations page, the Cal-B/C Corridor will include these benefits in the overall benefit-cost calculation.

Since the model's initial development in 2009, the Department and its partners have had experience running Cal-B/C Corridor for several different types of projects. These evaluations have demonstrated that Cal-B/C Corridor can be used with many kinds of model data. For example, travel demand and micro-simulation model data can be summarized in one mile per hour (1-mph) speed bins. In this way, Cal-B/C Corridor is capable of analyzing an entire network, not just a specific corridor. Alternatively, Cal-B/C Corridor can be used to analyze specific segments on the corridor or data generated from external analyses of VMT and VHT impacts.

The next three sections describe the main user pages of Cal-B/C Corridor.

## Exhibit IX-2: Cal-B/C Corridor Model Inputs Page

**2A DEFINITIONS OF MODEL GROUPS AND YEARS**

	Name	Description	Avg. Vehicle Occupancy (AVO)	Percent Trucks
Model Group 1	AM Peak Auto			
Model Group 2	PM Peak Auto			
Model Group 3	Mid-Day Auto			
Model Group 4	Evening Auto			
Model Group 5	Night Auto			
Model Group 6	AM Peak HOV			
Model Group 7	PM Peak HOV			
Model Group 8	Mid-Day HOV			
Model Group 9	Evening HOV			
Model Group 10	Night HOV			
Model Group 11	AM Peak Truck			
Model Group 12	PM Peak Truck			
Model Group 13	Mid-Day Truck			
Model Group 14	Evening Truck			
Model Group 15	Night Truck			
Model Group 16				
Base Year			1	
Forecast Year			20	

**2B AGGREGATE MODEL DATA - YEAR 1**

	Number of Trips	Vehicle Miles Traveled (VMT)	Vehicle Hours Traveled (VHT)	Speed	Avg. Vehicle Occupancy (AVO)	Percent Trucks
<b>No Build</b>						
1 AM Peak Auto				55.0	0.00	0.0%
2 PM Peak Auto				55.0	0.00	0.0%
3 Mid-Day Auto				55.0	0.00	0.0%
4 Evening Auto				55.0	0.00	0.0%
5 Night Auto				55.0	0.00	0.0%
6 AM Peak HOV				55.0	0.00	0.0%
7 PM Peak HOV				55.0	0.00	0.0%
8 Mid-Day HOV				55.0	0.00	0.0%
9 Evening HOV				55.0	0.00	0.0%
10 Night HOV				55.0	0.00	0.0%
11 AM Peak Truck				55.0	0.00	0.0%
12 PM Peak Truck				55.0	0.00	0.0%
13 Mid-Day Truck				55.0	0.00	0.0%
14 Evening Truck				55.0	0.00	0.0%
15 Night Truck				55.0	0.00	0.0%
16 Not Used				55.0	0.00	0.0%
TOTAL	0	0	0			
<b>Build</b>						
1 AM Peak Auto				55.0	0.00	0.0%
2 PM Peak Auto				55.0	0.00	0.0%
3 Mid-Day Auto				55.0	0.00	0.0%
4 Evening Auto				55.0	0.00	0.0%
5 Night Auto				55.0	0.00	0.0%
6 AM Peak HOV				55.0	0.00	0.0%
7 PM Peak HOV				55.0	0.00	0.0%
8 Mid-Day HOV				55.0	0.00	0.0%
9 Evening HOV				55.0	0.00	0.0%
10 Night HOV				55.0	0.00	0.0%
11 AM Peak Truck				55.0	0.00	0.0%
12 PM Peak Truck				55.0	0.00	0.0%
13 Mid-Day Truck				55.0	0.00	0.0%
14 Evening Truck				55.0	0.00	0.0%
15 Night Truck				55.0	0.00	0.0%
16 Not Used				55.0	0.00	0.0%
TOTAL	0	0	0			

**2C AGGREGATE MODEL DATA - YEAR 20**

	Number of Trips	Vehicle Miles Traveled (VMT)	Vehicle Hours Traveled (VHT)	Speed	Avg. Vehicle Occupancy (AVO)	Percent Trucks
<b>No Build</b>						
1 AM Peak Auto				55.0	0.00	0.0%
2 PM Peak Auto				55.0	0.00	0.0%
3 Mid-Day Auto				55.0	0.00	0.0%
4 Evening Auto				55.0	0.00	0.0%
5 Night Auto				55.0	0.00	0.0%
6 AM Peak HOV				55.0	0.00	0.0%
7 PM Peak HOV				55.0	0.00	0.0%
8 Mid-Day HOV				55.0	0.00	0.0%
9 Evening HOV				55.0	0.00	0.0%
10 Night HOV				55.0	0.00	0.0%
11 AM Peak Truck				55.0	0.00	0.0%
12 PM Peak Truck				55.0	0.00	0.0%
13 Mid-Day Truck				55.0	0.00	0.0%
14 Evening Truck				55.0	0.00	0.0%
15 Night Truck				55.0	0.00	0.0%
16 Not Used				55.0	0.00	0.0%
TOTAL	0	0	0			
<b>Build</b>						
1 AM Peak Auto				55.0	0.00	0.0%
2 PM Peak Auto				55.0	0.00	0.0%
3 Mid-Day Auto				55.0	0.00	0.0%
4 Evening Auto				55.0	0.00	0.0%
5 Night Auto				55.0	0.00	0.0%
6 AM Peak HOV				55.0	0.00	0.0%
7 PM Peak HOV				55.0	0.00	0.0%
8 Mid-Day HOV				55.0	0.00	0.0%
9 Evening HOV				55.0	0.00	0.0%
10 Night HOV				55.0	0.00	0.0%
11 AM Peak Truck				55.0	0.00	0.0%
12 PM Peak Truck				55.0	0.00	0.0%
13 Mid-Day Truck				55.0	0.00	0.0%
14 Evening Truck				55.0	0.00	0.0%
15 Night Truck				55.0	0.00	0.0%
16 Not Used				55.0	0.00	0.0%
TOTAL	0	0	0			

Title | 1) Project Information | **2) Model Inputs** | 3) Results | Travel Time | Vehicle Operating Costs | Emissions | Final Calculations | PARAMETERS |

## 2.0 PROJECT INFORMATION

Cal-B/C Corridor has a simple interface similar to Cal-B/C, but it eliminates the Instruction page found in Cal-B/C. The Project Information page is the first page after the title page. This page is greatly simplified compared to the one in Cal-B/C, because the Model Inputs page is the primary place to enter data in Cal-B/C Corridor. As Exhibit IX-3 shows, many of the inputs in Cal-B/C are eliminated from Cal-B/C Corridor. The formatting and the box numbering reflect the fact that Cal-B/C Corridor is a modified version of Cal-B/C. Although the page has eliminated several inputs, users should enter the project data and project costs requested on the page.

### Exhibit IX-3: Cal-B/C Corridor Project Information Page

Division:

PROJECT:

EA:

PRNG:

Enter all project costs (in today's dollars) in columns 1 to 7. Costs during construction should be entered in the first eight rows. Project costs (including maintenance and operating costs) should be net of costs without project.

**PROJECT DATA**

**Project Location** (enter 1 for So. Cal., 2 for No. Cal., or 3 for rural)

Length of Construction Period  years

Year	INITIAL COSTS			SUBSEQUENT COSTS			Transit Agency Cost Savings	TOTAL COSTS (in dollars)	
	Project Support	ITF V	Construction	Maint. Op.	Rehab.	Mitigation		Constant Dollars	Present Value
<b>Construction Period</b>									
1								\$0	\$0
2								0	0
3								0	0
4								0	0
5								0	0
6								0	0
7								0	0
8								0	0
<b>Project Oper</b>									
1								\$0	\$0
2								0	0
3								0	0
4								0	0
5								0	0
6								0	0
7								0	0
8								0	0
9								0	0
10								0	0
11								0	0
12								0	0
13								0	0
14								0	0
15								0	0
16								0	0
17								0	0
18								0	0
19								0	0
20								0	0
<b>Total</b>	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

Present Value = Future Value / (1 + Real Discount Rate)<sup>Year</sup>

Exhibit IX-4 shows the Project Data requested on the Project Information Page. As in Cal-B/C, users must enter the project location, so the model can estimate emissions benefits correctly. The Length of the Construction Period input is treated the same way as in Cal-B/C. User benefits are expected to start after the construction period is completed. The Time to Construction Start input allows users to shift the start of the construction period. User benefits are discounted by the length of the construction period plus the time to construction start.

### Exhibit IX-4: Cal-B/C Corridor Project Information Page – Project Data

1A **PROJECT DATA**

**Project Location** (enter 1 for So. Cal., 2 for No. Cal., or 3 for rural)

Length of Construction Period  years

Time to Construction Start  years

As shown in Exhibit IX-5, the project cost inputs for Cal-B/C Corridor are identical to Cal-B/C. The box is labeled “1E” because Boxes 1B through 1D are part of the detailed project data inputs used in Cal-B/C and not included in Cal-B/C Corridor.

**Exhibit IX-5: Cal-B/C Corridor Project Information Page - Project Costs**

1E <b>PROJECT COSTS (enter costs in thousands of dollars)</b>									
Col. no.	(1)	(2)	(3)	(4)	(5)	(6)	(7)		
Year	DIRECT PROJECT COSTS			SUBSEQUENT COSTS		Mitigation	Transit Agency Cost Savings	TOTAL COSTS (in dollars)	
	Project Support	R / W	Construction	Maint./ Op.	Rehab.			Constant Dollars	Present Value
<b>Construction Period</b>									
1				<- Must enter a cost ->				\$0	\$0
2								0	0
3								0	0
4								0	0
5								0	0
6								0	0
7								0	0
8								0	0
<b>Project Open</b>									
1								\$0	\$0
2								0	0
3								0	0
4								0	0
5								0	0
6								0	0
7								0	0
8								0	0
9								0	0
10								0	0
11								0	0
12								0	0
13								0	0
14								0	0
15								0	0
16								0	0
17								0	0
18								0	0
19								0	0
20								0	0
<b>Total</b>	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

**3.0 MODEL INPUTS**

The Model Inputs page is where users can define the model groups and enter model data for the no-build and build scenarios.

Exhibit IX-6 shows Box 2A of the Model Inputs page. This box is where users define the model groups. For each of up to 100 model groups, users can enter a short name and a longer description. The names entered appear on subsequent tables in the model.

**Exhibit IX-6: Cal-B/C Corridor Model Inputs Page - Model Group Definitions**

2A

### DEFINITIONS OF MODEL GROUPS AND YEARS

	Name	Description	Avg. Vehicle Occupancy (AVO)	Percent Trucks
Model Group 1				
Model Group 2				
Model Group 3				
Model Group 4				
Model Group 5				
Model Group 6				
Model Group 7				
Model Group 8				
Model Group 9				
Model Group 10				
Model Group 11				
Model Group 12				

Base Year	1
Forecast Year	20

Average Vehicle Occupancy (AVO) and percent truck data help to determine the type of model group. For instance, users can enter 100 percent as the percent trucks for a model group that contains trucks only. Alternatively, a model group that contains a mix of automobile and trucks might contain a truck percentage much closer to the statewide average of 9 percent trucks. These percentages determine the correct values of time, fuel consumption rates, non-fuel operating costs, and emission rates used for the model groups. The AVO figures are used to calculate travel time benefits. Users can enter higher AVO figures for High Occupancy Vehicle (HOV) model groups than for non-HOV model groups.

Boxes 2B and 2C allow users to enter aggregate model data for the base and forecast years. Exhibits IX-7 and IX-8 show an example with only 12 model groups, but the actual boxes in Cal-B/C Corridor have space for 100 model groups. The years defined in the red cells of Box 1A (see Exhibit IX-6) appear as the titles in Boxes 2B and 2C. The model years should be entered as integers and indicate the number of years relative to when the analysis is conducted. For example, if the analysis is conducted in 2015 and the base year is 2020, "5" should be entered as the base year.

Exhibit IX-7: Cal-B/C Corridor Model Inputs Page - Year 1 Model Data

2B

AGGREGATE MODEL DATA - YEAR 1

	Number of Trips	Vehicle Miles Traveled (VMT)	Vehicle Hours Traveled (VHT)	Speed	Avg. Vehicle Occupancy (AVO)	Percent Trucks
<b>No Build</b>						
1 Not Used				55.0	0.00	0.0%
2 Not Used				55.0	0.00	0.0%
3 Not Used				55.0	0.00	0.0%
4 Not Used				55.0	0.00	0.0%
5 Not Used				55.0	0.00	0.0%
6 Not Used				55.0	0.00	0.0%
7 Not Used				55.0	0.00	0.0%
8 Not Used				55.0	0.00	0.0%
9 Not Used				55.0	0.00	0.0%
10 Not Used				55.0	0.00	0.0%
11 Not Used				55.0	0.00	0.0%
12 Not Used				55.0	0.00	0.0%
TOTAL	0	0	0			

<b>Build</b>						
1 Not Used				55.0	0.00	0.0%
2 Not Used				55.0	0.00	0.0%
3 Not Used				55.0	0.00	0.0%
4 Not Used				55.0	0.00	0.0%
5 Not Used				55.0	0.00	0.0%
6 Not Used				55.0	0.00	0.0%
7 Not Used				55.0	0.00	0.0%
8 Not Used				55.0	0.00	0.0%
9 Not Used				55.0	0.00	0.0%
10 Not Used				55.0	0.00	0.0%
11 Not Used				55.0	0.00	0.0%
12 Not Used				55.0	0.00	0.0%
TOTAL	0	0	0			



**Exhibit IX-8: Cal-B/C Corridor Model Inputs Page - Year 20 Model Data**

2C

### AGGREGATE MODEL DATA - YEAR 20

		Vehicle Miles Traveled (VMT)	Vehicle Hours Traveled (VHT)	Speed	Avg. Vehicle Occupancy (AVO)	Percent Trucks
<b>No Build</b>						
1 Not Used				55.0	0.00	0.0%
2 Not Used				55.0	0.00	0.0%
3 Not Used				55.0	0.00	0.0%
4 Not Used				55.0	0.00	0.0%
5 Not Used				55.0	0.00	0.0%
6 Not Used				55.0	0.00	0.0%
7 Not Used				55.0	0.00	0.0%
8 Not Used				55.0	0.00	0.0%
9 Not Used				55.0	0.00	0.0%
10 Not Used				55.0	0.00	0.0%
11 Not Used				55.0	0.00	0.0%
12 Not Used				55.0	0.00	0.0%
<b>TOTAL</b>	<b>0</b>	<b>0</b>	<b>0</b>			
<b>Build</b>						
1 Not Used				55.0	0.00	0.0%
2 Not Used				55.0	0.00	0.0%
3 Not Used				55.0	0.00	0.0%
4 Not Used				55.0	0.00	0.0%
5 Not Used				55.0	0.00	0.0%
6 Not Used				55.0	0.00	0.0%
7 Not Used				55.0	0.00	0.0%
8 Not Used				55.0	0.00	0.0%
9 Not Used				55.0	0.00	0.0%
10 Not Used				55.0	0.00	0.0%
11 Not Used				55.0	0.00	0.0%
12 Not Used				55.0	0.00	0.0%
<b>TOTAL</b>	<b>0</b>	<b>0</b>	<b>0</b>			

For each model group, the primary data required are VMT and VHT. Cal-B/C Corridor calculates speeds directly from these two figures. Users can override the calculated speeds if the average speeds are included in the regional travel demand or simulation model output. Cal-B/C Corridor populates the percent truck and AVO fields with the values provided in Box 2A. These should be changed only if they vary from the base year to the forecast year or from the no-build scenario to the build scenario.

Boxes 2B and 2C also allow users to enter trip data. This information is not required and is used only to estimate induced demand. If the trip data is not entered, the model calculates benefits without induced demand. The detailed travel time tables list the number of trips as 1, but this does not affect the calculations and should not be changed.

#### 4.0 BENEFIT CALCULATIONS

Cal-B/C Corridor has only three detailed user benefit pages, because safety benefits cannot be calculated easily for an aggregate network. If users have estimates of safety

benefits, they can be calculated externally and entered on the Final Calculations page (where the safety benefits are set to 0 by default). The remaining three benefit pages are like the ones found in Cal-B/C, but the calculations are generic and defined by the model groups entered on the Model Inputs page.

Each of the three user benefits pages has 100 tables to calculate user benefits for the model groups. Exhibit IX-9 shows an example of a benefit calculation table. In this example, the table is labeled as “Not Used.” In an actual run of Cal-B/C Corridor, the benefit tables are labeled with the model group names assigned by the user on the Model Inputs page. Likewise, the benefits are estimated using the AVO and percent truck definitions supplied by users.

### Exhibit IX-9: Example of Cal-B/C Corridor Benefit Calculation

A

MODEL BENEFITS

1 Not Used

Year	TOTAL VMT (veh-miles/yr)		TOTAL VHT (veh-hrs/yr)		AVERAGE SPEED (mph)		PERCENT TRUCKS (%)		BENEFITS (\$/yr)		Constant Dollars	Present Value
	No Build	Build	No Build	Build	No Build	Build	No Build	Build	Fuel Costs	Non-Fuel Costs		
1	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
20	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
1	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
2	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
3	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
4	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
5	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
6	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
7	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
8	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
9	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
10	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
11	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
12	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
13	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
14	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
15	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
16	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
17	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
18	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
19	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
20	0	0	0	0	55.0	55.0	0.0%	0.0%	\$0	\$0	\$0	\$0
<b>Total</b>												<b>\$0</b>

The Final Calculations, Results, and Parameters pages are linked to these benefit pages and look similar to those found in Cal-B/C. Exhibit IX-10 shows an example of the Final Calculations page. While Cal-B/C allows users to analyze up to three “roads,” Cal-B/C Corridor provides room for four locations. The additional (fourth) location allows users to calculate benefits for up to 400 model groups - 100 groups at a time for four times.

The Model Inputs page has a macro button labeled “Prepare Model for Next Location.” The macro allows users to get the model ready for the next set of model group data. This shifts the total benefits summarized in the Final Calculations page over one location and clears the model group definitions on the Model Input page. Cal-B/C Corridor should be saved before the macro button is pressed to retain detailed interim results.

## Exhibit IX-10: Cal-B/C Corridor Final Calculations Page

A. NET PRESENT VALUE CALCULATION

Year	PRESENT VALUE OF USER BENEFITS (Location 1)				PRESENT VALUE OF USER BENEFITS (Location 2)				PRESENT VALUE OF USER BENEFITS (Location 3)				PRESENT VALUE OF USER BENEFITS (Location 4)				Present Value of Total User Benefits	Present Value of Total Project Costs	NET PRESENT VALUE	
	Travel Time Savings	Vehicle Op. Cost Savings	Accident Reductions	Vehicle Emission Reductions	Travel Time Savings	Vehicle Op. Cost Savings	Accident Reductions	Vehicle Emission Reductions	Travel Time Savings	Vehicle Op. Cost Savings	Accident Reductions	Vehicle Emission Reductions	Travel Time Savings	Vehicle Op. Cost Savings	Accident Reductions	Vehicle Emission Reductions				
<b>Construction Period</b>																				
1																	\$0	\$0	\$0	
2																	\$0	\$0	\$0	
3																	\$0	\$0	\$0	
4																	\$0	\$0	\$0	
5																	\$0	\$0	\$0	
6																	\$0	\$0	\$0	
7																	\$0	\$0	\$0	
8																	\$0	\$0	\$0	
<b>Project Open</b>																				
1				#N/A													#N/A	\$0	#N/A	
2				#N/A													#N/A	\$0	#N/A	
3				#N/A													#N/A	\$0	#N/A	
4				#N/A													#N/A	\$0	#N/A	
5				#N/A													#N/A	\$0	#N/A	
6				#N/A													#N/A	\$0	#N/A	
7				#N/A													#N/A	\$0	#N/A	
8				#N/A													#N/A	\$0	#N/A	
9				#N/A													#N/A	\$0	#N/A	
10				#N/A													#N/A	\$0	#N/A	
11				#N/A													#N/A	\$0	#N/A	
12				#N/A													#N/A	\$0	#N/A	
13				#N/A													#N/A	\$0	#N/A	
14				#N/A													#N/A	\$0	#N/A	
15				#N/A													#N/A	\$0	#N/A	
16				#N/A													#N/A	\$0	#N/A	
17				#N/A													#N/A	\$0	#N/A	
18				#N/A													#N/A	\$0	#N/A	
19				#N/A													#N/A	\$0	#N/A	
20				#N/A													#N/A	\$0	#N/A	
<b>Total</b>	\$0	\$0		#N/A	\$0	\$0		#N/A	\$0	\$0		#N/A	\$0	\$0		#N/A	\$0	#N/A	\$0	#N/A

<input type="checkbox"/> Person Hours of Time Saved	<input type="checkbox"/> Person Hours of Time Saved	<input type="checkbox"/> Person Hours of Time Saved	<input type="checkbox"/> Person Hours of Time Saved
<input type="checkbox"/> CO <sub>2</sub> Emissions Saved (tons)	<input type="checkbox"/> CO <sub>2</sub> Emissions Saved (tons)	<input type="checkbox"/> CO <sub>2</sub> Emissions Saved (tons)	<input type="checkbox"/> CO <sub>2</sub> Emissions Saved (tons)
#N/A	#N/A	#N/A	#N/A

Exhibit IX-11 shows a snapshot of the Cal-B/C Corridor Results page. This page is nearly identical to the Cal-B/C Results page. The only difference is that accident cost savings are shaded gray, because Cal-B/C Corridor does not calculate these savings. The formulas are still linked to the Final Calculations page, so users can manually enter safety savings estimated externally on this page and include the benefits in the overall benefit-cost calculation.

Cal-B/C Corridor has a Parameters page identical to the one in Cal-B/C. The Parameters page (the last sheet in Cal-B/C Corridor) contains all of the economic values and rate tables. Project-specific parameters, such as weaving adjustments, are retained to highlight the fact that Cal-B/C Corridor is a modified version of Cal-B/C. This also facilitates updates to the parameters in both models.

### Exhibit IX-11: Cal-B/C Corridor Results Page

District: **HQ** EA:

PROJECT: **Hypothetical Project** PPNO:

3

#### INVESTMENT ANALYSIS

##### SUMMARY RESULTS

<b>Life-Cycle Costs (mil. \$)</b>		\$0.0			
<b>Life-Cycle Benefits (mil. \$)</b>		#N/A			
<b>Net Present Value (mil. \$)</b>		#N/A			
<b>Benefit / Cost Ratio:</b>		N/A			
<b>Rate of Return on Investment:</b>		N/A			
<b>Payback Period:</b>		N/A			

	Average Annual	Total Over 20 Years
<b>ITEMIZED BENEFITS (mil. \$)</b>		
<b>Travel Time Savings</b>	\$0.0	\$0.0
<b>Veh. Op. Cost Savings</b>	\$0.0	\$0.0
<b>Accident Cost Savings</b>	\$0.0	\$0.0
<b>Emission Cost Savings</b>	#N/A	#N/A
<b>TOTAL BENEFITS</b>	#N/A	#N/A
<b>Person-Hours of Time Saved</b>	0	0
<b>CO<sub>2</sub> Emissions Saved (tons)</b>	0	0
<b>CO<sub>2</sub> Emissions Saved (mil. \$)</b>	#N/A	#N/A

**Should benefit-cost results include:**

1) Induced Travel? (y/n)   
Default = Y

2) Vehicle Operating Costs? (y/n)   
Default = Y

3) Accident Costs are not included

4) Vehicle Emissions? (y/n)   
Default = Y  
includes value for CO<sub>2</sub>e

## 5.0 INTERCHANGE EXAMPLE

This section provides a brief example of using Cal-B/C Corridor to analyze an interchange project. The project shown was evaluated in a VISSUM micro-simulation model for the build and no-build conditions in the base year and forecast year as part of a Project Report. VMT and VHT results were extracted for each of 12 major travel movements through the interchange. These data can be entered into Cal-B/C Corridor, which monetizes the benefits and calculates the benefit-cost ratio.

The micro-simulation data are critical to the analysis - Cal-B/C Corridor does not have rules of the thumb to estimate project benefits. Unlike Cal-B/C, the corridor version of the model requires analysis in an external model to generate the VMT and VHT results.

Exhibits IX-12 and IX-13 show the data entered on the Cal-B/C Corridor Project Information page to analyze the interchange benefits. The time to construction start is set to one year. This discounts the construction costs and benefits estimated by an additional year to take into account an anticipated construction start one year from

Cal-B/C Corridor

IX-13

System Metrics Group, Inc.

now. The four-year construction period means that first-year benefits are discounted by five years (i.e., one year time to construction start plus four years construction period).

**Exhibit IX-12: Project Data Inputted into Cal-B/C Corridor  
Project Information Page**

1A
PROJECT DATA

**Project Location** (enter 1 for So. Cal., 2 for No. Cal., or 3 for rural) 1

Length of Construction Period 4 years

Time to Construction Start 1 years

The capital outlays anticipated for the project are entered directly into the model for a four-year construction period as shown in Exhibit IX-13. This construction schedule assumes that costs are expended 20 percent in the first year, 30 percent each in the next two years, and 20 percent in the final year. As in Cal-B/C, the model assumes project benefits begin after construction ends.

### Exhibit IX-13: Project Costs Inputted into Cal-B/C Corridor Project Information Page

1E PROJECT COSTS (enter costs in thousands of dollars)									
Col. no.	(1)	(2)	(3)	(4)	(5)	(6)	(7)		
Year	INITIAL COSTS			SUBSEQUENT COSTS		Mitigation	Transit Agency Cost Savings	TOTAL COSTS (in dollars)	
	Project Support	R / W	Construction	Maint./ Op.	Rehab.			Constant Dollars	Present Value
<b>Construction Period</b>									
1			\$61,496					\$61,495,600	\$57,472,523
2			92,243					92,243,400	80,568,958
3			92,243					92,243,400	75,298,092
4			61,496					61,495,600	46,914,699
5								0	0
6								0	0
7								0	0
8								0	0
<b>Project Open</b>									
1								\$0	\$0
2								0	0
3								0	0
4								0	0
5								0	0
6								0	0
7								0	0
8								0	0
9								0	0
10								0	0
11								0	0
12								0	0
13								0	0
14								0	0
15								0	0
16								0	0
17								0	0
18								0	0
19								0	0
20								0	0
<b>Total</b>	\$0	\$0	\$307,478	\$0	\$0	\$0	\$0	\$307,478,000	\$260,254,272

The detailed model data from the simulation model are entered into the Cal-B/C Corridor Model Inputs page as shown in Exhibits IX-14 through IX-16. There are 12 user groups defined by a combination of travel movements and peak periods. These are identified in the box shown in Exhibit IX-14. The AVO for all model groups is assumed to be the standard 1.15 people per vehicle used in the Cal-B/C framework for peak period travel. The percent trucks is not entered in this box because the percentage is expected to vary between the two future years.

The forecast years from the simulation model correspond to Year 1 and Year 24 of the project lifecycle. These are identified in the box shown in Exhibit IX-14, so Cal-B/C Corridor can correctly interpolate the VMT and VHT data. Cal-B/C Corridor estimates benefits for a 20-year lifecycle, so the final year of analysis corresponds to interpolated values four years before the final simulation model forecast.

### Exhibit IX-14: Definition of User Groups Entered into Cal-B/C Corridor Model Inputs Page

2A

#### DEFINITIONS OF MODEL GROUPS AND YEARS

	Name	Description	Avg. Vehicle Occupancy (AVO)	Percent Trucks
Model Group 1	AM15SThru	AM I-15 SB Thru traffic	1.15	
Model Group 2	AM15S215S	AM I-15 SB to I-215 SB	1.15	
Model Group 3	AM15NThru	AM I-15 NB Thru traffic	1.15	
Model Group 4	AM15N215S	AM I-15 NB to I-215 SB	1.15	
Model Group 5	AM215N15N	AM I-215 NB to I-15 NB	1.15	
Model Group 6	AM215N15S	AM I-215 NB to I-15 SB	1.15	
Model Group 7	PM15SThru	PM I-15 SB Thru traffic	1.15	
Model Group 8	PM15S215S	PM I-15 SB to I-215 SB	1.15	
Model Group 9	PM15NThru	PM I-15 NB Thru traffic	1.15	
Model Group 10	PM15N215S	PM I-15 NB to I-215 SB	1.15	
Model Group 11	PM215N15N	PM I-215 NB to I-15 NB	1.15	
Model Group 12	PM215N15S	PM I-215 NB to I-15 SB	1.15	
Base Year			1	
Forecast Year			24	

The VMT and VHT data are entered in the next two boxes on the Cal-B/C Corridor Model Inputs page. These are shown in Exhibits IX-15 and IX-16. The speed is calculated automatically from the VMT and VHT and the AVO is referenced from the box shown in Exhibit IX-14. The percent trucks data are entered independently for each forecast year, since they are expected to be different in the two years. Note that the years in the two exhibits change automatically to reflect the years entered in the red boxes in Exhibit IX-14 (i.e., Year 1 and Year 24).

The existing year traffic in the simulation model was calibrated to actual freeway conditions measured by the Caltrans Freeway Performance Measurement System (PeMS) and through traffic counts. Future forecasts were developed for the project opening year and 23 years later. These forecasts are consistent with the latest regional travel demand model and are documented in the Project Report.

## Exhibit IX-15: Model Data for Year 1 Entered into Cal-B/C Corridor Model Inputs Page

2B

### AGGREGATE MODEL DATA - YEAR 1

		Vehicle Miles Traveled (VMT)	Vehicle Hours Traveled (VHT)	Speed	Avg. Vehicle Occupancy (AVO)	Percent Trucks
<b>No Build</b>						
1	AM15SThru	76,893	1,768	43.5	1.15	12.4%
2	AM15S215S	42,221	944	44.7	1.15	4.8%
3	AM15NThru	39,179	669	58.6	1.15	10.6%
4	AM15N215S	5,947	112	53.1	1.15	5.2%
5	AM215N15N	14,677	254	57.8	1.15	15.6%
6	AM215N15S	6,541	132	49.6	1.15	5.7%
7	PM15SThru	71,767	1,330	54.0	1.15	13.3%
8	PM15S215S	29,853	587	50.9	1.15	9.1%
9	PM15NThru	91,310	2,607	35.0	1.15	15.4%
10	PM15N215S	7,283	199	36.7	1.15	4.7%
11	PM215N15N	44,705	1,068	41.9	1.15	5.4%
12	PM215N15S	8,567	164	52.1	1.15	5.0%
	<b>TOTAL</b>	<b>0</b>	<b>438,942</b>			
<b>Build</b>						
1	AM15SThru	76,893	1,270	60.5	1.15	12.4%
2	AM15S215S	42,221	692	61.0	1.15	4.8%
3	AM15NThru	39,179	634	61.8	1.15	10.6%
4	AM15N215S	5,947	98	60.8	1.15	5.2%
5	AM215N15N	14,677	248	59.2	1.15	15.6%
6	AM215N15S	6,541	117	56.1	1.15	5.7%
7	PM15SThru	71,767	1,186	60.5	1.15	13.3%
8	PM15S215S	29,853	488	61.2	1.15	9.1%
9	PM15NThru	91,310	1,574	58.0	1.15	15.4%
10	PM15N215S	7,283	121	60.3	1.15	4.7%
11	PM215N15N	44,705	753	59.4	1.15	5.4%
12	PM215N15S	8,567	154	55.5	1.15	5.0%
	<b>TOTAL</b>	<b>0</b>	<b>438,942</b>	<b>7,335</b>		



### Exhibit IX-16: Model Data for Year 24 Entered into Cal-B/C Corridor Model Inputs Page

2C

#### AGGREGATE MODEL DATA - YEAR 24

	Number of Trips	Vehicle Miles Traveled (VMT)	Vehicle Hours Traveled (VHT)	Speed	Avg. Vehicle Occupancy (AVO)	Percent Trucks
<b>No Build</b>						
1 AM15SThru		122,296	2,470	49.5	1.15	13.2%
2 AM15S215S		69,485	1,492	46.6	1.15	3.6%
3 AM15NThru		71,742	1,912	37.5	1.15	15.9%
4 AM15N215S		10,070	273	36.9	1.15	3.3%
5 AM215N15N		29,051	649	44.8	1.15	11.3%
6 AM215N15S		7,496	151	49.7	1.15	9.3%
7 PM15SThru		123,739	2,886	42.9	1.15	16.3%
8 PM15S215S		59,667	1,228	48.6	1.15	6.3%
9 PM15NThru		140,993	5,182	27.2	1.15	16.2%
10 PM15N215S		11,811	364	32.4	1.15	7.0%
11 PM215N15N		73,409	2,768	26.5	1.15	5.2%
12 PM215N15S		10,690	311	34.4	1.15	4.4%
<b>TOTAL</b>	<b>0</b>	<b>730,449</b>	<b>19,685</b>			
<b>Build</b>						
1 AM15SThru		122,296	2,070	59.1	1.15	13.2%
2 AM15S215S		69,485	1,180	58.9	1.15	3.6%
3 AM15NThru		71,742	1,230	58.3	1.15	15.9%
4 AM15N215S		10,070	170	59.4	1.15	3.3%
5 AM215N15N		29,051	502	57.8	1.15	11.3%
6 AM215N15S		7,496	140	53.7	1.15	9.3%
7 PM15SThru		123,739	2,084	59.4	1.15	16.3%
8 PM15S215S		59,667	994	60.0	1.15	6.3%
9 PM15NThru		140,993	2,567	54.9	1.15	16.2%
10 PM15N215S		11,811	203	58.2	1.15	7.0%
11 PM215N15N		73,409	1,291	56.9	1.15	5.2%
12 PM215N15S		10,690	205	52.1	1.15	4.4%
<b>TOTAL</b>	<b>0</b>	<b>730,449</b>	<b>12,636</b>			

The Project Report also presents detailed accident data and an analysis of safety conditions. The report includes actual three-year accident data by accident type for multiple separate locations along the corridor as well as the corresponding accident rates from the Caltrans Traffic Accident Surveillance and Analysis System (TASAS) database. In addition, the Project Report includes an accident analysis that identifies causes of excess accidents and locations where the build alternative is expected to reduce rates to the statewide average.

Since Cal-B/C Corridor does not estimate safety benefits, the benefits must be estimated externally in a spreadsheet created specifically for the analysis. The safety benefits are estimated yearly using the monetization factors found on the Parameters page of Cal-B/C Corridor. The discounted benefits are inputted into the Final Calculations page of Cal-B/C Corridor. The model automatically includes the safety results in the analysis. However, the safety benefits continue to be shown in gray on the Cal-B/C Corridor Results page unless the user changes the text color to black.