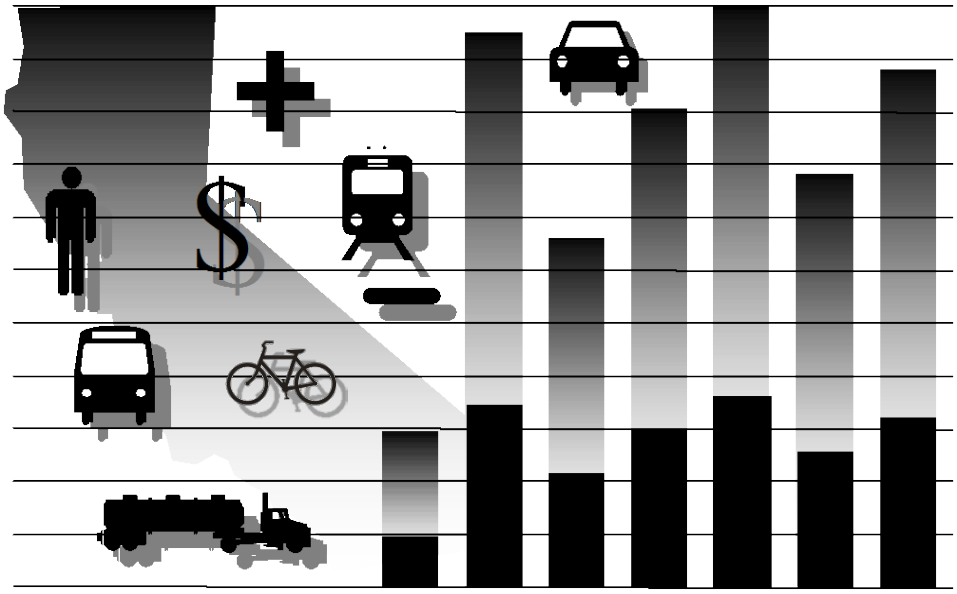
California Department Of Transportation

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

Technical Supplement to User's Guide

Volume 4: Active Transportation, Park and Ride, and Risk Analysis

December 2017



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I.

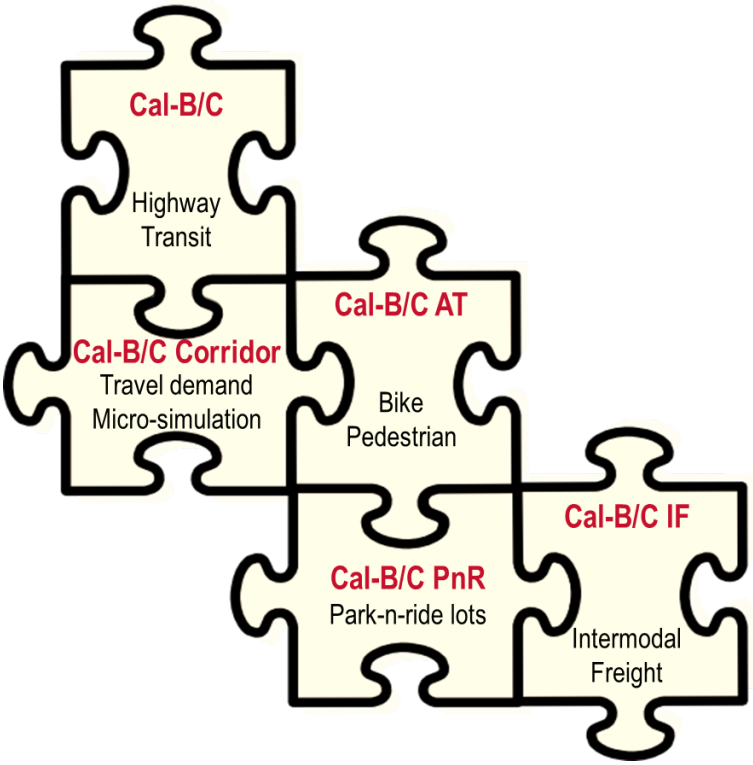
Introduction

I. Introduction

This volume of the Technical Supplement (Volume 4) describes changes made to Cal-B/C for version 6.2. Other volumes of the Technical Supplement describe earlier model development and other aspects of Cal-B/C. 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, which incorporated methods to analyze high occupancy toll (HOT)/express lanes, grade separated rail crossings, and queuing analysis. The 2009 and 2012 revisions also added Cal-B/C Corridor to the Cal-B/C suite of tools.

While the original Cal-B/C model is a spreadsheet-based, sketch planning tool that can prepare analyses of highway, transit, and passenger rail, the latest update expands the Cal-B/C framework to include several other modes. Exhibit I-1 shows all five tools in the Cal-B/C framework, which together allow users to consider many different types of projects.

Exhibit I-1: Cal-B/C Framework



Complementing the original Cal-B/C model, which focuses on highway and transit models, are two sketch planning models tailored to active transportation (AT) projects and park-and-ride (PnR) programs. In addition, a fourth model, called Cal-B/C Corridor, allows users to post-process travel demand and micro-simulation model data, while a fifth model is available to analyze intermodal

freight (IF) improvements. All five tools in the Cal-B/C suite use consistent methods, rely on the same parameters, and produce comparable results.

All five models have instructions pages built into their spreadsheets. Cal-B/C and Cal-B/C AT have their own User's Guides, while Volume 3 of the Technical Supplement provides additional instructions on Cal-B/C Corridor. Cal-B/C PnR and Cal-B/C IF are documented in Volume 4.

The latest (2017) revision to Cal-B/C considered methods to analyze freight projects better in the original Cal-B/C model. It also considered the development of standalone freight models. The review resulted in an updated Cal-B/C that allows users to report on freight and passenger benefits separately.

The 2017 revision also resulted in the development of Cal-B/C AT. This model reflects recommended updates to a first-generation BCA model that Caltrans developed in 2014 in conjunction with the Active Transportation Program (ATP) project selection process. Refinements to the methods and data of the original Cal-B/C Active Transportation model were developed through a comprehensive literature review and coordination with a number of people and organizations. These refinements include:

- Improved specification of data entry requirements;
- Expanded set of benefit categories;
- Updated benefit estimation methods and data; and
- Integration of additional data from 2010 California Household Transportation Survey, Bureau of Labor Statistics (BLS), US Census Bureau, California Department of Public Health, US Department of Health and Human Services, and Caltrans' Local Roadway Safety Manual for Californian Road Owners.

Although the new model is a second generation model, it is labeled 6.2 to be consistent with the version numbers for other Cal-B/C models.

In addition, the 2017 revision added the ability to evaluate park and ride/intermodal strategies to the Cal-B/C suite of tools. Cal-B/C PnR is based upon a tool developed in 2013 for Caltrans District 12 in conjunction with other districts and park and ride programs statewide to estimate the benefits of new park and ride lots, park and ride lot expansions, and leased lots. The tool includes consideration of bicycle and pedestrian access modes and can be used with Cal-B/C AT for a complete, multi-modal assessment.

Cal-B/C PnR is essentially the same as the original District 12 model, which was developed for compatibility with Cal-B/C. The Cal-B/C development team reformatted the model slightly to be consistent with other Cal-B/C models. The parameters were updated and incorporated into the parameters page shared by all Cal-B/C models. Also, the development team incorporated a macro that allows more destinations to be considered in an analysis.

The 2017 revision resulted in the development of Cal-B/C IF. This model provides the ability to conduct benefit-cost analysis of intermodal freight projects. The model estimates the benefits for bulk/break bulk and containerized shipments. It undertakes a holistic approach in estimating

project benefits by considering full freight movements, drayage, and transloading operations. In general, project types that can be assessed by Cal-B/C IF include:

- Modal Diversion
- Network Expansion and Improvements
- Terminal Efficiency Improvements.

The revision also updated all economic values and parameters and incorporated risk analysis into the Cal-B/C suite. A special version of Cal-B/C was developed to support the analysis of project uncertainty. This version uses an Excel add-in called Risk Analyzer to conduct Monte Carlo simulations. These simulations allow multiple model inputs to be varied simultaneously within predefined probability distributions. This approach also recognizes correlations between variables and coefficients. The Cal-B/C development team considered which variables to include in risk analysis, identified appropriate distributions, and prepared instructions on how to conduct Monte Carlo simulation. There is a Monte Carlo-ready version of the base model only. Monte Carlo versions of other models in the Cal-B/C suite may be developed in future updates after risk analysis is tested on projects using the base model.

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

- *Economic and Parameter Updates* – describes the new economic and parameter values adopted for Cal-B/C 6.2. In the 2017 revision, the Cal-B/C development team updated the economic values to 2016 dollars. The same parameters are used in all tools in the Cal-B/C suite.

- *Active Transportation* – discusses the development of Cal-B/C AT. The chapter provides an overview of the benefit-cost literature for active transportation modes. It also provides a description of the methods used in Cal-B/C AT.

- *Park and Ride* – documents the original model developed for Caltrans District 12 and discusses the updates made for Cal-B/C PnR.

- *Risk Analysis* – contains recommendations for input parameter values and distribution types when conducting risk analysis in Cal-B/C using Risk Analyzer software. It also provides instructions on how to use Risk Analyzer in conjunction with the special version of Cal-B/C that supports risk analysis.

- *Intermodal Freight* – documents the functionality, capabilities, and limitations of the Cal-B/C IF model.

II.

Economic and Parameter Value Updates

II. Economic and Parameter Updates

This chapter describes the updates that the Cal-B/C development team made to the model parameters for Cal-B/C 6.2. The material is revised from Chapter III of the Technical Supplement Volume 3 (Revision 2) to reflect changes made for the latest Cal-B/C models, which use economic values in 2016 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 4.0 and 5.0. As the latest document of the economic parameters, it replaces comparable chapters in earlier volumes of the Technical Supplement.

In addition, the Cal-B/C development team reviewed many of the basic parameters during the Cal-B/C 5.0 update to make sure they were current. Some of these parameters were further updated for Cal-B/C 6.2. For example, the emissions rates reflect those found in the latest California Air Resources Board (CARB) model, EMFAC2014. Cal-B/C 6.2 retains the two biggest updates from Cal-B/C 4.0 - 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.

Cal-B/C 6.2 also adds economic values for the evaluation of active transportation (AT) projects. These values will be incorporated into the final version of the technical documentation.

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
- Active Transportation Parameters
- References.

1 General Economic Values

1.1 Year of Current Dollars

The prior version of Cal-B/C (v5.0) calculates economic results in 2011 dollars. Cal-B/C 6.2 uses 2016 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 publishes 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 II-1 shows the GDP deflator figures from the 2017 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. As can be seen in the exhibit, inflation has been fairly low over the last five years. In cases were new source data were not available, old Cal-B/C economic values were adjusted by a factor of 1.0846 (or 1.1164/1.0293) to restate 2011 dollar values in 2016 dollars.

Exhibit II-1: Gross Domestic Product (GDP) Deflator

Fiscal Year	Chained GDP Price Index	Year-Over-Year Inflation	Annual Inflation Factor
2011	1.0293	-	-
2012	1.0481	1.83%	1.83%
2013	1.0661	1.72%	1.77%
2014	1.0843	1.71%	1.75%
2015	1.0990	1.36%	1.65%
2016	1.1164	1.58%	1.64%

Source: Office of Management and Budget, Budget of the United States Government, Fiscal Year 2017 Budget (FY17), Table 10.1—Gross Domestic Product and Deflators Used in the Historical Tables: 1940-2021.

Revision Made to Cal-B/C: adjusted economic values without new source data by a factor of 1.0846 to restate in 2016 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 7 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 II-2 shows historical nominal interest rates from the November 2015 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 2011 revision, rates were below 4 percent. Now, nominal interest rates are around 3.5 percent.

Exhibit II-2: Table of Past Year Nominal Interest Rates from Appendix C of OMB Circular No. A-94, Revised November 2015

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
2013	0.5	1.1	1.5	2.0	2.7	3.0
2014	1.0	1.9	2.5	3.0	3.6	3.9
2015	1.7	2.2	2.5	2.8	3.1	3.4
2016	2.0	2.4	2.7	2.9	3.2	3.5

Source: Office of Management and Budget, Memorandum M-16-05, 2016 Discount Rates for OMB Circular No. A-94, <https://www.whitehouse.gov/sites/default/files/omb/assets/a94/dischist-2016.pdf>, accessed June 27, 2016.

In its February 2016 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. Nominal interest rates need to be adjusted for inflation in order to discount user benefits in constant dollars. Exhibit II-3 shows the nominal and real discount rates reported in the November 2015 OMB circular. The circular suggests using a much lower real discount (1.5 percent rate) than the one used Cal-B/C 5.0 (4.0 percent rate).

Exhibit II-3: Table of Suggested Discount Rates from Appendix C of OMB Circular No. A-94, Revised November 2015

Nominal Discount Rates. A forecast of nominal or market interest rates for calendar year 2016 based on the economic assumptions for the 2017 Budget is 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)

3-Year	5-Year	7-Year	10-Year	20-Year	30-Year
2.0	2.4	2.7	2.9	3.2	3.5

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 2017 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)

3-Year	5-Year	7-Year	10-Year	20-Year	30-Year
0.3	0.6	0.8	1.0	1.2	1.5

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, Discount Rates for OMB Circular No. A-94, <https://www.whitehouse.gov/omb/circulars_a094/a94_appx-c>, accessed June 27, 2016.

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 and FASTLANE 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 20 years (i.e., 4 to 5 percent).

As part of the 2009 Cal-B/C update, the Cal-B/C development team examined the interest earned on the Pooled Money Investment Account (PMIA) to compare these national rates with California figures. 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 fiscal 1971/72 and monthly yields since 1977 on its website.

Exhibit II-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 II-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 prior versions 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. Although the lower discount rate increases lifecycle costs, it also reduces the discounting of future benefits and increases benefit-cost ratios overall. Other rates, such as 3.0 percent and 7.0 percent can be tested in sensitivity analysis or when the model is used as part of grant applications (e.g., TIGER and FASTLANE) that require the use of these rates.

Revision Made to Cal-B/C: retained real discount rate of 4.0 percent

2 Highway Operations Parameters

For Cal-B/C 6.2, the development team established new values for the average vehicle occupancy (AVO) and the percent of travel by time of day using information from the 2010-2012 California Household Travel Survey. The time of day information leads to slightly lower percentages of traffic during the peak period, which lowers project benefits compared to prior versions of Cal-B/C. The source used to estimate the percentage trucks is no longer available. However, an analysis of 2009 truck count data during the 2012 Cal-B/C update corroborated the prior value.

The discussion that follows explains updates made to the highway operations parameters for Cal-B/C 6.2. In addition, the text includes discussions from prior Cal-B/C updates when it is still relevant or adds historical context.

2.1 Average Vehicle Occupancy (AVO)

Cal-B/C 3.2 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 were based upon national statistics reported for California. There is no single group within the Department dedicated to collecting ongoing 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 also does not collect AVO data. Future Federal guidelines may 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 once every ten years, the Department conducts a statewide travel survey. The latest was conducted in 2012. The final report for the 2010-2012 California Household Travel Survey does not list AVO figures, but the Statewide Travel Analysis Branch was able to provide AVO data queried from the travel survey database. This information provides the following AVO figures:

- All Trips (24 hours) – 1.5
- All Trips (7 AM to 9 AM) – 1.6
- Home-Work Trips (24 hours) – 1.2
- Home-Work Trips (7 AM to 9 AM) – 1.4.

District HOV Reports. District HOV branches within the Division of Traffic Operations collect AVO data twice per year through manual observations as part of their HOV studies. This information is gathered 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. For the 2009 update, 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).

Newer HOV reports are not available for District 3, but more recent HOV reports are available for Districts 4 and 7. AVO data collection stopped after 2011 as the focus of the HOV reports shifted to the performance of the HOV lanes and the reports were renamed Managed Lane reports.

According to the 2004 HOV report for District 3, 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 II-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 II-5: AVO on HOV Corridors in the Sacramento Area

Route 99						
Year (# of Lanes)	Northbound – AM			Southbound - PM		
	HOV Lane	Mixed Flow Lanes	All Lanes	HOV Lane	Mixed Flow Lanes	All Lanes
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

US 50						
Year	Westbound – AM			Eastbound - PM		
	HOV Lane	Mixed Flow Lanes	All Lanes	HOV Lane	Mixed Flow Lanes	All Lanes
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 a more extensive HOV system than does Sacramento. According to the 2011 HOV report for District 4, nearly 438 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: 2.0 to 2.9 persons per vehicle, with most measurements around 2.4 (an increase from the 2.1 reported in the 2004 report)
  - An outlier occurs on US 101 in Marin with 3.3 persons per vehicle.
  - Another occurs on SR-84 in Alameda with 4.3 persons per vehicle.
- Peak period mixed flow occupancy rate: 1.0 to 1.4 persons per vehicle, with most measurements around 1.1.
- Overall occupancy rate for the peak period: 1.1 to 1.8 persons per vehicle with most measurements around 1.3.

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

- Peak period HOV occupancy rate: 2.6 to 4.3 persons per vehicle with most measurements around 3.4 persons per vehicle (note: lower occupancies are possible due to motorcycles and two-seater vehicles.)

- Peak period mixed flow occupancy rate: 1.1 to 1.2 persons per vehicle, with most measurements around 1.2.

Los Angeles (District 7) also has an extensive HOV system, with 514 lane-miles of HOV facilities in 2011. 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: 2.02 to 2.67 persons per vehicle, with most measurements around 2.2 persons per vehicle
- Peak period mixed flow occupancy rate: 1.01 to 1.17 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: 4.17 to 4.59 persons per vehicle, which is higher than 4.0 due to a large number of buses.
- Peak period mixed flow occupancy rate: 1.04 to 1.13 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 2009 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 (as of 2009), 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 II-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 II-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 sources, the Cal-B/C development team decided to retain the AVO defaults developed in the 2009 update for Cal-B/C 6.2:

- 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: existing AVO figures retained based on 2010-2012 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:

Speed = Free-Flow Speed / (1 + 0.15*(v/c) ^10), where
v = volume
c = "practical" capacity

The model calculated capacity, c, as:

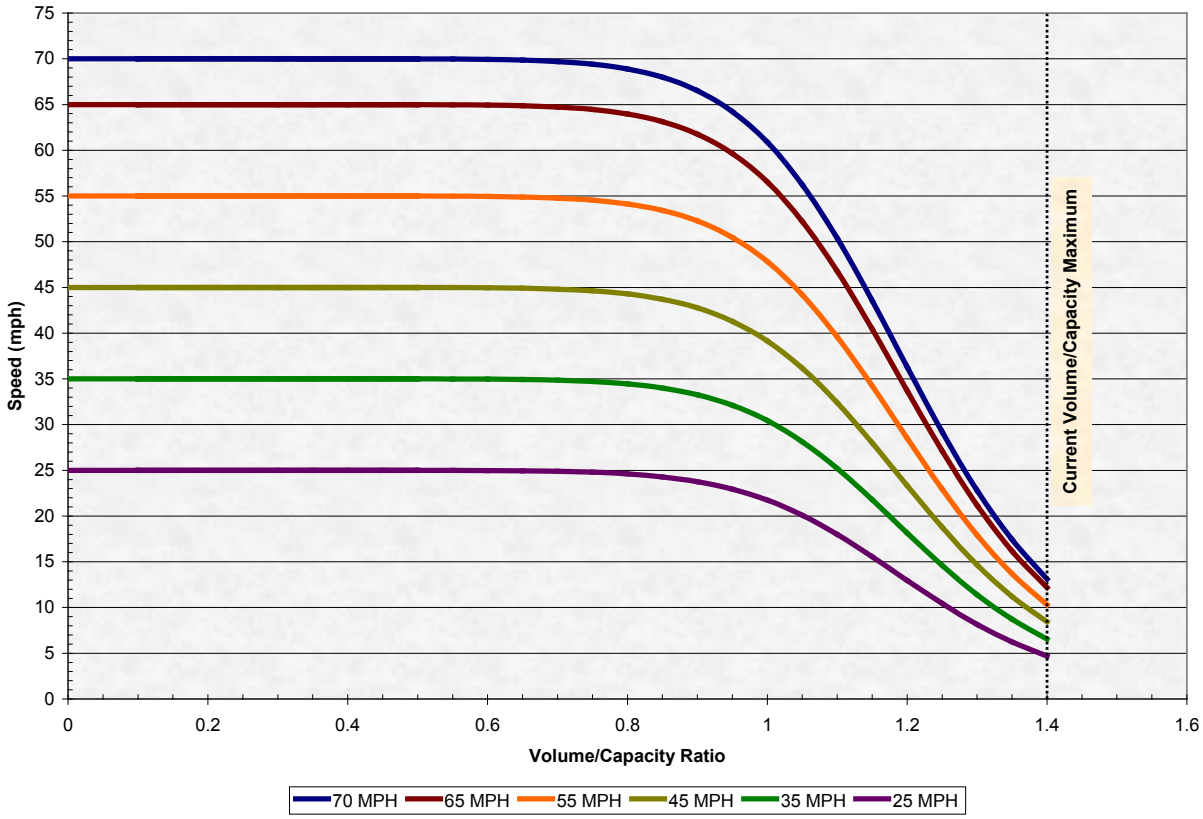
Capacity = Duration of Peak Period * Number of Lanes * Capacity per Lane

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.

Prior to the 2009 update, the Cal-B/C 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 earlier versions 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 II-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.

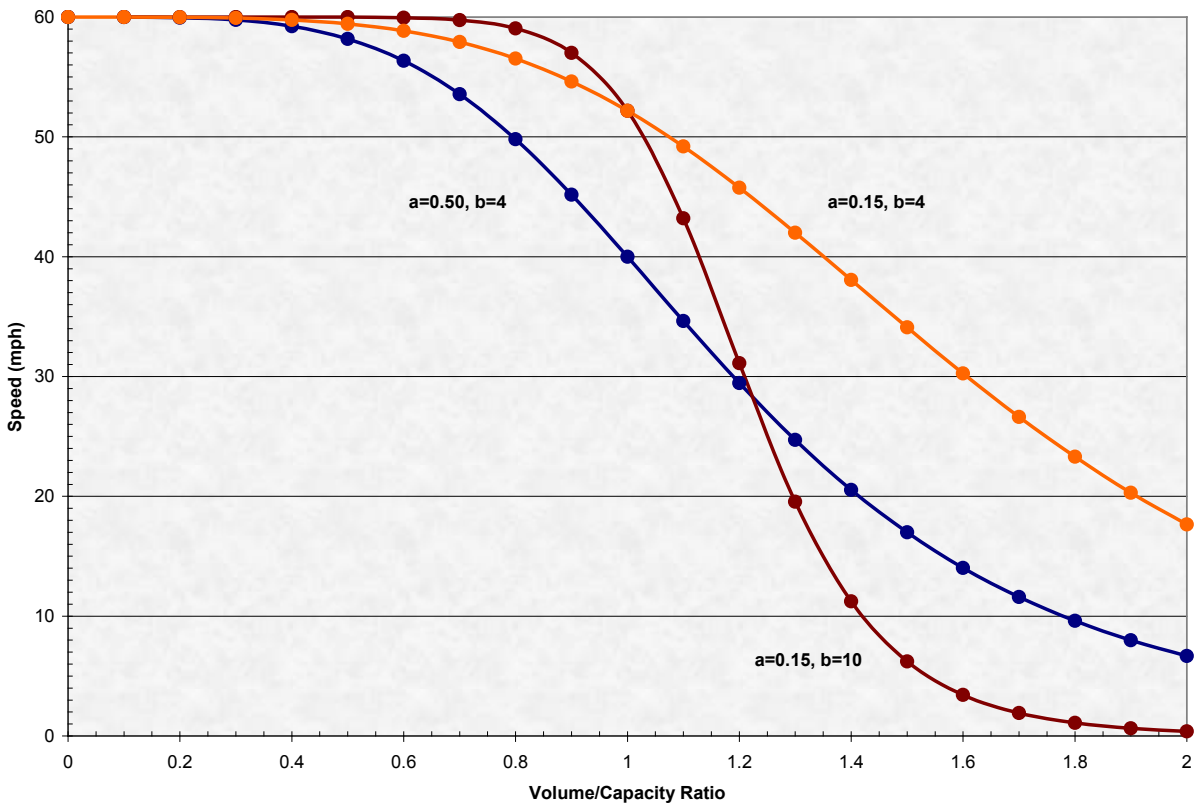
Exhibit II-7: Speeds Estimated Using BPR Parameter in the Prior Version of Cal-B/C



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 II-8). The red line is the BPR curve used in versions of Cal-B/C before the 2009 update.

Exhibit II-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 Metropolitan Transportation Commission (MTC) being the one 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 II-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_0	=	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_a	=	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 model 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:

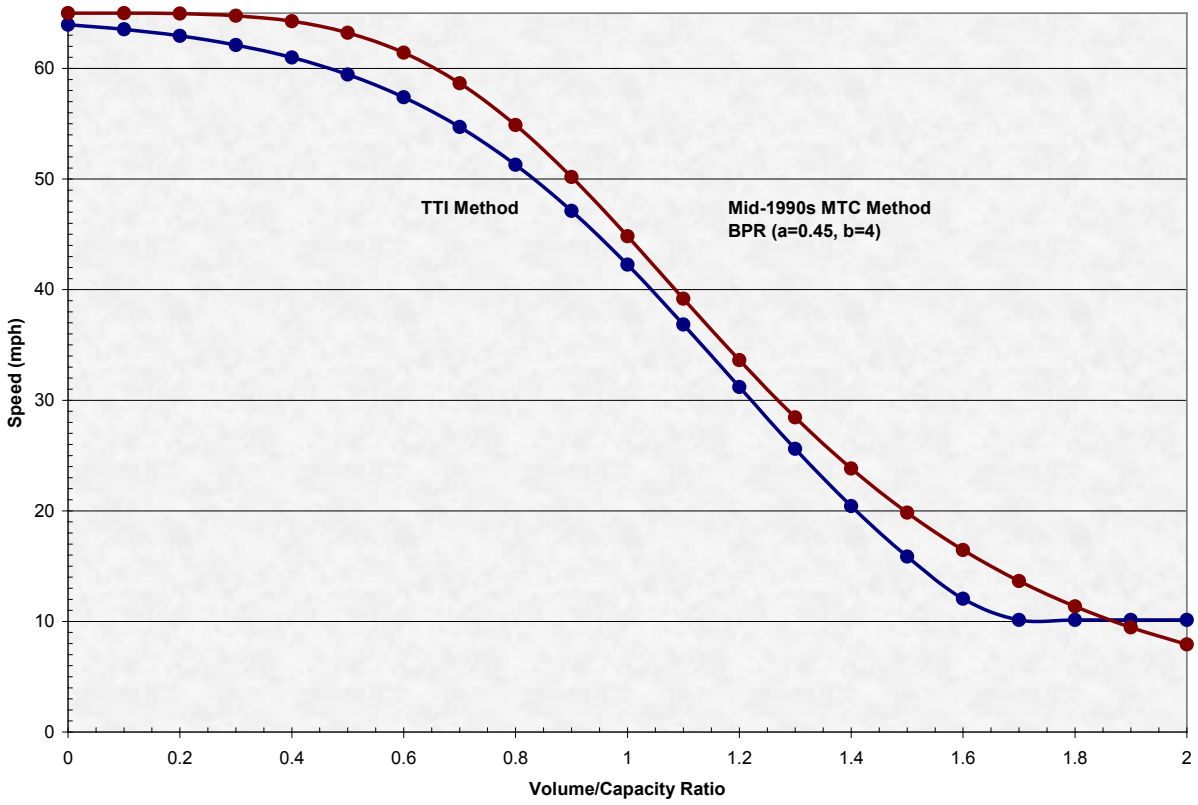
- Interstate – 70 mph
- Freeway – 65 mph
- Other principal arterial – 40 to 55 mph
- Minor arterial – 35 to 50 mph
- Major collector – 30 to 40 mph
- Minor collector – 30 to 35 mph
- Local – 30 mph.

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_X emissions after considering the BPR formula and the Greenshields method (another speed estimation technique).

As shown in the Exhibit II-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 II-9: TTI Speed Estimations Compared to the Mid-1990s MTC BPR Curve

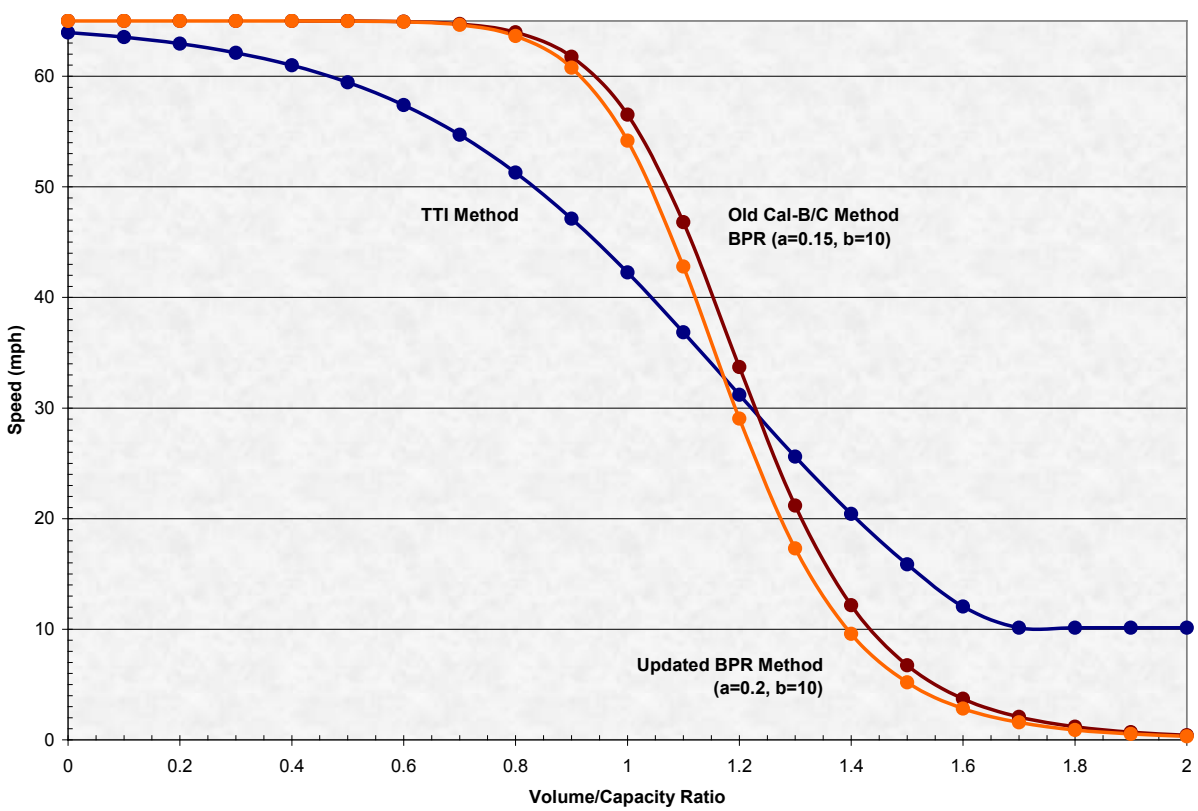


According to the ICF Consulting report, the updated BPR formula uses the parameters recommended for freeways in NCHRP 387 and for arterials in Skabardonis and Dowling (1999):

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

Exhibit II-10 shows a comparison of the updated BPR curve proposed in NCHRP 387 for freeways with the TTI method and the method used in versions of Cal-B/C prior to the 2009 update. 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 II-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:

$$For\ S_P > 50\ mph, Free\ Flow\ Speed = 0.88 \times S_P = 14$$
$$For\ S_P < 50\ mph, Free\ Flow\ Speed = 0.79 \times S_P = 12$$

where:

S_p = posted speed limit

As shown in Exhibit II-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 II-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:

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

where:

L	=	length of facility (in miles)
S_{MB}	=	mid-block free-flow speed = 0.79 × 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 for the 2009 update. Many California MPOs had chosen to use Akçelik functions rather than BPR functions. However, three MPOs that used BPR functions summarized the coefficients found in their models:

- ACCMA used a = 0.20 and b = 6.0 for freeways and freeway ramps. The v/c ratio was divided by 0.75.
- Los Angeles Metro used a = 1.16 and b = 4.33 for freeway links and a = 0.15 and b = 4.0 for all other roadways.
- MTC used 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 as part of the 2009 update. However, the updated added 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 II-12.

Exhibit II-12: BPR Parameters and Highway Capacities Found in Cal-B/C 4.0

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: retain the use of NCHRP 387 BPR curves and 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 original model's maximum of 1.4 was intended to keep model results reasonable, but it was set arbitrarily. As part of the 2012 update, 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 II-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 II-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 II-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**:* maximum v/c ratio retained at 1.56

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

Earlier versions 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. As part of the 2009 update, the Cal-B/C development team decided to review the approach, because Cal-B/C results were fairly sensitive to the number of hours in the peak period.

The values found in Cal-B/C prior to the 2009 update 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.

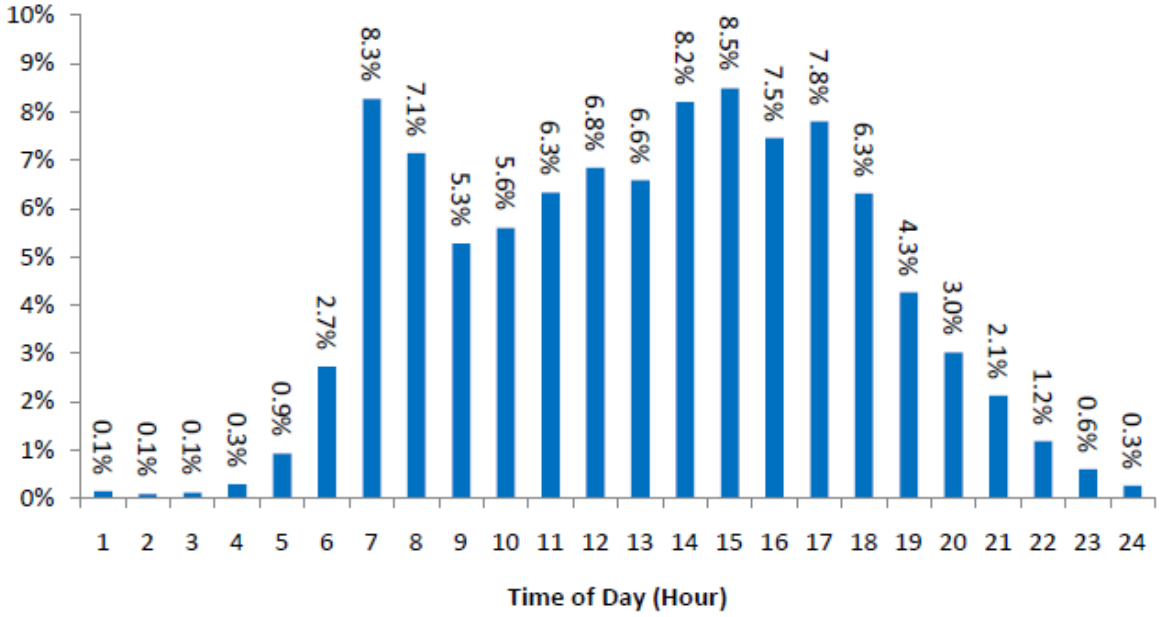
In every area surveyed in 1991, the top five hours accounted for about 39 percent of total daily traffic, which is an average of 7.8 percent per hour. A particular facility might be congested for a shorter or longer period, so Cal-B/C allowed the number of hours to be adjusted on the project input page. 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.

2010-2012 Statewide Travel Survey. In the 2009 review, the Cal-B/C development team examined data from the 2000-2001 California Statewide Travel Survey (2001 Survey), which suggested 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 with only one occurring in the morning and the other four occurring in the evening. In the 1991 Statewide Travel Survey, the hours were distributed two in the morning and three in the afternoon.

For Cal-B/C 6.2, the Cal-B/C development team reviewed data from the 2010-2012 California Household Travel Survey (2010 Survey). As shown in Exhibit II-14, the 2010 Survey shows similar patterns to the 2001 Survey. One noticeable trend is the spreading of demand to other parts of the day since 2001. The congested period is increasing in length and encompassing the midday. This is indicated by the next highest travel hours falling between the morning and afternoon. The net result is that the top five travel hours range from 7.5 to 8.5 percent of total trips for a total of 40.3%. The average of these top five hours is 8.5.

In the 2009 update, the Cal-B/C methodology was changed, so the model looks up the cumulative percent of total traffic for the number of hours in the peak period (rather than applying a simple average). This methodology can account for the spreading of travel demand, but the lower percentages in the peak mean that relatively less traffic demand is concentrated in the peak, so total travel time benefits will be reduced.

Exhibit II-14: 2010-2012 Hourly Trip Distribution by Departure Hours



Source: California Department of Transportation, 2010-2012 California Household Travel Survey, Final Report Appendix, June 2013.

Traffic Census Data. For the 2009 update, 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. From the traffic census data, the Cal-B/C development team decided to differentiate travel patterns by geographic region. A key Cal-B/C feature is its ease of use for a range of applications from specific route segment studies to high-level regional or statewide analyses. The Cal-B/C development team wanted to continue to minimize the number of user inputs, while maintaining the highest accuracy possible for such a tool.

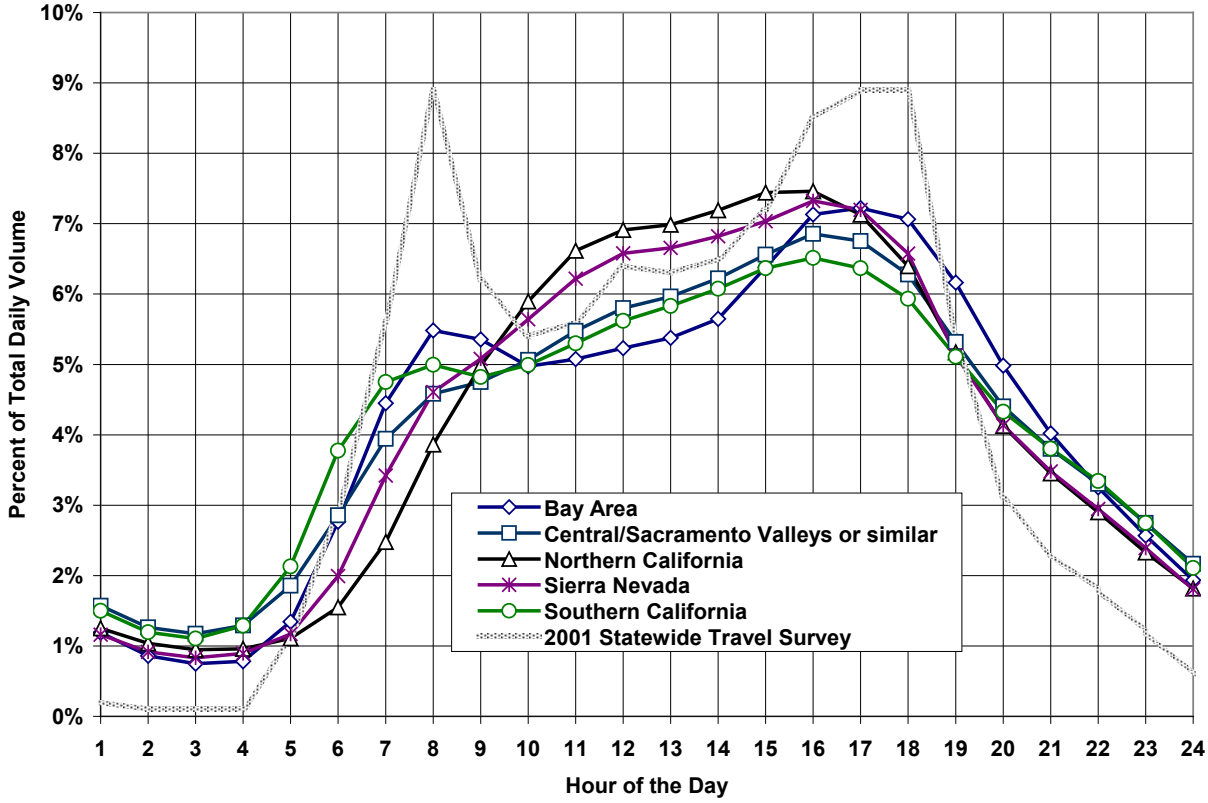
For example, rural, tourism-oriented California regions, such as Lake and Mono Counties, have more midday and late afternoon travel, while urban areas have more defined morning and afternoon peak periods. To illustrate, the picture in Exhibit II-15 shows midday weekday traffic on SR-29 in Lake County 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 II-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 Exhibit II-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 II-16: Percent Daily "Rural" Freeway Traffic by Hour by Region



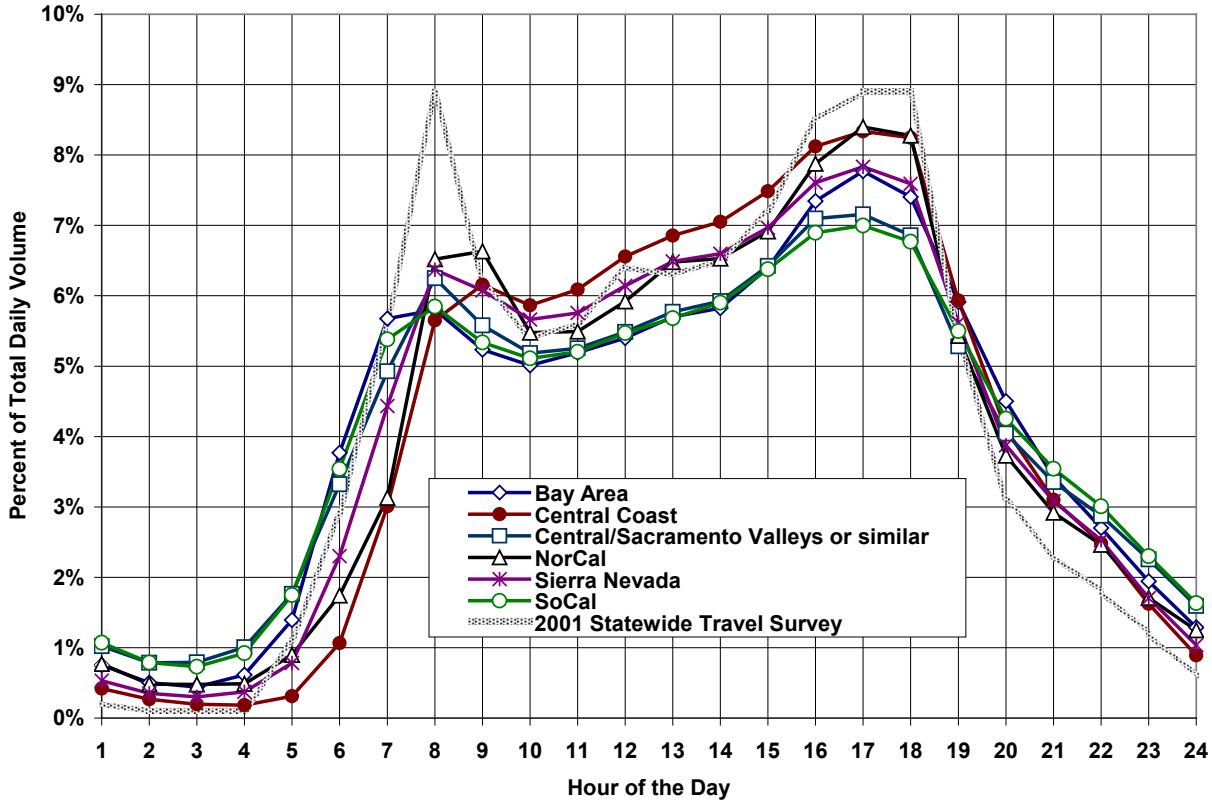
Source: SMG Analysis of Traffic Census data.

The development team also plotted the time-of-day distribution as estimated from the 2001 Survey on Exhibit II-16. As can be seen in the exhibit, the 2001 Survey indicted 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 II-17 shows these results. Data for a "Central Coast" region is available for freeways in this category. As can be seen in Exhibit II-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 II-17: Percent Daily "Small Urban" Freeway Traffic by Hour by Region

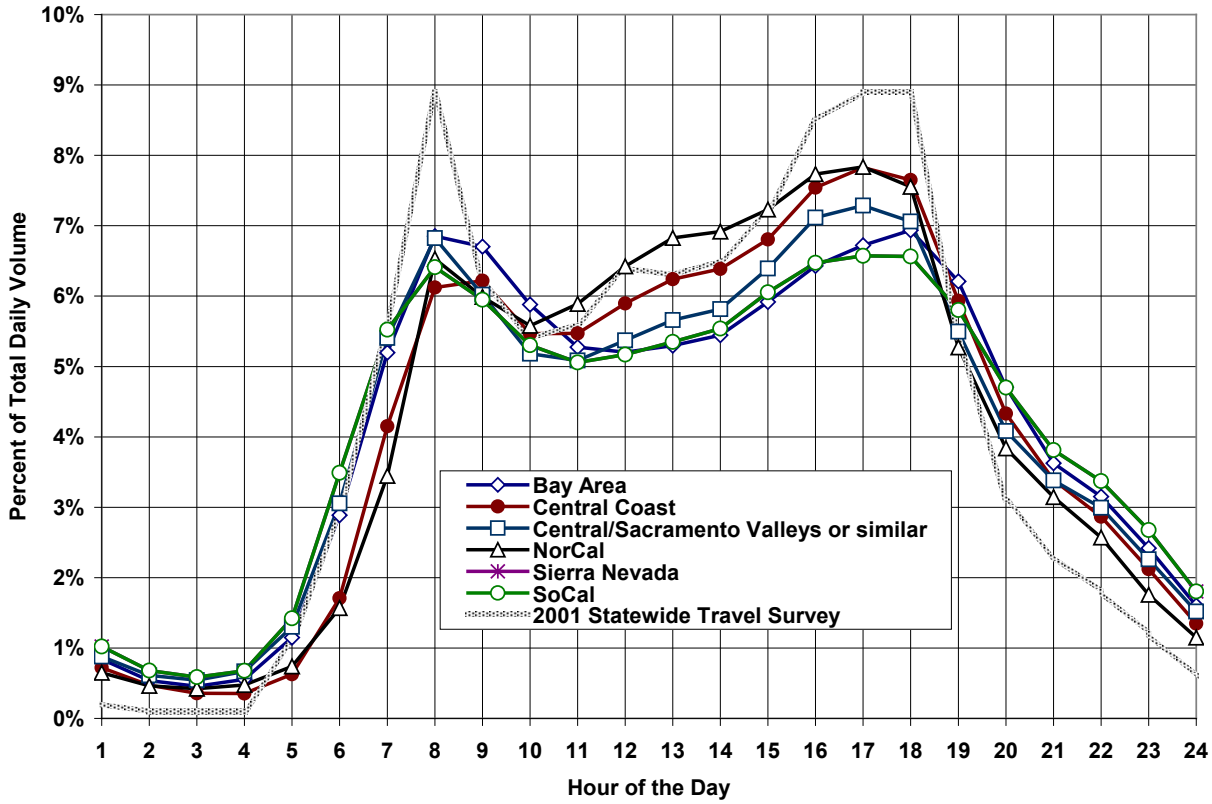


Source: SMG Analysis of Traffic Census data.

Exhibit II-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 2001 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 2001 Survey suggests. While the 2001 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 II-18: Percent Daily "Urban" Freeway Traffic by Hour by Region



Source: SMG Analysis of Traffic Census data.

The first factor is that Exhibit II-16 through Exhibit II-18 show year round information (i.e., weekdays and weekends), while the 2001 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 2001 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 II-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.

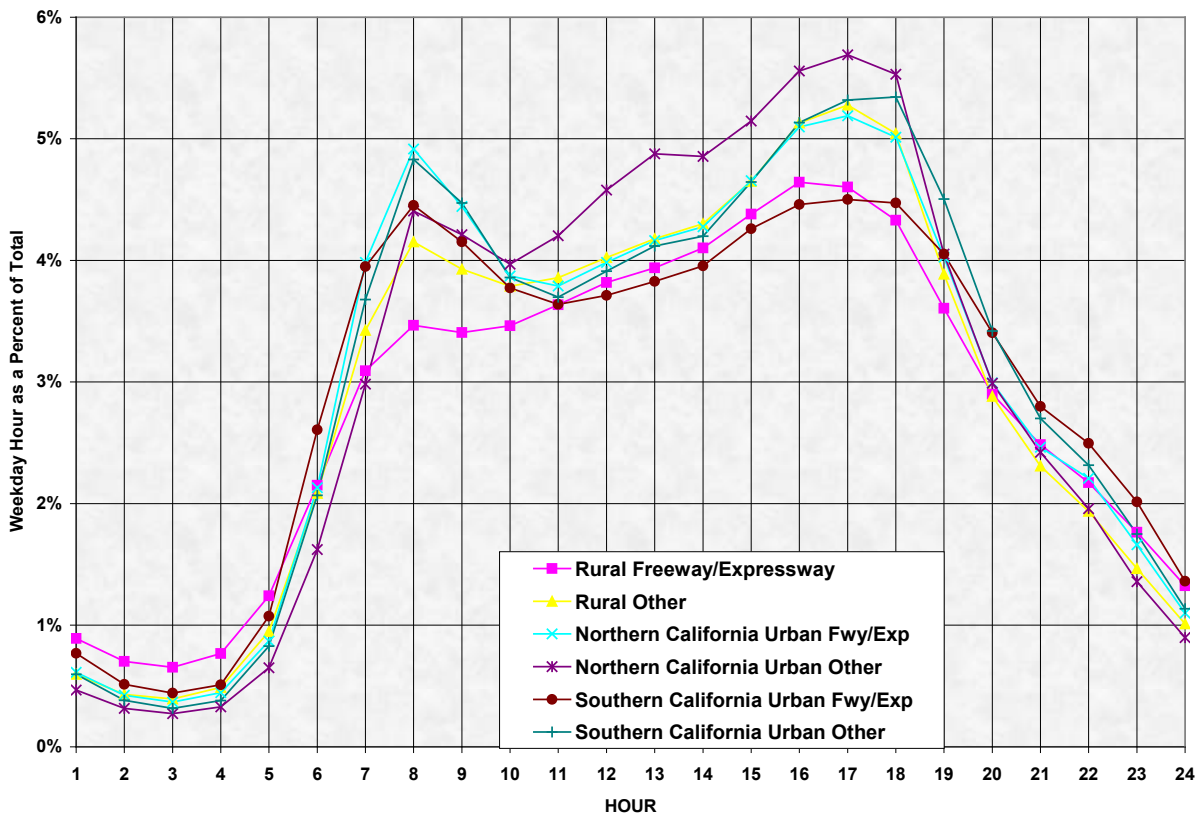
The charts for other state routes and arterials are not shown in this technical documentation, but the Cal-B/C development team conducted the same analysis for each roadway classification.

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: 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 II-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 II-19: Hourly Weekday Traffic as a Percent of Traffic for a Typical Day



In the 2009 update, 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.

For the 2009 update, the Cal-B/C development team originally 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 data from the statewide travel demand surveys. 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 II-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 Figure 8.3.2.2 of the 2010 Survey. The lookup table shows the cumulative percentage of weekday travel by the number of hours in the weekday peak period.

It is evident from the traffic census data that travel patterns vary by road type and location in state. Unlike the 2001 Survey, the 2010 Survey does not have information by MPO and combined rural areas. For the 2009 update, the Department decided use a single set of factors for all locations in the state. Cal-B/C 6.2 continues this approach using 2010 Survey data. However, the model retains separate columns for three locations and two road types in case the Department chooses to make distinctions in the future.

Exhibit II-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	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%
2	16.8%	16.8%	16.8%	16.8%	16.8%	16.8%
3	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%
4	32.8%	32.8%	32.8%	32.8%	32.8%	32.8%
5	40.3%	40.3%	40.3%	40.3%	40.3%	40.3%
6	47.4%	47.4%	47.4%	47.4%	47.4%	47.4%
7	54.2%	54.2%	54.2%	54.2%	54.2%	54.2%

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
8	60.8%	60.8%	60.8%	60.8%	60.8%	60.8%
9	67.1%	67.1%	67.1%	67.1%	67.1%	67.1%
10	73.4%	73.4%	73.4%	73.4%	73.4%	73.4%
11	79.0%	79.0%	79.0%	79.0%	79.0%	79.0%
12	84.3%	84.3%	84.3%	84.3%	84.3%	84.3%
13	88.6%	88.6%	88.6%	88.6%	88.6%	88.6%
14	91.6%	91.6%	91.6%	91.6%	91.6%	91.6%
15	94.3%	94.3%	94.3%	94.3%	94.3%	94.3%
16	96.4%	96.4%	96.4%	96.4%	96.4%	96.4%
17	97.6%	97.6%	97.6%	97.6%	97.6%	97.6%
18	98.5%	98.5%	98.5%	98.5%	98.5%	98.5%
19	99.1%	99.1%	99.1%	99.1%	99.1%	99.1%
20	99.4%	99.4%	99.4%	99.4%	99.4%	99.4%
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 2010-12 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. As part of the 2012 update, the Cal-B/C development decided to review the capacity per lane used for general purpose lanes as well as for 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 have used a higher capacity for operational analyses. For example, District 4 (the San Francisco Bay Area) used 2200 vphpl for calculations in the Highway Congestion Monitoring Program (HICOMP) report (now Mobility Performance 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 the particular segments.

As a matter of policy, the Department has decided that Cal-B/C should not use different highway capacities 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 II-21. The roadway facilities are grouped in the table by HPMS functional classification.

Exhibit II-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 lookup table in lieu of the equations. The report includes the practical capacity table provided in NCHRP 387 as an example of a lookup 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 as part of the 2012 Cal-B/C update. These capacities are summarized earlier in this technical documentation in Exhibit II-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 800 vphpl for other roadway types

2.6 Capacity per HOV Lane

Cal-B/C 4.0 used the same capacity per lane for HOV lanes (2000 vphpl) as it did 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. 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 starting with Cal-B/C 5.0. 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 for Cal-B/C 5.0 are in the HOT lane chapter. Cal-B/C 6.2 retains these values.

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

2.7 Percent Trucks

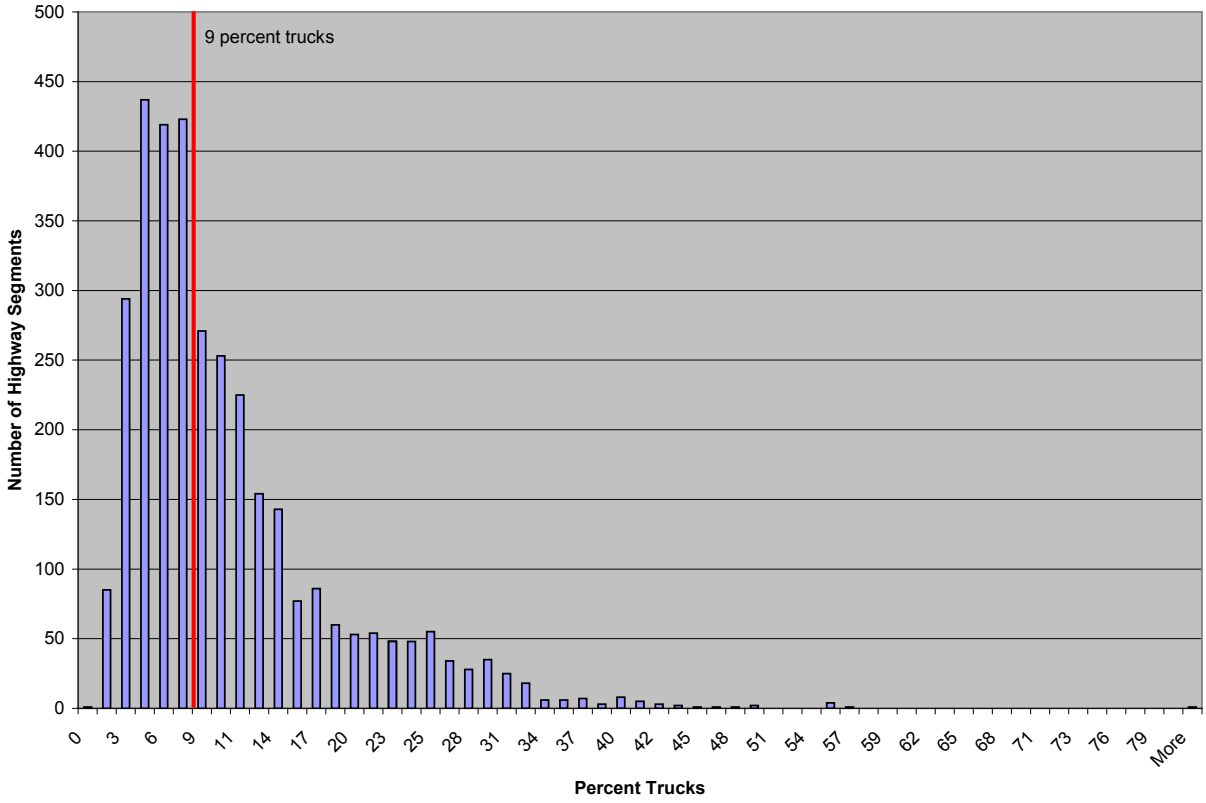
Cal-B/C uses the percent trucks to estimate the ADT associated with trucks. This is important for travel time calculations, which require a different value for trucks. It is also important for vehicle operating cost and emissions calculations, which use different factors for each vehicle

class. In addition, the percent trucks parameter is used to determine the amount of slow-moving traffic for passing lane and truck climbing projects.

Cal-B/C 5.0 retained the statewide default value of 9 percent trucks, because Departmental statistics suggested that the default was 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 2012 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 II-22, the percentage of trucks varies considerably among highway segments.

Exhibit II-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 for Cal-B/C 5.0. Cal-B/C 6.2 continues to use this value. 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 Travel Time Parameters

USDOT provides guidelines for valuing travel time in economic analyses. At the time of the Cal-B/C 5.0 update, USDOT had revised its guidelines only twice (in 2003 and 2011) since making its initial recommendations for valuing time in a 1997 memorandum. More recently, USDOT has updated the value of time (VOT) guidance annually. The revisions for Cal-B/C 6.2 are based on the 2015 memorandum, although the 2016 memorandum has recently become available.

The 2015 memorandum retains the same general structure as the last few annual updates to the USDOT VOT guidelines. The memorandum references consistent and easily available sources for estimating wages and the VOT. Cal-B/C 6.2 estimates travel time parameters following an approach consistent with previous versions of Cal-B/C, but using sources consistent with recent federal guidance. This section provides the discussion associated with prior updates as background as well as the calculation of parameters for the current update.

In addition to updating the values provided in previous guidance, the 2015 USDOT guidance suggests that the VOT changes over the years due to increasing labor productivity. As a result, a benefit-cost analysis could use a different VOT for each year of the analysis. In the 2015 VOT guidance, USDOT suggests increasing the VOT by 1.0 percent per year. The recently released 2016 VOT guidance removes any reference to changes in VOT due to labor productivity. The practice of increasing the VOT each year to account for increases in labor productivity was also dropped from the 2016 TIGER and FASTLANE guidelines. The other general guidance regarding the value of time is consistent with the 2015 guidance.

The Cal-B/C development team decided to retain the travel time “uprater” or escalation factor in Cal-B/C 6.2. This allows the user to assess projects using VOTs that change over time. However, the default for this parameter is set to 0 percent, so the VOT does not change during a typical benefit-cost analysis.

In its VOT 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 statewide as a matter of policy. For these reasons and the simplicity of a round number, the Cal-B/C development team chose to retain 50 percent of wage as the value of time for automobiles.

In its 2003 guidelines, USDOT calculated the local travel value using household income data from the 2000 Census. The intercity and business values were from total compensation cost per hour worked reported in the Bureau of Labor Statistics (BLS) Employer Costs for Employee Compensation (ECES), which was part of the National Compensation Survey (NCS).

The 2015 guidelines update the Census data to the 2013 Census estimates of median household income and the intercity and business values in BLS Occupational Employment and Wage Estimates. The Cal-B/C development team cannot determine why USDOT chooses to use household income rather than income by individual for the local travel value estimate.

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 calculated the value of time for trucks using wages from BLS Employment and Earnings and fringe benefits from BLS ECES. The 2015 guidelines keep 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 II-23 compares these sources, as they exist for the 2016 Cal-B/C revision. USDOT used the first source, the National Compensation Survey (NCS), for VOT calculations in its 2003 guidance, but state-level data are not available from the NCS. The second source, the Occupational Employment and Wage Estimates is comparable to the NCS. USDOT uses this source in its 2015 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. Starting with Cal-B/C 5.0, Caltrans has used estimates from the Occupational Employment and Wage Estimates, consistent with the latest USDOT guidance.

Exhibit II-23: Comparison of Federal Sources for California Wage Data (2016 Cal-B/C Revision)

Aspect	National Compensation Survey (NCS)	Occupational Employment and Wage Estimates	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

Aspect	National Compensation Survey (NCS)	Occupational Employment and Wage Estimates	Quarterly Census of Employment and Wages (QCEW)*
Geographic Locations	Nation, Census divisions, metro areas	Nation, states, metro areas	Nation, states, counties, core based statistical areas (CBSAs)
Relevance	Used for 2003 USDOT VOT	Comparable to NCS, but available by state, used for 2015 UDOT VOT	Used for VOT in prior versions of Cal-B/C
Source	National Compensation Survey: Occupational Wages in the Pacific Census Division, July 2010	May 2015 State Occupational Employment and Wage Estimates - California	Private industry by State and six-digit NAICS industry: Establishments, employment, and wages, 2015 annual averages
00-0000 All Occupations	Total Mean Hourly Earnings - $25.67 Total Mean Weekly Hours – 35.1	Median Hourly - $19.15 Mean Hourly - $26.57 Mean Annual - $55,260	Annual wages per employee - $61,276 Average weekly wage - $1,178
53-0000 Transportation and Material Moving Occupations	Total Mean Hourly Earnings - $17.21 Total Mean Weekly Hours – 37.4	Median Hourly - $14.20 Mean Hourly - $17.15 Mean Annual - $35,670	
Truck Drivers			
53-3032 Truck Drivers, Heavy and Tractor-Trailer	Total Mean Hourly Earnings - $20.92 Total Mean Weekly Hours – 39.0	Median Hourly - $20.20 Mean Hourly - $21.17 Mean Annual - $44,030	
53-3033 Truck Drivers, Light or Delivery Services	Total Mean Hourly Earnings - $19.00 Total Mean Weekly Hours – 39.0	Median Hourly - $15.25 Mean Hourly - $17.98 Mean Annual - $37,410	
48-49 Transportation and warehousing			Annual wages per employee - $51,531 Average weekly wage - $991

Aspect	National Compensation Survey (NCS)	Occupational Employment and Wage Estimates	Quarterly Census of Employment and Wages (QCEW)*
484 Truck transportation			Annual wages per employee - $48,012 Average weekly wage - $923

* Formerly called Covered Employment and Wages program

The Cal-B/C development team has updated all time values using data from the Occupational Employment and Wage Estimates. 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 prior versions of Cal-B/C) ignores the wages paid in other industries. Likewise, the use of Occupational Employment and Wage Estimates data 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 2016 dollars for Cal-B/C 6.2:

- **Statewide Average Hourly Wage:** According to the OES Survey, the mean hourly wage for California workers in all occupations was $26.57 in May 2015. The BLS Employment Cost Index historical listing (Table 6) provides current dollar indices (124.4 in June 2015 and 128.0 in June 2016) for private industry workers in the Pacific Census region, which can be used to estimate 2016 wages ($26.57*128.0/124.4 = $27.34). Cal-B/C includes this new hourly wage rate, resulting in a value of time for automobile and in-vehicle transit travel of $13.65 (i.e., half 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 the 129,170 Heavy and Tractor-Trailer Truck Drivers (Occupation 53-3032) in California was $21.17 in May 2015. The mean hourly wage for the 89,230 Light Truck or Delivery Services Drivers (Occupation 53-3033) in California was $17.98. After taking the weighted average using the number of employees in the two occupations [($21.17*129,170+$17.98*89,230)/(129,170+89,230)], the average hourly rate is $19.87. Adjusting to 2016 wages using the BLS Employment Cost Index ($19.87*128.0/124.4) results in wages of $20.44.

- **Heavy and Light Truck Driver Fringe Benefits:** According to the BLS Employer Costs for Employee Compensation historical listing (Table 4), the total compensation per hour worked for civilian workers in the Transportation, and Material Moving occupations was $27.84 nationally in June 2016. Of this total, $18.12 was for wages

and salaries, while $9.72 was for total benefits. To estimate the fringe benefits of California truck drivers ($10.96), the ratio of total compensation to wages and salaries was estimated ($27.84/$18.12-1) and applied to the average hourly wage ($20.44). This is a standard approach for estimating the value of benefits in human resources and is consistent with the USDOT VOT guidance. Adding the benefits to wages yields a total compensation of $31.40 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 ($31.40). As in the previous version of Cal-B/C, 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 $31.40.
- **Composite Value of Time:** Although Cal-B/C uses separate values of time for automobiles and trucks, the Department is occasionally asked to provide a composite value (e.g., in the Mobility Performance Report) that includes automobiles and trucks. Using the default mix of 9-percent trucks and accounting for average vehicle occupancy of 1.3 in automobiles results in a composite value of time equal to $18.95 (rounded to the nearest 5 cents).

Revision Made to Cal-B/C: Used $13.65 for the value of time for automobiles and in-vehicle transit travel, $31.40 for trucks, and $18.95 as the composite value of truck and automobile travel

4 Vehicle Operating Cost Parameters

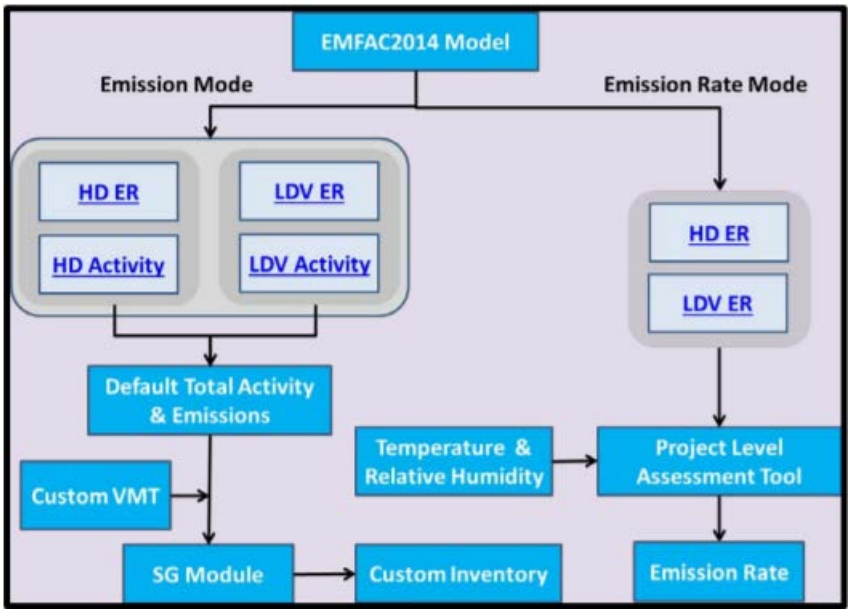
4.1 Fuel Consumption

To be consistent with the emissions factors for Cal-B/C, the development team estimated fuel consumption rates using data from the EMFAC2014 model. On December 30, 2014 the California Air Resources Board (CARB) updated EMFAC from the previous version, EMFAC2011. This revision is a minor update to the EMFAC2011 model that supports Senate Bill 375 (SB 375) analyses and extends emission estimates through 2050.

EMFAC2011 is comprised of a suite of three separate modules, HD, LD, and SG. EMFAC2011-HD was written in Visual Basic and MySQL, for which the database architecture facilitates the generation of more detailed information about the truck and bus fleet than had been possible in prior versions. EMFAC2011-LD estimates the emissions of passenger vehicles and uses the same algorithms as in EMFAC2007. The third module, EMFAC2011-SG, provides air quality planners, transportation planners, and other EMFAC users a tool for assessing emissions under different future growth scenarios.

EMFAC2014 improves upon EMFAC2011's modular structure and combines the three prior modules into one single model. Exhibit II-24 shows the structure of EMFAC2014.

Exhibit II-24: EMFAC2014 Model Structure



Source: California Air Resources Board, EMFAC2014 Volume III - Technical Documentation, May 12, 2015.

The Cal-B/C development team estimated fuel consumption curves for both automobiles and trucks using EMFAC2014. 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 2016 and 2036.

Cal-B/C uses a single set of fuel consumption parameters statewide. Idling fuel consumption cannot be extracted from EMFAC2014, 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 for funding transportation improvements.

The structure of transportation taxes in California is complicated. The Transportation Economics 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 goes 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.). 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 raised the sales tax rate on diesel fuel, while simultaneously lowering the state excise tax on diesel fuel. In the 2012 update, 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, 2016, the State of California will levy an excise rate of 27.8¢ per gallon on gasoline.

As of July 1, 2016, the excise tax on diesel will be 16¢ per gallon. This rate is higher than the 13¢ per gallon levied previously. The diesel excise tax will change over the next few years, but the expected change is considerably less than the variation in the price of diesel fuel. Cal-B/C uses the 16¢ per gallon to calculate the fuel costs for trucks.

The Fuel Tax Swap also changed sales tax on gasoline and diesel fuels. 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. The current sales tax rate on diesel is a basic 4.75 percent sales tax plus a 1.75-percent surcharge.

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 lists nineteen counties and four Transit Authorities that have added a sales tax.

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 (<gasprices.aaa.com/?state=CA>) 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 120,000 stations around the country. Data are 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 June 29, 2016. Consistent with prior Cal-B/C updates, the Cal-B/C development team used the average of two days (June 29, 2015 and June 29, 2016) to estimate fuel costs – the Daily Fuel Gauge Reports only limited historical data.

To account for the various tax changes associated with the Fuel Tax Swap, Cal-B/C includes 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 ($3.449 on June 29, 2015 and $2.901 on June 29, 2016). For truck fuel costs, the Cal-B/C development team used the average of prices for diesel fuel ($3.190 on June 29, 2015 and $2.810 on June 29, 2016). The equations below show the calculation of fuel costs including the changes in applicable excise and sales taxes:

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

$$\text{Automobile Fuel Cost} = \left[\frac{\text{Average}(\$3.449, \$2.901)}{1 + (2.25\% + 0.5\%)}\right] - \$0.184 - \$0.278 = \$2.63 \text{ per gallon}$$

$$\text{Truck Fuel Cost} = \left[\frac{\text{Average}(\$3.190, \$2.810)}{1 + (5.75\% + 1.75\%)}\right] - \$0.244 - \$0.16 = \$2.39 \text{ per gallon}$$

Cal-B/C rounds these figures to $2.65 and $2.40, 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 ($2.65 per gallon) and trucks ($2.40 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 they do not vary with vehicle mileage (or at least are not very sensitive). 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 from 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 more than 30 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 II-25 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 II-25: Component Prices for Estimating Vehicle Operating Costs in HERS-ST v2.0 (in 1997 dollars)

Vehicle Type	Fuel ($/gallon)	Oil ($/quart)[a]	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 2009 review suggests that Cal-B/C could have continued to use the original STEAM non-fuel cost estimates plus separate estimates of depreciation. However, a more current source was 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) was 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 2016 AAA figures to be consistent with the other economic values in Cal-B/C.

Consistent with previous editions, the 2016 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 deductable 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) consists of 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 estimating vehicle operating costs in 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 the national average interest rate for five credit rating categories weighted by

market share 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 (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 4WD 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 – 5.28 cents per mile
- Tires – 1.00 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 = $278 annually or 5.56 cents per additional mile ($278/5000 miles)

- Increased depreciation from 15,000 to 20,000 miles per year = $219 annually or 4.38 cents per additional mile ($219/5000 miles).

These two figures average to a depreciation of 4.97 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 during the 2012 update, the Cal-B/C development team was unable to determine what caused this drop in rates in recent Your Driving Cost publication.

As a result, the Cal-B/C development team decided to adopt a simpler and more consistent method during the 2012 update – dividing the depreciation at the 15,000 standard mileage by the mileage. For the latest update, this calculation results in depreciation of 25.06 cents per mile ($3,759/15,000). A review of "Your Driving Costs" from previous years suggests that this estimate is consistent over the 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 2016 IRS reimbursement rate is 54 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., 23 cents per mile for 2012 and 2013, 22 cents per mile for 2014, and 24 cents per mile for 2015 and 2016). These values are very similar to the 25.06 cents estimated from AAA.

Added to the earlier maintenance (5.28 cents) and tires estimates (1.00 cents), the new depreciation cost (25.06 cents) results in a non-fuel cost per mile of 31.34 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. For the 2016 revision, the Cal-B/C development team updated truck costs using values available from the American Transportation Research Institute (ATRI - the research arm of the American Trucking Associations Federation). ATRI has conducted several analyses of the operational costs of trucking. These studies use costs derived directly from the trucking industry motor vehicle fleet operations.

ATRI published the first report, *An Analysis of the Operational Costs of Trucking*, in late 2008. 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. Since the 2011 update, ATRI has published annual reports in an effort to provide more accurate average cost data for motor vehicle operations, the 2015 update was used for this version of Cal-B/C.

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 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 2015).

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 2014, since they represent costs for a complete year. The Cal-B/C development team updated these figures to 2016 dollars using the GDP deflator (1.1164/1.0843). Exhibit II-26 shows the original ATRI values and the final 2015 values used in Cal-B/C.

Exhibit II-26: Calculation of Non-Fuel Truck Operating Costs from ATRI

Category	Original ATRI (2014$)	Final Cal-B/C (2016$)
Repair and Maintenance	$0.158	$0.163
Tires	$0.044	$0.045
Truck/Trailer Payments	$0.215	$0.221
Total Non-Fuel Costs	**$0.417**	**$0.429**

Estimated from ATRI, An Analysis of the Operational Costs of Trucking: 2015 Update, September 2015..

Revision Made to Cal-B/C: used 31.3 cents per mile for non-fuel automobile operating costs and 42.9 cents per mile for non-fuel truck operating costs

5 Accident Cost Parameters

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 highway accident types (i.e., 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 should 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 based on BLS Census of Fatal Occupational Injuries (CFOI) data. The CFOI-based studies substantially raise the value of life estimates. USDOT now issues annual updates to the value of statistical life based on this new data. An August 2015 interim adjustment (USDOT 2015) 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 (2004) 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 the Hanley report.

The largest 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 occasionally, but the summary of economic costs is very comprehensive. The last NHTSA estimate, which reported 2010 data, was published in 2014 and revised in 2015. The previous estimate reported 2000 data and was published in 2002. Another update is unlikely for another eight to ten years.

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. This scale is also called the Maximum Abbreviated Injury Scale (MAIS). On a per person (injury) basis, the average comprehensive costs for 2010 updated to 2016 using the GDP deflator (1.1164/1.0088) are:

- Fatal (AIS 6) - $10,121,523
- Critical (AIS 5) - $6,174,743
- Severe (AIS 4) - $2,691,501
- Serious (AIS 3) - $1,092,965
- Moderate (AIS 2) - $438,916
- Minor (AIS 1) - $45,430
- Property Damage Only (PDO) - $2,705.

Converted to the ANSI KABCO scale using data from NHTSA and rounded, these correspond to:

- Death (K) - $10,100,000

- Incapacitating Injury (A) - $492,200
- Non-Incapacitating Injury (B) - $140,800
- Possible Injury (C) - $76,400
- Property Damage Only (PDO) - $2,700

Prior versions of Cal-B/C relied 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 (i.e., KABCO scale). The latest comprehensive data available are for 2014. These are available online (http://www.nsc.org/NSCDocuments_Corporate/estimating-costs-unintentional-injuries-2016.pdf) or in the 2014 NSC annual report.

At the time of the 2012 update, USDOT had adopted higher values for fatalities and injuries based on the new CFOI data. NSC took a cautious approach and chose not to adopt the higher values immediately. The Cal-B/C development team contacted Ken Kolosh of the National Safety Council, who indicated that NSC was considering a revision to its calculation methodology to be consistent with the Center for Disease Control (CDC). NSC indicated that a trend toward consistency among the agencies was desirable and that the NSC value would likely rise in future updates.

The latest NSC report has a revised methodology for estimating injury costs and higher fatality values in line with the USDOT guidance. NSC does not provide details on the methodology updates adopted, but this methodology is presumably consistent with CDC as Ken Kolosh had mentioned in 2012. The new injury values differ in magnitude substantially from the USDOT and NHTSA values as well as the ones (from NSC) previously used in Cal-B/C.

On a per person (injury) basis, the average comprehensive costs from NSC for 2014 updated to 2016 using the GDP deflator (1.1164/1.0843) are:

- Death - $10,200,000
- Incapacitating Injury (A) - $1,114,000
- Non-Incapacitating Injury (B) - $306,800
- Possible Injury (C) - $142,200
- No Injury - $47,100

Since the methodology for calculating these values was not documented and the magnitude of the injury values differed substantially from other sources and the previous Cal-B/C values, the Cal-B/C development team felt uncomfortable adopting them in the 2016 update. The team decided to review the new USDOT value of statistical life guidance. This guidance is cited at the national level for TIGER and FASTLANE grant applications and is now updated frequently. Unlike NHTSA and NSC, the USDOT values indicate the willingness to pay, but unlike these other sources, they do not include direct, out-of-pocket costs (which NHTSA adds to the USDOT values).

The Cal-B/C team decided to adopt the USDOT values, even though they exclude these direct costs, because they are used for TIGER and FASTLANE grant applications and are now updated annually. In addition, the injury values are consistent in magnitude with the injury values in the prior versions of the NSC reports and Cal-B/C. According to the 2016 guidance dated August 8, 2016 (USDOT 2016), the value of statistical life is $9.6 million in 2015 dollars. When this value is updated to 2016 dollars using the GDP deflator (1.1164/1.0990) and the relative fractions for the value of preventing injuries are applied, the following rounded values result:

- Death - $9,800,000
- Incapacitating Injury (A) - $466,400
- Non-Incapacitating Injury (B) - $127,000
- Possible Injury (C) - $64,900
- No Injury - $3,300

Cal-B/C uses these values plus the PDO value ($2,700) from NHTSA because the No Injury value from USDOT does not correspond to a PDO accident.

The Cal-B/C development team cannot calculate the average injury severity from Traffic Accident Surveillance and Analysis System (TASAS) data. The injury levels AIS A through C have already been summarized as “injuries” in the CHP data sent the Department. The detailed data are 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 CHP annual safety summary. The latest version is the 2013 Annual Report of Fatal and Injury Motor Vehicle Traffic Collisions.

According to Table 4C, injury severities occur with the following frequencies:

- Severe Injury (A) - 10,664 out of 223,128 injuries or 4.78 percent
- Other Visible Injury (B) – 56,986 out of 223,128 injuries or 25.54 percent
- Complaint of Pain (C) – 155,478 out of 223,128 injuries or 69.68 percent.

As indicated in Table 7Q, there were 3,104 people killed in 2,853 fatal accidents for 1.1 deaths per fatal accident in 2013. 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 2010 through 2013. 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 2016 USDOT values plus the NHTSA value for PDO accidents updated to 2016 by the GDP deflator as well as injury severity and accident event data from TASAS

5.3 Statewide Accident Rates

Prior versions of Cal-B/C have included average statewide accident rates from a Department publication called "Collision Data on California State Highways." This report has not been produced for the last few years – the latest one was published in 2012. Cal-B/C 6.2 uses average statewide accident rates computed from a special TASAS run titled "2013 Statewide Collision Total Check. " The accident information from this report have been combined with vehicle-miles traveled information from the 2013 California Public Road Data, which is derived from the Highway Performance Monitoring System. The following values are included in Cal-B/C:

- Fatal accident rate: 1,105 fatal accidents / 178,281.8 million vehicle-miles (MVM) = 0.0062 per MVM
- Injury accident rate: 51,378 injury accidents /178,281.8 MVM = 0.2882 per MVM
- PDO accident rate: 98,338 PDO accidents / 178,281.8 MVM = 0.5516 per MVM

These publications do not have information on the non-freeway accident rate, so Cal-B/C 6.2 retains the value form the prior version, which is derived from 2009 Collision Data on California State Highways data:

- Non-freeway accident rate: 1.05 accidents per MVM (from the page 7 summary).

These figures have been rounded to 0.006, 0.29, 0.52, and 1.05, respectively, in Cal-B/C.

Revision Made to Cal-B/C: adopted statewide accident rates from 2013 data

6 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. Cal-B/C also includes the calculation of greenhouse gas emissions added in the 2009 update. 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, EMFAC2014. As described earlier in this Chapter, CARB has continued to modify the structure of EMFAC. EMFAC2014 improves upon EMFAC2011 by integrating three separate modules into a single model. The Cal-B/C

development team estimated emissions rates for automobiles, trucks, and buses using EMFAC2014.

As in the 2012 update, the Cal-B/C development team found that EMFAC2014 generated uneven emission trends for trucks (see Exhibit II-27 for an example). For the 2012 update, the Cal-B/C development team chose to use the smoother trend produced by the EMFAC2011-LD module. This option is not available in EMFAC2014, so the more uneven trends have been adopted for Cal-B/C 6.2. In the cases of NO_X and PM10, this produces very different truck emissions factors than in Cal-B/C 5.0 (see Exhibit II-28 for NO_x example).

Exhibit II-27: Truck Carbon Monoxide (CO) Emissions per Mile

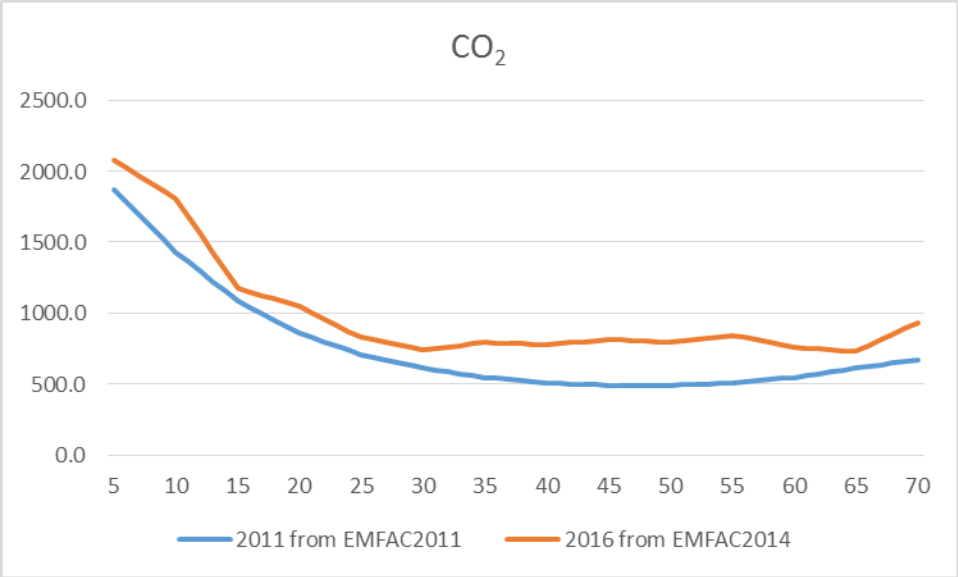
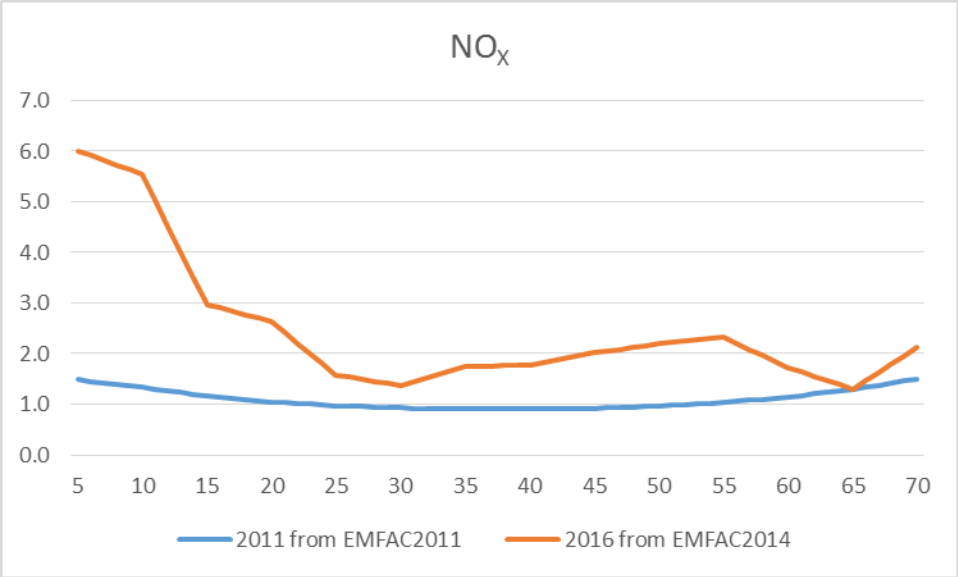


Exhibit II-28: Truck Nitrous Oxide (NO_X) Emissions per Mile

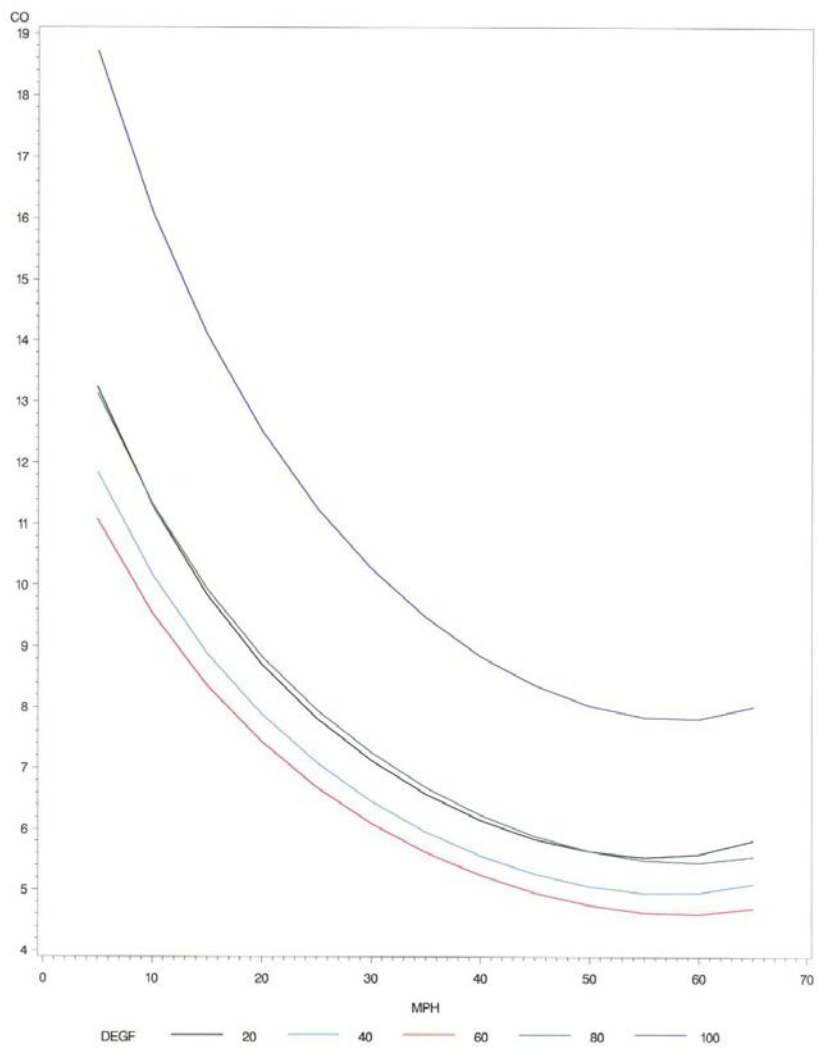


Prior to the 2009 revision, the Cal-B/C development team pulled preliminary data from EMFAC2007 to determine the major factors affecting emission rates. This analysis helped to determine how to summarize emissions rates and interpolate rates across years. The development team did not repeat this analysis using EMFAC2014. The original EMFAC2007 results are reported on the next few pages.

As shown in Exhibit II-29, 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 EMFAC2014 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 II-29: Carbon Monoxide (CO) Emissions per Mile



To test this idea, the Cal-B/C development team looked at pollutants by air basin using EMFAC2007 to see if any patterns emerged. Emissions were calculated by adding all sources for each item (e.g., tons of CO2, NOx, 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.

Exhibit II-30 through Exhibit II-35 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 emissions 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 required for a particular region, EMFAC can be used to generate appropriate emissions models for use in Cal-B/C.

Exhibit II-30: CO_2 Emissions per Mile

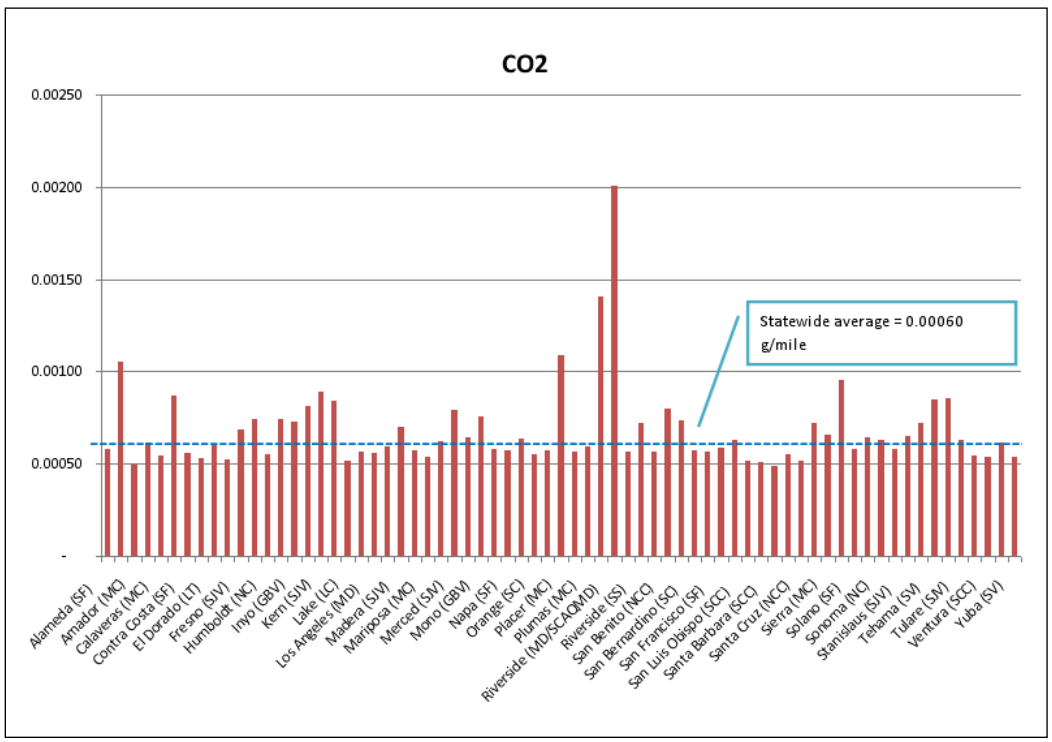


Exhibit II-31: CO Emissions per Mile

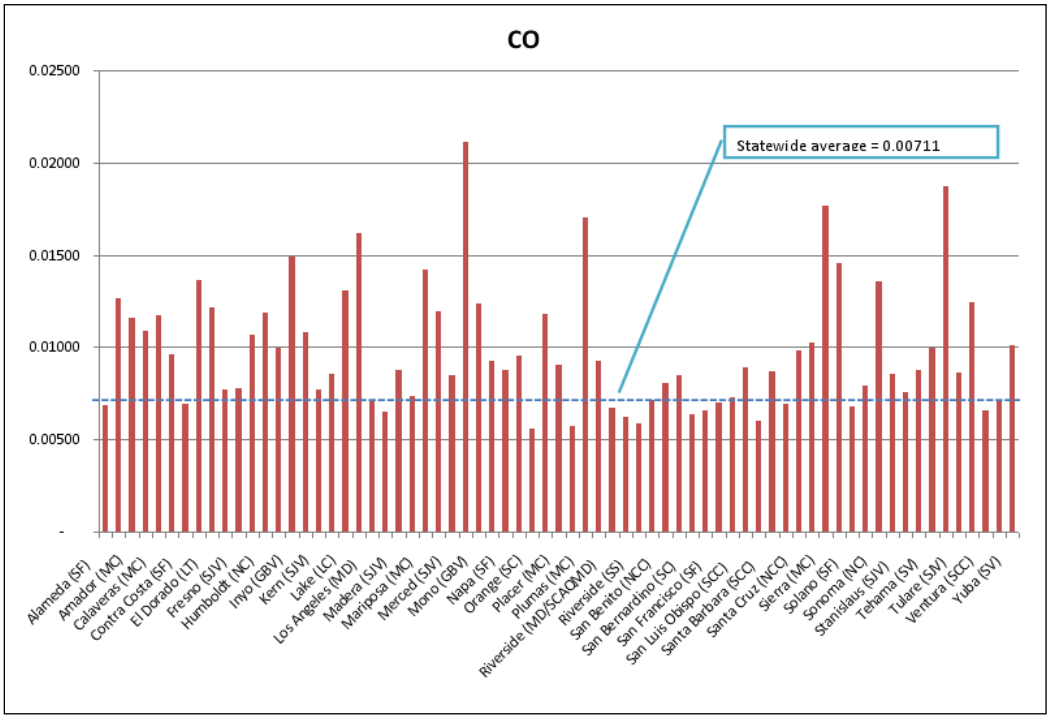


Exhibit II-32: NOx Emissions per Mile

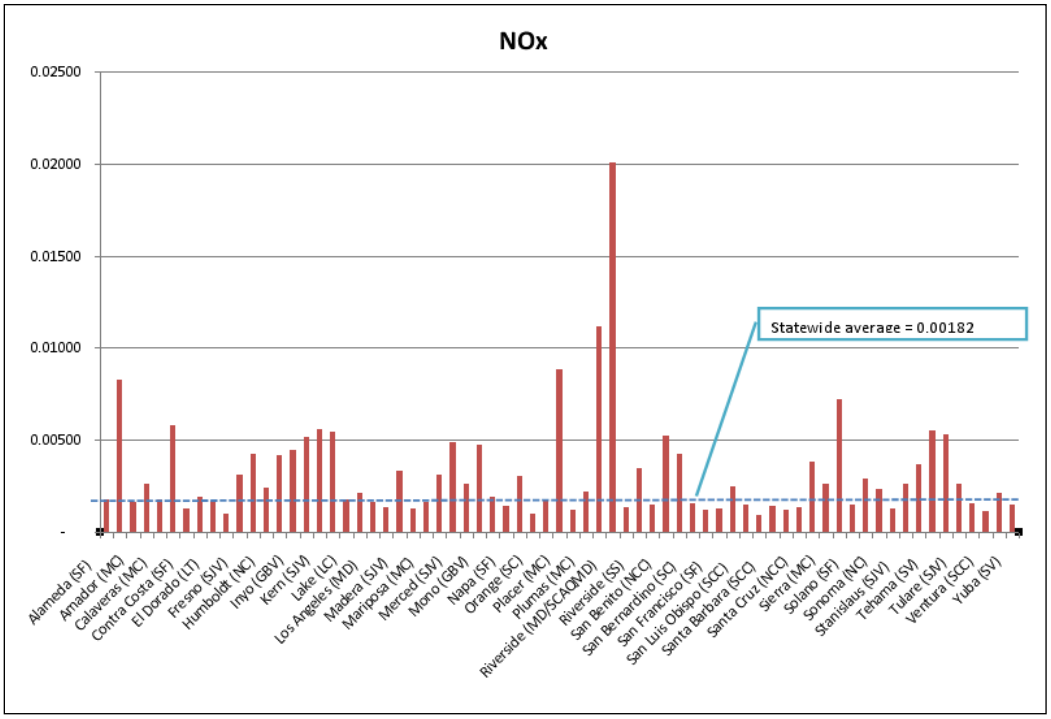


Exhibit II-33: PM10 Emissions per Mile

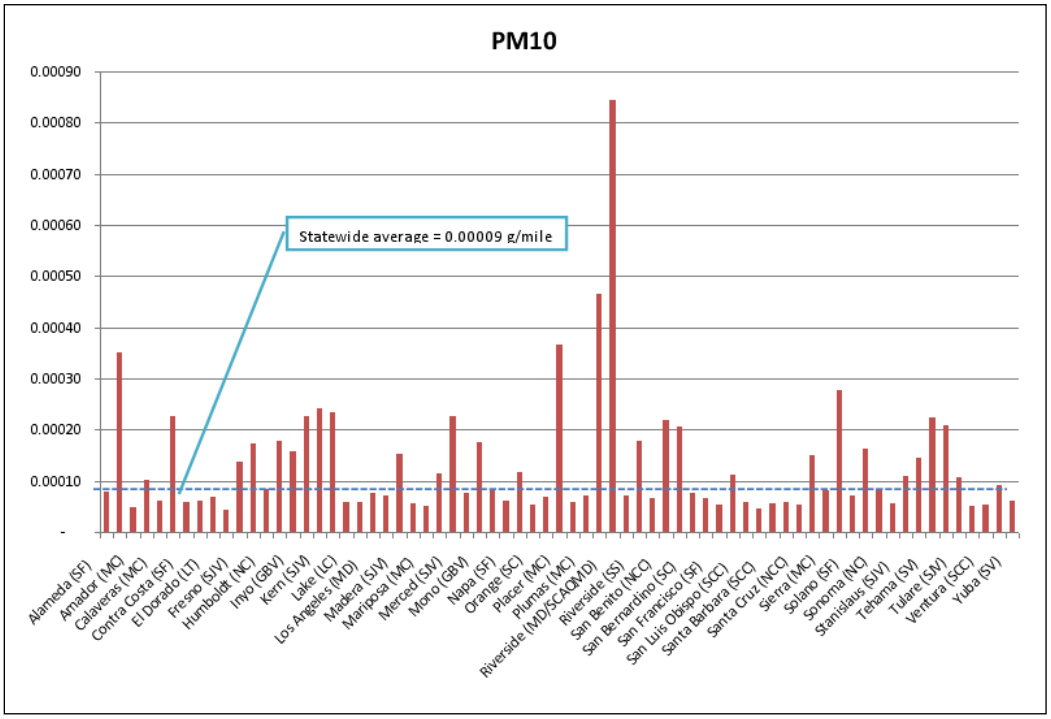


Exhibit II-34: Reactive Organic Gas (ROG) or Volatile Organic Compound (VOC) Emissions per Mile

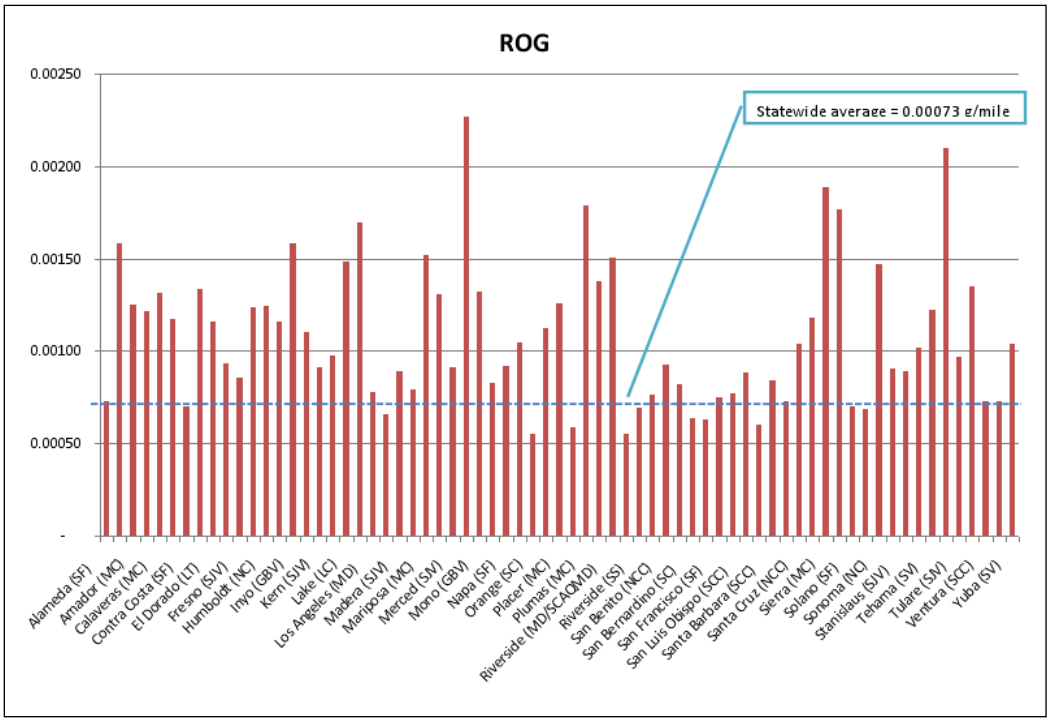
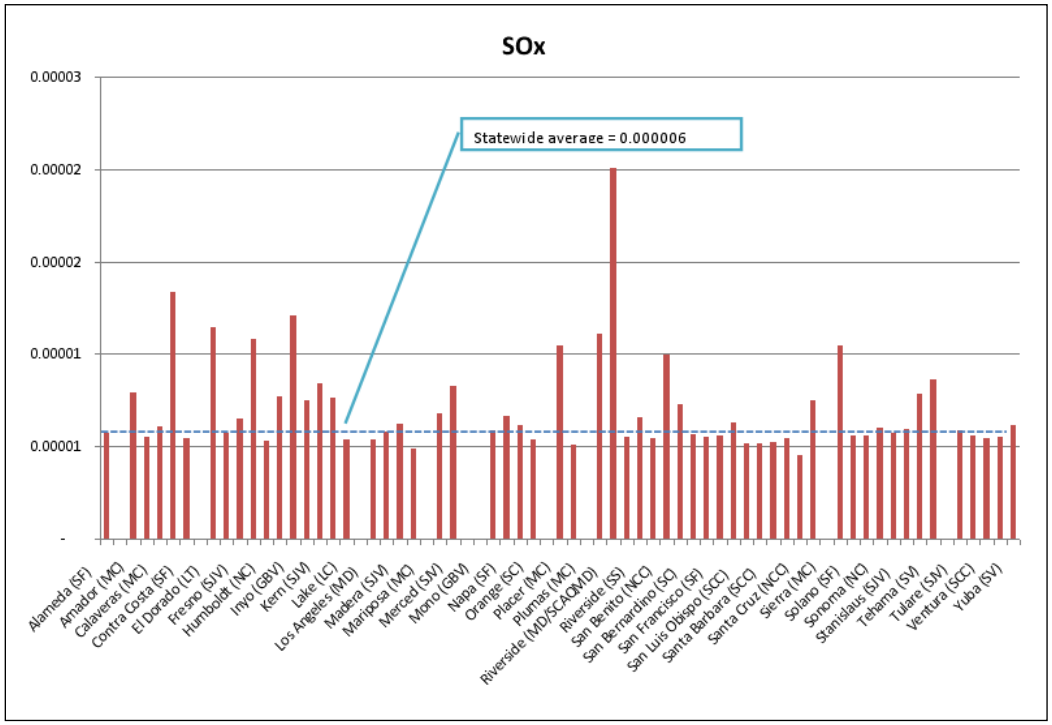


Exhibit II-35: SOx Emissions per Mile

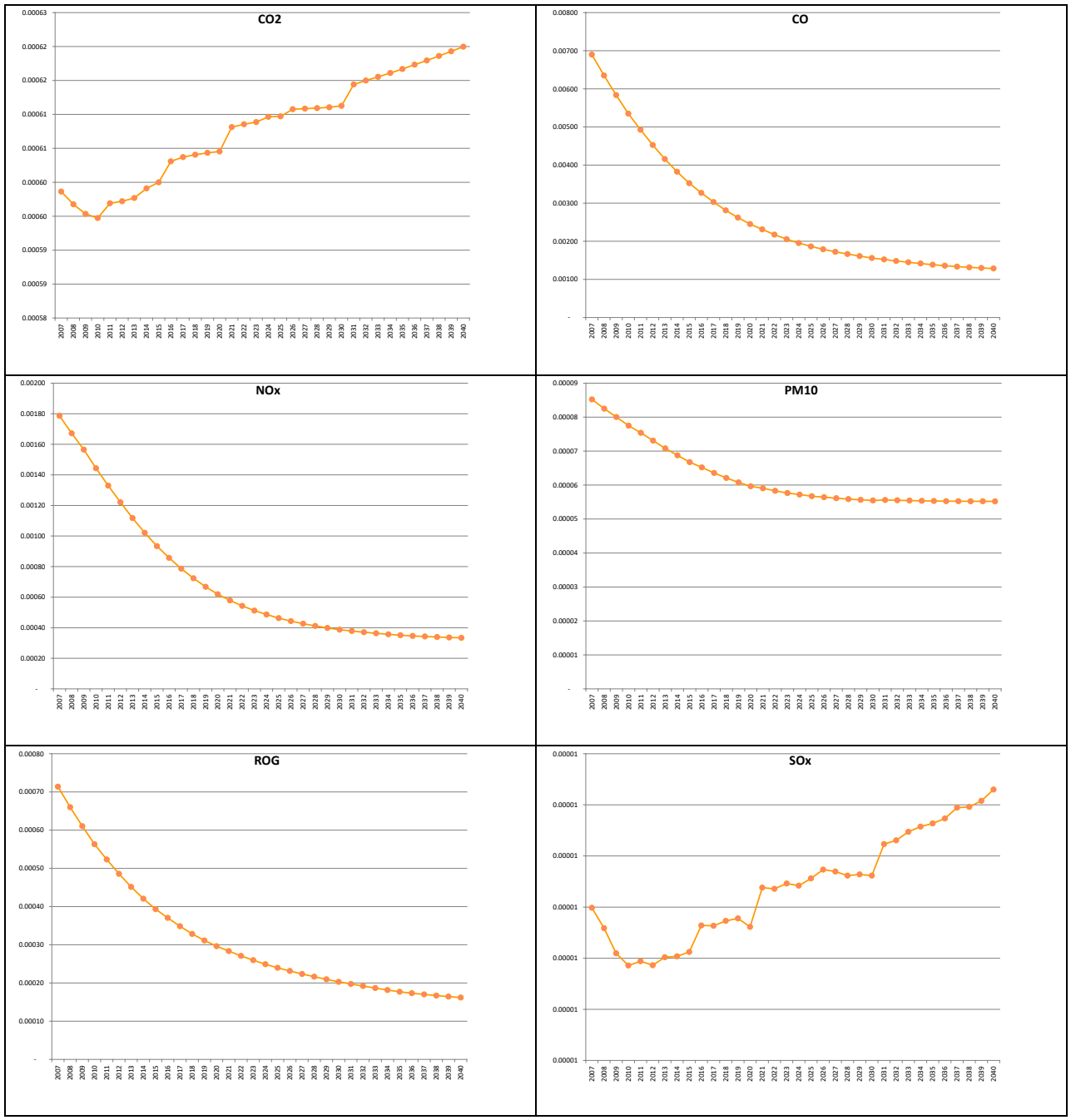


During the 2009 update, the Cal-B/C development team also spoke with representatives of the Mobile Source Analysis Section at the California Air Resources Board (CARB), who described how emission data were estimated. Researchers at the University of California, Los Angeles (UCLA), had conducted the most 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 had not yet been tested or captured in the EMFAC2007 factors.

Prior to the 2009 update, Cal-B/C had 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 2009 update, the Cal-B/C development team plotted average emission rates from EMFAC2007 for each pollutant by year.

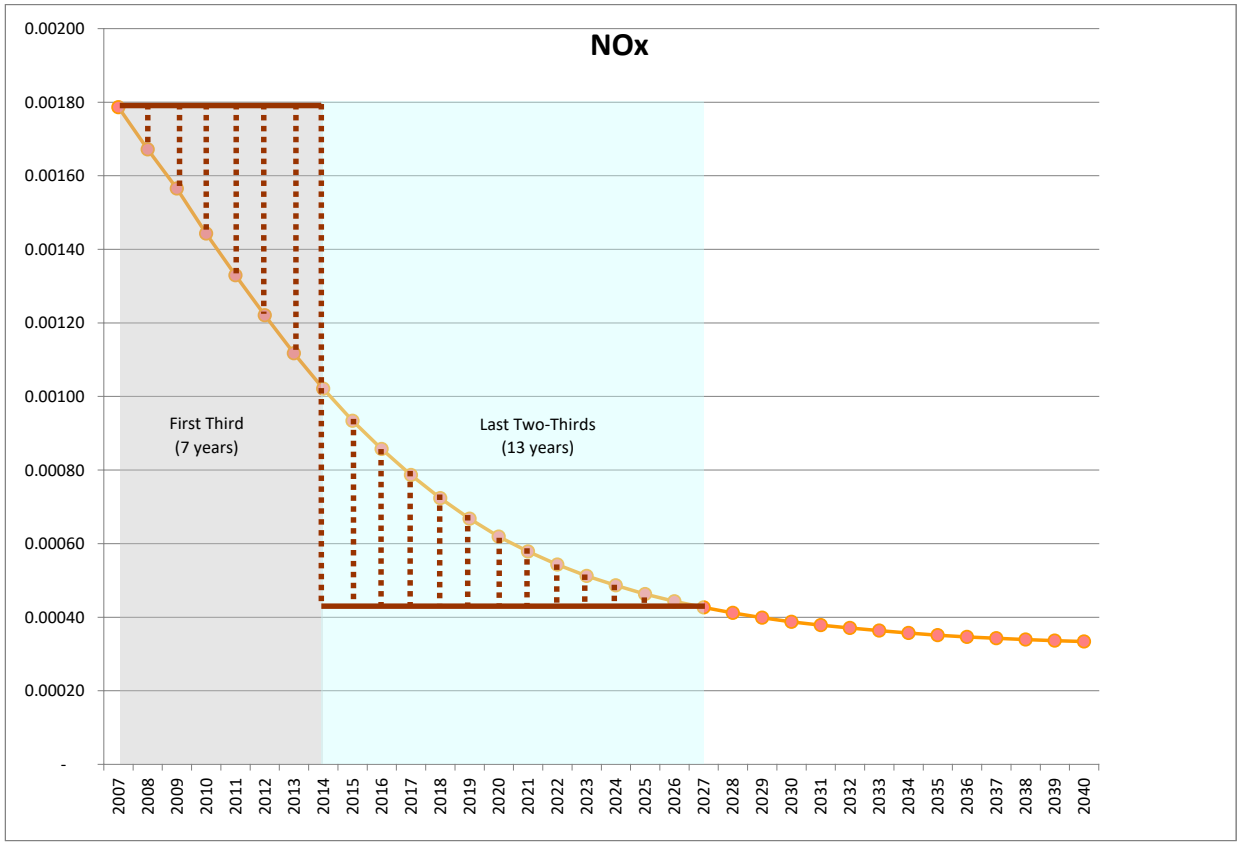
These rates are shown in Exhibit II-36. Four pollutants (CO, NOx, PM10, and ROG) follow smooth exponentially declining curves rather than straight lines. The other two pollutants (CO_2 and SOx) show increasing values over time and follow much more jagged lines, potentially because of policy milestones.

Exhibit II-36: Changes in Emission Rates over Time



The CO_2 and SOx 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 II-37 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 II-37: Approximation of Emissions using Two Years



For the current version of Cal-B/C, the Cal-B/C development team used EMFAC2014 to generate emissions factors for 2016 and 2036 EMFAC estimates. Cal-B/C uses the 2016 rates first seven years of benefit-cost analysis and the 2036 rates for the last 13 years of analysis for all pollutants. Although an even ten year split would be more appropriate for estimating CO_2 and SO_X 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. Since idling factors could not be separated in the emission factor calculations, Cal-B/C uses 5 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 EMFAC2014 at 5-mph intervals. These 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 2016 and 2036 from EMFAC2014

6.2 Emissions Costs

Cal-B/C continues to use emissions costs based on the 1996 study by Delucchi and McCubbin (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 McCubbin 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 McCubbin (1996). These values are the cost of direct motor-vehicle emissions. Cal-B/C includes values updated from the 2000 Cal-B/C values to 2016 dollars using the GDP deflator (an adjustment factor of 1.3703). Exhibit II-38 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 II-38: Health Cost of Transportation Emissions (in 2016 dollars per ton)

Area	CO	NO_X	PM_{10}	SO_X	VOC
LA/South Coast	$160	$63,900	$523,300	$196,600	$3,970
CA Urban Area	$80	$18,700	$151,100	$75,500	$1,305
CA Rural Area	$75	$13,900	$107,700	$54,400	$1,025

Adapted from Delucchi and McCubbin (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 2016 TIGER VIII program, USDOT prepared a TIGER Benefit-Cost Analysis (BCA) Resource Guide (USDOT 2016). The guide references emissions values from the 2012 NHTSA

Final Regulatory Impact Analysis for Model Year (MY) 2017 – MY 2025 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 2012). Exhibit II-39 shows the values provided in the TIGER BCA Resource Guide, adjusted from 2015 dollars to 2016 dollars using the GDP deflator (an adjustment factor of 1.0158). The Cal-B/C development team will continue to research these values and consider adopting them in future updates.

Exhibit II-39: USDOT TIGER Value of Emissions (in 2016 dollars per ton)

Emission	Value per Short Ton	Value per Metric Ton
Volatile Organic Compounds (VOC)	$1,873	$2,064
Nitrogen oxides (NO_x)	$7,381	$8,137
Particulate matter (PM)	$337,668	$372,215
Sulfur dioxide (SO_x)	$43,627	$48,091

Source: USDOT, TIGER Benefit-Cost Analysis (BCA) Resource Guide, March 2016.

Revision Made to Cal-B/C: updated original emission costs to 2016 dollars

7 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_2 emissions saved because of transportation improvements. Practical experience using Cal-B/C suggests that highway projects that moderately improve speeds may have a negative greenhouse gas impact. However, many highway projects, particularly those with large speed improvements, have a positive impact. Transit projects generally have a positive greenhouse gas 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_2 in EMFAC and as the State's Climate Action Program develops strategies for the future.

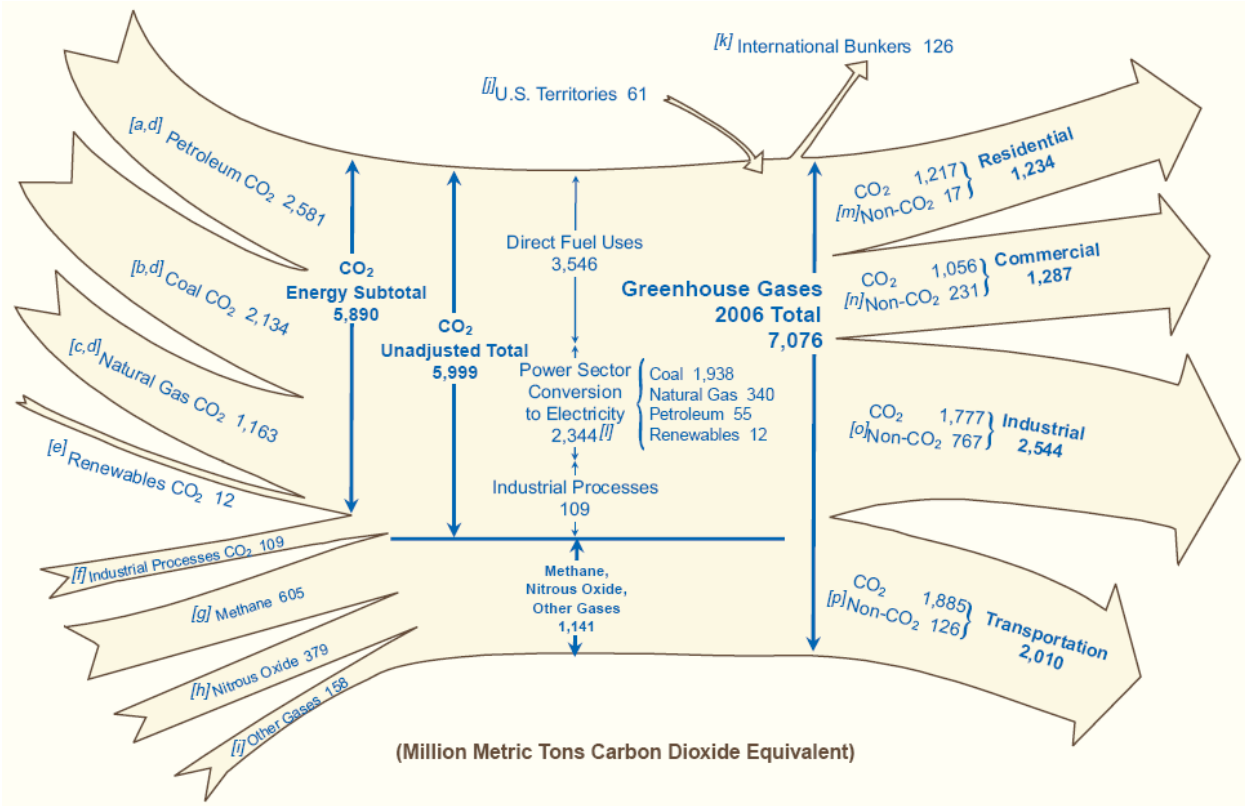
7.1 Emissions Rates

Cal-B/C reports greenhouse gas emissions in terms of the amount of CO_2 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 II-40, taken from the 2007 report, shows that the majority of greenhouse emissions produced by vehicles are in the form of CO_2. Non-CO_2 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_2 since 1999. A general diagram of greenhouse gas emissions in the US economy is shown in Exhibit II-40.

Exhibit II-40: 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 established a comprehensive program of regulatory and market mechanisms to achieve quantifiable and cost-effective reductions of greenhouse gases. AB 32 required the State's greenhouse gas emissions to 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. <u>Automobile Regulation (Assembly Bill 1493, Pavley)</u> – 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_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF6), 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. The updated query tool covers the years 2000 to 2013.

EMFAC2014 can produce CO_2 and CH_4 emission estimates and is a tool for assessing alternative growth scenarios associated with regional transportation planning for greenhouse gas reductions (SB 375). Unlike prior versions, EMFAC2014reflects planned GHG emissions standards and their impact on future year fleet mix. Cal-B/C uses CO_2 estimates from EMFAC2014 as its basic emissions rates.

The Results page of Cal-B/C reports the tons of CO_2 saved because of project construction. This represents the difference in CO_2 emissions between the Build and the No Build cases. The estimates are based on the EMFAC factors for CO_2 only.

Revision Made to Cal-B/C: CO_2 rates based on EMFAC2014

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_2 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 varied somewhat from the UK estimates, the methodology for monetizing greenhouse gas emissions was 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>.

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_2 equivalent (CO_2e) 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>.

The original Cal-B/C methodology followed the DEFRA approach for valuing greenhouse gas emissions. The DEFRA approach relies on a shadow price per metric ton of CO_2e 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_2e. 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 received an update in May 2013 and was further revised in July 2015. It provides values under four scenarios (average social carbon costs with discount rates of 5 percent, 3 percent, and 2.5 percent as well as 95th 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 II-41.

Exhibit II-41: Revised Social Cost of CO_2, 2010 to 2050 (in 2007 dollars)

Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	10	31	50	86
2015	11	36	56	105
2020	12	42	62	123
2025	14	46	68	138
2030	16	50	73	152
2035	18	55	78	168
2040	21	60	84	183
2045	23	64	89	197
2050	26	69	95	212

Source: Interagency Working Group on Social Cost of Carbon, United States Government, Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, May 2013 (Revised July 2015).

As a moderate estimate of the benefits associated with CO_2 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 ($36 per metric ton in 2007 dollars for 2015 emissions). This value was updated to 2016 dollars using the GDP deflator (1.1164/0.9684), uprated by 2.0 percent for one year (discussed next), and converted to US tons. The resulting value was rounded to $38 per US ton of CO_2e.

Consistent with guidance from the US Interagency Working Group, Cal-B/C uses a value of CO_2e that increases with each year of analysis because" future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed" (Interagency Working Group 2015). The values for subsequent years are estimated using an uprater (or growth factor) of 2.0 percent per year. This uprater is consistent with the growth shown in Exhibit II-41 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 $36 estimate for the first year of project benefits. The model includes the 2.0-percent "uprating"

factor, so that subsequent years reflect increasing values. Since Cal-B/C evaluates all projects with starting values based on 2016 emissions, the approach underestimates the value of greenhouse gas emissions with project openings delayed substantially into the future.

Revision Made to Cal-B/C: greenhouse gas emissions estimated in Cal-B/C using EMFAC2014 emission rates for CO_2 and the 2015 revised US Interagency Working Group values for greenhouse emissions

8 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 2015.

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 2015 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 2-33, 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 2-34. The Cal-B/C development team decided to use data from Table 2-33 (consistent with the original Cal-B/C) because the non-accident incidents are not directly related to the amount of service provided (revenue vehicle-miles traveled).

Exhibit II-42 shows the updated transit accident rates for Cal-B/C. The Cal-B/C development team used the average of safety statistics for 2003 through 2012.

Exhibit II-42: Average of Transit Accident Rates for 2003-2012

(events per million vehicle-miles)

Event	Passenger Train	Light Rail	Bus
Fatality	0.0555	0.2480	0.0349
Injury	0.2519	3.9469	3.6535
All Accidents	0.2775	5.3817	2.6733

Source: US Department of Transportation, Transportation Statistics Annual Report, 2015.

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 also available online.

The accident rates in Exhibit II-42 are lower than the accident rates used in Cal-B/C before the 2007 revision. As noted in National Transportation Statistics, transit accident rates have dropped 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 AIS A or B for highway accidents). This newer 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. As of the 2015 update, reportable events are no longer limited to those that affect revenue service.

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>). 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 II-43 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 2011 and rounded for use in Cal-B/C. The transit mode definitions are the same as those used for the accident rates.

Exhibit II-43: Cost of Transit Accident Events (2011)

Value	Passenger Train	Light Rail	Bus
Total Property Damage Cost	$18,130,110	$5,179,121	$22,564,745
Total Number of Accidents	230	418	6,008
Property Damage ($/event)*	$78,800	$12,400	$3,800

** Rounded*

Source: Federal Transit Administration, Transit Safety & Security Statistics & Analysis Annual Report, available at <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. EMFAC2014 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 (NOx), particulate matter (PM_{10}), and hydrocarbons (HC).

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

9 Active Transportation Parameters

Cal-B/C 6.2 includes an active transportation module called Cal-B/C 6.2 AT. This section summarizes the active transportation parameters and their sources. More information can be found in the technical documentation for Cal-B/C 6.2 AT.

General Travel Activity Characteristics. Cal-B/C assumes that walking and cycling occurs 365 days per year for active transportation projects. This assumption is consistent with the annualization used for transit and highway projects. For safe routes to school, Cal-B/C assumes that there are 180 school days per year when benefits occur.

Vehicle Statistics. For estimating automobile emissions, Cal-B/C assumes that the automobiles new cyclists or pedestrians used in the No Build were traveling at 25 miles per hour. AVO is estimated to be 1.25 persons per vehicle using data from the 2010-2012 California Household Travel Survey. The survey also provides average distance per trip and percent trip purpose information.

Active Transportation User Characteristics. The average cycling speed is estimated to be 11.8 mph from research by Hood et al. (2011). Cal-B/C uses an average walking speed of 3.0 mph based on the assumptions in the World Health Organization (WHO) HEAT model. To estimate the percentage of trips with round trip journeys, the Cal-B/C development team analyzed data from the 2010-2012 California Household Travel Survey and found that on average 95 percent of cycling trips and 90% of pedestrian trips involve round trips. Cal-B/C includes an estimation of the diversion of cyclists and pedestrians from automobiles. This is assumed to be 50 percent.

Value of Time. Cal-B/C uses the same value of time for pedestrians and cyclists as it does for other models. This is currently set at $13.65 per hour. Children are assumed to have the same value of time as adults, but a separate parameter is provided in case the Department choses to use a different value of time for children in the future.

Journey Quality Values. Cal-B/C calculates journey quality benefits for cyclists as a function of distance by trail class based on research by Hood et al. (2011). Journey quality benefits for pedestrians are calculated in cents per mile for various amenities provide along the corridor. These amenity values are based on Heuman et al. (2005), who estimated the value of pedestrian facilities in the greater London area using state preference research. The valuation approach developed by Heuman (2005) differs from cycling valuation because each of these identified improvements provides an additive value to users per distance traveled on a walking trip. UK Department for Transport (DfT) Transport Analysis Guidance (TAG) notes that the methodologies do not take into account potentially negative interactions between cyclist and pedestrian journey quality. Overestimation could occur if journey quality benefits to cyclists and pedestrians are added together, but this overestimation may be minor.

Absenteeism Reduction. Health benefits are assumed to be the result of two impacts – reductions in absenteeism and reductions in mortality. Absenteeism is estimated based on the average absence of employees based on data from the Centers for Disease Control and Prevention (CDC 2011). The Cal-B/C development team could not find data on short-term sick leave coverage in California, so the team used the 95 percent assumption used in the UK TAG 2014 documentation. Coverage in California may be lower due to the difference in insurance structures between California and the UK.

Thirty minutes of activity per day are expected to reduce sick days by 6 percent per year according to research from WHO (2003), which was the basis of the UK Web TAG guidance. The WHO research found that workplace physical activity programs in the US involving 30 minutes of daily exercise can reduce short-term sick leave by 6 to 32 percent. Cal-B/C has adopted the lower value for a conservative estimate of benefits.

Mortality Reduction. Cal-B/C uses demographic age groups to estimate mortality reductions using data from the 2010-2012 California Household Transportation Survey. The average reduction in mortality per 365 annual cycling miles (4.5 percent) and 365 annual walking miles (9 percent) is based upon the WHO HEAT Model (WHO 2016). The mortality rates used in Cal-B/C are from 2010-2014 Death Rates from the California Department of Health.

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III.

Active Transportation

III. Active Transportation

This chapter documents the development of the Cal-B/C 6.2 Active Transportation (AT) model, one of the newest analytical tools to be developed as part of the Cal-B/C suite of tools. The chapter provides background on economic literature and data reviewed for the model and the resulting methods for estimating a variety of relevant benefit categories for active travelers. This version of the model reflects recommended updates to a first-generation BCA model that Caltrans developed in 2014. The original model was used in conjunction with the Active Transportation Program (ATP) project selection process.[1] Although the new model is a second generation model, it is labeled 6.2 to be consistent with the version numbers for other Cal-B/C models.

Refinements to the methods and data of the original Cal-B/C Active Transportation model have been developed through a comprehensive literature review and coordination with a number of people and organizations. These entities include: Caltrans Project Manager, other members of the Caltrans Economic Analysis Branch, a Benefit-Cost (B/C) User's Group,[2] Caltrans Division of Traffic Operations, and California Department of Public Health. Improvements to the existing Cal-B/C model cover several areas including:

- Improved specification of data entry requirements;
- Expanded set of benefit categories;
- Updated benefit estimation methods and data; and
- Integration of additional data from California Household Transportation Survey[3], Bureau of Labor Statistics (BLS), US Census Bureau, California Department of Public Health, US Department of Health and Human Services, and Caltrans' Local Roadway Safety Manual for Californian Road Owners.

The tool is designed to estimate benefits for projects and cost-effectiveness measures for programs. Eligible projects fall into several categories including:

- **Infrastructure Projects (IF):** Projects involving capital improvements (e.g., construction) that will further the goals of the ATP. This typically includes planning, design, and construction of facilities;
- **Non-infrastructure Projects (NI):** Programs related to education, encouragement, enforcement, and planning activities that further the goals of the ATP; and
- **Combined IF and NI:** Projects that include both infrastructure and non-infrastructure components.

[1] At that time, the application process provided credit for simply completing the BCA and providing comments on the tool data, methods and documentation.
[2] Caltrans Division of Transportation Planning, Sustainable Community Planning, and Multi-Modal System Planning
[3] http://www.dot.ca.gov/hq/tpp/offices/omsp/statewide_travel_analysis/chts.html

Projects and programs are further classified into:

- **Safe Routes to School (SR2S):** Projects that improve the safety of children walking and bicycling to school; and
- **Non-Safe Routes to School (Non-SR2S):** Projects that do not specifically involve access to public schools, but meets other ATP goals (e.g., improvements to existing bikeways and walkways, which improve mobility, access, or safety for users).

Caltrans classifies active transportation facilities into several types that differ largely with respect to the level of separation from vehicles. These classes can differ in generating demand and in the value of their use. The four classes in the Caltrans system include:

- **Class I (Bike Paths):** Paths that are dedicated to cyclist and pedestrian users and are designed to be at least 5 feet from any road;
- **Class II (Bike Lanes):** Facilities in which cyclists (only) share a road with motorized vehicles, but where lane striping marks the lanes dedicated to cyclists and excludes motorized vehicles;
- **Class III (Bike Routes[4]):** These facilities are intended only for cyclists and are identified with signs as shared roads between motorized vehicles and bicycles; and
- **Class IV (Separated Bikeways, Cycle Tracks):** These facilities are similar to Class II facilities except that the design includes some type of barrier which separates cyclists from motorized vehicles. Class IV is considered to be safer than Class II or III.[5]

The distinction between Class II and Class III lies mainly in road striping and dedicated zones where only bicyclists are permitted to use the road right-of-way (ROW). Class III facilities are characterized by “sharrows” (e.g., lane markings indicating shared use, but no striping) or signage asserting the bicyclist’s right to use the full roadway. Class IV would represent a value that is similar to Class II, but perhaps with a greater feeling of protection. Overall, these facilities are primarily designed for cyclists, however Class I can be used by pedestrians. In addition, apart from the facility classification, no additional specification of safety features such as signalized crossings, bridges, or signage for each Class is specified.

The rest of this chapter is organized as follows:

- Literature Review
- Technical Description of Cal-B/C AT
- References.

[4] Throughout this document “Bike routes”, “trails” or “routes” is used to describe the options of traveling between an origin and destination, this is not the same as Bike Class III, which is a route designed for cyclists.
[5] However, perceived safety can be compromised if parked cars serve as the “barrier” that separates cyclists from moving vehicles because accidents can occur when car doors are opened unexpectedly.

1 Literature Review

This section provides a review of recent economic studies as a foundation for the data and methods applied in this model. The literature includes a comprehensive review of two documents – National Cooperative Highway Research Program 552 (NCHRP 552, 2012) and UK Department for Transportation (DfT) Transport Analysis Guidance (UK DfT TAG) from United Kingdom Department for Transport – that provide guidelines on a complete set of benefit categories. While these documents are not primary research sources for economic valuation parameters, they are important reference points because jointly, they consider the full range of potential benefit categories and explicitly aim to avoid the risk of overestimating benefits by "double-counting." In addition to these more comprehensive guidelines, this section also discusses a variety of more recent research on different benefit categories. Also, where relevant, BCA guidance[6] that USDOT developed for applications to their TIGER grant program is also discussed.

1.1 Project Evaluation Methods by Benefit Category

Journey Quality

This benefit category represents the primary value of mobility[7] gained by active transportation users and can be derived from their sense of *journey ambiance*, *ease of use*, and *feeling of safety* (from vehicles). Higher values are observed for active transportation facilities with greater separation from conflicting modes, safety features and aesthetic value. Journey quality can be associated with users with different trip purposes, including those with a specific destination (e.g. work or school) and those with a purely recreational purpose whose trips begin and end in the same place – so-called "loop" trips. As discussed below, NCHRP and UK TAG differ in how benefits for these users are estimated. In addition, of note is that the latest USDOT TIGER BCA guidelines indicate that benefits to recreational users should not be included in final benefit estimates.

NCHRP 552 GUIDELINES

NCHRP 552 guidelines discuss values of journey quality for different types of bike facilities that originally come from Krizek et al. (2005). Estimated valuation metrics are derived from Krizek et al. (2005) who conducted a stated preference survey with employees at the University of Minnesota. The research generated responses from participants on their stated willingness to spend extra time on a hypothetical journey to work if it could involve using a bike facility.[8] Respondents were asked about their preferences for using a bike facility that involved different levels of additional travel time, given a hypothetical travel time that did not involve a bike facility. Respondents provided preferences for different types of facilities with higher and lower levels of vehicular traffic. The results of survey preferences for extended travel times are then monetized with an estimate of users' value of time, which following standard economics practice, is derived

[6] Guidelines have been developed as part of the USDOT TIGER Grant program. See pg. 12 in: https://www.transportation.gov/sites/dot.gov/files/docs/TIGER_BCA_Guidance.pdf

[7] The terms "mobility" and "journey quality" are used by different authors to reflect some of the same aspects of bike facilities the create value to users, namely: *journey ambiance*, *ease of use*, and *feeling of safety* (from vehicles). Accordingly, they are used interchangeably in this tool to account for users' preferences for a bike facility.

[8] The questionnaire approach used an *Adaptive Stated Preference Survey* that modified questions depending on participant responses. Additional details are discussed in the document.

from median wage rates. Krizek et al. (2005) found that facilities with greater levels of separation from motorized vehicles are valued more highly than those with less separation. The distance an average commuter is willing to travel to use bike facilities that offer greater separation from vehicles ranges from 15.8 to 20.4 minutes per trip. These results could be applicable to valuing each Bike Class in CA.

UK DFT TAG GUIDELINES

UK TAG guidelines on journey quality benefits account for users' enjoyment of active transportation facilities. The research was originally conducted by Hopkinson and Wardman (1996) and Wardman et al., (1997), who performed stated preference surveys for bicycle facilities between different cities in the UK. The survey respondents indicated their willingness to pay for the different classes of facilities – especially in terms of separation from motorized vehicles. The research determined that while respondents placed higher value on facilities that provided greater environmental quality, comfort, and convenience, their primary interest was a reduced risk of accidents. The results generated monetary values for active transportation facilities based on the time and distance users spent on the bike facility.[9] In addition, Wardman et al., (2007) estimated the value to cyclists for trip-end cycle facilities, such as secure cycle parking facilities and shower facilities.

UK TAG guidelines also cover valuing pedestrian facilities through stated preference research conducted by Heuman (2005) along walkways in greater London. Facilities can be improved with a variety of features that pedestrians value. These include: Street lighting; (b) Curb level; (c) Crowding; (d) Pavement evenness; (e) Information panels; (f) Benches; and (g) Directional signage. Taken together, these features reflect the same interests as cyclists in improved *journey ambiance*, *ease of use*, and *feeling of safety.* The valuation approach developed by Heuman (2005) though differs from cycling valuation because each of these identified improvements provides an additive value to users per distance traveled on a walking trip. UK DfT TAG notes that the methodologies do not take into account potentially negative interactions between cyclist and pedestrian journey quality. Overestimation could occur if journey quality benefits to cyclists and pedestrians are added together, but this overestimation may be minor.

RECENT LITERATURE

Newer studies have begun to take advantage of global positioning system (GPS) tracking information to assess the *revealed preferences* of riders in terms of their actual route choices. These data are better able to detect riders' actual preference for a variety of characteristics of route alternatives including options to take a bike facility (and avoid an open road), but also the presence of hills, turns, and traffic levels. Ranjit et al. (2015), for example, used Bikeshare tracker data in Phoenix AZ to determine the revealed utility that a rider gains when they divert from the shortest path between their journey origin and destination. Ranjit et al. (2015) found travel on bike-specific facilities is equivalent to decreasing the distance traveled by 44.9 to 53.3 percent for destination cyclists.

[9] This measure is in direct contrast to the approach of Krizek (2005) in NCHRP 552, who inferred value from the *extra* time a rider is willing to spend to reach a bike facility.

Hood et al. (2011) used GPS data collected from smartphone users in San Francisco to conduct a revealed preference analysis of the route choices of destination cyclists. These data led to the estimation of *Marginal Rates of Substitution* (MRS) for different attributes of a route, including types of cycling facilities. MRS values are used to value a person's preference for different types of bike facilities, relative to each other or an unmarked road without bike facilities.

The results from Hood et al. (2011) provide a stronger basis for estimating bike facility use value as compared to NCHRP and UK DfT TAG for several reasons. First, the Hood et al. (2011) methodology relies on *revealed* preference data as compared to the stated preference data of NCHRP and UK DfT TAG. In addition, this work was conducted in California and reflects climatic and cultural / behavioral preferences there (as compared for example to NCHRP, which included survey respondents who worked at a college in Minneapolis). This study also includes relative facility preference values for a variety of facility types that are comparable to those under consideration in the ATP.

Other relevant research is conducted by Broach et al. (2012), who used a revealed preference method of cyclist route choices, but generated a different type of measure than Hood et al. (2011). Broach et al. (2012) determined the value of bike facilities according to the *percentage increase* in the length of a trip a cyclist is willing to take in order to use those facilities. For example, they find that cyclists commuting to work are willing to increase their trip distances by up to 16 percent of the length of the bike class that they use.[10] They used GPS tracking data for the bike trips of 154 participating cyclists in Portland, OR from March to November 2007. Their analysis divides the results by commuter and non-commuter destination travel. Recreational exercise trips are excluded. Other variables considered were geography, gender and the frequency of cycling.

Additional information obtained from a data review includes characteristics of bike facility users. For example, the average length of a bike trip in California, according to the 2010-2012 California Household Survey, is around 2 miles and the average duration is 18.2 minutes. Broach et al. (2012) finds that the average length of a commuter trip in San Francisco is 3.7 miles and has an average duration of around 18.8 minutes. These data are important because the current ATP model uses NCHRP findings, which state that the average cyclist would be willing to divert their trip 15.83 to 20.38 minutes to use bike facilities. These findings do not take into account the trip distance of the cyclist. The survey conducted by NCHRP presented travel distances between 20 and 60 minutes to the interviewees. Since the 2010-2012 California Household Survey shows that the average duration of a bike trip is 18.2 minutes and Broach et al. (2012) finds that the average duration is around 18.8 minutes, the NCHRP values may be too high. The range of cycle times presented to the interviewees in Hopkinson and Wardman (1996) is 10 to 25 minutes, which is closer to the average travel times of Californian cyclists.

As a last step in reviewing this literature, estimated journey quality benefits are computed using results from the literature and a common set of other parameters, such as cycling speed, distance

[10] Interestingly, Broach et al. results on the additional distance that a user is willing to travel to reach a bike facility provides a foundation for estimating the number of users for that facility. That is, this additional distance can be used to determine a buffer area of potential cyclists

and value of time. The results are presented in Exhibit III-1 and a description of assumptions is discussed below:

- Hood et al. (2011) provides a comparison of their results by assuming a value of time of $12.50[11] ($2015) per hour for commuters based on local data. They apply this value to the estimated 15.8 to 20.4 minutes of time that an average commuter cyclist is willing to spend to use bike facilities outlined in NCHRP. This results in an additional value to users of $4.20 to $3.80 per trip depending on the facility type.
- Estimated journey quality benefits, outlined in Hopkinson and Wardman (1996) and Wardman et al. (1997) are between 7 to 17 cents per minute when converted to 2015 dollars. To compare these results, assume that commuter cyclist trips have an average duration of 18.8 minutes, as indicated by Broach et al. (2012). These assumptions result in an estimated journey quality benefit of between $1.34 and $3.28 per trip, depending on the facility type.
- Estimating the value of journey quality benefits from Hood et al. (2011) require data on average travel speeds and value of time. If the average speed of a commuter cyclist in San Francisco is 11.8 miles per hour, according to Broach et al. (2011), then the average time taken to travel one mile is about 5 minutes. Using the same $12.50 per hour for commuters for users' value of time, the estimated benefits are between $0.31 and $1.69 per trip, depending on the facility type.
- Data required to estimate journey quality benefits from Ranjit et al. (2015) and Broach et al. (2012) include average trip length, the average speed and the value of time. Assuming that 3.7 miles for the average length of a commuter trip in San Francisco and the same values for speed and value of time from Hood et al. (2011), as used above, the estimated benefits from Ranjit et al. (2015) are between $1.80 and $2.10 per trip, and from Broach et al. (2012) are $0.42 to $0.63 per trip, depending on the facility type.

SUMMARY FINDINGS

The results of this comparative assessment reveal differences between study findings. First, the NCHRP 552 results are the highest in valuation parameters. The other values found in Hopkinson and Wardman (1996), Hood et al. (2011) and Ranjit et al. (2015) are similar in magnitude. This similarity suggests that the Hood et al. (2011) study in San Francisco can provide a sound basis for evaluating the value of mobility in San Francisco and other major CA cities. None of these studies however cover the value of bike facility preferences in rural areas. In rural areas, lower traffic volumes would suggest that the preference for bike facility would be lower than in cities. However, lower numbers of cyclists on roads would reduce the feeling of security on roads that is derived from having 'safety in numbers'. Since the actual affect of these opposing influences is unknown and there are no specific values for rural areas, the same values from Hood et al. (2012) are proposed for rural areas.

[11] A value of time of $12.50 per hour is consistent with standard Cal-B/C parameter values.

Exhibit III-1: Per Trip Mobility Benefit Comparison (2015 dollars)

ID	Class I	Class II	Class III	Class IV	All Classes	Per	User Types	Surveyed Population	Source	Method
1	$4.20	$3.80				Trip	Existing and Induced Commuters	Employees of St. Paul University, Minnesota	NCHRP 552	Stated Preference
2		$1.34				Trip	Existing and Induced Cyclists	Riders on routes in several UK cities	Wardman et al. (1997)	Stated Preference
3	$3.28			$1.39		Trip	Existing and Induced Cyclists	Riders on routes in several UK cities	Hopkinson and Wardman (1996)	Stated Preference
4	$1.69	$2.00	$0.31			Trip	Existing Destination Cyclists	Participants self-selected from bike groups in San Francisco, CA	Hood et al. (2011)	Revealed Preference
5					$1.80-$2.10	Trip	Destination travelers	Bike share system and no investigation of individual bike facilities	Ranjit et al. (2015)	Revealed Preference
6	$0.63		$0.42			Trip	Existing Commuters	Participants self-selected from bike groups in Portland, OR	Broach et al. (2012)	Revealed Preference

Recreation

Alternative perspectives exist on whether and how benefits should be estimated for cycling and walking for recreational purposes. Some active transportation BCA approaches have considered recreational trips to be sufficiently different from other trip purposes that they require different data and analytical methods, especially in using data from travel cost studies.[12] For instance, USDOT TIGER BCA guidelines exclude recreational trips from total project benefits, preferring instead to prioritize the value of cycling as a mode of transportation, not recreation.

Recreational trips certainly differ considerably from destination-oriented trips since they are taken primarily for exercise and leisure purposes. Each trip constitutes a single "loop" trip that starts and ends in the same place. Recreational users may place no value though on aspects of the alignment of facilities that generates time savings because their primary motivation is exercise and enjoyment of the space. Also, in contrast to other trip purposes, recreational trips by the definition here do not replace a vehicle trip.

However, with respect to valuing the journey quality of a trip, recreational users are likely to derive value from the same facility features (e.g. accessibility, safety, and aesthetic) as users with different trip purposes. Accordingly, in contrast to USDOT, Caltrans may recognize the interests of any user of roadways and sidewalks as UK DfT TAG does. For example, cyclists are permitted to use most roadways, independent of purpose. As well, any vehicular drivers prefer to avoid cyclists on roadways because of their different speeds of travel and need to pass cyclists on single lane roads. Similarly, sidewalks and paths are constructed to provide pedestrians with safe and comfortable passage without regard to their trip purpose.

NCHRP 552 GUIDELINES

NCHRP 552 applies the results of research by Lindsey and Przybylski (1998) to estimate the benefits of active transportation facilities for recreational purposes. Their work developed a "travel cost" approach that estimates a traveler's value of a facility from data on expenses and time value of a traveler to reach a facility. Lindsey and Przybylski (1998) estimated that the net value of recreational use is $40 per day (2004 dollars), which is the equivalent of $50.19 per day (2015 dollars). NCHRP 552 converts these daily values to a value per hour by assuming that users spent four hours per day on their trip. This benefit is applicable only to new recreational cyclists and the annual recreational benefit is the product of the average daily time spent cycling, new recreational cyclists, and an annualization factor.

Several weaknesses exist in applying NCHRP values for BCA purposes. First, the Lindsey and Przybylski (1998) economic value is estimated in terms of value per day. However, information is not available on trip characteristics (e.g. duration of trip, distance traveled to destination, costs, out of pocket costs, and combined activities with cycling) to adjust values for a new contexts in CA. In particular, to determine an estimate of the value per hour a major assumption is required on the number of hours spent per trip in the Lindsey and Przybylski (1998) study. Moreover, even as a 'value per hour' measure, additional assumptions are required about vehicle speed to

[12] Travel cost methods involve approaches to estimating non-market values of environmental resources by the money and time that visitors spend to reach a destination.

estimate benefits on the basis of 'value per distance traveled'. Thus, because of the additional assumptions required to use the NCHRP 552 cited study, this value is not recommended for this the Cal-B/C AT Model.

UK DFT TAG GUIDELINES

UK DfT TAG does not develop separate methodologies for recreational users. Instead, the value of a bike facility for these users would be captured by the same journey quality valuation approach as discussed above.

SUMMARY FINDINGS

Valuation of trips specifically for recreational purposes is not well developed in the economic literature. However, the valuation parameters for journey quality benefits developed by Hood et al. (2011) could be a reasonable approximation of this value. While recreational cycling has different characteristics from trips to reach a destination, especially in terms of length of trip, designated bike facilities are still likely to be preferred, possibly to the same degree, because of the facilities' relative safety and improved connectivity with a wider bike facility network. Accordingly, it is reasonable to apply the same value of recreational cyclists and pedestrians as with all other trip purposes. The Cal-B/C AT tool is designed such that recreational benefits can be included or excluded depending on the policy or evaluation purpose at the time.

Health

People who choose active transportation modes compared to motorized modes benefit from improvements in personal health. These benefits include reductions in diabetes, heart disease and other ailments, as well as improvements in psychological well-being – factors that contribute ultimately to a person's risk of morbidity and mortality. Analysts normally assume that existing cyclists and pedestrians already benefit in these ways. However, projects that induce new trips from existing users or induced trips can improve those users' health conditions.

A central challenge in estimating these benefits is that not all users generate the same level of health benefits from active transportation. Trips of longer length for example generate greater health benefits but only up to a maximum level of health improvement. Since benefits are estimated from the number of people affected, the estimated number of daily one-way trips must be adjusted by the proportion of one-way trips that are combined with a roundtrip to determine the number of people taking those trips. Some estimation approaches involving highly elaborate models (such as ITHIM, discussed below) that differentiate impacts based on background health risks and user activity characteristics (e.g. trip frequency and trips length).

As discussed below, UK DfT TAG considers two forms of health benefits – one that relates directly to the social cost of reduced long-term health risk, and one that draws from the reduced risk of short-term absenteeism at work. The methodology is applicable to new commuters and recreational pedestrian and cyclists.

NCHRP 552 GUIDELINES

NCHRP 552 reviewed a wide range of studies for their appropriateness to estimate the health benefits of active transportation. The survey notes that methods for estimating connections between physical activity and health effects can vary considerably. Most studies separate

respondents by whether they cycle at least 30 minutes per day for five days per week. Results from these studies are derived from differences in aggregated medical expenditures that relate to this high level of physical activity. Annualized cost savings span a considerable range from $19 to $1,175. This wide range is partly due to differences in methods. NCHRP recommends using a median value of $128, which was estimated by Colditz (1999). In 2015 dollars, this value is about $146 per person per year and would be applicable to new cyclists and pedestrians assumed not to have previously used active transportation modes.

UK DFT TAG GUIDELINES – LONG TERM

The UK DfT TAG approach for long-term health benefits uses average travel time (based on the average distance and speed along the specific route or area) by commuters, recreational cyclists and pedestrians to estimate changes in mortality risk. This approach draws from a number of studies examining improved levels of health for people who engage in walking or cycling. UK DfT TAG recommends research from Andersen et al. (2000) who determined the relative risk reduction in mortality overall for cyclists. They find that people who ride at least three hours per week are 28 percent less likely to die from any cause compared to those who do not. Additional analysis by the World Health Organization (WHO, 2011) indicates that pedestrians who walk at least 5 days per week for about 30 minutes per day on average (or about 150 minutes per week in total) are about 22 percent less likely to die of any cause.

The long-term heath benefits of active transportation, according to UK DfT TAG, are attributable to the overall increase in pedestrians' and cyclists' use of facilities. The lower mortality risk findings from Anderson (2000) and WHO (2011) are applied to increased usage based on local demographic data on baseline mortality rates and ridership characteristics (e.g., average distances traveled, trip frequency). The UK DfT TAG approach does not limit health benefits to only those who ride more than 3 hours per week, or walk more than 30 minutes per week. The UK DfT TAG assumes that incremental health benefits accrue to users on a proportional basis for lower levels of activity.

UK DFT TAG GUIDELINES – ABSENTEEISM

UK DfT TAG guidance includes short-term health benefits that relate to reduced absenteeism at work for cyclists and pedestrians. While this topic has not yet been fully explored in the United States, UK DfT TAG guidance provides an established methodology based on a WHO study (2003). The study indicates that workplace physical activity programs in the US involving 30 minutes of daily exercise can reduce short-term sick leave by 6 to 32 percent. As a result, health care costs decrease by 20 to 55 percent. Productivity is expected to increase by 2 to 52 percent. UK DfT TAG guidance estimates this benefit by accounting for the baseline level of absences and the percentage that physical activity would reduce absences. The average daily wage represents the monetary value of this change in terms of workplace productivity.

RECENT LITERATURE

A model called, Health Economic Assessment Tool ("HEAT") developed by WHO has been widely cited and applied to compute reduced-mortality benefits.[13] Recent updates to this tool enable it to be readily used to evaluate health impacts of new users and trips at project level, with some

[13] See: http://www.heatwalkingcycling.org

simplifications and assumptions. This methodology is similar to that recommended by UK DfT TAG to compute decreased mortality benefits.

The HEAT methodology is based on a reduction in the relative risk of mortality for active facility users. The baseline assumption in risk reduction is that if a person were not participating in active transportation, their mortality risk profile would match that of the general population. But, by being active, their risk of mortality is lowered. The data on reduced relative risk is drawn from WHO's synthesis of the literature and an expert panel review on the health impacts of walking and cycling, as reported in HEAT guidance document. One of the key benchmarks of their review includes research findings that a 10% reduction in mortality risk is associated with 168 minutes of walking per week or about 100 minutes of cycling. WHO reports further that mortality risk changes linearly with activity levels (either in time, or distance traveled) up to a maximum of 120 minutes per day, after which no appreciable reduction in risk occurs.

A key result that can be transferred from the HEAT model is that for every 1 mile in average daily trip length, or fraction thereof, there is fixed rate of reduced annual mortality risk. For cyclists, a 1 mile daily average trip length, or 365 miles traveled per year, leads to a 4.5 percent annual risk reduction. For walking, the same 365 miles traveled per year translates to a 9 percent annual risk reduction in mortality. Differences in percentage risk reduction are based on the relative level of physical effort involved in each activity.

Reduced mortality risk for those who engage in this level of activity are compared with a baseline risk of death for people in the same age cohort (e.g., from 20-64 for cycling and 20-74 for walking), to determine the annual reduction in the number of people who would die because of their active transportation choices.

A similar reduced risk approach but in a more sophisticated model is called Integrated Transport and Health Impact Tool (ITHIM).[14] ITHIM is developed at UKCRC Centre for Diet and Activity Research (CEDAR) and estimates the health and safety benefits from increases in active transportation. The tool uses the change in physical activity (measured in Metabolic Equivalents) of pedestrians by age and gender, the risk of injury in active transportation, and the exposure to air pollution. Cyclists are assumed to travel at an average speed of 10 to 12 miles per hour. The tool calculates the expected change in all-cause mortality as well as the reduced risks of cardiovascular diseases, depression, dementia, diabetes, and several forms of cancer.

Using this tool, Maizlish et al. (2012) found a reduction in disease burden across all diseases due to increased physical activity in the San Francisco Bay Area. Health benefits represent over 99 percent of total benefits, with the remainder (less than 1 percent) coming from reduced air pollution. Additionally, the authors report that forecasted injuries and deaths from accidents increased with higher levels of active transportation. This research is an important reference point because it was conducted in California, but at this time the results are not readily integrated into a BCA framework for new facilities.

[14] http://www.cedar.iph.cam.ac.uk/research/modelling/ithim/

SUMMARY FINDINGS

A challenge in using either the HEAT or ITHIM tool is that they are developed as separate, standalone tools and as such cannot be directly integrated into the Cal-B/C AT tool. Between these two approaches, the ITHIM model offers a better future potential for integration because it has been adapted for a CA context (using CA-specific background health data) in connection with CA Department of Public Health initiatives and it exists in a spreadsheet format. In comparison, HEAT exists only as an on-line tool.

However, the HEAT tool can be run on line for a variety of scenarios to determine values that can be used for the Cal-B/C AT tool. In particular, key parameters that can be extracted from HEAT tool model runs relate to the risk of reduced mortality for different levels of activity. Specifically, the HEAT model is built around an estimated percentage reduction in mortality risk that is linearly related to the annual miles traveled for each active transportation mode. This percentage reduction in mortality risk can be used to estimate the reduced numbers of annual deaths per mile of travel, up to a maximum level of activity of 120 minutes per day. For activity levels beyond this maximum, no appreciable change in mortality risk reduction would be observable. Since 120 minutes per day is an extremely high average level of among users, this condition in HEAT would not be violated in the Cal-B/C AT Model.

Reduced Vehicle Use

Most of the induced trips are likely to be mode shifts from motorized vehicles, and of these, some are shifts from personal vehicles. Personal vehicles contribute to roadway congestion, pavement damage, pollution emissions, and roadway accidents. This benefit category measures the reduction in externalities that arise from reductions in personal trips due to shifts to active transportation. In most cases, the impact on other drivers is not likely observable because the total number of cyclists that shift from personal vehicle use is small. However, since standards transportation economic analyses tend to account for *any* change in travel time however small, the associated small reduction in congestion due to cycling mode shifts would still be valid if standard transportation valuation parameters are applied.

The Cal-B/C AT v1.0 accounts for two types of benefits from reduced vehicle use: environmental pollution reduction and fuel cost savings. It is assumed that for the environmental benefits of reduced pollution, around half of new cycling and pedestrian trips replace auto VMT. However, the fuel cost savings refer to changes in user costs due to mode shifts. This cost may not be fully justified as a separate benefit category since the tradeoffs in out-of-pocket costs, mobility value, and other costs across modes would be captured in a rule-of-half estimation of induced benefits.[15]

NCHRP 552 GUIDELINES

NHCRP 552 guidelines indicate that increased numbers of cyclists and pedestrians are likely to have a small impact on reduced Auto VMT due the high proportion of recreational trips and a roughly 40 percent shift in destination trips from personal vehicles. NHCRP guidelines recommend setting the reduction in auto VMT equal to the VMT for induced new destination trips.

[15] The value of new trips, often assumed to come from shifts from another mode, is often estimated using a simplifying concept of the “rule-of-half”. This simplification assumes that the marginal improvement in value between the original mode and new mode corresponds with a linear demand curve.

The sub-categories of benefits from reduced auto VMT include reductions in: (a) criteria air contaminant and greenhouse gas emissions; (b) public infrastructure spending; (c) congestion for remaining vehicles; and (d) accident risks for remaining vehicles. NCHRP 552 guidelines indicate that reduced out-of-pocket transportation costs for cyclists and pedestrians should *not* be included in calculations because these costs would be offset by riders' longer journeys and the often unrecognized, but potentially significant, maintenance costs for bicycles on a per-mile basis.[16] Valuation parameters for these sub-categories of benefits would be drawn from standards of practice in transportation economics and applied in the existing Cal-B/C model for estimating benefits for motor vehicle use.

UK DFT TAG GUIDELINES

UK DfT TAG guidelines account for a full set of reduced external costs of vehicle use due to facility users who shift from this mode. The guidelines provide diversion rates to represent the degree of mode shift but recommend that local studies be referenced to determine the rates. In addition, decreases in congestion, accidents and roadway maintenance impacts should be estimated from local sources if possible.

Safety

Bike facility improvements that enhance safety either as standalone improvements (e.g., signals, bridges, physical barriers, and other crash reduction features) or creating separation along the bike facility from vehicles are likely to reduce accidents. These improvements are important factors in the value of a bike facility to users and would likely be captured to some extent in the valuation metrics for journey quality. The approach to estimating accident reduction benefits for facility improvements must be considered carefully to avoid double-counting benefits between journey quality and safety. In fact, UK DfT TAG guidelines specifically state that the perceived (and actual) risk of reduced accidents is included in a "journey quality" value and therefore should be excluded as an additional benefit category.

However, in cases where it is relevant to include specific safety improvements,[17] data and guidelines for the analysis of accidents is the Californian Local Roadway Safety Guidelines. This report uses a crash reduction-based methodology to determine the safety benefits of new pedestrian and bicycle facilities. The Californian Local Roadway Safety Guidelines encourages only three countermeasures to be considered per project. The total safety benefit is the sum of the benefit from the avoided fatality, injury and property damage only collisions expected from the countermeasures. This methodology considers only the reduction in the annual average of the last five years of historical collisions.

NCHRP 552 GUIDELINES

NCHRP guidelines exclude consideration of safety benefits as a separate and additional category of bike facility value because the data are not available. This perspective however is more an outcome of the authors' purpose – to develop a generalizable standalone tool.

[16] Incidentally, the authors also comment that decreases in fuel costs from decreases in auto usage could require comparisons with increases in food consumption costs due to higher levels of physical activity.
[17] It is argued below that safety improvements at intersections can be considered as additional sources of benefits, and would not necessarily double count with journey quality benefits.

UK DFT TAG GUIDELINES

In the case of active transportation facilities, UK DfT TAG recognizes that the choices of facility users are specifically associated with the perceptions of safety and the decision associated with route choice includes the value of a safer route. As such, UK DfT TAG recommends that to avoid double-counting and thus overestimating benefits, separate estimation of safety benefits should be avoided if journey quality benefits are included.

UK DFT TAG RECENT LITERATURE

Research into the influence that perceptions and actual risks of accidents have on cyclist choices has important considerations in determining the value of safety improvements. First, according to Sanders (2013), cyclists may well have a greater understanding of the risks of a given route than would be implied from comparing bike counts to historic collision rates as near collisions between cars and bikes are not reported. This finding would explain why Ranjit et al. (2015) finds the collision rate on road use has far less impact on cyclists' choices than does the AADT of a road. However, Hood et al. (2011) finds no relationship between AADT and cyclist routes choices, suggesting this is not universal.

Another difficulty in comparing the literature on safety is that definitions and groupings of bike facilities and safety measurements can differ. Studies may measure accidents, injuries, crashes or collisions, but there is no guarantee they mean the same thing. Caltrans uses the Bike Class system however Class IV is a mix of on-road segregated bike lanes and bike lanes separated by rows of parking spaces, the former being far safer than the latter.

The interaction of cyclists and pedestrians is also not easily measured. Kassim (2014) shows that when drivers are willing to share the road with cyclists, higher volumes of pedestrian travelers lead to fewer auto-cyclist collisions, however when drivers are not usually willing to share the road with cyclists, higher volumes of pedestrians have no effect.

SUMMARY FINDINGS

UK DfT TAG makes a compelling case in stating that journey quality value captures the overall feeling (and reality) that the bike facility is generally safer than the road. Accordingly, to avoid overestimating benefits, estimation of safety benefits should only be considered when the risk of double-counting benefits is minimized.

Several cases of double-counting deserve consideration. Note first that any estimated journey quality value cannot be disaggregated to specific safety features along a route where the value is estimated. The value of safety would be primarily felt by users along the corridor and would be primarily related to separation from motorized vehicles – a primary distinguishing factor among facility types.

Safety improvements at intersections where the bike facility users *cross* roadways may not cause double-counting in all contexts. Intersections are specific reference points where accident risks are common to all facility types and where risks may be higher than along bike facilities. The risk of an accident at an intersection relates to local road conditions and any specific safety features at that intersection. To include benefits from safety improvements, several cases should be considered including:

1. New facility is constructed with safety features;
2. Existing facility is upgraded to a higher value category with some types of corresponding safety features; and,
3. Safety features are added to an existing facility without changing the facility type.

In Cases 1 and 2, UK DfT TAG guidelines recommend that the value of improved safety for bike facility users is captured in journey quality benefits and no additional safety benefits should be included. In Case 3, the journey quality value of the facility is not changing however, safety features, particularly those that occur at intersections *could* lead to measurable and additive safety benefits. In this case, UK DfT TAG guidelines are not violated since the safety improvements occur at intersections.

1.2 Evaluation of Active Transportation Programs

In addition to capital projects, state and local agencies have implemented a variety of programs to encourage ridership and safe cycling habits. Litman (2015) notes that these education and encouragement programs are designed to help people overcome barriers that people have to walking and cycling (e.g., ignorance, social stigma, a habit of driving) and in turn, increase their related activity. Often, programs linked to facility improvements have higher levels of impact.

Litman (2015) identifies a number of factors that affect the effectiveness of education and encouragement program benefits. These include how well the program targets local community needs and attracts community support through linkages with other activities. Measures of performance include the number of people likely to increase their walking and cycling activity and the degree that participants reduce their driving. Litman (2015) states that an effective approach to estimating the value of active transportation programs would involve applying a percentage increase in the shift from motorized transportation to active transportation above any new capital project. However, Litman (2015) did not include such measures.

Progress in developing more information on the effectiveness of active transportation programs has been made in a recent study by FHWA, the Nonmotorized Transportation Pilot Program (NTPP) Evaluation (FHWA, 2012 and 2014). This study assessed the costs, travel impacts and benefits of programs and investments. The study was conducted in four pilot project areas (Columbia, Missouri; Marin County, California; Minneapolis area, Minnesota; and Sheboygan County, Wisconsin) and included capital investments in some projects and a variety of supporting outreach and educational programs. Overall, the program invested about $100 per capita in pedestrian and cycling improvements and resulted in an over 20 percent increase in walking and nearly 50 percent increase in cycling trips. The results of these studies are not generalizable enough to be readily applied to educational programs conducted elsewhere.

1.3 Summary of Literature Review

Exhibit III-2 summarizes findings and guidelines from NCHRP, UK DfT TAG and other research.

Exhibit III-2: Summary of Findings and Guidelines

Benefit Category	NCHRP 552	UK DfT TAG	Other Recent Research
Journey Quality	• Value by facility type is available to estimate benefits to destination-oriented users. • Valuation is based on stated preference methods and is less precise. • Valuation accounts for safety benefits.	• Value by facility type is available to estimate benefits to all users. • Valuation is based on stated preference methods and is less precise. • Valuation accounts for safety benefits.	• Value by facility type has been developed from new research. • Revealed preference methods and results provide new and potentially more reliable insights.
Recreation	• Separate value for recreational use is developed from environmental economic literature. • Estimation approach is not peer-reviewed for this application.	• Separate benefit category is not included because recreational users are included as beneficiaries, under a journey quality.	• Additional research on recreational purposes on bike facilities has not found. • Consideration may be given to using journey quality parameters for recreational trips.
Health	• Value of health cost savings of physical activity is available to estimate benefits to new cyclists and pedestrians. • Valuation is based on past literature on the economic costs of inactivity.	• Considers two forms of health benefits – one that directly relates to the social cost of reduced long-term health risk, and a second that draws from the reduced risk of short-term absenteeism at work. • Parameters of risk reduction are drawn from studies of riders and health conditions.	• Models (e.g. WHO HEAT and ITHIM) have been implemented to simplify and standardize analysis of health benefits and can be adapted for other contexts. • Parameters from the HEAT model can be applied to other models.
Safety	• Not addressed due to uncertainty on the issue and potential double counting.	• Perception of safety (and to some extend, actual safety improvements) are considered to be captured by facility choice valuation.	• Research has explored interactions among drivers and active travelers as influenced by cultural expectations, and 'safety in numbers' aspects of a biking experience. • More research is required before these findings can be generalized.
Reduced Vehicular Externalities	• Diversion of automobile drivers or passengers to active modes reduces external costs related to emissions, safety pavement damage, and potentially other factors.	• Diversion of automobile drivers or passengers to active modes reduces external costs related to emissions, safety pavement damage, and potentially other factors.	• Diversion of automobile drivers or passengers to active modes reduces external costs related to emissions, safety pavement damage, and potentially other factors.

2 Technical Description of Cal-B/C AT

2.1 Background and Scope of Analysis

The scope of analysis differentiates benefits by trip purpose and type of project (improvements to existing facility, or new facility construction). An overview of these benefits is discussed below. First, to clarify concepts on bike facility use, several definitions cover terms that are used throughout the tool with respect to “trip types” and “user types”. Also, since not all users benefit from projects in the same way, definitions that map users to benefit categories are provided.

Trip Types	Definitions
Trips	One-way daily volumes of trips for commuting, or other purposes. Estimated numbers of trips should be obtained from facility count data and then scaled to estimate daily trips, assuming that the annualization factor is 365 days for regular facility use. Trips for children as past of a Safe Route to School assessment would be annualized with 180 days, based on the school year duration.
Roundtrips	Most trips have a return journey of the same mode and some trips include other unlinked side trips. “Roundtrips” are generalized here for cyclists and pedestrians as including the number of unlinked trips per day. A roundtrip as defined here is used to identify the number of users that are taking trips.
Existing Trips	Baseline trips, either on an existing facility or unmarked street, where the project will create a new facility with specific improvements
Induced Trips	Additional trips above the baseline that arise because of the improvements to existing or new bike facilities
Trip Forecasts	Forecasts are developed for existing and new facility locations (if applicable). Model users determine numbers of current and induced trips, and other characteristics (e.g., roundtrip probability, purpose, distance, etc.)

Trip Purposes	Definitions
Commute to Work	Users who are taking the bike facility to or from work. These users are primarily adult or young-adult aged. Facility use by college students would be classified under "other destinations"
Other Destinations	Users who are taking the facility to reach a variety of other destinations besides work, such as shopping, meeting friends, college classes, etc. These are trips that would be otherwise taken by some type of motor vehicle
Recreational	Users who are taking the facility purely as a loop-trip for exercise purposes. These trips would not be otherwise taken by motor vehicle since the purpose is for fitness and recreation.
Safe Route to School	Users who are school-aged, i.e. 18 or under years old, and taking the facility to or from school. These estimated trips may be obtained from local schools who can survey the more well-defined population of children walking or riding to school.

Benefit Categories	Definitions
Journey Quality	Improvements in the quality of the trip for pedestrians and cyclists that arise from a greater feeling of safety, comfort, aesthetics, and other types of improvements. Improvements to existing and new bike facilities can generate benefits for current trips and induced trips. Benefits to induced users are estimated using "rule of half" approximation. Journey quality is assumed to have a zero value for existing users along routes where there is no existing facility. The value of journey quality includes the perception of safety improvement and thus, to avoid double counting, additional accident reduction value along the routes is excluded. However, safety improvements at intersections along existing bike facilities generate additional benefits that are discussed below.
Intersection Delay (Time Savings from Improved Intersections on Existing Facilities)	Improvements to existing facility intersections (e.g. lights, bridges, etc.) can lead to time savings for trips by reducing waiting time at intersections, for say a break in vehicular traffic. Time savings benefits can arise for existing and induced pedestrians and cyclists at each intersection that they cross. The number of intersections crossed by users of a facility on each trip is determined by the total length of the existing facility, the average distance traveled per user type, and the number of intersections with improvements. Benefits to induced users are estimated using "rule of half" approximation.
Health Benefits - Reduced Absenteeism of Commuters	Health benefits related to a reduction in absenteeism are generated by induced walking and cycling commuters. The benefits are monetized by higher productivity due to fewer sick days. Benefits to these induced users are not estimated using "rule of half" approximation since the value is observed by the employer.
Health Benefits - Reduced Mortality Risk	Health benefits related to improved long-term health and reduced risk of disease and early death. These benefits are derived from parameters established by the World Health Organization (WHO) and formalized in their online HEAT tool and documentation. Benefits are derived from reduced mortality risk in populations that range from 20-64 for cyclists and 20-74 for pedestrians. Reduced mortality risk depends on the amount of cycling (average distance) undertaken over a one year period.
Intersection Safety (Accident Reduction at Improved Intersections of Existing Facilities)	Improvements to existing facility intersections (e.g. lights, bridges, etc.) can lead to reduced accidents at intersections. Benefits can arise for existing and induced pedestrians and cyclists at each intersection crossed. The number of intersections crossed per trip is determined by the total length of the existing facility, the average distance traveled per user type, and the number of intersections with improvements. The magnitude of impacts is determined by the percent reduction in existing accidents due to specific safety measures. Induced trips benefits apply "rule of half" approximation.
Auto Accident Costs and Auto Emissions (Diverted Auto Trips only)	Some of the induced pedestrian and cycling trips entail diversions from auto use. Benefits from reduced auto use include reduced frequency of accidents and level of auto emissions. Benefits are estimated for each diverted auto trip by using standard methods and data for estimating the value of auto use externalities.

2.2 Benefit Categories by Facility Type

The matrix below indicates the applicability of benefits to different types of trips and facility projects. Facility projects include existing facility improvements and new facility construction. Trips differ between: (a) existing trips already being taken, or which would be taken in the future given expected growth rates; and, (b) new, induced trips that arise because of the facility improvement.

	Existing Facility Improvement		New Facility Construction	
	Existing Trips	**Induced Trips**	**Existing Trips**	**Induced Trips**
Journey Quality	Yes	Yes	Yes	Yes
Intersection Delay (Time Savings from Improved Intersections on Existing Facilities)	Yes	Yes		
Intersection Safety (Accident Reduction at Improved Intersections of Existing Facilities)	Yes	Yes		
Health Benefits - Reduced Absenteeism of Commuters		Yes (Commuters, only)		Yes (Commuters, only)
Health Benefits - Reduced Mortality Risk		Yes (Age dependent)		Yes (Age dependent)
Auto Accident Costs and Auto Emissions		Yes		Yes

2.3 Benefit Estimation of AT Projects

Journey Quality

Journey Quality benefits are considered for both cyclists and pedestrians with different trip purposes. Different methodologies are however applied for each type of mode. The tool also distinguishes between destination-oriented (including commuting and other purposes) and recreational trips. This distinction is necessary because USDOT BCA guidelines exclude consideration of recreational trips (i.e. trips defined as 'loop trips' for only exercise purposes) in estimating journey quality benefits for mobility to a destination. However, Caltrans may wish to depart from these guidelines to consider benefits for recreational users for several reasons. First, recreational cyclists certainly share the road with other vehicles if no bike facility exists. New projects would enable them to adjust their route of travel to facilities that would in turn improve performance and travel speeds for vehicular road users. Moreover, recreational trip purposes can be considered as valid as any other trip purpose, even if very few vehicular users of a road drive for recreational purposes. Because of these alternative perspectives, the tool is established to permit users to determine if recreational users are included in journey quality benefits.

Cyclists

Journey quality benefits for cycling are driven primarily by revealed preference research on cyclist route choices in Hood et al. (2011). The discrete choice theory that underpins the Hood et al. (2011) research assumes that when cyclists make choices between routes, they make these choices based on their values on the attributes of the route (e.g., the route is Bike Class II). By

comparing cyclists' choices within a set of reasonable route options, the value of the route attributes to the cyclist can be determined. Note that in consideration of the above perspectives on recreational purpose cycling, the parameters reported in Hood et al. (2011) do not distinguish values by trip purpose.

These values capture the preference for a designated bike route in comparison with a basic roadway. Analytically, the term that quantifies the preference for a bike facility is the *marginal rate of substitution* (MRS), in which the distance that a user travels on a bike facility is compared against 1 mile traveled on a normal road. Each type of Bike Class for Caltrans has a different MRS value. To interpret the MRS value, consider rider's choice between a Class II facility and a road, the MRS is 0.49. This value means that riding one mile on a Bike Class II facility is equivalent to *saving* 0.51 miles from a journey that would be otherwise taken on a road without bike facilities. Thus, for every mile traveled on a Bike Class II facility, there is a corresponding 0.51 mile-savings equivalent for each mile of a journey on the bike facility. MRS values that are closer to 1 generate a lower value per mile and vice versa. The monetary value of these mile-equivalent savings is determined from additional information on the time it takes to travel this distance and the value of time.

The estimation of journey quality benefits is presented below in three parts: scale of impact, factors in assessing impact per unit, and value of impact (Exhibit III-3). Data to compute these benefits is described in Exhibit III-4 and parameter values are shown in Exhibit III-5.

Exhibit III-3: Key Factors in Estimating Cycling Journey Quality Benefits

Scale of Impact	Factors in Impact per Unit	Value of Impact
Annual existing and induced trips of cyclists	• Time spent on bike facility, based on average travel distance and travel speed • Preference for bike facility versus road, as a *marginal rate of substitution* where riders express preference for riding on bike facility versus road • Average travel distance varies regionally in based on data from the CA Household Travel Survey (2012)	• Value of time (hourly) • Estimation of value for induced riders (from other modes) applies "rule of half"

User Metric: Trips • AF

Where:

- Trips = Daily one-way journeys for existing or induced users;
- AF = Annualization Factor, equals 365 days with a standardized definition of a daily trip

Factors in Impact per Unit: D • (1 - MRS) • (1/ MPH_C)

Where:

- D = Mean distance traveled per trip for cyclists in CA, varies by location;

- MRS = Marginal rate of substitution for *not* riding on a bike facility versus riding on a bike facility;
- MPH_C = Mean cycling speed, in miles per hour, per trip per user in California; and
- (1/ MPH_C) = Inverse of MPH is the pace or mean cycling travel time for a given distance.

Value of Impact: VOT

Where

- VOT = Value of Time, in dollars per hour.

The equation applied in Cal-B/C 6.2 AT is therefore the following:

Tot. Ann. Journey Q. Benefits = [Trips • AF] • [D • (1 - MRS) • (1/ MPH_C)] • [VOT]

Exhibit III-4: Summary of Bike Journey Quality Benefit - User Inputs

Variable	Definition	Value	Unit	Source
Trips	One-way daily trips, measured originally as bike facility counts and estimated on a daily basis	#	Trips/Day	Provided by User

Exhibit III-5: Summary of Bike Journey Quality Benefit Inputs - Model Parameters

Variable	Definition	Value	Unit	Source
D	Mean distance traveled per trip for cyclists, varies by location in CA	Varies regionally for cities in north, south of CA, and rural areas (See Exhibit III-6).	Miles per trip	Computed from CHTS (2012)
MRS	Marginal rate of substitution for road travel (i.e. a mile-equivalent value of road travel distance versus bike facility travel distance)	Bike Class I: 0.57	Ratio	Hood et al. (2011)
		Bike Class II: 0.49		
		Bike Class III: 0.92		
		Bike Class IV: 0.49		
MPH_C	Mean cycling speed, in miles per hour, per trip in CA	11.8	Miles per hour	Broach et al. (2012)
VOT	Value of Time as 50% of CA Median Wage	$12.5	$ per hour	Consistent with other Cal-B/C values of time

Exhibit III-6: Average Distance for Active Transportation Trips by Mode and Location

	Region		
Average Distance per Trip	Urban South	Urban North	Rural
Average Dist. - Cycling - Adults	1.83	1.85	2.48
Average Dist. - Walking - Adults	0.88	1.03	0.69
Average Dist. - Cycling - Children <16	0.52	0.66	1.12
Average Dist. - Walking - Children <16	0.46	0.58	0.57

Source: Computed from CHTS (2012)

Pedestrians

Heuman, D. (2005) conducted stated preference surveys to determine the Journey Quality benefits of pedestrian infrastructure. This methodology focused on the monetized benefit per mile-traveled.

The estimation of journey quality benefits is presented below in three parts: scale of impact, factors in assessing impact per unit, and value of impact (Exhibit III-7). Data to compute these benefits are described in Exhibit III-8 and parameter values are shown in Exhibit III-9.

Exhibit III-7: Key Factors in Estimating Pedestrian Journey Quality Benefits

Scale of Impact	Factors in Impact per Unit	Value of Impact
Annual existing and induced trips of pedestrians	• Average travel distance per trip, varies regionally by project location • Type of amenity found on route	• Willingness to pay per amenity • Estimation of value for induced riders (from other modes) applies “rule of half”

Scale of Impact: Trips • AF

Where:

- Trips = Daily one-way journeys for existing or induced users; and,
- AF = Annualization Factor, equals 365 days with a standardized definition of a daily trip

Factors in Impact per Unit: D

Where:

- D = Mean distance traveled per trip for pedestrians in CA, varies by location

Value of Impact: VPM

Where:

- VPM = Value of journey quality per amenity per mile of travel

The equation applied in Cal-B/C 6.2 AT is therefore the following:

Annual Pedestrian Journey Quality Benefit = [Trips • AF] • [D] • [VPM]

Exhibit III-8: Summary of Pedestrian Journey Quality Benefit - User Inputs

Variable	Definition	Value	Unit	Source
Trips	One-way daily trips	#	Trips/Day	Provided by User

Exhibit III-9: Summary of Pedestrian Mobility Benefit - Model Parameters

Variable	Definition	Value	Unit	Source
D	Mean distance traveled per trip, varies by location in CA	Varies regionally for cities in north, south of CA, and rural areas. (See Exhibit III-6)	Miles per trip	Computed from CHTS (2012)
VPM	Journey Quality value per mile per pedestrian	Street lighting: $0.05	Dollars per mile per trips; converted from estimated values in British pounds per km (2010), as reported in UK DfT TAG.	Heuman, D. (2005)
		Curb level: $0.03		
		Crowding: $0.02		
		Pavement evenness: $0.01		
		Information panels: $0.01		
		Benches: $0.01		
		Directional signage: $0.01		

Intersection Safety

Cal-B/C 6.2 AT estimates safety benefits for each model if changes at intersections of existing facilities reduce risk of accidents. Data on three types of crash are considered: (a) Fatality collisions; (b) Injury collisions; and (c) PDO collisions. Ideally, at least 5 years of historical accident data should be collected, aggregated and averaged across all such intersections along the existing facility.

The estimation of intersection safety benefits is presented below in three parts: scale of impact, factors in assessing impact per unit, and value of impact (Exhibit III-10). In this case, the user metric is captured by the annual average number of collisions that have occurred among existing facility users, independent of trip purpose. The number of accidents reflects the actual risk that all users face. Reducing this risk leads to benefits for all users. Data to compute these benefits are described in Exhibit III-11 and parameter values are shown in Exhibit III-12.

Note that several crash reduction improvements are applicable only for estimating benefits for pedestrians from avoided accidents. These include:

- Install sidewalk/pathway (to avoid walking along roadways)
- Install pedestrian crossing (with enhanced safety measures)
- Install pedestrian crossing

The installation of sidewalks and other safety measures is assumed to be located in areas with a history of high accident risks.

Exhibit III-10: Key Factors in Estimating Bike Safety Benefits

Scale of Impact	Factors in Impact per Unit	Value of Impact
Historical rate and severity of accidents at intersections, including all users	Impact of safety countermeasures for reducing frequency of accidents	Monetary value of life, injury and property damage per event

Scale of Impact: C

Where:

- C = Annual average crash rate by crash type

Factors in Impact per Unit: CR

Where:

- CR = Crash reduction factors as a percentage reduction in the crash rate by crash type

  CR = 1-(1-CR1)*(1-CR2)*(1-CR3), where CR1, CR2, and CR3 are the three largest single crash reduction factors in percentage terms.

Value of Impact: VPC

Where:

- VPC = Cost of a crash by crash type.

The equation applied in Cal-B/C 6.2 AT is therefore the following:

Annual Safety Benefit = [C] • [CR] • [VPC]

Exhibit III-11: Summary of Safety Benefit - User Inputs

Variable	Definition	Value	Unit	Source
Crash rate	Historic Annual Average Crash Rate, by crash type	Numbers of crashes by type (i.e. fatalities, injuries, and physical damage only)	#/year by type of crash	Provided by User

Exhibit III-12: Summary of Safety Benefit - Model Parameters

Variable	Definition	Value	Unit	Source
CR	Percentage reduction in the crash rate, by crash type	Signalized intersection, install pedestrian countdown signal head: 25%	%	Local Roadway Safety Manual for California Local Road Owners
		Signalized intersection, install pedestrian crossing: 25%		
		Signalized intersection, install advance stop bar before crosswalk (bicycle box): 15%		
		Signalized intersection, install pedestrian overpass/underpass: 75%		
		Unsignalized intersection, install raised medians/refuge islands: 45%		
		Unsignalized, install pedestrian crossings (new signs and markings only): 25%		
		Unsignalized install pedestrian crossing: 35%		
		Unsignalized install pedestrian signal: 55%		
		Install sidewalk/pathway (to avoid walking along roadways: 80%		
		Install pedestrian crossing (with enhanced safety measures: 30%		
		Install Pedestrian crossing: 35%		
VPC	Cost of a crash by crash type	Fatality = $4,800,000; Injury = $67,400; Property Damage = $10,200	$ per crash	USDOT Guidance

Intersection Delay

Some projects that improve intersections to make them safer, also generate benefits for users based on a potential reduction in delay while waiting to cross an intersection. As an example, a bridge for active mode users to avoid a roadway provides a complete safety improvement and can save users time since they no longer have to slow, stop and wait to cross.

Cal-B/C 6.2 AT estimates delay reduction benefits for each mode where applicable using standard valuation methods for the value of time savings. Time savings would be estimated for each improved intersection along an existing facility. Then, depending on the average length of a cycling or walking trip, it can be determined how many intersections would be cross by an average trip. The total average time savings per trip would then be valued using ½ of the median wage rate, following standard practice.

Exhibit III-13: Key Factors in Estimating Bike Safety Benefits

Scale of Impact	Factors in Impact per Unit	Value of Impact
Number of trips per year	• Time savings per intersection; • Number of improved intersections crossed per trip	Value of time (hourly)

User Metric: Trips • AF

Where:

- Trips = Daily one-way journeys for existing or induced users;
- AF = Annualization Factor, equals 365 days with a standardized definition of a daily trip

Factors in Impact per Unit: D • N / L • S

Where:

- D = Mean distance traveled per trip by mode, varies by location;
- N = Number of improved intersection along entire facility
- L = Facility length
- S = Average delay reduction per intersection, in minutes

Value of Impact: VOT

Where

- VOT = Value of Time, in dollars per hour.

The equation applied in Cal-B/C 6.2 AT is therefore the following:

Tot. Ann. Intersection Delay = [Trips • AF] • [D • N / L • S] • [VOT]

Exhibit III-14: Summary of Intersection Delay Benefit - User Inputs

Variable	Definition	Value	Unit	Source
Trips	One-way daily trips, measured originally as bike facility counts and estimated on a daily basis	#	Trips/Day	Provided by User

Exhibit III-15: Summary of Intersection Delay Benefit Inputs - Model Parameters

Variable	Definition	Value	Unit	Source
D	Mean distance traveled per trip for cyclists, varies by location in CA	Varies regionally for cities in north, south of CA, and rural	Miles per trip	Computed from CHTS (2012)

Variable	Definition	Value	Unit	Source
		areas (See Exhibit III-6).		
N	Number of improved intersection along entire facility	Depends on project	#	Provided by User
L	Facility length	Depends on project	Miles	Provided by User
S	Time savings per intersection	Depends on project	Minutes	Provided by User
VOT	Value of Time as 50% of CA Median Wage	$12.5	$ per hour	Consistent with other Cal-B/C values of time

Health – Reduced Absenteeism

The methodology and some of the data to estimate health benefits from reduced absenteeism is derived from the literature review and two papers: WHO (2003) and UK DfT TAG (2014). The study from WHO indicates that workplace physical activity programs in the U.S. involving 30 minutes of daily exercise can reduce short-term sick leave by between 6 percent and 32 percent. This analysis uses 6 percent as a conservative estimate. The estimation of journey quality benefits is presented below in three parts: scale of impact, factors in assessing impact per unit, and value of impact (Exhibit III-13). Data to compute these benefits are described in Exhibit III-14 and parameter values are shown in Exhibit III-15.

Exhibit III-16: Key Factors in Estimating Reduced Absenteeism Benefits

Scale of Impact	Factors in Impact per Unit	Value of Impact
Induced roundtrips by cyclists and pedestrians who are commuters	• Average absence per employee (sick days taken) • Proportion accounted by short-term sick leave • Proportion of sick days reduced for being active for at least 30 minutes a day	▪ Average daily wage per worker

Scale of Impact: $\text{Trips}_N \cdot P_C / R$

Where:

- Trips_N = Daily one-way journeys of induced users;
- P_C = Proportion of induced trips made by commuters;
- R = Number of unlinked trips

Note that the model requests data in terms of number of new daily trips from the applicant. The tool converts new daily trips to new daily users using a roundtrip factor.

Factors in Impact per Unit: $S \cdot P_{SL} \cdot P_{SR}$

Where:

- S = Average absence at work of typical employees(days per year);
- P_{SL}= Percentage of absences accounted for by short-term sick leave; and
- P_{SR}= Percentage reduction in sick days by being active.

Value of Impact: W_D

Where

- W_D **=** Average daily wage of new user

The equation applied in Cal-B/C 6.2 AT is therefore the following:

Tot. Ann. Benefits - Reduced Absenteeism = $[Trips_N \cdot P_C / R] \cdot [S \cdot P_{SL} \cdot P_{SR}] \cdot [W_D]$

Exhibit III-17: Summary of Reduced Absenteeism Benefits Inputs - User Inputs

Variable	Definition	Value	Unit	Source
$Trips_N$	Induced one-way daily trips	#	Trips/Day	Provided by User

Exhibit III-18: Summary of Reduced Absenteeism Benefits Inputs - Model Parameters

Variable	Definition	Value	Unit	Source
P_C	Percentage of users that commute to and from work	7% to 11% for cyclists and 4% to 9% for pedestrians, varies regionally	%	Computed from CHTS (2012)
R	Number of unlinked trips per day	1.93 for cyclists; 2.38 for pedestrians	#	Computed from CHTS (2012)
S_E	Average absence of employees	3.6	Days/ Year	Summary Health Statistics for U.S. Adults: National Health Interview Survey, 2007, U.S. Department of Health and Human Services, Centers for Disease Control and Prevention (CDC, 2007)
P_{SL}	Percentage accounted for by short-term sick leave	95	%	Department for Transport. (2014). TAG UNIT A4.1 Social Impact Appraisal. Transport Analysis Guidance. (UK DfT TAG, 2014)
P_{SR}	Percentage of sick days reduced by being active for	6	%	World Health Organization (WHO) (2003). Health and development through

Variable	Definition	Value	Unit	Source
	at least 30 minutes a day			physical activity and sport. Geneva.
W_D	Average daily wage per worker (California)	207.28*	$/Day (2014 dollar)	Occupational Employment and Wage Estimates for California, May 2014, Bureau of Labor Statistics

Health – Reduced Mortality

Cal-B/C adapts the method and data applied in the WHO HEAT model to estimate benefits of reduced mortality.[18] The HEAT approach determines benefits as a reduction in the relative risk of death for bike facility users due to improved health conditions. The estimated reduction in risk for cycling and walking activity has been parameterized in a simplified form that is based on the distance traveled by mode. For cycling, there is a 4.5% reduction in risk for every 365 miles traveled per year (equal also to a 1 mile travel distance per day, every day). For walking, the annual risk reduction per 365 miles traveled is 9%. In addition, risk reduction is maximized at 30% for cycling and 45% for walking.[19]

The Cal-B/C model applies the HEAT model's risk reduction rate to estimate reduced deaths among users of a specific age group. Baseline risk of death for people in specific cohorts (e.g. from 20-64 for cycling and 20-74 for walking) are obtained from the CA Department of Public Health. Data from the California Household Transportation Survey are used to estimate proportions of cyclists and pedestrians in these age groups whose risk would be lowered.

The data necessary to perform the analysis of reduced mortality for cycling and walking is presented in (Exhibit III-16). Data to compute these benefits are provided by users and economic parameters below.

Exhibit III-19: Key Factors in Estimating Reduced Mortality Benefits

Scale of Impact	Factors in Impact per Unit	Value of Impact
Annual existing and induced roundtrips of cyclists and pedestrians	• Average distance traveled per user by mode • Existing proportion of deaths in an age cohort who die each year from any cause; age cohorts are defined as ages 20-64 (for cycling) and ages 20-74 (for walking) • Risk reduction in expected deaths and among cyclists and pedestrians	▪ Value of a prevented fatality

Scale of Impact: $Trips_N \cdot P_A / R$

Where:

[18] See: http://www.heatwalkingcycling.org
[19] For trips lasting longer than this maximum value, no appreciable improvement in health is observable.

- $Trips_N$ = Daily one-way journeys of induced users;
- P_A = Percentage of users in age cohort: Cyclists: Ages 20-64, Pedestrians: Ages 20-74;
- R = Roundtrip factor

Note that the model requests data in terms of number of new daily trips from the applicant. The tool converts daily trips to daily users using a roundtrip factor.

Factors in Impact per Unit: D • M • (1-RR)

Where:

- D = Mean distance traveled per trip for users in CA, varies by location;
- M = Numbers of people per 100,000 who die each year from all causes in California; and
- 1-RR = Percentage mortality risk reduction for induced active travelers compared to baseline, non-active population.

Value of Impact: VSL

Where:

- VSL = Value of a Statistical Life - (2014 dollars)

The equation applied in Cal-B/C 6.2 AT is therefore the following:

$$\textbf{Tot. Ann. Benefits - Reduced Mortality} = [Trips_N \cdot P_A / R] \cdot [D \cdot M \cdot (1\text{-}RR)] \cdot [VSL]$$

Exhibit III-20: Summary of Reduced Mortality Benefits - User Inputs

Variable	Definition	Value	Unit	Source
$Trips_N$	Induced one-way daily trips	#	Trips/Day	Provided by User

Exhibit III-21: Summary of Reduced Mortality Benefits - Model Parameters

Variable	Definition	Value	Unit	Source
R	Number of unlinked trips per day	1.93 for cyclists; 2.38 for pedestrians	#	Computed from CHTS (2012)
D	Mean distance traveled per trip, varies by location in CA	Varies regionally for cities in north, south of CA, and rural areas. (See Exhibit III-6)	Miles per trip	Computed from CHTS (2012)
P_A	Percentage of users in age cohort: Cyclists: Ages 20-64, Pedestrians: Ages 20-74	Varies regionally for cities in north, south of CA, and rural areas. (See Exhibit III-20)	% of users, by mode	Computed from CHTS (2012)
M	Baseline annual mortality rate from all causes, by age cohort:	266 for cyclists; 395 for pedestrians (see Exhibit III-19)	# of deaths per 100,000	Death Statistical Data Exhibit III-5-2 - CA Dept. of Public

Variable	Definition	Value	Unit	Source
	Cyclists: Ages 20-64, Pedestrians: Ages 20-74			Health (See Exhibit III-19)
RR	Reduction in risk of mortality due to active transportation activity	4.5% for cyclists; 9.0% for pedestrians	% risk reduction in 365 annual miles traveled	WHO HEAT Tool (2016)
VSL	Value of a statistical life	$4,130,347	$/Fatality (2014 dollars)	Appendix D, Local Roadway Safety: A manual for CA's Local Road Owners. Caltrans. (2013)

Exhibit III-22: Data for Computing Baseline All-Cause Mortality by Age Cohort (2104)

All Cause Mortality - 2014			
Age	**Deaths**	**Population (1,000s)**	**Death Rate**
15-19	980	2,656	37
20-24	1,907	2,903	66
25-34	4,485	5,510	81
35-44	6,698	5,160	130
45-54	16,653	5,230	318
55-64	32,471	4,546	714
65-74	41,246	2,836	1,454
Age Group - 20-64	62,214	23,349	266
Age Group - 20-74	103,460	26,185	395

Source: * See: https://www.cdph.ca.gov/data/statistics/Documents/VSC-2014-0502.pdf

Exhibit III-23: Proportions of Bike facility Users by Age Cohort

Age Cohorts for Mortality Risk Reduction Benefits	Region		
Average Distance per Trip	**Urban North**	**Urban South**	**Rural**
Age 16-64 - Cycling	73.4%	70.5%	66.0%
Age 16-74 - Walking	80.7%	76.2%	70.0%

Source: Computed from CHTS (2012)

Emissions Reductions

Reduced vehicle use, due a shift of travelers to active transportation, creates public benefits by reducing the externalities of air emissions and accidents from auto use. The proposed methods for Cal-B/C AT apply the methods that are contained in other Cal-B/C tools. For instance, reduced air emissions due to a reduction in VMT (corresponding to increased cycling trips) would be computed from the EMFAC emissions model (for criteria air contaminants, such as carbon monoxide (CO), oxides of nitrogen (NO_X), volatile organic compounds (VOC), particulate matter (PM), and oxides of sulfur (SO_X)) and a Greenhouse Gas Inventory model for greenhouse gases. These emissions rates on a per VMT basis would be multiplied with the annual reduction in vehicle

miles and value of pollutant emissions to determine the benefits. The monetary values of pollutant emissions per unit are derived from the same sources as the other Cal-B/C tools.

Additional discussion on data and methods can be found in the Technical Appendix to User's Guide of Cal-B/C (1999).

Exhibit III-24: Key Factors in Estimating Reduced Emissions Benefits

Scale of Impact	Factors in Impact per Unit	Value of Impact
Annual induced trips of cyclists and pedestrians	• Average Travel Distance • Average Vehicle Occupancy • Average speed of passenger vehicle • Emissions rates per vehicle, by pollutant	▪ Valuation per unit of emissions, by pollutant

Scale of Impact: $Trips_N \cdot P_D / O \cdot AF$

Where:

- $Trips_N$ = Daily one-way journeys for induced users;
- P_D = Percentage of induced riders who divert from a passenger vehicle;
- O = Vehicle Occupancy; and
- AF = Annualization Factor, equals 365 days with a standardized definition of a "daily" trip

Factors in Impact per Unit: D • E

Where:

- D = Mean distance traveled per trip for users, varies by location;
- E = Emissions rates of automobile pollutants per mile (given an average vehicle speed)

Value of Impact: VPP

Where:

- VPP = Value per pollutant, as measured in $ per ton of pollutant emitted

The equation applied in Cal-B/C 6.2 AT is therefore the following:

Total Annual Benefits - Reduced Mortality = $[Trips_N \cdot P_D / O \cdot AF] \cdot [D \cdot E] \cdot [VPP]$

Exhibit III-25: Summary of Reduced Emissions Benefits - User Inputs

Variable	Definition	Value	Unit	Source
$Trips_N$	Induced one-way daily trips	#	Trips/Day	Provided by User

Exhibit III-26: Summary of Reduced Emissions Benefits - Model Parameters

Variable	Definition	Value	Unit	Source
D	Mean distance traveled per trip, varies by location in CA	Varies regionally for cities in north, south of CA, and rural areas. (See Exhibit III-6)	Miles per trip	Computed from CHTS (2012)
O	Average vehicle occupancy	1.5	Persons per vehicle	Computed from CHTS (2012)
E	Pollutant emissions per ton, by pollutant, given an average vehicle speed	Varies by pollutant	Tons / mile	Source: California Air Resources Board, EMFAC 2011
VPP	Value per pollutant	Varies by pollutant	$/ton	McCubbin and Delucchi (1996); US Interagency Group on Social Cost of Carbon

Auto Accident Costs

Accident rates may decline when drivers shift to cycling or walking from motorized vehicles simply because there are fewer cars on the road. Developing reasonable estimates of these benefits depends on the availability of local data on accident rates in the corridor where an active transportation project is implemented. These data would include numbers of motorized vehicle accidents per year by level of severity and total annual VMT. Such data may be derived from the SWITRS database, TASAS, or other local traffic data sources. A ratio of annual accidents to annual VMT, when multiplied with the reduced VMT of diverted drivers, generates an estimate of the reduced number of accidents by level of severity. The economic value of a change in accident rates is estimated with an average cost per accident severity.

To estimate the impact of a transportation project on accident costs, Cal-B/C compares accident costs under two scenarios: with the project and without the project. Accident costs are compared over the lifetime of the project, which is assumed to be twenty years. Accident benefits are summed over the twenty-year period to derive the total impact. Individual projects may improve or adversely impact vehicle accidents, so the net result may be positive or negative.

Additional discussion on data and methods can be found in the Technical Appendix to User's Guide of Cal-B/C (1999).

Exhibit III-27: Key Factors in Estimating Auto Accident Costs

Scale of Impact	Measures of Impact	Value of Impact
Annual induced trips of cyclists and pedestrians	• Average Travel Distance • Average Vehicle Occupancy • Statewide average accident rate (# /million miles)	▪ Cost of an accident, by severity type

Scale of Impact: $Trips_N \cdot P_D / O \cdot AF$

Where:

- $Trips_N$ = Daily one-way journeys for induced users;
- P_D = Percentage of induced riders that divert from a passenger vehicle;
- O = Vehicle Occupancy; and,
- AF = Annualization Factor, equals 365 days with a standardized definition of a daily trip

Factors in Impact per Unit: $D \cdot C_S$

Where:

- D = Mean distance traveled per trip (California) for induced users, varies by location;
- C_S = Crash rates of automobile per million miles

Value of Impact: VPC

Where:

- VPC = Value per pollutant, as measured in $ per accident, by severity type

The equation applied in Cal-B/C 6.2 AT is therefore the following:

Total Annual Benefits - Reduced Mortality = $[Trips_N \cdot P_D / O \cdot AF] \cdot [D \cdot C_S] \cdot [VPC]$

Exhibit III-28: Summary of Reduced Auto Accident Benefits - User Inputs

Variable	Definition	Value	Unit	Source
$Trips_N$	Induced one-way daily trips	#	Trips/Day	Provided by User

Exhibit III-29: Summary of Reduced Auto Accident Benefits - Model Parameters

Variable	Definition	Value	Unit	Source
D	Mean distance traveled per trip, varies by location in CA	Varies regionally for cities in north, south of CA, and rural areas. (See Exhibit III-6)	Miles per trip	Computed from CHTS (2012)
O	Average vehicle occupancy	1.5	Persons per vehicle	Computed from CHTS (2012)
C_S	Statewide crash rates for different levels of severity	Varies by type of accident	Crashes per million vehicle miles	Source: California Department of Transportation, TASAS Unit, 2007 to 2009 average
VPC	Value per crash, by severity	Varies by crash severity	$/incident, by level of severity	Source: California Department of Transportation, TASAS Unit, 2007 to 2009 average

2.4 Cost-Effectiveness Assessment of Non-Infrastructure Programs

At present, methods and data are not sufficiently developed to accurately estimate the economic value of AT non-infrastructure programs. The effectiveness of AT non-infrastructure programs depends on many characteristics of the programs (e.g., knowledge of staff, outreach effort, duration of program, etc.) as well as having direct linkages with AT facilities.

While anecdotal evidence exists on the effectiveness of programs in inducing additional diversion from motorized vehicles, it is not reasonable to attribute these findings to only the program (exclusive of a capital project) nor is it reasonable to assume that another program would have a similar level of effectiveness. Moreover, since ATP fund applicants supply evidence on existing and new trips, they may already be accounting for programming activity in estimating the increase in facility use. Therefore, it is reasonable to characterize projects with accompanying AT non-infrastructure programs as having a *qualitatively* higher level of value than a similar project without such programs.

A datasheet though has been formed to collect information about the proposed initiative and applies a scoring framework to determine the overall program impact score. The score is influenced by the numbers of people reached who are not currently engaging in active transportation. In addition, four program performance criteria are established to assess the effectiveness of the initiative, each with different measures of relative value. The criteria themselves have an equal relative weight of 25 percent each. The scoring system is designed to provide a maximum potential score of 1.0. The percentage is applied to the number of currently non-active transportation mode users, who would switch to an active transportation mode, to determine a program impact score. The cost of the program is then divided by the score to determine the cost per program impact score – which can be a common basis for comparing programs across applicants.

3 References

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IV.

Park and Ride

IV. Park and Ride

This chapter provides documentation for Cal-B/C PnR, which allows users to estimate the benefits of new park and ride lots, park and ride lot expansions, and leased lots. Cal-B/C PnR is an update of a tool developed in 2013 by System Metrics Group for Caltrans District 12. As part of the current Cal-B/C update, the Cal-B/C development team incorporated the park and ride tool into the Cal-BC suite.

Cal-B/C PnR is essentially the same as the original District 12 model, which had been developed to be compatible with Cal-B/C. The Cal-B/C development team made the following minor updates to make the tool consistent with other Cal-B/C models and add functionality:

- Changed the formatting of the tool to be consistent with other Cal-B/C tools
- Updated the parameters in Cal-B/C PnR using the common parameters page shared across all Cal-B/C models
- Incorporated a macro that allows the tool to be used for park and ride lots that serve more than three destinations.

The rest of this chapter provides documentation for the updated Cal-B/C PnR model. This documentation borrows heavily from the final report for the Caltrans District 12 project with much of the language copied verbatim.[1] That material is included here for completeness in Cal-B/C documentation. It has been updated to reflect the changes made to Cal-B/C PnR.

The rest of this chapter is organized into the following sections:

- Tool Overview
- Model Structure
- Using the Model.

1 Tool Overview

Cal-B/C PnR provides a method for preparing simple economic analyses for park-and-ride lot projects. Given required input data for a project, the model calculates its lifecycle costs, lifecycle benefits, net present value, benefit-cost ratio, internal rate of return, and payback period.

Cal-B/C PnR is intended to be used to prioritize park and ride lot investments, evaluate alternatives, and compete for project funding. The tool can also be used as part of sketch planning. The tool uses a similar structure, formatting, and parameters to other models in the Cal-B/C suite of tools. As a result, Cal-B/C PnR can prepare benefit-cost analyses for park and ride lots comparable to those calculated for projects using other Cal-B/C tools. When used with

[1] System Metrics Group, Cost-Benefit Analysis of Park & Ride/Intermodal Strategies within the State Highway System in Southern California.

other Cal-B/C tools (e.g., Cal-B/C AT for active transportation), the evaluation can include access modes to a park and ride lot.

The literature review for the original Caltrans District 12 study found only two other benefit-cost tools available for assessing the benefits of park and ride lots. One tool was developed by the Washington State Department of Transportation (WSDOT) to analyze park and ride projects in Washington State. The other was developed in Scotland to assess a series of park and ride investments in metropolitan Edinburgh. Cal-B/C PnR calculates benefits similar to the Washington State tool, but incorporates elements from the Scottish tool and the Cal-B/C framework. More information on these other tools can be found in the final report for the Caltrans District 12 study.

Like the Washington State tool, Cal-B/C PnR estimates benefits for park and ride lot users traveling to different destinations. Model users can define up to three destinations that serve as proxies for typical travel from the park and ride lot being analyzed. The tool estimates benefits for four types of park and ride lot users:

- New Transit Riders (users who switch from automobile to express bus)
- Existing Transit Riders (users who switch from local bus to express bus)
- New Carpoolers (users who switch from automobile to carpool)
- Existing Carpoolers (users who switch to a park and ride lot that requires less driving).

During the latest update, the Cal-B/C development team added a macro that allows the model user to save the results for the first three destinations and add information for three more destinations. The macro can be run twice, so up to nine destinations can be included in the benefit-cost analysis. This functionality is similar to the macro available in the original Cal-B/C model for bypass and intersection projects as well as in Cal-B/C Corridor.

Although Cal-B/C PnR is similar to the Washington State tool, it contains a number of important enhancements:

- Uses the Cal-B/C framework (i.e., model structure, formatting, benefit types, assumptions, and parameters)
- Estimates the safety, emission, and greenhouse gas benefits of park and ride projects
- Calculates fuel and emissions savings based on vehicle operating speed using the same assumptions as other Cal-B/C tools
- Allows the user to specify a future year when the lot reaches capacity (benefits in earlier years are lower since the lot is not at capacity)
- Includes a space to input no build park and ride lot information, so park and ride lot expansion projects can be analyzed
- Assumes average vehicle occupancy (AVO) is the same for all park and ride lot users rather than forcing the model user to estimate many AVO values
- Calculates benefits for park and ride lot users that switched from another park and ride lot, which is more common in an area with many park and ride lots
- Simplifies the input of travel time information

- Assumes that average transit riders and carpoolers are unwilling to wait more than 10 minutes
- Estimates vehicle-miles traveled (VMT) reductions and the benefits of CO_2 reductions.

Like other Cal-B/C tools, Cal-B/C PnR estimates four types of user benefits:

- **Travel time savings** due to people driving alone and local transit riders switching to carpools and express buses that can take managed lanes.
- **Vehicle operating cost savings** from fewer vehicles on the road due to carpooling and transit usage. Private vehicle operating costs become agency costs in the case of transit. These increased costs should be included in the project evaluation if increased transit service is part of the project being assessed.
- **Safety benefits** due to fewer vehicles on the road. These benefits reflect buses being generally safer than private vehicles.
- **Emissions benefits** from fewer vehicles on the road and fewer miles driven.

Benefits are estimated for each travel destination using the demand and travel information entered by the model user. The tool does not estimate park and ride lot demand – this information must be estimated outside the model and provided by the model user. The Caltrans District 12 study developed a separate cost estimation tool that can be used for this purpose.

2 Model Structure

Like other Cal-B/C models, Cal-B/C PnR is a simple spreadsheet file. The spreadsheet includes 10 pages:

- **Title** – introduction page with model contact information
- **Instructions** – general description of the model and its assumptions as well as step-by-step instructions for using the model
- **Project Information** – sheet for entering project data, park and ride lot information, destination information (e.g., demand, travel times, etc.), and cost information
- **Results** – summary of cost-benefit results
- **Travel Time** – detailed calculation of travel time impacts
- **Vehicle Operating Costs** – detailed calculation of changes in highway vehicle operating costs and user out-of-pocket costs
- **Accidents** – detailed calculation of changes in highway accident costs
- **Emissions** – detailed calculation of changes in vehicle emissions
- **Final Calculations** – detailed calculation of net present value, internal rate of return, and payback period
- **Parameters** – economic assumptions, lookup tables, and other model parameters consistent with other Cal-B/C models.

Most people will use only the “1) Project Information” and “2) Results” sheets. The project information page is used to enter information about the project, while the results page provides the summary of the economic analysis. In addition, users may refer to the instructions page,

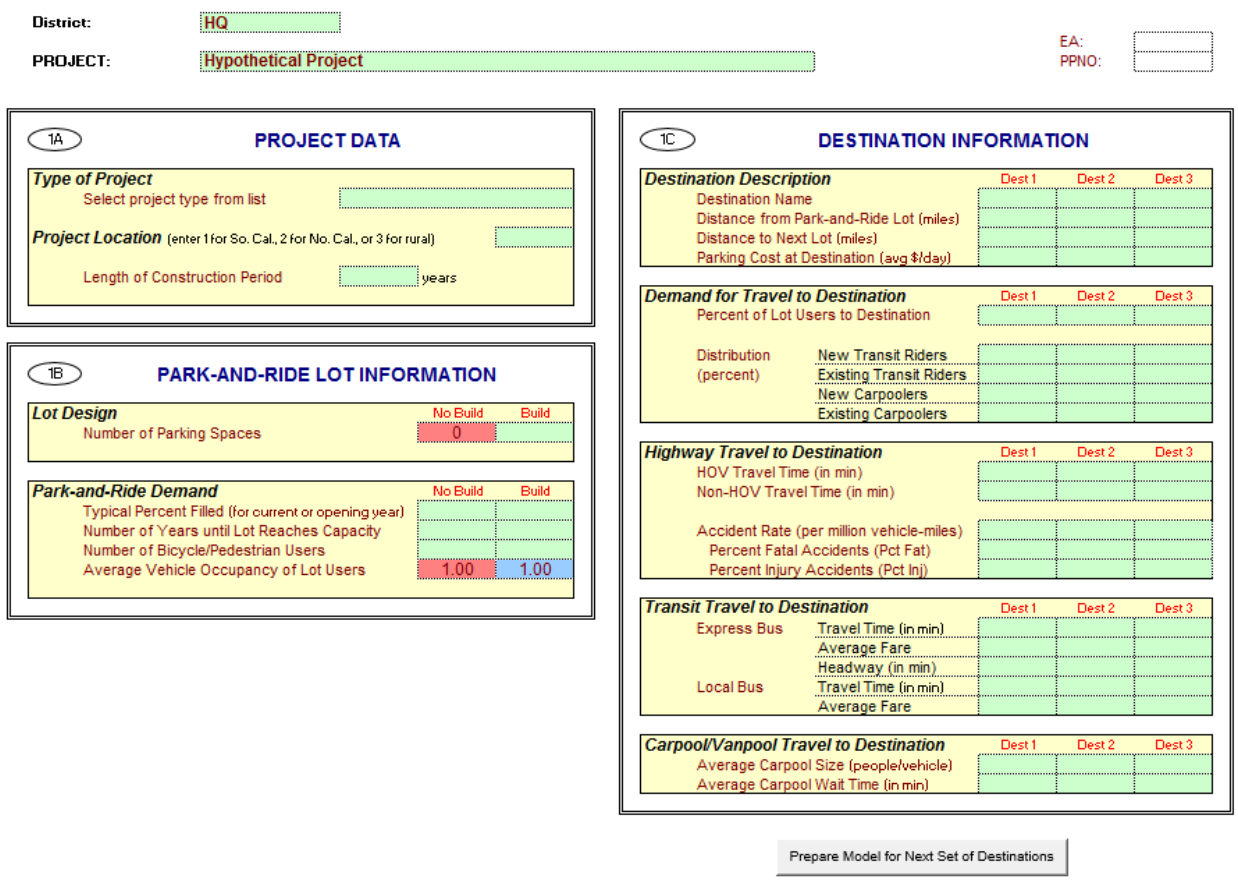
which contains step-by-step instructions on how to use the model and explanations for the input data required. These instructions can be printed as a reference. Most of the remaining pages (i.e., travel time, vehicle operating costs, accidents, and emissions) contain the detailed calculations of the user benefits. The typical model user will not refer to these pages.

The final calculations page aggregates all of the user benefits into the final estimates of net present value, internal rate of return, and payback period. The parameters page contains the economic assumptions, lookup tables, and other model parameters.

3 Using the Model

The user enters data about the project on the project information page. As shown in Exhibit IV-1, the first three boxes are used to enter information about the park and ride lot, its design, location, expected demand, and different travel conditions to the likely traveler destinations. In Box 1A, the user enters information about the project and its location. In Box 1B, the user enters information about the number of parking spaces in the lot and the time that it takes to reach capacity. The user can also enter information about bicyclists and pedestrians.

Exhibit IV-1: Project Information Page



In Box 1C, the user provides detailed information about the destinations that travelers may want to reach from the park and ride lot. The user can enter data for up to three destinations, but

additional destinations can be analyzed by using the "Prepare Model for Next Set of Destinations" button. Percentages must be entered to distribute the park and ride lot demand to the three destinations and four types of park and ride lot users. In addition, information is required on the travel conditions and average accident rates along typical routes for reaching the destinations.

As shown in Exhibit IV-2, the user also enters project cost data on the project information page. Box 1D is formatted the same as other Cal-B/C project cost tables except that it allows the user to enter the residual value of the park and ride project at the end of the project lifecycle. The model automatically includes the residual value of the right-of-way in the analysis. This is an important consideration for park and ride lots because the land used for the park and ride lot can be sold at the end of the project lifecycle.

Exhibit IV-2: Project Cost Data

1D

PROJECT COSTS (enter costs in thousands of dollars)

Col. no.	(1)	(2)	(3)	(4)	(5)	(6)	(7)		
	DIRECT PROJECT COSTS								
	INITIAL COSTS			SUBSEQUENT COSTS				TOTAL COSTS (in dollars)	
Year	Project Support	R / W	Construction	Maint./ Op.	Rehab.	Mitigation	Transit Agency Cost Savings	Constant Dollars	Present Value
Construction Period									
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
Project Open									
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
Total	$0	$0	$0	$0	$0	$0	$0	$0	$0

Residual Value in Year 21
(in thousands of dollars) $0

Present Value = Future Value (in Constant Dollars) / (1+ Real Discount Rate)^Year

Exhibit IV-3 shows an example of Cal-B/C PnR results page. This page looks identical to the one in the base Cal-B/C model with three exceptions:

- Cal-BC PnR also reports vehicle-miles traveled (VMT) reductions, which are an important goal of park and ride projects.
- Cal-B/C PnR includes the residual value benefit of the land.
- The base Cal-B/C model was changed during this update to show freight and passenger benefits separately.

Exhibit IV-3: Results Page

District: HQ

PROJECT: Hypothetical Project

EA:
PPNO:

2

INVESTMENT ANALYSIS

SUMMARY RESULTS

Life-Cycle Costs (mil. $)	$0.0
Life-Cycle Benefits (mil. $)	$0.0
Net Present Value (mil. $)	$0.0
Benefit / Cost Ratio:	N/A
Rate of Return on Investment:	N/A
Payback Period:	N/A

ITEMIZED BENEFITS (mil. $)	Average Annual	Total Over 20 Years
Travel Time Savings	$0.0	$0.0
Veh. Op. Cost Savings	$0.0	$0.0
Accident Cost Savings	$0.0	$0.0
Emission Cost Savings	$0.0	$0.0
Residual Value		$0.0
TOTAL BENEFITS		$0.0
Person-Hours of Time Saved	0	0
VMT Reduction	0	0
CO_2 Emissions Saved (tons)	0	0
CO_2 Emissions Saved (mil. $)	$0.0	$0.0

Should benefit-cost results include:

1) Induced Travel is not considered

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

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

4) Vehicle Emissions? (y/n) — Y (Default = Y)
includes value for CO_2e

V.

Risk Analysis

V. Risk Analysis

The Cal-B/C development team researched how to incorporate risk analysis into Cal-B/C using an Excel Add In called Risk Analyzer. As a result of this research, the team developed a special version of Cal-B/C that simplifies the use of Risk Analyzer with the model. This chapter provides guidance in two standalone sections that cover:

- Recommendations for input parameter values and distribution types when conducting risk analysis in Cal-B/C using Risk Analyzer
- Instructions on how to use Risk Analyzer in conjunction with the special version of Cal-B/C that supports risk analysis.

Recommendations for Input Parameter Distributions for Cal-B/C Monte Carlo Analysis

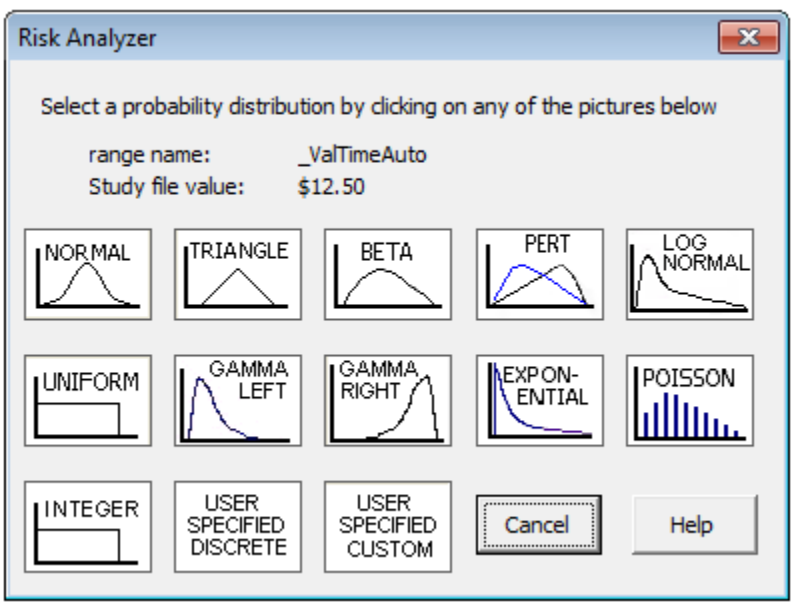
Overview

This section contains recommendations for input parameter values (low and high estimates) and distribution types when implementing risk analysis into the Cal-B/C model using *Risk Analyzer* software. These are general guidelines that represent a starting point for the treatment of uncertain input variables and can be refined with project specific estimates of uncertainty when available. For example, if multiple future year traffic volumes have been forecasted for a project based on different socioeconomic growth projections, these can be used to inform the input distribution for this variable.

Selecting the Appropriate Distribution

Many distributions are available to define input variables in *Risk Analyzer* as shown in Exhibit V-1.

Exhibit V-1: Available Distributions in Risk Analyzer Software



Source: Risk Analyzer Software, Release 14

For simplicity in definition and modeling of input parameters, it is often preferable to select distributions that can be defined by few data points, such as minimum, maximum, and study value, rather than distributions that require summary statistics such as mean and standard deviation. Risk analyzer allows for most available distributions to be defined with a minimum, maximum and study value as shown in Exhibit V-2.

Exhibit V-2: Parameters for Risk Analyzer Distributions

Distribution	Allows Minimum/ Maximum/ Study Value Definition	Notes
Normal	In some cases	Yes, "Specify minimum and maximum values and let Risk Analyzer set the initial normal distribution parameters" option is selected.
Triangle	Yes	-
Beta	Yes	-
Pert	Yes	However, user must indicate a skew to right or left, which may result in a most likely value significantly different from the study value. In cases where a skewed distribution is not intended, the Beta distribution should be used instead.
Log Normal	In some cases	Minimum value must be set to zero initially, which may not be preferable for the selected input variable. This can later be changed to a non-zero value. If minimum and maximum are too close to each other the distribution cannot be defined.
Uniform	Yes	-
Gamma Left	Yes	-
Gamma Right	Yes	-
Exponential	Yes	-
Poisson	In some cases	The Poisson distribution is best used for study values less than 10, where the study is within 10 units of the minimum value.
Integer	In some cases	The minimum, maximum and study values must be integers.
User Specified Discrete	No	Each value individual must be assigned a probability
User Specified Custom	No	Each range of values must be assigned a probability

Recommended Risk Input Variables in Cal-B/C

The variables to be considered within the Monte Carlo analysis depend on the project type being analyzed within Cal-B/C. Exhibit V-3 provides a listing of the recommended variables based on the project type within Cal-B/C.

Exhibit V-3: Recommended Risk Input Variables by Project Type

Variable Description	Highway Capacity Expansion								Rail or Transit Cap Expansion			
	General Highway	HOV Lane Addition	HOT Lane Addition	Passing Lane	Intersection	Bypass	Queuing	Pavement	Passenger Rail	Light-Rail (LRT)	Bus	Hwy-Rail Grade Cross
Project Specific Input Variables												
Average Daily Traffic (ADT) (Year 20 No Build)	x	x	x	x			x	x	x	x	x	x
Percent Trucks (No Build)	x	x	x	x			x	x				
Percent of ADT in Peak Period	x	x	x	x			x	x	x	x	x	x
Project Costs	x	x	x	x			x	x	x	x	x	x
Accident Reduction Factor				x								
HOV ADT (HOV projects only) (Year 20 No Build)	x	x	x									
Transit Person Trips (Transit Projects Only) (Year 20 No Build)									x	x	x	
Transit Travel Times (Transit Projects Only) (No Build) - Peak									x	x	x	
Gate down time (Grade Crossing Projects Only)												x
Number of Trains (Grade Crossing Projects Only)												x
Truck Speed				x								x
Arrival Rate							x					x
Economic Input Variables												
Value of Travel Time - Auto	x	x	x	x			x	x	x	x	x	x
Value of Travel Time - Truck	x	x	x	x			x	x	x	x	x	x
Fuel Price - Auto	x	x	x	x			x	x	x	x	x	x
Fuel Price - Truck	x	x	x	x			x	x	x	x	x	x
Cost of a Fatality	x	x	x	x			x	x	x	x	x	x
Cost of an Injury - Level A (Severe)	x	x	x	x			x	x	x	x	x	x
Cost of an Injury - Level B (Moderate)	x	x	x	x			x	x	x	x	x	x
Cost of an Injury - Level C (Minor)	x	x	x	x			x	x	x	x	x	x

Note: Intersection and Bypass projects require multiple runs within Cal-B/C and therefore Monte Carlo analysis is not supported for these project types at this time

Exhibit V-3: Recommended Risk Input Variables by Project Type (continued)

Variable Description	Hwy Operational Improvement								Transp Mgmt Systems (TMS)							
	Auxiliary Lane	Freeway Connector	HOV Connector	HOV Drop Ramp	Off-Ramp Widening	On-Ramp Widening	HOV-2 to HOV-3 Conv	HOT Lane Conversion	Ramp Metering	Ramp Metering Signal Coord	Incident Management	Traveler Information	Arterial Signal Management	Transit Vehicle Location (AVL)	Transit Vehicle Signal Priority	Bus Rapid Transit (BRT)
Project Specific Input Variables																
Average Daily Traffic (ADT) (Year 20 No Build)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Percent Trucks (No Build)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Percent of ADT in Peak Period	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Project Costs	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Accident Reduction Factor					x											
HOV ADT (HOV projects only) (Year 20 No Build)			x	x			x	x	x		x	x				
Transit Person Trips (Transit Projects Only) (Year 20 No Build)														x	x	x
Transit Travel Times (Transit Projects Only) (No Build) - Peak														x	x	x
Gate down time (Grade Crossing Projects Only)																
Number of Trains (Grade Crossing Projects Only)																
Truck Speed																
Arrival Rate																
Economic Input Variables																
Value of Travel Time - Auto	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Value of Travel Time - Truck	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Fuel Price - Auto	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Fuel Price - Truck	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cost of a Fatality	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cost of an Injury - Level A (Severe)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cost of an Injury - Level B (Moderate)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cost of an Injury - Level C (Minor)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Guidelines for Input Distributions

Input variables that are available to define as distributions will be determined by the selected project type within Cal-B/C for a given project. These include both project specific and economic input variables. For each variable, it is important to clearly define and explain the variable in order to determine the suitable range and distribution shape.

A Note on Correlation of Input Variables

Within risk analysis, certain input variables may need to be correlated to represent their interactions. Within Risk Analyzer, any correlations between input variables must be defined within Excel formulas. For example, to allow for correlation between build and no-build traffic forecasts, traffic projections for the build alternative traffic would be defined in two parts: 1) the risk input for the no-build traffic forecast; 2) the risk input for the delta between the build and no-build traffic forecasts. Within Excel, the total traffic forecast for the build alternative would then be set to equal the sum of these two parts.

Due to limitations in Risk Analyzer software for defining correlations and the current structure of the Cal-B/C calculations, at this point only no-build variables are recommended to be used as risk inputs. Build scenario variables can be linked or calculated as a function of the no-build variables in Cal-B/C to allow for uncertainty in these variables as well. For example, if traffic volumes are the same in the No Build and Build, the Build traffic volume can be set to equal the no-build traffic volume.

The following is an example of a potential need to correlate input variables. Uncertainty in future year Build and No Build traffic forecasts may be a function of underlying economic and demographic assumptions that are expected to be similar between the Build and No Build alternatives. Therefore, one may wish to correlate Build and No Build traffic forecasts to hold these underlying assumptions constant between alternatives in each iteration of the risk analysis simulation. Failing to correlate these variables may result in counterintuitive results in the risk analysis, such as higher traffic volumes in the No Build relative to the Build. Within the current Cal-B/C model using Risk Analyzer, correlation for future year traffic forecasts can be defined follows. If we have Average Daily Traffic (ADT) (Year 20 No Build) of 100,000 and Average Daily Traffic (ADT) (Year 20 Build) of 120,000, one can define No Build ADT as a risk input and define Build ADT as function of the No Build ADT cell plus the difference in ADT from the No Build to the Build (e.g., Build ADT = ADT20NB + 20,000).

Project Specific Input Variables

The values selected for project specific input variables, including the upper and lower bounds should be informed by project specific data and observations to the extent possible. The following provides general guidelines for distribution shape and range bounds to use as a starting point for risk analysis.

AVERAGE DAILY TRAFFIC (ADT) (YEAR 20 NO BUILD)

This variable represents the average daily traffic in Year 20 of the forecast for the No Build scenario. Sources of uncertainty in the ADT forecast may include uncertainty in underlying assumptions for drivers of future year traffic, such as demographic and economic projections, as

well as inaccuracies in forecasting models. If variability is assigned to this input, and similar variability is expected in the Build scenario, the associated Build variable should be linked to this input such that both scenarios have similar uncertainty.

The range assigned to this input variable can be informed by research into the topic of accuracy of travel demand forecasts. Flyvbjerg (2005) evaluated the accuracy of demand forecasts in public works projects. This study found that 50 percent of all road projects evaluated had a difference between forecasted and actual traffic volumes of at least ±20%. Further, the authors found a fairly even split between the number of forecasts that overstated or understated actual demand. Based on the findings of this study, the following input parameters are recommended:

Exhibit V-4: Risk Analysis Input Distribution for Average Daily Traffic (ADT) (Year 20 No Build)

Variable Description	Variable Name	Potential Distribution Type	Potential Lower Bound	Potential Upper Bound
Average Daily Traffic (ADT) (Year 20 No Build)	ADT20NB	Normal	-20%	+20%

Source: Bent Flyvbjerg, Mette K. Skamris Holm, and Søren L. Buhl, "How (In)accurate Are Demand Forecasts in Public Works Projects? The Case of Transportation," Journal of the American Planning Association, Spring 2005, Vol. 71, No. 2. http://flyvbjerg.plan.aau.dk/Traffic91PRINTJAPA.pdf

PERCENT TRUCKS (NO BUILD)

This variable represents the observed (or estimated) daily truck traffic volume divided by the observed (or estimated) total daily traffic volume. If variability is assigned to this input, and similar variability is expected in the Build scenario, the associated Build variable should be linked to this input such that both scenarios have similar uncertainty.

Uncertainty in the daily traffic volume is already considered in the "Average Daily Traffic (ADT) (Year 20 No Build)" input variable, therefore variability in this variable should account for uncertainty only in the daily truck traffic volume. Uncertainty may stem from time of day, day of week, time of year, etc. when the observations are made. Since this is a fixed variable over the timeframe of analysis, there may also be uncertainty associated with change in the rate over time that can be captured in this range (i.e., if one believes truck traffic may increase from x% to y% over the timeframe of analysis, this can inform the range).

Exhibit V-5: Risk Analysis Input Distribution for Percent Trucks (No Build)

Variable Description	Variable Name	Potential Distribution Type	Potential Lower Bound	Potential Upper Bound
Percent Trucks (No Build)	PerTruckNB	Normal	-10%	+10%

PERCENT OF ADT IN PEAK PERIOD

This variable represents the observed (or estimated) traffic volume in the peak period divided by the observed (or estimated) total daily traffic volume. Uncertainty in the daily traffic volume is already considered in the "Average Daily Traffic (ADT) (Year 20 No Build)" input variable, therefore variability in this variable should account for uncertainty only in the traffic volume within the defined peak period. Since this is a fixed variable over the timeframe of analysis, there may also be uncertainty associated with change in the rate over time that can be captured in this range (i.e., if one believes peak period traffic may increase from x% to y% over the timeframe of analysis, this can inform the range).

Exhibit V-6: Risk Analysis Input Distribution for Percent of ADT in Peak Period

Variable Description	Variable Name	Potential Distribution Type	Potential Lower Bound	Potential Upper Bound
Percent of ADT in Peak Period	TPerPeak	Normal	-10%	+10%

PROJECT COSTS

Project costs can be a significant source of uncertainty in project valuation. Estimates typically become more refined and the quality of the estimate increases as project development progresses. Sources of uncertainty in project costs may include the current level of design, changes in assumptions, and market conditions, as well as consideration of different alternatives or significant changes in scope. The consideration of multiple alternatives and significant scope changes should not be reflected in the input range as they may impact on traffic data and roadway characteristics. These should be separated out from the risk analysis and accounted for in different scenarios within Cal-B/C. The variability in the cost estimate should account for potential variations in the project cost estimate given the project's current scope and be consistent with the traffic data and roadway characteristics utilized in the analysis.

Association for the Advancement of Cost Engineering (AACE) provides recommendations on the expected accuracy range of estimates based on level of project development that can inform the range assigned to project costs, as summarized in Exhibit V-7.

Exhibit V-7: AACE International Cost Estimate Ranges by Project Development Level

Project Development Level	Project Maturity (% Design Complete)	Purpose of Estimate	Low and High Range
Planning	0% to 2%	Concept screening	L: -20% to -50% H: +30% to +100%
	1% to 15%	Study or feasibility	L: -15% to -30% H: +20% to +50%
Scoping	10% to 30%	Budget authorization or control	L: -10% to -20% H: +10% to +30%
Design	10% to 90%	Control or bid/tender	L: -5% to -15% H: +5% to +20%
PS&E	90% to 100%	Check estimate or bid/ tender	L: -3% to -10% H: +3% to +15%

Adapted from AACE International, 18R-97: Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries, March 1, 2016. http://www.aacei.org/toc/toc_18R-97.pdf

As shown in Exhibit V-8, the lower and upper bounds are defined as ranges themselves. The narrower of these bounds have been selected for each estimate purpose to account to avoid accounting for multiple alternatives and significant scope changes within the range, as discussed above.

Exhibit V-8: Risk Analysis Input Distribution for Project Costs

Variable Description	Variable Name	Potential Distribution Type	Purpose of Estimate	Potential Lower Bound	Potential Upper Bound
Project Costs	CostFactor	Triangular	Concept screening	-20%	+30%
			Study or feasibility	-15%	+20%
			Budget authorization or control	-10%	+10%
			Control or bid/tender	-5%	+5%
			Check estimate or bid/tender	-3%	+3%

ACCIDENT REDUCTION FACTOR

This applies only to Passing Lane (default value 30%), Off-Ramp Widening (default value 50%) and Ramp Metering (default value 30%) project types. This variable represents the estimated percent reduction in accidents due to the proposed project. These factors are estimated based on observations of safety improvements similar projects in the past. The uncertainty represents how likely it is that a given project will yield similar safety improvements to past similar projects. Additionally, since this is a fixed variable over the timeframe of analysis, there may also be uncertainty associated with change in the rate over time that can be captured in this range (i.e., if we believe there may be a ramp up in the accident reductions over time, this can inform our range).

Exhibit V-9: Risk Analysis Input Distribution for Accident Reduction Factor

Variable Description	Variable Name	Potential Distribution Type	Potential Lower Bound	Potential Upper Bound
Accident Reduction Factor	AccReduceFac	Normal	-15%	+15%

HOV ADT (HOV PROJECTS ONLY) (YEAR 20 NO BUILD)

This variable represents the average daily traffic in year 20 of the forecast for the No Build scenario within high-occupancy vehicle (HOV) lanes. If variability is assigned to this input, and similar variability is expected in the Build scenario, the associated Build variable should be linked to this input such that both scenarios have similar uncertainty.

The recommended distribution and range values for this variable are based on the recommendation for Average Daily Traffic (ADT) (Year 20 No Build). Refer to that section of the document for additional information.

Exhibit V-10: Risk Analysis Input Distribution for HOV ADT

Variable Description	Variable Name	Potential Distribution Type	Potential Lower Bound	Potential Upper Bound
HOV ADT (HOV projects only) (Year 20 No Build)	HOVvolNB	Normal	-20%	+20%

TRANSIT PERSON TRIPS (YEAR 20 NO BUILD)

This variable represents the daily transit person trips in Year 20 of the forecast for the No Build scenario. If variability is assigned to this input, and similar variability is expected in the Build scenario, the associated Build variable should be linked to this input such that both scenarios have similar uncertainty.

The recommended distribution and range values for this variable are based on the recommendation for Average Daily Traffic (ADT) (Year 20 No Build). Refer to that section of the document for additional information.

Exhibit V-11: Risk Analysis Input Distribution for Transit Person Trips (Year 20 No Build)

Variable Description	Variable Name	Potential Distribution Type	Potential Lower Bound	Potential Upper Bound
Transit Person Trips (Transit Projects Only) (Year 20 No Build)	TAPT20NB	Normal	-20%	+20%

TRANSIT TRAVEL TIMES (NO BUILD) - PEAK

This variable represents the travel time for transit trips in the no-build for the peak period. If variability is assigned to this input, and similar variability is expected in the Build scenario, the associated Build variable should be linked to this input such that both scenarios have similar uncertainty. This default value recommendation for this variable is a uniform distribution with a range of ±10%.

Exhibit V-12: Risk Analysis Input Distribution for Transit Travel Times (No Build) - Peak

Variable Description	Variable Name	Potential Distribution Type	Potential Lower Bound	Potential Upper Bound
Transit Travel Times (Transit Projects Only) (No Build) - Peak	TInTimeNBP	Uniform	-10%	+10%

GATE DOWN TIME

This variable represents amount of time a gate is down in minutes at a rail-roadway grade crossing per train. Some factors that may influence the gate down time duration may include the length and speed of the train. It is recommended to skew this distribution towards the upper bound, as the study value likely represents the expected duration. It is less likely that the gate down time will be shorter but there is potential for a longer duration due to delays. The Pert distribution is recommended as this distribution allows skewing the distribution.

Exhibit V-13: Risk Analysis Input Distribution for Gate Down Time

Variable Description	Variable Name	Potential Distribution Type	Potential Lower Bound	Potential Upper Bound
Gate down time (Grade Crossing Projects Only)	GateTime20	Pert	-10%	+25%

NUMBER OF TRAINS

This variable represents the daily number of trains at a crossing. Since this is a fixed variable over the timeframe of analysis, there may also be uncertainty associated with change in the rate over time that can be captured in this range. The recommended variability for this variable is shown below.

Exhibit V-14: Risk Analysis Input Distribution for Number of Trains

Variable Description	Variable Name	Potential Distribution Type	Potential Lower Bound	Potential Upper Bound
Number of Trains (Grade Crossing Projects Only)	NumTrain20	Normal	-5%	+5%

TRUCK SPEED

This variable represents the average speed of trucks in miles per hour. The recommended variability for this variable is shown below.

Exhibit V-15: Risk Analysis Input Distribution for Truck Speed

Variable Description	Variable Name	Potential Distribution Type	Potential Lower Bound	Potential Upper Bound
Truck Speed	TruckSpeed	Normal	-15%	+15%

ARRIVAL RATE

This variable represents the number of vehicles arriving per hour (to a queue or grade crossing). The recommended variability for this variable is shown below.

Exhibit V-16: Risk Analysis Input Distribution for Arrival Rate

Variable Description	Variable Name	Potential Distribution Type	Potential Lower Bound	Potential Upper Bound
Arrival Rate	ArrRate1	Exponential	-10%	+50%

Economic Input Variables

The distribution type and defined ranges for economic input variables should be kept similar between projects to provide consistent comparisons between similar projects, unless there is sound justification otherwise.

Certain economic input variables can be viewed as value parameters that policy makers have control over, and therefore should not be risk inputs.[1] For example, some applications of BCA may require the use of specific, deterministic input values (e.g. US DOT recommended values for TIGER Discretionary Grant applications). However, these economic inputs can be a source of uncertainty in the underlying data and assumptions used in deriving these values. Therefore the model has the flexibility in this regard. The model has the option to include economic input variables as risk variables. This toggle can be set to "Yes" to include these input variables.

DISCOUNT RATE

The discount rate represents how an agency values future changes in welfare. It is not recommended that the discount rate is defined as a risk input. Variability in the discount rate can add an immense amount of variability to the results when coupled with uncertainty on other inputs. This is a value parameter that decision makers have control over, and therefore should be run as a sensitivity scenario in order to understand the implications of a change in the assumption on the results, rather than a risk input variable.

Exhibit V-17: Risk Analysis Input Distribution for

Variable Description	Variable Name	Potential Distribution Type	Potential Lower Bound	Potential Upper Bound
Discount Rate	DiscRate	n/a – not recommended as a risk variable; test as sensitivity scenario instead		

Source: Granger, M. Morgan and Max Henrion, A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis, Cambridge University Press, 1990.

VALUE OF TRAVEL TIME – AUTO AND VALUE OF TRAVEL TIME - TRANSIT

These variables measure the value of one hour spent traveling for automobile and transit users and are calculated functions of income. The study values in Cal-B/C are based on 50% of statewide average hourly wage. Similarly, U.S. Department of Transportation (Rogoff 2014) recommends estimating the value of time at 50% of the hourly median household income for personal trips. This guidance also provides lower and upper bounds at 35% and 60% of the hourly income respectively, which correspond to a -30% and +20% of the base 50% value. Based on USDOT Value of Time guidance, the plausible range of value of time for personal trips is -30% to +20% of the base value. As uncertainty in value of time is a function of the uncertainty in how to value time, not in income itself, the normal distribution is recommended for this variable.

[1] *Granger, M. Morgan and Max Henrion, A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis, Cambridge University Press, 1990.*

Exhibit V-18: Risk Analysis Input Distribution for Value of Travel Time – Auto and Transit

Variable Description	Variable Name	Potential Distribution Type	Potential Lower Bound	Potential Upper Bound
Value of Travel Time – Auto and Transit	ValTimeAuto ValTimeTransit	Normal	-30%	+20%

Source: Rogoff, Peter (2014, July 9) Revised Departmental Guidance on Valuation of Travel Time in Economic Analysis. Washington, DC: U.S. Department of Transportation. https://www.transportation.gov/sites/dot.gov/files/docs/USDOT%20VOT%20Guidance%202014.pdf

VALUE OF TRAVEL TIME - TRUCK

The value of time measures the value of one hour spent traveling for truck drivers. It is calculated as function of the employer's for one hour of the driver's time (wage and benefits). The study value in Cal-B/C is based on 100% of Average Hourly Wage and Benefits Cost for Transportation and Warehouse employees. Similarly U.S. Department of Transportation (Rogoff 2014) recommends estimating the value of time that employers place on their employees at 100% of their gross hourly compensation (wages and benefits). This guidance also provides lower and upper bounds at 80% and 120% of gross hourly compensation respectively. This translates to a -20% and +20% range relative to the study value of 100%. As uncertainty in value of time is a function of the uncertainty in how to value time, not in income itself, the Normal distribution is recommended for this variable.

Exhibit V-19: Risk Analysis Input Distribution for Value of Travel Time – Truck

Variable Description	Variable Name	Potential Distribution Type	Potential Lower Bound	Potential Upper Bound
Value Of Travel Time - Truck	ValTimeTruck	Normal	-20%	+20%

Source: Rogoff, Peter (2014, July 9) Revised Departmental Guidance on Valuation of Travel Time in Economic Analysis. Washington, DC: U.S. Department of Transportation. https://www.transportation.gov/sites/dot.gov/files/docs/USDOT%20VOT%20Guidance%202014.pdf

FUEL PRICE - AUTO

This value represents the cost of one gallon of fuel for autos. The U.S. Energy Information Administration publishes annual forecasts of low, high, and reference scenarios for fuel prices which can inform the variability of fuel prices. Based on their Annual Energy Outlook 2016, the average annual variability for retail gasoline prices is expected to range from approximately -30% to +60%. Note, this range accounts for annual variability in fuel prices, not year-to-year (or inflationary growth in fuel prices), as all prices are forecasted in constant dollars.

Exhibit V-20: Risk Analysis Input Distribution for Value of Travel Time – Truck

Variable Description	Variable Name	Potential Distribution Type	Potential Lower Bound	Potential Upper Bound
Fuel Price - Auto	FuelPriceAuto	Normal	-30%	+60%

Source: Informed by U.S. Energy Information Administration, Annual Energy Outlook 2016, Petroleum Product Prices, AEO 2016 Forecast of Retail Gasoline Price (low, high, and reference scenario) for 2016 to 2035

FUEL PRICE - TRUCK

This value represents the cost of one gallon of fuel for trucks. The U.S. Energy Information Administration publishes annual forecasts of low, high, and reference scenarios for fuel prices which can inform the variability of fuel prices. Based on their Annual Energy Outlook 2016, the average annual variability for retail diesel fuel prices is expected to range from approximately -30% to +70%. Note, this range accounts for annual variability in fuel prices, not year-to-year (or inflationary growth in fuel prices), as all prices are forecasted in constant dollars.

Exhibit V-21: Risk Analysis Input Distribution for Value of Travel Time – Truck

Variable Description	Variable Name	Potential Distribution Type	Potential Lower Bound	Potential Upper Bound
Fuel Price - Truck	FuelPriceTruck	Normal	-30%	+70%

Source: Informed by U.S. Energy Information Administration, Annual Energy Outlook 2016, Petroleum Product Prices, AEO 2016 Forecast of Retail Diesel Fuel Price (low, high, and reference scenario) for 2016 to 2035

ACCIDENT COSTS

There are a number of accident cost variables in the model that can be defined as risk inputs:

- Cost of a Fatality;
- Cost of an Injury - Level A (Severe);
- Cost of an Injury - Level B (Moderate); and
- Cost of an Injury - Level C (Minor).

The Cost of a Fatality input variable represents a proxy for the appropriate level of investment to avoid one statistical death. The study value with Cal-B/C is defined as $9,800,000 per event, consistent with US DOT guidelines. USDOT refers to the cost of a fatality as the value of a statistical life and offers guidance on lower and upper bounds relative to their most likely value. These bounds are approximately ±40% and provide the basis of the recommended range to test in the risk analysis. The Cost of an Injury – Level A, B, and C are derived from the Cost of a

Fatality. Therefore the same uncertainty range is recommended for these variables. While the injury costs are a function of the cost of a fatality, these inputs are allowed to vary independently in the risk analysis to account for uncertainty in the relationship between cost of a fatality and injury costs.

Exhibit V-22: Risk Analysis Input Distribution for Accident Costs

Variable Description	Variable Name	Potential Distribution Type	Potential Lower Bound	Potential Upper Bound
Cost of a Fatality	FatValue	Normal	-40%	+40%
Cost of an Injury - Level A (Severe)	InjAValue	Normal	-40%	+40%
Cost of an Injury - Level B (Moderate)	InjBValue	Normal	-40%	+40%
Cost of an Injury - Level C (Minor)	InjCValue	Normal	-40%	+40%

Source: US DOT, Guidance on Treatment of the Economic Value of a Statistical Life in U.S. Department of Transportation Analyses (2016); http://www.dot.gov/office-policy/transportation-policy/guidance-treatment-economic-value-statistical-life

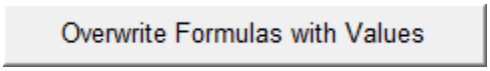
Steps to Implement Risk Analysis into Cal-B/C using Risk Analyzer

Preparing Cal-B/C for Risk Analysis

1. Open Excel.
2. Open Cal-B/C Model. Model should already be finalized and have deterministic input values and results.
3. *Suggestion*: Save a copy of the Cal-B/C model.
4. Print sheet '4)MC Inputs' from the Cal-B/C model to reference while using Risk Analyzer
5. The Cal-B/C model includes a toggle to include or exclude Economic Input Variables as risk inputs. This option is located in a dropdown box on sheet '4)MC Inputs' above the overwrite formulas with values button.

Within the example in this walkthrough, these variables are included.

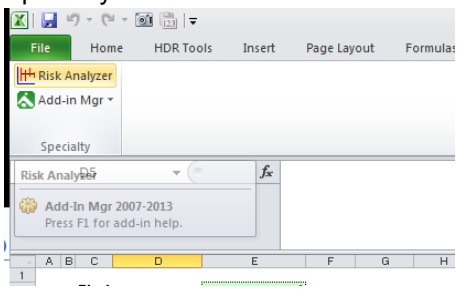
6. Click the toggle button on sheet '4)MC Inputs' to overwrite formulas with values.



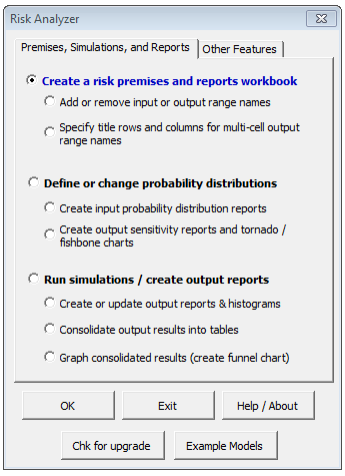
   a. Risk analyzer requires all input cells be values, not formulas. This will temporarily overwrite the formulas with the cell values.
   b. If changes are made to the input values/ formulas in Cal-B/C when the formulas are overwritten with values these changes will be lost when the formulas are restored at the completion of the risk analysis (see **Step 37** for additional information).

Creating the Risk Analysis Model

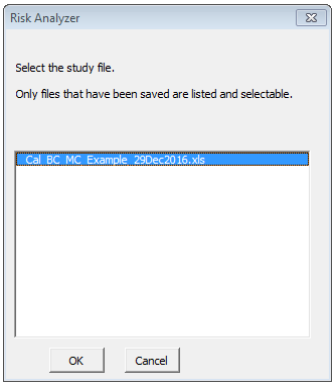
7. Open the Risk Analyzer add-in from the Specialty Menu in Excel.



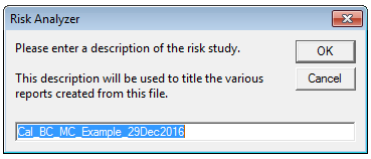
8. Select **Create a risk premises and reports workbook** and click OK.



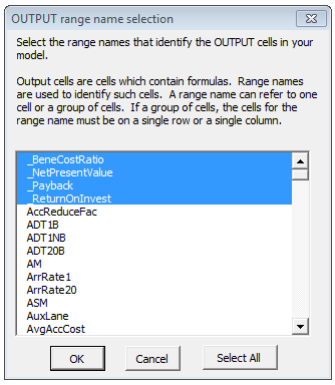
9. Select the relevant Cal-B/C model file and click OK.



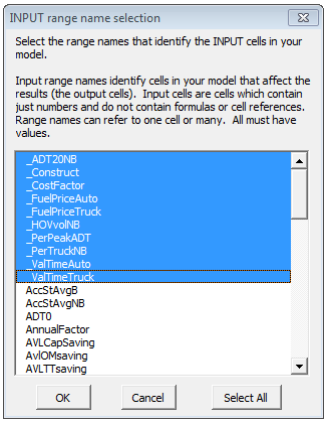
10. Enter a description of the risk study and click OK.



11. Select outputs: the inputs and outputs selected for this analysis have an underscore appended to the start of the name so they display at the top of the list. Note: To select multiple outputs hold the Ctrl key. The recommended outputs are:
    a. **BeneCostRatio**: Benefit/Cost Ratio (Life-Cycle Benefits/Life-Cycle Costs)
    b. **NetPresentValue**: Net Present Value ($)
    c. **ReturnOnInvest**: Rate of Return on Investment
    d. **Payback:** Payback Period

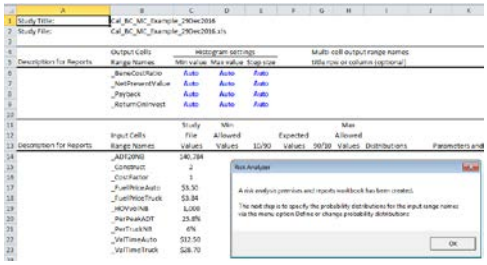


12. Select inputs: cells will be listed based on the range name in Excel. Input cells cannot contain formulas. Note: To select multiple outputs hold the Ctrl key. Refer to the printout from **Step 4** for the list of recommended input cells based on the selected project type. The inputs selected will depend on the project type. In this example (HOV Lane Addition), the following are selected:
    a. ADT20NB
    b. Construct
    c. CostFactor
    d. FuelPriceAuto
    e. FuelPriceTruck
    f. HOVVolnNB
    g. PerPeakADT
    h. PerTruckNB
    i. ValTimeAuto
    j. ValTimeTruck

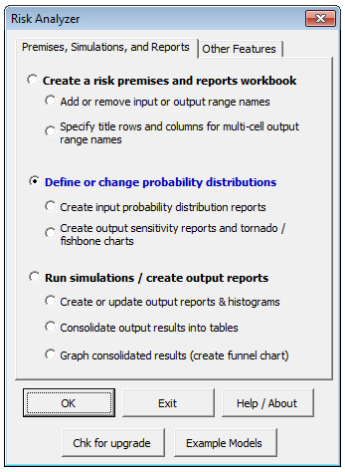


Defining Risk Input Distributions

13. A risk premises report has been created. Click OK to continue.

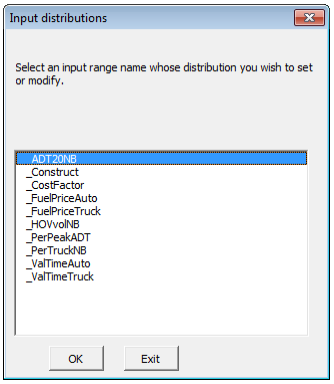


14. The next step is to define probability distributions. Select **Define or change probability distributions** and click OK.

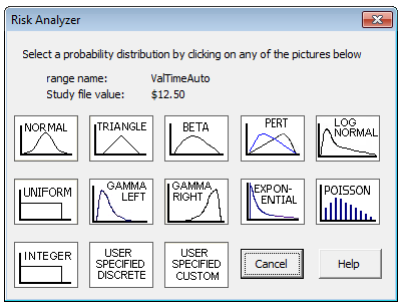


15. Risk Analyzer will now display a list of the input cells selected in **Step 12**. Select the first input distribution and click OK. Reference the information on the printout of the '4)MC Inputs' sheet to define the input distributions. In this

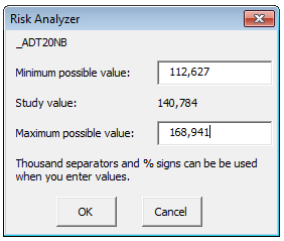
example the distribution for *ADT20NB* is shown.



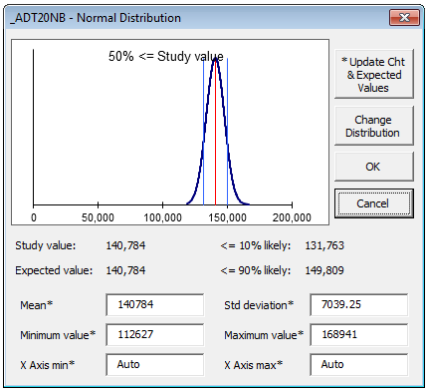
16. Select the input Distribution Type. For *ADT20NB* a Normal distribution is used.



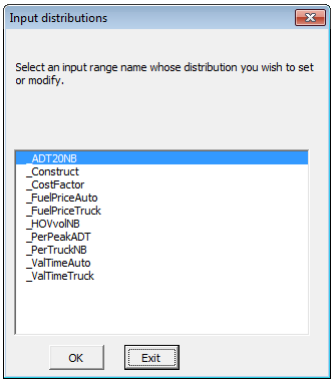
17. Enter the minimum and maximum possible values. In this example for value of time. The study value will already be filled with the value from the Cal-B/C model. For *ADT20NB* the minimum value is 112,627 (20% less than the study value) and the maximum value is 168,941 (20% more than the study value). Click OK.



18. A window showing a graph of the input distribution will appear. Click OK.

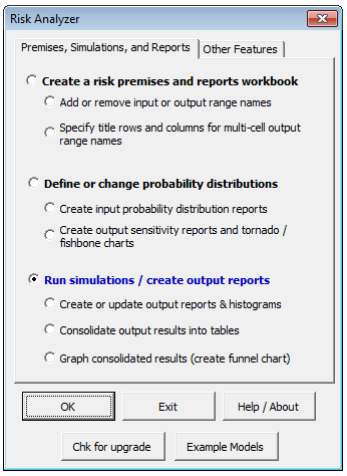


19. Repeat **Steps 15 to 18** until distributions for all input cells are defined.
20. Once all distributions are defined, click Exit.

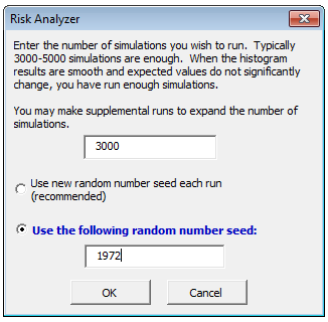


Running the Monte Carlo Simulation

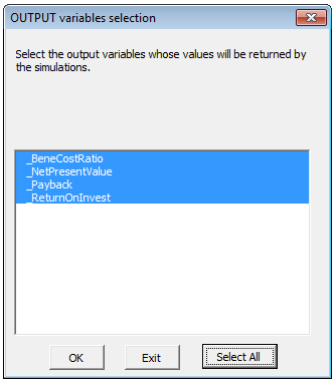
21. Select “Run simulations/ create output reports” and click OK.



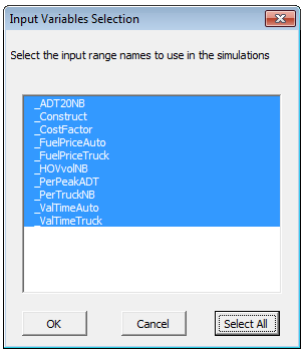
22. Enter # of iterations, suggested at least 3,000 and enter random seed number 1972.



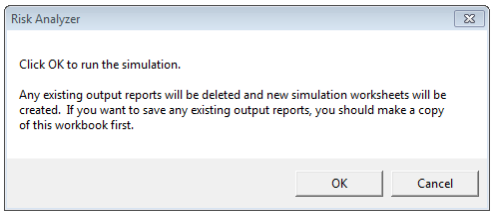
23. Select all output variables and click OK.



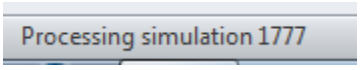
24. Select all input variables and click OK.



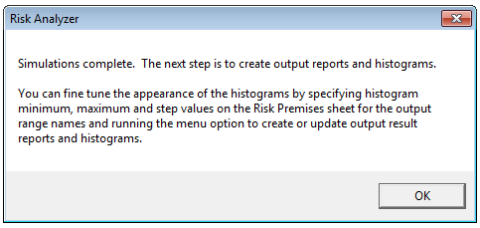
25. Click OK to run Simulation and wait for simulation to complete.



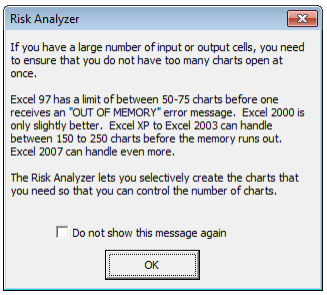
26. The current iteration number will show in the Excel task bar.



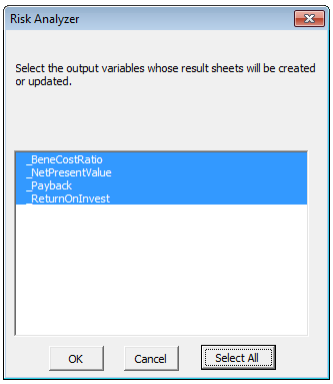
27. Once it reaches the total # of iterations entered (at least 3,000), the simulation is complete.



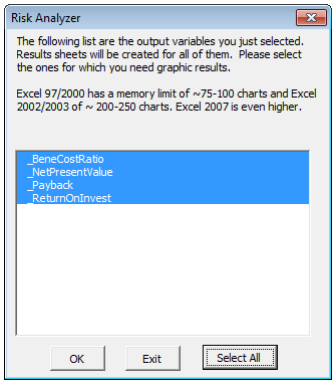
28. A warning may appear regarding the number of inputs and outputs. This should not be an issue for Cal-B/C models as there are fewer than 50 inputs and outputs. Click OK.



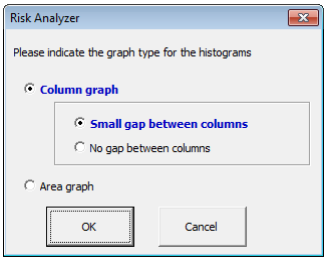
29. Select all output variables to create results sheets.



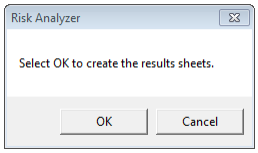
30. Select all output variables to create graphic results.



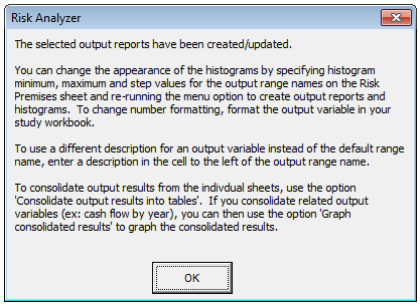
31. Select the graph type.



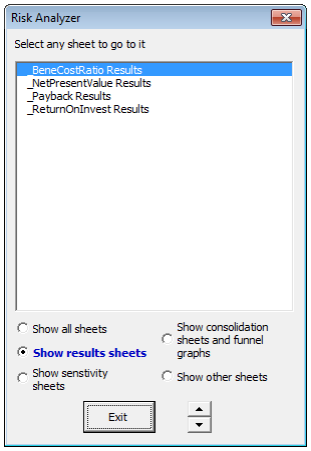
32. Click OK to create the results sheets.



33. Once the output reports have been created, click OK.



34. Select an output sheet to view and click Exit to view results.



Closing the Analysis

35. Save and close the Excel file created by Risk Analyzer. This file can be revisited in the future to update the risk analysis.
36. Restore the formulas in Cal-B/C input cells by clicking the toggle button on sheet '4)MC Inputs' to restore formulas.

This restores the formulas that were in the cells prior to the start of the risk analysis exercise. Any changes made to the input cell values/ formulas during the risk analysis exercise will be overwritten therefore it is critical that no changes are made to the input values/ formulas in Cal-B/C when the formulas are overwritten with values.

VI.

Intermodal Freight

VI. Intermodal Freight

This chapter documents the functionality, abilities, and limitations of the Cal-B/C 6.2 Intermodal Freight (IF) model, one of the newest analytical components to be developed as part of the Cal-B/C suite of tools. Specifically, this chapter provides an overview of the model's functionality, data requirements, and the technical methodology applied in estimating a range of benefit categories. Common terms and acronyms used in this chapter are defined in Exhibit VI-1 to assist the reader's understanding of Cal-B/C IF.

Cal-B/C IF provides the ability to conduct benefit-cost analysis in order to determine the feasibility of intermodal freight projects. The model considers three benefits:

- Shipper cost savings
- Accident cost savings
- Emissions cost savings

The model estimates the benefits for bulk/break bulk and containerized shipments. It undertakes a holistic approach in estimating project benefits by considering full freight movements, drayage, and transloading operations. In general, project types that can be assessed by Cal-B/C IF include:

- Modal Diversion
- Network Expansion and Improvements
- Terminal Efficiency Improvements

Overall, the model is set up to assess freight volumes based on tonnage (in short tons of freight), or containers (in TEUs). In the case of automobile cargo, auto volumes must first be converted into tonnage that includes the gross weight of the autos, as well as any intermodal auto racks; the tonnage can then be input under bulk/break bulk sections of the model.

The remainder of this chapter is organized as follows. Section 1 presents an overview of Cal-B/C IF's functionality and describes the benefit categories and project types used in the model, as well as their relationships with each other. Section 2 presents detailed methodology and key inputs used in estimating benefits. Section 3 provides a discussion of model limitations. Section 4 concludes with an overview of the interpolation methodology used in Cal-B/C IF.

Exhibit VI-1: Acronyms and Definitions

Term	Definition
Bulk	Bulk cargo is loose cargo such as grain, coal, and iron ore. Bulk freight is not unitized or packaged and typically transported in cargo holds via bulk carriers. Bulk volumes are measured in short tons in Cal-B/C IF.
Break bulk	Break bulk cargo is cargo that is unitized and loaded individually. Break bulk cargo is generally packaged (e.g. bags, boxes, barrels, etc.) and not containerized. Break bulk volumes are measured in short tons in Cal-B/C IF.
Short tons	Short tons/US ton is measurement of weight equal to 2,000 pounds. Used as the unit of measure for bulk/break bulk volumes in Cal-B/C IF.
TEU	Twenty-foot equivalent unit (TEU) refers to container freight equivalent to a 20-foot-long intermodal container. For instance, a 40-foot container would be equivalent to 2 TEU's.
Intermodal	Freight transportation that requires multiple modes of transportation without any handling of the freight itself when changing modes.
Intermodal Train	A type of freight train that carries goods and/or commodities loaded into domestic and/or international shipping containers and/or highway semi-trailers on their own wheels.
Transload	The process of transferring a shipment from one mode of transportation to another.
Drayage	The transportation of goods over a short distance and usually part of a longer overall move – for instance from a port to a nearby rail yard.
Empty-haul trip	The movement of empty freight trucks and railcars.
No Build	The scenario where the project does not proceed as planned.
Build	The scenario where the project proceeds as planned.
Current Year	The year the analysis is done. Model results are discounted to current year values.
Base Year	The first year the project is operational, defined as Year 1.
Forecast Year	The final year of the project lifecycle, defined in the model as 20 years after the project opens.
Interpolation	A method of constructing new data points within the range of a discrete set of known data points.
MPH	Miles per hour (mph) is a measurement of vehicle speed.
VMT	Vehicle-miles traveled (VMT) is a measurement of miles traveled by vehicles for a specific time period including truck-miles and train-miles.
Ton-mile	Unit equivalent to one ton of freight moved one mile.
Modal Diversion	The process of diverting freight volumes from one transportation mode to another. For instance, diverting freight shipments from trucks to rail.
Manifest Train	A type of freight train that carries goods and/or commodities for multiple shippers between multiple origins and multiple destinations.
Unit Train	A type of freight train carrying a single bulk commodity typically from a single origin to a single destination for a single shipper.
Railcar	An individual non-powered component of a train used to haul goods or commodities. Railcars are coupled together to comprise a train.
Carload	Used to define a railcar that is loaded with a good or commodity.

1 Overview of Cal-B/C IF Functionality

This section describes the benefit categories considered in Cal-B/C IF and the project types the tool is designed to handle. This section then provides examples of the listed project types and their relationships with the benefits estimated in Cal-B/C IF. The model includes functionality to consider various project types related to intermodal freight including modal diversion, network expansion and improvements, and terminal efficiency improvements. However, users are not limited to the project types described below. The model's robustness allows for many different types of projects that involve modal diversion or efficiency impacts to be analyzed. It is recommended model users understand the benefits explained under each project type to leverage the model for specific needs.

Section 1.1 provides a description of the benefit types considered in Cal-B/C IF. Section 1.2 provides examples of project types that may be analyzed using the model. Each project type is discussed taking into account the applicable benefit categories to provide users with an overview of model functionality.

1.1 Benefit Categories

Shipper Cost Savings

A major benefit generated from intermodal freight projects are cost savings for shippers. These benefits are generally realized through shipments diverted to a less costly mode. For instance, freight shipments by rail tend to be more cost effective than by trucks for long hauls on a per-mile basis (all else held constant); however, trucking is typically less costly and more convenient in terms of logistics for short to medium hauls (typically less than 300-500 miles). Thus, shippers who divert long haul shipments from truck to rail are expected to realize supply chain cost savings.

In order to provide enhanced functionality and allow model users to estimate specific shipper cost savings, Cal B/C IF disaggregates shipper cost savings into two separate components:

- Modal diversion and freight network improvements
- Transload operations and terminal efficiency improvements

Shipper cost savings directly benefit freight shippers and can translate to more competitive prices or savings for local businesses and consumers through trickle-down effects.

MODAL DIVERSION AND FREIGHT NETWORK IMPROVEMENTS

As mentioned previously, one way for shippers to realize cost savings is by diverting freight volumes from one mode to another. One of the key cost differential drivers between modes is the difference in freight capacities by mode, while another is the logistics involved. Rail has the ability to transport a far greater volume of goods relative to trucks, but has logistical constraints for short-haul trips. Similarly, capacity improvements for a given mode can be a substantial driver of benefits. For instance, moving goods by unit trains carrying 120 railcars per train will reduce the overall rail trips compared to shipping by manifest trains with an average of 80 railcars per train.

TRANSLOAD OPERATIONS AND TERMINAL EFFICIENCY IMPROVEMENTS

Shippers can also realize cost savings from improved intermodal operational efficiency. These could arise from enhancements that improve the efficiency of transloading facilities and streamline operations, or reduce the need for transloading services altogether. Concurrently, changes in requirements for draying freight between facilities and the effects on local terminal and traffic congestion have a direct impact on shipper costs.

Accident Cost Savings

In general, freight transportation accidents are costly and have negative implications on productivity. Safe transportation plays a key role in determining the long-term viability of freight supply chains and generates increased public confidence in the overall freight transportation network.

Compared to trucks, freight rail is known to be one of the safest modes of transporting freight in North America, with accidents generally resulting from external factors such as collisions with vehicles driving through an active crossing or with trespassers.

Emission Cost Savings

Environmental sustainability and health costs are increasingly considered an important component in the evaluation of transportation projects. The impacts of exhaust emissions impose wide-ranging social costs on people, materials, and vegetation. For instance, railroads and automotive companies have invested heavily in fuel-efficient technologies over the past several years to improve operational efficiency and reduce greenhouse gas emissions. In particular, thousands of new energy efficient locomotives have be acquired, while older locomotives have been retrofitted or retired. Moreover, the implementation of idling-reducing technology has allowed main engines to be shut down in various conditions.[1] Reducing overall vehicle movements by shortening the travel distance, improving capacity, and streamlining operations can all have a substantial impact on the overall emissions of greenhouse gas and localized criteria air contaminants.

1.2 Project Types

Modal Diversion and Freight Network Improvements

In general**,** modal diversion projects involve a shift in how commodities are transported. The construction of a new intermodal facility or logistics hub, as an example, allows shippers the option to divert volumes to rail that may currently be shipped by truck. Moving freight long distances by rail is typically cheaper than moving it by truck (all else constant) and freight shipments by rail are associated with fewer accidents and lower emission rates than similar shipments by truck, resulting in net benefits to society. Fewer trucks on the road also means reduced highway congestion, and ultimately, increased travel speeds for other highway vehicles.

[1] American Association of Railroads, “Freight Railroads Help Reduce Greenhouse Gas Emissions,” 2017.

Freight transportation network improvements, such as the additions of new intermodal facilities, railway infrastructure improvements, or the addition of new railway or highway connections between markets can generate similar benefits in terms of cheaper costs, and shorter travel distances. Vehicle capacity improvements, which include economies of scale from larger truck or railcar capacities, as well as longer trains with more railcars, can reduce the overall vehicle-miles traveled. This can have a direct bearing on shipper costs and net benefits to society.

Examples of specific modal diversion and freight network improvement projects include:

RAIL CORRIDOR CAPACITY IMPROVEMENTS
Increasing the amount of freight that can be shipped through a rail corridor can reduce travel times and costs for existing rail traffic, and accommodate increased train traffic for goods that are otherwise moved by less efficient modes like truck.

TRUCK CORRIDOR CAPACITY IMPROVEMENTS
Increasing capacity along freight highway corridors can improve travel speeds for trucks, reduce travel distance, and reduce shipper costs for trucks that otherwise circumvent heavily congested areas.

PROJECTS ENABLING DEDICATED FREIGHT MOVEMENTS IN UNIT TRAINS
Infrastructure that allows shifting traffic from manifest trains to dedicated unit trains can reduce shipping costs, move more railcars per train, and require fewer train trips.

LOOP TRACK CONSTRUCTION
Construction of a loop track to handle longer trains that allows for fewer trips along the rail corridor. Loop tracks also allow for the handling of unit trains which results in further efficiencies and reduced shipping costs.

WYE CONSTRUCTION / EXTENSION
Extension or construction of a new wye connection (a triangular rail junction where trains can pass each other) that improves the efficiency of rail movements by offering shorter travel distances and haul times.

RAIL INFRASTRUCTURE UPGRADES AND ENHANCEMENTS
Enhancing or upgrading existing infrastructure, such as track, bridges, or train control systems to accommodate railcars with a maximum gross weight of 286,000 lbs., allowing for more freight per railcar and fewer train trips for the same volume of freight.

OTHER PROJECTS THAT DIVERT FREIGHT MOVEMENTS FROM TRUCKS TO RAIL
Infrastructure that allows shippers to divert traffic from truck to rail results in fewer truck trips, reduces shipping costs, improves safety, reduces emissions, and increases local highway speeds.

Transload Operations and Terminal Efficiency Improvements

Terminals are under increased strain due to the rapid growth of domestic and trade-related freight movements. Projects that seek to improve terminal efficiency may include expanding terminal facilities to allow for a greater volume of trucks and trains or railcars to be serviced,

installing new equipment, or implementing technology that reduces truck and train delays at terminals through queue detection and monitoring technologies. New equipment that facilitates the transloading process results in improved terminal efficiency by reducing associated costs. Similarly, improvements that reduce the distance or the proportion of freight that has to be drayed between facilities can have substantial societal impacts in terms of shipper costs, safety, and emissions. Finally, reducing delay and idle time at terminals reduces operator costs and reduces emissions from idle locomotives.

Examples of specific transload operations and terminal efficiency improvement projects include:

NEW PORT/TERMINAL TECHNOLOGY IMPLEMENTATION
Implementation of intelligent transportation system (ITS) solutions that improve port/terminal efficiency, reduce operations costs, or reduce congestion and terminal wait times.

NEW TERMINAL CONSTRUCTION
Construction of a new freight handling terminal that allows intermodal traffic to access closer market gateways or reduce dray distances. The reduction in travel distance can be complemented by a potential reduction in drayage costs as well as transload costs due to improved efficiency of a new facility.

PORT/TERMINAL CAPACITY IMPROVEMENTS
Expansion of a port/terminal's ability to handle an increased volume of freight shipments can reduce travel costs and distance for freight that otherwise would have traveled to a distant facility due to handling constraints.

2 Benefit Estimation

Each benefit described in Section 1.1 is calculated under a No Build (*NB*) and Build (*B*) scenario. Specifically, the total impact generated by each benefit category is defined as the total difference between the No Build and Build cases over the project lifecycle, which is assumed to be 20 years from the year the project opens. These values are denoted in present value terms and reported as a total over the project lifecycle, as well as an average annual value over the project lifecycle. If the reported net present value is positive, it implies the project generates an economic benefit, while a negative value implies the project generates an economic burden or cost.

Exhibit VI-2 presents key user inputs that are required for the benefit calculations. In particular, these key user inputs are used to interpolate freight shipment volumes throughout the project lifecycle and determine the annual number of truck and train trips and shipments. It can be seen from the table that some required inputs may be entered in both short tons and twenty-foot-equivalent units (TEUs) for bulk/break bulk and containerized shipment types, respectively. While annual freight volumes within the project lifecycle are interpolated, unit costs and prices are escalated year over year based on the user-defined growth rate net of inflation.

Exhibit VI-2: Cal-B/C IF Key User Inputs

Variable	Definition	Unit
Y_C	The year the analysis is done. Model results are discounted to current year values.	year
Y_1	The first year the project is operational, defined as the Base Year (Year 1).	
Y_{20}	The final year of the project lifecycle, defined as the Forecast Year (Year 20).	
AC^T	Average capacity per truck.	short tons or TEUs
AC^R	Average capacity per railcar.	
ART	Average number of railcars per train.	railcars / train
$Dist^T$	Average trip distance (miles, one - way) for trucks.	miles
$Dist^R$	Average trip distance (miles, one - way) for rail.	
FV_C^T	Total freight volume shipped by truck in the current year.	short tons or TEUs
FV_C^R	Total freight volume shipped by train in the current year.	
FV_{20}^T	Total freight volume shipped by truck in the forecast year.	
FV_{20}^R	Total freight volume shipped by train in the forecast year	

2.1 Shipper Cost Savings

Shipper cost saving benefits are generated from changes in shipment modes or processes, transportation costs, facility operational efficiency, or reduced congestion. This can be disaggregated into two separate benefit categories as mentioned in Section 1.1. Disaggregating the impacts allows the model user to identify which aspect is generating the benefits. The two categories are:

- Modal Diversion & Freight Network Improvement Benefit Calculations

- Transload Operations and Terminal Efficiency Improvements

The annual shipper cost saving benefits is defined as:

$$\text{SCBenefit} = \text{MDBenefit} + \text{TEBenefit}$$

Where *MDBenefit* represents the quantified benefits from modal diversion and freight network improvements, while *TEBenefit* is the quantified benefits from transload and operational efficiency improvements.

Modal Diversion and Freight Network Improvements Benefit Calculations

Modal diversion and freight network improvements are meant to capture the benefits to shippers associated with diverting volumes between freight trucks and rail. Benefits from modal diversion and freight network improvements are driven primarily by differences in transportation costs between the No Build and Build cases. In addition, benefits may accrue from a reduction in the overall number of trucks and trains used to transport freight, as determined by their respective capacities, as well as the average distance traveled. Specifically, the number of trucks and train movements is determined by the product of the volume transported by mode to their respective capacities.

User input values used in the benefit calculation are presented in Exhibit VI-3, while parameter and model-calculated values are presented in Exhibit VI-4.

Exhibit VI-3: Summary of Modal Diversion and Freight Network Improvement Benefits – User Inputs

Variable	Definition	Unit
Y_1	The first year the project is operational, defined as the Base Year (Year 1).	year
AC^T	Average capacity per truck.	short tons or TEUs
AC^R	Average capacity per railcar.	
ART	Average number of railcars per train.	railcars / train
SC_1^T	Truck shipping cost in project opening year.[2]	$ / truck
SC_1^R	Rail shipping cost in project opening year.[3]	$ / carload
g_{SC}^T	Growth of truck shipping costs.	percentage
g_{SC}^R	Growth of rail shipping costs.	

Exhibit VI-4: Summary of Modal Diversion and Freight Network Improvement Benefits – Model Inputs

Variable	Definition	Value	Unit	Source
FV_t^T	Volume transported by truck in a given year *t*.	#	short tons or TEUs	Model-calculated through interpolation.
FV_t^R	Volume transported by rail in a given year *t*.	#	short tons or TEUs	

[2] Shipping costs for containers are inputted as $/TEU moved by truck and the model calculates the $/truck
[3] Shipping costs for containers are inputted as $/TEU moved by train and the model calculates the $/carload

MODAL DIVERSION & FREIGHT NETWORK IMPROVEMENT BENEFIT CALCULATIONS

Cal-B/C IF quantifies total shipping costs using the annual number of trains and trucks, as well as their respective shipping costs. The formula is summarized as follows:

$$TSC_t = \frac{FV_t^T}{AC^T} \cdot SC_t^T + \frac{FV_t^R}{AC^R \cdot ART} \cdot SC_t^R \cdot ART$$

Where *t* denotes a year within the lifecycle of the project and TSC_t represents the total shipping costs in year *t*. The respective shipping costs in any given year is defined by the following equations:

- $SC_t^T = SC_1^T \cdot \left(1 + g_{SC}^T\right)^{t - Y_1}$
- $SC_t^R = SC_1^R \cdot \left(1 + g_{SC}^R\right)^{t - Y_1}$

The annual benefits from modal diversion and freight network improvements can be expressed by:

$$MDBenefit = TSC_{NB} - TSC_B$$

Transload Operations and Terminal Efficiency Improvements Benefit Calculations

Transload operations and terminal efficiency improvements are designed to capture benefits generated from changes in transload operations, freight drayage requirements, and terminal congestion or processing delays. Specifically, the benefits realized consist of three components: requirements for and cost of transload operations, requirements for and cost of freight drayage between facilities, and the reduction in terminal congestion and associated delays. For both transload cost savings and drayage cost savings, benefits may be realized through changes in the proportion of truck and rail volumes transloaded or drayed, as well as changes in associated costs. Terminal efficiency savings can be accrued from either reductions in delay times or changes in operator costs.

User input values used in the benefit calculation are presented in Exhibit VI-5, while parameter and model-calculated values are presented in Exhibit VI-6.

Exhibit VI-5: Summary of Transload Operations and Terminal Efficiency Improvement Benefits – User Inputs

Variable	Definition	Unit
Y_1	The first year the project is operational, defined as the Base Year (Year 1).	year
AC^T	Average capacity per truck.	short tons or TEUs
AC^R	Average capacity per railcar.	
ART	Average number of railcars per train.	railcars / train
FT_1^T	Percent of total truck volume transloaded in project opening year. Default value set to 100 percent.	percentage
FT_{20}^T	Percent of total truck volume transloaded in the final year of project lifecycle. Default value set to 100 percent.	
FT_1^R	Percent of total rail volume transloaded in project opening year. Default value set to 100 percent.	

Variable	Definition	Unit
FT_{20}^{R}	Percent of total rail volume transloaded in the final year of project lifecycle. Default value set to 100 percent.	
FD_{1}^{T}	Portion of truck shipment volume drayed in the year project opened. Default value set to 100 percent.	
FD_{20}^{T}	Portion of truck shipment volume drayed in the final year of project lifecycle. Default value set to 100 percent.	
FD_{1}^{R}	Portion of rail shipment volume drayed in the year project opened. Default value set to 100 percent.	
FD_{20}^{R}	Portion of rail shipment volume drayed in the final year of project lifecycle. Default value set to 100 percent.	
Del_{1}^{T}	Terminal delay per truck in project opening year.	minutes / truck
Del_{1}^{R}	Terminal delay per train in project opening year.	minutes / train
TC_{1}	Cost per volume transloaded.	$ / short ton or TEU
DC_{1}	Drayage cost per movement by truck.	$ / truck movement
OC_{1}^{T}	Truck operator cost per hour of delay.	$ / hour
OC_{1}^{R}	Rail operator cost per hour of delay.	
g_{TC}	Growth rate of transload cost. Default value set to 0 percent.	percentage
Ag_{DC}	Growth rate of drayage costs. Default value set to 0 percent.	
g_{OC}^{T}	Growth rate of truck operator cost per hour of delay. Default value set to 0 percent.	
g_{OC}^{R}	Growth rate of rail operator cost per hour of delay. Default value set to 0 percent.	
g_{Del}^{T}	Growth rate of truck terminal dwell time. Default value set to 0 percent.	
g_{Del}^{R}	Growth rate of rail terminal delay time. Default value set to 0 percent.	

Exhibit VI-6: Summary of Transload Operations and Terminal Efficiency Improvement Benefits – Model Inputs

Variable	Definition	Value	Unit	Source
FV_{t}^{T}	Volume transported by truck in a given year *t*.	#	short tons or TEUs	Model-calculated through interpolation.
FV_{t}^{R}	Volume transported by rail in a given year *t*.	#	short tons or TEUs	
FT_{t}^{T}	Portion of total truck volume transloaded in a given year *t*.	% of total volume shipped by truck	percentage	
FT_{t}^{R}	Portion of total rail volume transloaded in a given year *t*.	% of total volume shipped by rail	percentage	
FD_{t}^{T}	Portion of total truck volume drayed in a given year *t*.	% of total volume shipped by truck	percentage	

Variable	Definition	Value	Unit	Source
FD_t^R	Portion of total rail volume drayed in a given year *t*.	% of total volume shipped by rail	percentage	

TRANSLOAD & OPERATIONAL EFFICIENCY IMPROVEMENT BENEFIT CALACULATIONS

Cal-B/C IF calculates total transload and drayage cost savings using total volumes shipped by mode, the fraction of total volumes shipped that require transloading or drayage, and costs to transload or dray the goods. For terminal efficiency costs, the model considers the number of trucks and trains using the terminal, as well as their respective terminal delay times and operating costs. The formulas below provide a summary of the methodology used.

$$TTC_t = (FV_t^T \cdot FT_t^T + FV_t^R \cdot FT_t^R) \cdot TC_t$$

$$TDC_t = \frac{(FV_t^T \cdot FD_t^T + FV_t^R \cdot FD_t^R)}{AC^T} \cdot DC_t$$

$$TEC_t = \frac{FV_t^T \cdot FT_t^T}{AC^T} \cdot Del_t^T \cdot \frac{1\text{ hour}}{60\text{ mins}} \cdot OC_t^T + \frac{FV_t^R \cdot FT_t^R}{AC^R \cdot ART} \cdot Del_t^R \cdot \frac{1\text{ hour}}{60\text{ mins}} \cdot OC_t^R$$

Where *t* denotes a year within the lifecycle of the project. Thus, for a given year *t*, TTC_t is the total transload cost, TDC_t is the total drayage cost, and TEC_t is the total terminal efficiency costs as a result of terminal delays. The respective costs for transload, drayage, and terminal operations are described by the following:

- $TC_t = TC_1 \cdot (1+g_{TC})^{t - Y_1}$
- $DC_t = DC_1 \cdot (1+g_{DC})^{t - Y_1}$
- $OC_t^T = OC_1^T \cdot (1+g_{OC}^T)^{t - Y_1}$
- $OC_t^R = OC_1^R \cdot (1+g_{OC}^R)^{t - Y_1}$

For both truck and rail, terminal delays for a specific year within the project lifecycle is defined as follows:

- $Del_t^T = Del_1^T \cdot (1+g_{Del}^T)^{t - Y_1}$
- $Del_t^R = Del_1^R \cdot (1+g_{Del}^R)^{t - Y_1}$

The annual benefits from transload and operational efficiency improvements can be expressed by:

$$TEBenefit = (TTC_{NB} + TDC_{NB} + TEC_{NB}) - (TTC_B + TDC_B + TEC_B)$$

2.2 Accident Cost Savings

Accident costs are a function of vehicle-miles traveled (VMT) by mode, where the variation in VMT is derived using the number of trains and trucks, and their respective average distances

traveled. Benefits are accrued by applying this difference to their respective accident rates by mode.

The benefits also take into account the number of empty-haul trips returning to the point of origin, in order to capture the full distance traveled. In particular, this adjustment allows the model user to capture the distance traveled by empty trucks and trains returning without freight.

Developing reasonable estimates of accident cost savings depends on the availability of local data on accident rates for freight trucks. Default truck accident rates are calculated using data extracted from the Traffic Accident Surveillance and Analysis System (TASAS) and are applied to both freight trucks and trucks used for drayage movements. In particular, the default values provided in Cal-B/C IF are statewide average rates for California obtained from a special "2013 Statewide Collision Total Check" TASAS report. Thus, while the model provides default accident rates, project-specific accident rates may be derived. Project-specific rates should be used only if the total number of incidents by level of severity and the total VMT for a given time period is available to the model user.

Freight rail accident costs are derived using accident data from the Federal Railway Administration (FRA). Using information between 2008 and 2017, a weighted average was constructed to determine national rates of fatalities, injuries, and PDOs for every million rail-miles traveled.

Additional discussion on data and methods may be found in the Technical Appendix to User's Guide of Cal-B/C (1999).

User input values used in the benefit calculation are presented in Exhibit VI-7, while parameter and model-calculated values are presented in Exhibit VI-8.

Exhibit VI-7: Summary of Accident Cost Savings Benefits – User Inputs

Variable	Definition	Unit
AC^T	Average capacity per truck.	short tons or TEUs
AC^R	Average capacity per railcar.	
ART	Average number of railcars per train.	railcars / train
FD_1^T	Portion of truck shipment volume drayed in the year project opened. Default value set to 100 percent.	percentage
FD_{20}^T	Portion of truck shipment volume drayed in the final year of project lifecycle. Default value set to 100 percent.	
FD_1^R	Portion of rail shipment volume drayed in the year project opened. Default value set to 100 percent.	
FD_{20}^R	Portion of rail shipment volume drayed in the final year of project lifecycle. Default value set to 100 percent.	
$TotalAcc^T$	Total truck accidents during a defined reporting period.	count of total accidents
$FatalAcc^T$	Total fatal truck accidents during a defined reporting period.	count of total fatal accidents
$InjAcc^T$	Total of truck accidents resulting in injuries only during a defined reporting period.	count of total injury only accidents

Variable	Definition	Unit
$PDAcc^T$	Total number of truck accidents resulting in property damage only during a defined reporting period.	count of accidents resulting in only property damage
VMTRP	Total vehicle miles traveled by truck during a defined reporting period.	miles
$RFatalAcc^T$	Fatal accident reduction factor.	ratio
$RInjAcc^T$	Injury accident reduction factor.	
$RPDOAcc^T$	PDO accident reduction factor.	
$Dist^T$	Average trip distance (miles, one-way) for trucks.	miles
$Dist^R$	Average trip distance (miles, one-way) for rail.	
$Dist^D$	Average distance drayed (miles, one-way).	
$EHTrip^T$	Number of empty-haul trips returning to point of origin for every full truckload. Default is set to 1.00 but can be adjusted by user.	ratio of empty trucks / trains returning to origin for every loaded freight shipment
$EHTrip^R$	Number of empty-haul trips returning to point of origin for every full trainload. Default is set to 1.00 but can be adjusted by user.	

Exhibit VI-8: Summary of Accident Cost Savings Benefits – Model Inputs

Variable	Definition	Value	Unit	Source
FV_t^T	Volume transported by truck in a given year *t*.	#	short tons or TEUs	Model-calculated through interpolation.
FV_t^R	Volume transported by rail in a given year *t*.	#	short tons or TEUs	
FD_t^T	Portion of total truck volume drayed in a given year *t*.	% of total volume shipped by truck	percentage	
FD_t^R	Portion of total rail volume drayed in a given year *t*.	% of total volume shipped by rail	percentage	
$EHTrip^D$	Number of empty-haul trips returning to point of origin for every full truckload drayed.	1.00	empty-haul / full truckload	Common industry assumption.
$FatalAcc^R$	Freight rail fatalities per million mile traveled.	0.992	incidents / million VMT	Calculated using data from the Federal Railroad Administration Office of Safety Analysis.
$InjAcc^R$	Freight rail injury only accidents per million mile traveled.	7.786	incidents / million VMT	
$PDAcc^R$	Freight rail property damage incidents per million mile traveled.	13.542	incidents / million VMT	
$CostFatal^T$	Cost of fatal accident.	$10,800,000	$ / accident (truck)	Calculated using 3 sources. Source 1: California Highway Patrol, 2013 SWITRS Annual Report. Source 2: California Department of Transportation, TASAS
$CostInj^T$	Cost of injury accident.	$148,800	$ / accident (truck)	

Variable	Definition	Value	Unit	Source
$\mathbf{CostPD^T}$	Cost of property damage only accident.	$9,700	$ / accident (truck)	Unit; 2010 to 2013 average. Source 3: U.S. Department of Transportation, Value of Statistical Life.
$\mathbf{CostFatal^R}$	Cost of fatality or value of life.	$9,800,000	$ / fatality (train)	Calculated based on data from the U.S. Department of Transportation, Value of Statistical Life.
$\mathbf{CostInj^R}$	Cost of injury.	$180,500	$ / injury (train)	
$\mathbf{CostPD^R}$	Cost of property damage.	$147,600	$ / property damage (train)	Federal Railway Administration, Office of Safety Analysis, Table 3.16, 2014 to 2016 average.

Accident Cost Savings Benefit Calculations

One of the main components in calculating the accident costs is deriving the total vehicle-miles traveled (VMT). The general method in determining VMT for mode *m* in year *t* is defined by:

$$\mathrm{VMT_t^m = Dist^m \cdot \frac{FV_t^m}{Cap^m}}$$

Where $V(m)_t$ represents the total volume shipped, Cap^m is the capacity, and m is defined as either truck or rail. It should be noted that capacity for truck is represented by AC^T, while train capacity is defined as $AC^R \cdot ART$, which is the product of average railcar capacity and the number of railcars per train. The annual number of trucks and trains is determined by the ratio of the volume shipped by mode to their respective capacities.

If the project has a drayage component, then the VMT for trucks used for dray movements must be account for. The formula used to derive drayage VMT is as follows:

$$\mathrm{VMT_t^D = Dist^D \cdot \frac{\left(FV_t^T \cdot FD_t^T + FV_t^R \cdot FD_t^R\right)}{AC^T}}$$

The other component is the per-mile accident costs (*CostAcc*). The per-mile accident costs for each mode are derived using the incident rates by accident types and their respective costs. The formula used to calculate the per mile accident rates is expressed as:

$$\mathrm{CostAcc^m = (FatalAcc^m \cdot CostFatal^m + InjAcc^m \cdot CostInj^m + PDAcc^m \cdot CostPD^m)}$$

While the general formulation for accident costs is the similar for trucks and rail, there is a subtle difference regarding the derivation of accident costs. Trucks accident costs consider inclusive collision events, while train costs solely consider the events themselves. In other words, truck accident costs, such as the cost of a fatal accident ($CostFatal^T$), includes a combination of fatalities, injuries and property damage events. Meanwhile, the cost of a fatal accident by rail ($CostFatal^R$) is just the cost of a fatality. These costs are then multiplied by the respective accident

rate per million VMT. These definitions and calculations are consistent with those used in other Cal-B/C models.

Given the VMT and accident rates, the total accident cost by mode can be calculated. Total accident costs for trucks will take into account VMT from drayage movements. In addition, adjustments for the number of empty-haul return trips for trucks and trains are included in the total accident costs. This allows the number of empty trucks and trains returning to their respective point of origin to be considered along with the additional safety costs involved. Thus, for any year within the project lifecycle, total accident costs for truck and rail can be expressed with the following equations:

$$\mathrm{TotAcc}^{\mathrm{T}}=(\mathrm{VMT}^{\mathrm{T}} \cdot \left(1+\mathrm{EHTrip}^{\mathrm{T}}\right)+ \mathrm{VMT}^{\mathrm{D}} \cdot (1+\mathrm{EHTrip}^{\mathrm{D}})) \cdot \mathrm{CostAcc}^{\mathrm{T}}$$

$$\mathrm{TotAcc}^{\mathrm{R}}=\mathrm{VMT}^{\mathrm{R}} \cdot \left(1+\mathrm{EHTrip}^{\mathrm{R}}\right) \cdot \mathrm{CostAcc}^{\mathrm{R}}$$

The annual accident cost saving benefits can be expressed by:

$$\mathrm{ACBenefits} = \left(\mathrm{TotalAcc}_{\mathrm{NB}}^{\mathrm{T}}+\mathrm{TotalAcc}_{\mathrm{NB}}^{\mathrm{R}}\right) - (\mathrm{TotalAcc}_{\mathrm{B}}^{\mathrm{T}}+\mathrm{TotalAcc}_{\mathrm{B}}^{\mathrm{R}})$$

2.3 Emission Cost Savings

While freight transportation inherently produces greenhouse gas and criteria air contaminant emissions, individual projects can create a net reduction in emissions through modal diversion between truck and rail, or reduction in travel distances or delay times. The change in emissions produced vary by mode and their respective emissions factors are obtained from the California Air Resources Board (CARB).

In addition to emissions rates, the calculation of freight rail emissions require total ton-miles traveled, annual terminal dwell time, and the annual number of trains. For emissions produced by trucks, Cal-B/C IF considers trucks used for both freight and drayage. In order to calculate the total annual emissions produced from truck shipments, the annual number of trucks, average speeds and distance, as well as the truck emissions factors are required. Similar to accident costs, emissions cost estimates factor in the adjustment for the number of empty-haul trips returning to the point of origin. This allows the model user to capture the total distance traveled by mode and consider the additional emission costs generated from the empty trucks and trains returning.

Additional discussion on data and methods may be found in the Technical Appendix to User's Guide of Cal-B/C (1999).

User input values used in the benefit calculation are presented in Exhibit VI-9, while parameter and model calculated values are presented in Exhibit VI-10.

Exhibit VI-9: Summary of Emissions Cost Savings Benefits – User Inputs

Variable	Definition	Unit
$\mathrm{FT}_1^{\mathrm{R}}$	Percent of total rail volume transloaded in project opening year. Default value set to 100 percent.	percentage
$\mathrm{FT}_{20}^{\mathrm{R}}$	Percent of total rail volume transloaded in the final year of project lifecycle. Default value set to 100 percent.	

Variable	Definition	Unit
FD_1^T	Portion of truck shipment volume drayed in the year project opened. Default value set to 100 percent.	
FD_{20}^T	Portion of truck shipment volume drayed in the final year of project lifecycle. Default value set to 100 percent.	
FD_1^R	Portion of rail shipment volume drayed in the year project opened. Default value set to 100 percent.	
FD_{20}^R	Portion of rail shipment volume drayed in the final year of project lifecycle. Default value set to 100 percent.	
$Dist^T$	Average trip distance (miles, one-way) for trucks.	miles
$Dist^R$	Average trip distance (miles, one-way) for rail.	
$Dist^D$	Average distance drayed (miles, one-way).	
$EHTrip^T$	Number of empty-haul trips returning to point of origin for every full truckload. Default is set to 1.00 but can be adjusted by user.	Ratio of empty trucks / trains returning to origin for every loaded shipment
$EHTrip^R$	Number of empty-haul trips returning to point of origin for every full trainload. Default is set to 1.00 but can be adjusted by user.	
g_{Del}^R	Growth rate of rail terminal dwell time. Default set to 0 percent.	percentage
S_1^T	Average truck speed for long-hauls in project opening year.	mph
S_{20}^T	Average truck speed for long-hauls in the final year of project lifecycle.	
S_1^D	Average truck speed for drayage in project opening year.	
S_{20}^D	Average truck speed for drayage in the final year of project lifecycle.	

Exhibit VI-10: Summary of Emissions Cost Savings Benefits – Model Inputs

Variable	Definition	Value	Unit	Source
FV_t^R	Volume transported by rail in a given year *t*.	#	short tons or TEUs	Model-calculated through interpolation.
FT_t^R	Portion of total rail volume transloaded in a given year *t*.	% of total volume shipped by rail	percentage	
FD_t^T	Portion of total truck volume drayed in a given year *t*.	% of total volume shipped by truck	percentage	
FD_t^R	Portion of total rail volume drayed in a given year *t*.	% of total volume shipped by rail	percentage	
$EHTrip^D$	Number of empty-haul trips returning to point of origin for every full truckload drayed.	1.00	empty-haul / full truckload	Common industry assumption.
S_t^T	Average truck speed for long-hauls in a given year *t*.	#	mph	Model calculated through interpolation.
S_t^D	Average truck speed for drayage in a given year *t*.	#	mph	

Variable	Definition	Value	Unit	Source
RFE	Freight rail fuel efficiency.	468	ton-miles / gallon	Association of American Railroads, The Environmental Benefits of Moving Freight by Rail, June 2017
RFI	Fuel burned at idle for trains.	4.00	gallon / hr	California Environmental Protection Agency / Air Resources Board, Technology Assessment: Freight Locomotives, November 2016.
CO^T	CO emissions produced by trucks depending on truck speed.	#	g / mile	California Air Resources Board, EMFAC 2014.
CO_2^T	CO_2 emissions produced by trucks depending on truck speed.	#	g / mile	
NO_X^T	NO_X emissions produced by trucks depending on truck speed.	#	g / mile	
PM_{10}^T	PM_{10} emissions produced by trucks depending on truck speed.	#	g / mile	
SO_X^T	SO_X emissions produced by trucks depending on truck speed.	#	g / mile	
VOC^T	VOC emissions produced by trucks depending on truck speed.	#	g / mile	
CO^R	CO emissions produced by rail.	#	g / gallon	Data provided by California Air Resources Board.
CO_2^R	CO_2 emissions produced by rail.	#	g / gallon	
NO_X^R	NO_X emissions produced by rail.	#	g / gallon	
PM_{10}^R	PM_{10} emissions produced by rail.	#	g / gallon	
SO_X^R	SO_X emissions produced by rail.	#	g / gallon	
VOC^R	VOC emissions produced by rail.	#	g / gallon	
P_{CO}	Health cost of CO emissions.	$	$ / ton	McCubbin and Delucchi, 1996. Health cost of pollutants depends on location (i.e. Southern, Northern, and rural California).
P_{CO_2}	Health cost of CO_2 emissions.	$	$ / ton	
P_{NO}	Health cost of NO_X emissions.	$	$ / ton	
$P_{PM_{10}}$	Health cost of PM_{10} emissions.	$	$ / ton	
P_{SO}	Health cost of SO_X emissions.	$	$ / ton	
P_{VOC}	Health cost of VOC emissions.	$	$ / ton	

Emission Cost Savings Benefit Calculations

Calculating overall emissions costs requires emission rates and the social cost of pollutants In Cal-B/C IF, the 6 pollutants monetized are: CO, CO_2, NO_X, PM_{10}, SO_X, and VOC. For mode *m*, the emission costs are calculated as follows:

$$EC^m = (CO^m \cdot P_{CO} + CO_2^m \cdot P_{CO_2} + NO_X^m \cdot P_{NO} + PM_{10}^m \cdot P_{PM_{10}} + SO_X^m \cdot P_{SO} + VOC^m \cdot P_{VOC}) \cdot \frac{1 \text{ short ton}}{907{,}185 \text{ grams}}$$

Truck emissions are dependent on the average speed (mph) and distance traveled. If a project has a drayage component, then the annual total distance traveled and the average truck speed for trucks used in drayage operations are used in calculating the total trucks emissions costs. Thus, for a given year within the project lifecycle, the truck emission costs are calculated as:

$$EM^T = VMT^T \cdot \left(1 + EHTrip^T\right) \cdot EC^T\left(S_t^T\right) + VMT^D \cdot (1 + EHTrip^D) \cdot EC^D(S_t^D)$$

Rail emission costs consider emissions arising from transportation and any rail terminal dwell time. Transportation rail emissions are calculated by considering the annual total ton-miles, and locomotive fuel consumption. Meanwhile, idle locomotive emissions are derived using the annual number of trains involved in transload operations, average dwell time per train, and the fuel consumption rate for idling locomotives.

$$EM^R = \left(\frac{FV_t^R \cdot Dist^R \cdot \left(1 + EHTrip^R\right)}{RFE} + \frac{FV_t^R \cdot FT_t^R}{AC^R \cdot ART} \cdot Del_t^R \cdot \frac{1 \text{ hour}}{60 \text{ mins}} \cdot RFI\right) \cdot EC^R$$

It should be noted that while the model considers emissions due to locomotive idling, it is assumed that trucks delayed in terminals do not idle. Rather, trucks are assumed to turn off their engines resulting in no idle emissions by trucks in terminals.

Given the components, the annual emission cost saving benefits are derived as follows:

$$\boxed{\mathbf{ECBenefits} = \left(EM_{NB}^T + EM_{NB}^R\right) - \left(EM_B^T + EM_B^R\right)}$$

3 Limitations of Cal-B/C IF

One limitation of Cal-B/C IF is that the model is not designed to assess induced freight movements. The importance of identifying and excluding induced volumes in benefit calculations follows the idea that induced shipper impacts were not originally captured in the No Build case, and thus follow a baseline different from the defined No Build case. With a different baseline, induced shipments cannot receive the same value of benefits as the existing shipments. Typically, adjustments, such as “the rule of half”, are applied to account for potential impacts of induced volumes. However, the model makes no such adjustments and captures all impacts for induced shipments at full value. In the case where total volumes differ between the No Build and Build case, and in particular, if the Build case volumes exceed those of the No Build case, the model calculations can create misleading results.

For example, if the No Build is defined as 1 million tons of freight moving 10 miles, at a cost of $0.10 per ton-mile, the No Build cost per year is $1 million. If the build case is then defined as the same 1 million tons moving 10 miles by different mode, at a cost of $0.05 per ton-mile, the Build cost per year would be $500 thousand and the net benefit would be correctly calculated as $500 thousand per year ($1 million minus $500 thousand). If, however, the user defines the build case as 2 million tons because the project would induce shippers from other modes, the model would calculate the Build costs to be 2 million times 10 miles, time $0.05 per ton-mile, equals $1 million. The net benefit to the project would then be incorrectly displayed as zero. In reality, there should be a $500 thousand net benefit to existing users, and an unknown impact to the induced volumes (since these may have been moving by different mode, or potentially did not exist at all).

Similarly, the Cal-B/C IF model assumes that project impacts do not result in complete cessation of freight movements (that total freight volumes do not drop to zero). In other words, the model is set up to assess net societal impacts from changes in the freight supply chain rather than pure changes in freight volumes.

4 Interpolation Methodology

Volume Interpolation

Cal-B/C IF derives annual shipment volumes though linear interpolation between the current and forecasted (year 20) shipment volumes. Calculations take into account freight capacity by mode and shipment types, and adjusts volumes for either increasing or decreasing volume growth rates.

The model calculates an average growth rate for shipment volumes using the current year and year 20 volumes provided by the user, and provides it as a calculated variable (as g^{m}_{vol}) that can be replaced or overridden by the user.

The functionality to replace the model-calculated growth rate allows the user to impose a more aggressive (higher magnitude) freight growth trajectory up to the limit defined by the forecast year volumes. Specifically, when a user enters a different growth rate, the model estimates an 'unconstrained' forecast year volume and uses linear interpolation to estimate the increase in each year of the study period to that 'unconstrained' value. That said, overall volume is capped at the user-input forecast value, so once it reaches the forecasted value, freight volumes remain constant for the remainder of the study period.

In other words, the forecast year volumes entered by the user can represent the actual volumes expected 20 years after the project opens, or they can be emulated to represent the maximum capacity of freight that would be influenced by the project. For instance, if the current year freight volumes are 1 million tons, and the forecast volume is 2 million tons due to general commodity flow growth, the model will interpolate this growth and display a model-calculated growth rate of 2%. If, on the other hand, one were evaluating a facility that would increase freight throughput from 1 million tons to 2 million tons and one would expect volumes to ramp up within the first few years at an approximate rate of 10%, the user could enter 2 million tons in the forecast year, and override the 2% growth rate with a rate of 10%. The model would then estimate an "unconstrained" forecast value (e.g., an unrealistic 6.7 million tons after 20 years) and begin to interpolate growth of 300 thousand tons of freight per year. At that rate, the user-input forecast value of 2 million tons would be reached in year 4, at which point it would be capped and remain constant for the remainder of the study period.

At its core, overriding the growth rate allows the user to manipulate the rate at which project freight volumes ramp up to the future total. Exhibit VI-11 presents an example of the interpolated volumes using the model-calculated growth rates for shipment volumes. Exhibit VI-12 highlights the case where the growth rates are overridden by the user, with the grey line highlighting the original shipment volumes (as presented in Exhibit VI-11) prior to user adjustments of the growth rate.

Exhibit VI-11: Standard Current Year / Forecast Year Inputs

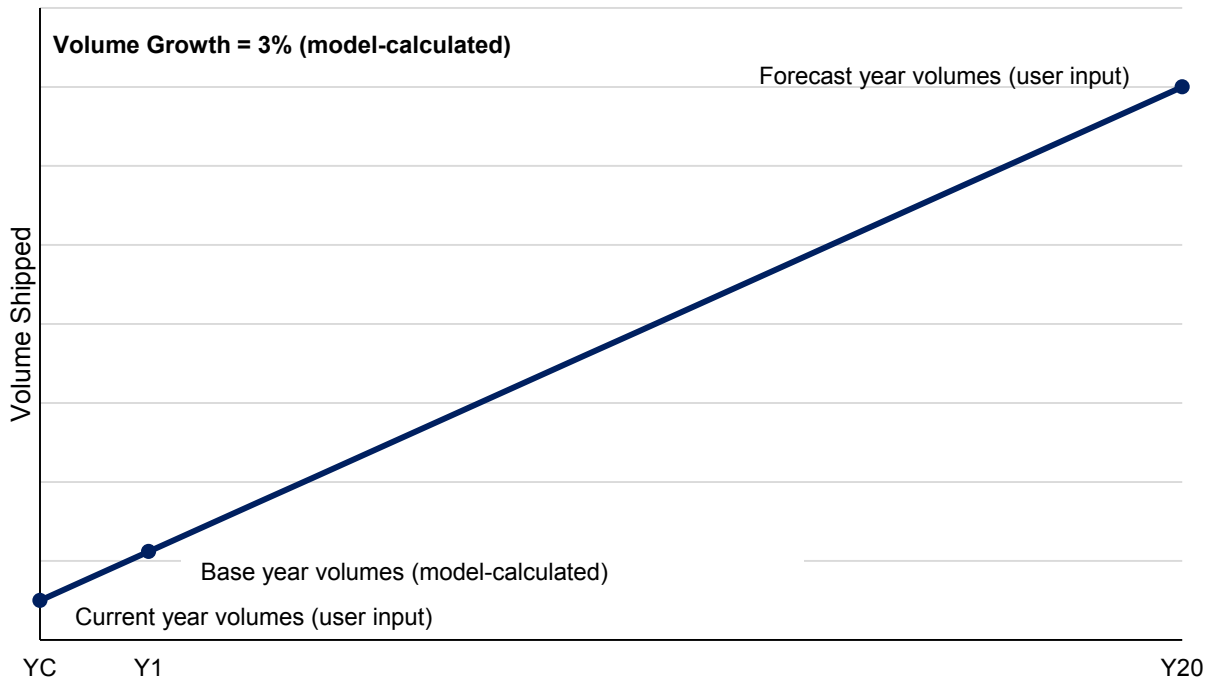
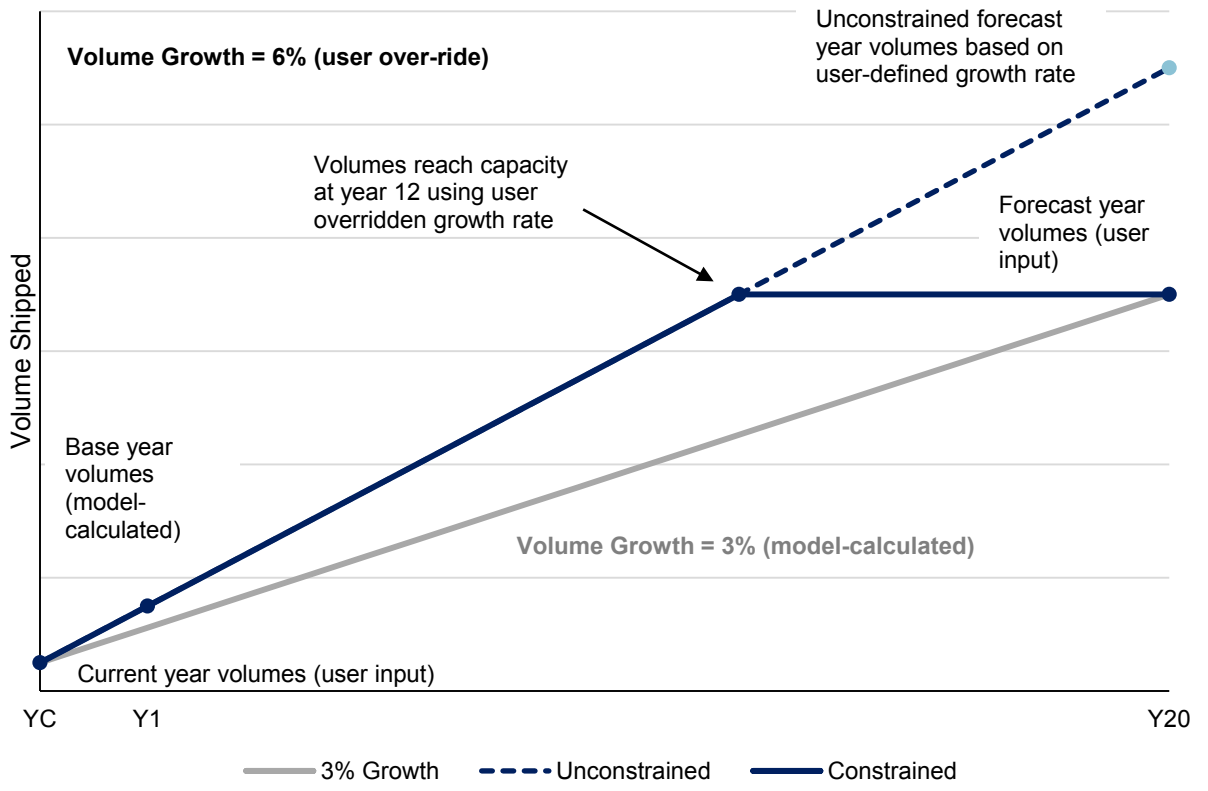


Exhibit VI-12: Current Year / Forecast Year Inputs with Growth Rates Override by User



VOLUME INTERPOLATION CALCULATION

The model interpolation calculations use an unconstrained projected freight volume based on the active growth rate, defined as:

$$ucFV_{20} = FV_C \cdot (1+g_{vol})^{Y_{20} - Y_C}$$

Where:

- $ucFV_{20}$ is the total 'unconstrained' year 20 volume
- Y_{20} is the final year of the project lifecycle (i.e. year 20)
- Y_C is the current year
- FV_C is the total volume shipped in the current year (i.e. $FV_C = FV_C^T + FV_C^R$)
- g_{vol} is the growth rate for shipment volumes that follows a CAGR formula, defined as:

$$g_{vol} = \frac{FV_{20}^{\frac{1}{Y_{20} - Y_C}}}{FV_C} - 1$$

- FV_{20} is the total forecasted final year volume (i.e. $FV_{20} = FV_{20}^T + FV_{20}^R$)

Then for a given mode, the annual increase in volume is calculated using the unconstrained final year volumes, project lifecycle duration, the fraction of final year volume transported by mode, and the year 1 volume transported by mode. This can be expressed by the following formula:

$$AV_i^m = \left(ucFV_{20_i} \cdot \left(\frac{FV_{20_i}^m}{FV_{20_i}} \right) - FV_{1_i}^m \right) \cdot \frac{1}{Y_{20} - Y_1}$$

Where:

- i denotes the shipment type (i.e. bulk/break bulk or container)
- m is the transportation mode (i.e. freight truck or rail)
- AV_i^m is the annual change in volume shipped by mode and shipment type
- Y_1 is the project opening year
- $FV_{1_i}^m$ is the volume shipped during the project opening year by mode and shipment type, which is calculated using:

$$FV_{1_i}^m = FV_C^m + \frac{\left(ucFV_{20_i} \cdot \frac{FV_{20_i}^m}{V_{20_i}} - FV_C^m \right)}{Y_{20} - Y_C} \cdot (Y_1 - Y_C)$$

- $FV_{20_i}^m$ is the forecasted final year volume transported by mode and shipment type

For each year between the project opening and the final year of the project lifecycle, the interpolated volume for each shipment type is determined by:

$$FV_t^m = \begin{cases} \text{if } g_{vol}^m > 0 & \text{Min}(FV_1^m + AV^m \cdot (t - Y_1), FV_{20}^m) \\ \text{if } g_{vol}^m < 0 & \text{Max}(FV_1^m + AV^m \cdot (t - Y_1), FV_{20}^m) \end{cases}$$

Where:

- FV_t^m is the future volume in the *t* for mode *m*
- *t* is a year within the project lifecycle

The calculated volumes, by mode, are then used to derive the number of trucks, trains, vehicle miles, and ton-miles. The latter values required average distances traveled while the number of trucks and trains are calculated based capacity variables inputted by the model user.

While Cal-B/C IF allows the model to reach the volume restrictions prior to the final year of the project through growth rate manipulation, there is a special case where that does not hold true. In particular, the model cannot reach zero units prior to the final year.

Other Interpolations Variables

Other variables interpolated within the model include annual average truck speeds as well as the annual proportion of volumes transloaded and drayed. The methodology used is simpler than the calculation performed for volume interpolation. In particular, the general concept is to derive a constant linear change using the values inputted by the user for the project opening year and the final year of the project lifecycle.

TRUCK SPEED INTERPOLATION CALCULATION

Average annual truck speeds are calculated as follows:

$$S_t = S_1 + \frac{S_{20} - S_1}{Y_{20} - Y_1} \cdot (t - Y_1)$$

Where:

- S_t is the average truck speed in year *t*
- S_1 is the average truck speed in the project opening year; S_{20} is the average truck speed in the final year of the project lifecycle

TRANSLOAD VOLUME INTERPOLATION CALCULATION

For each shipment type, the general method in calculating the annual proportion of volumes transloaded is as follows:

$$FT_t^m = FT_1^m + \frac{FT_{20}^m - FT_1^m}{Y_{20} - Y_1} \cdot (t - Y_1)$$

Where:

- *m* is the transportation mode (i.e. truck or rail)
- FT_t^m is the portion of volume that is transloaded in year *t*
- FT_1^m is the percentage of volumes transloaded in the project opening year; FT_{20}^m is the percentage of volumes transloaded in the final year of the project lifecycle

DRAYAGE VOLUME INTERPOLATION CALCULATION

For each shipment type, an identical formula is used for the annual portion of volume drayed. Specially, the annual portion volume drayed follows:

$$FD_t^m = FD_1^m + \frac{FD_{20}^m - FD_1^m}{Y_{20} - Y_1} \cdot (t - Y_1)$$

Where:

- *m* is the transportation mode (i.e. truck or rail)
- FD_t^m is the portion of volume that is drayed in year *t*
- FD_1^m is the portion of volume drayed in the project opening year; FD_{20}^m is the portion of volume drayed in the final year of the project lifecycle

5 References

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