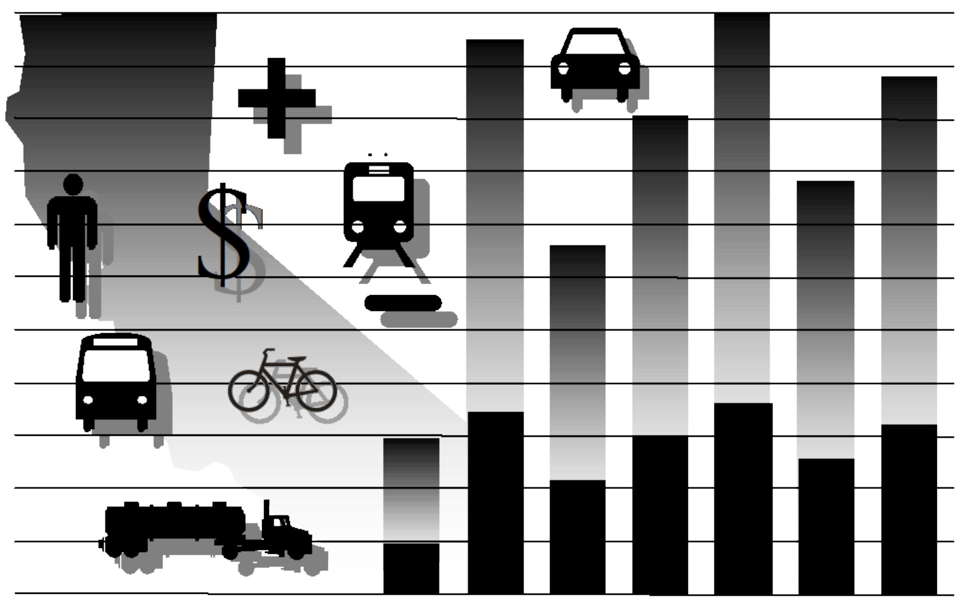
California
Department
Of
Transportation

Cal-B/C

Parameter Guide

Version 7.1

November 2019



Acknowledgements

The material included in the Cal-B/C Parameters Guide is based upon previous writing and contributions from System Metrics Group and HDR. In many cases, material has been copied verbatim from earlier work.

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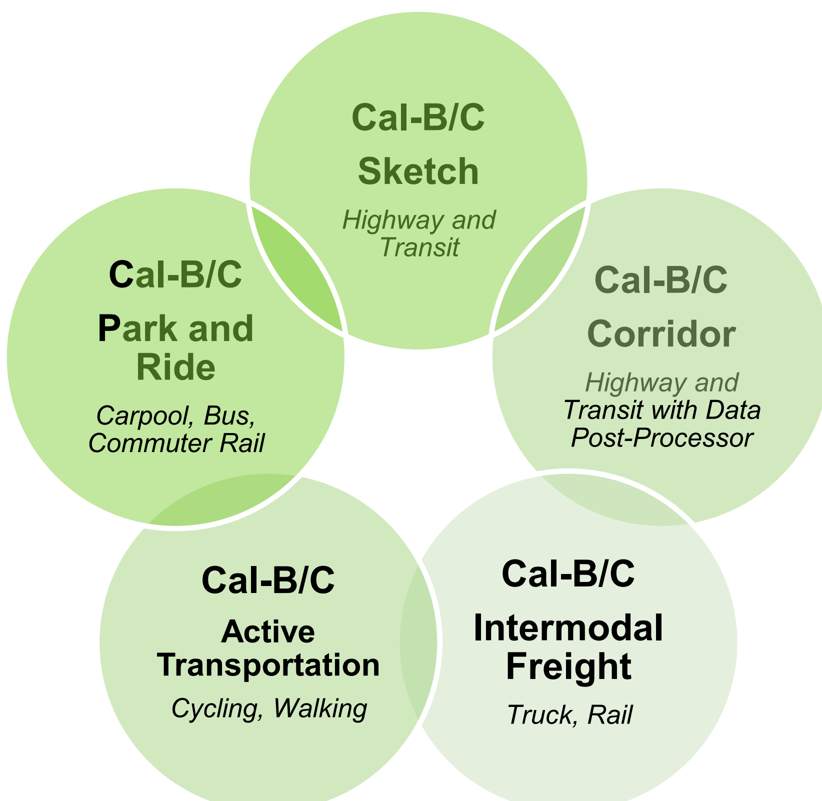
1. Overview of Cal-B/C

Welcome to California Department of Transportation (Caltrans) California Life-Cycle Benefit/Cost Analysis suite of tools. Caltrans uses this set of spreadsheet-based tools to conduct investment analyses of projects proposed for the interregional portion of the State Transportation Improvement Program (STIP), the State Highway Operations and Protection Program (SHOPP), applications to the Active Transportation Program (ATP), Senate Bill (SB) 1 programs, and other ad hoc analyses requiring benefit-cost analysis.

The original Cal-B/C model focused on highway and transit modes. This model has been updated several times and ultimately renamed as the **Cal-B/C Sketch** model. This model now covers a wide variety of highway and transit physical and operational improvements. Closely related to the Cal-B/C Sketch model is **Cal-B/C Corridor**, which is based on the same platform, but allows users to post-process travel demand and micro-simulation model data. In addition, several relatively new sketch planning models have been tailored to evaluate active transportation (**Cal-B/C AT**) projects (e.g., biking and walking facilities), park-and-ride (**Cal-B/C PnR**) programs (e.g., commuter parking and ride-sharing facilities), and intermodal freight (**Cal-B/C IF**) improvements (e.g., freight network expansion and terminal efficiency). Exhibit 1 shows all five tools in the Cal-B/C framework, which allows users to consider many different types of projects.

Exhibit 1: Suite of Tools in Cal-B/C Framework



All of the tools in the Cal-B/C framework use consistent methods, rely on the same parameters, and produce comparable results. Together, these tools multi-modal analyses of highway, transit, bicycle, pedestrian, Intelligent Transportation System (ITS), operational improvement, and passenger rail projects. In addition, there are other versions of the Cal-B/C model available for more experienced analysts. One version incorporates the additional benefits of improved reliability, beyond those of predictable time savings alone, and could be used if the proposed project warrants it. A separate version of Cal-B/C has been developed to enable users to assess the degree to which uncertainty influences project outcomes. Risk analysis is performed on the same model, but with an Excel add-in module called Risk Analyzer that is used to perform Monte Carlo simulation on user-specified parameters.

2. Introduction to Parameter Guide

This document describes the parameters currently integrated into the Cal-B/C suite of models. The parameters in this document are 2016 rates and values unless otherwise noted. The base year for parameters is reestablished every few years and as new information is available.

Users of Cal-B/C tools can adjust parameters, as necessary, to best fit their analyses. For example, the wage rate and annualization are common factors to change. Users can also update monetary values to the present year by adjusting the economic update factor, which is typically calculated from changes in the Gross Domestic Product (GDP) deflator.

The original material for this guide comes from material revised from Chapter II of the original Technical Supplement Volume 4 and reflects a number of updates of parameters from previous models. To prepare this document, the Cal-B/C development team reviewed many of the basic parameters to make sure the model was applying the current and consistent sources of impact and value. For example, the emissions rates reflect those found in the California Air Resources Board (CARB) model, EMFAC2014 (CARB, 2015). Cal-B/C Sketch, Version 7.1 retains significant updates from previous versions related to the conversion of the peak period parameter from a single value per hour to a lookup table and the addition of greenhouse gas emissions to the model.

The next sections in this document discuss information on updated parameters covering topics in: (a) General Economic Values; (b) Highway Operations; (c) Benefits Parameters; and (d) Model-Specific Parameters. An accompanying document, called the Cal-BC Resource Guide, provides background and a literature review on analytical methods evaluated during previous Cal-B/C iterations.

3. General Economic Values

YEAR OF CURRENT DOLLARS

Cal-B/C 7.1 uses 2016 dollars. For economic data without new research available, the Cal-B/C development team updated the values using the 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 2 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 several years.

Exhibit 2: 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.

REAL DISCOUNT RATE

The Cal-B/C Development Team has considered a number of sources that provide a rationale for setting real discount rates. OMB sets the standard for federal projects, including transportation. 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. Interest rates have dropped considerably since the early 1990s. In its February 2016 memorandum on discount rates, OMB clarified that the current real rates should be used for lease-purchase and cost-effectiveness analysis, but that the 7 percent real rate should remain in use for regulatory analysis or benefit-cost analysis of public investment. In guidance for recent BUILD 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.”

The Cal-B/C development team also examined the interest earned on the Pooled Money Investment Account (PMIA) in CA for a comparison with OMB. 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. The data on nominal and real annual returns over different periods are shown in Exhibit 3. 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 varied considerably.

Exhibit 3: Nominal and Real Annual Returns on the Pooled Money Investment Account

Period	Number of Years	Nominal Annual Return	Inflation Measured by GDP	Real Annual Return
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%

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

In consideration of the differences, it is important to note that the PMIA data is backward looking, while the US Treasury data reported in the OMB circular is forward looking. However, both sources of current data from the US Treasury and PMIA sources suggest using a real discount rate of 3.0 percent or lower. Based on this evidence, the Cal-B/C development team adopted a value of 4.0 percent. Although the lower discount rate (compared to 7.0 percent, as stipulated by OMB) 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 still in sensitivity analysis or when the model is used as part of grant applications (e.g., BUILD and FASTLANE) that require the use of these rates.

4. Highway Operations Parameters

The latest version of the Cal-B/C models have updated values for a variety of parameters including the average vehicle occupancy (AVO) and the percent of travel by time of day using information from the 2010-2012 California Household Travel Survey (CHTS, 2012). 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 discussion below discusses the parameters for key variables.

AVERAGE VEHICLE OCCUPANCY (AVO)

Cal-B/C applies AVO values as defaults that were established in the original model and then refined with new information. The current values apply to different types of projects. For example, High Occupancy Vehicle (HOV) lanes require a minimum number of occupants for drivers to use the facility properly. A single AVO value is also established for the Cal-B/C AT model because of uncertainty on when these modes are undertaken by travelers. If tool users have reason to revise these values, they should be justified. For example, these values should be updated for High Occupancy Toll (HOT) or managed lanes, which affect the AVO through their pricing policies.

Cal-B/C incorporates the following average numbers of people per vehicle, which can be changed:

- Non-Peak General Traffic – 1.30
- Peak General Traffic – 1.15
- General traffic – Arterials (Active Transportation model only) – 1.25
- HOV 3+ Restriction – 3.15
- HOV 2+ Restriction – 2.15.

The model assumes that the AVO for trucks is 1.0

BUREAU OF PUBLIC ROADS (BPR) CURVE

The Cal-B/C model calculations are particularly sensitive to estimated speeds. An earlier version of Cal-B/C calculated speeds using a form of the standard Bureau of Public Roads (BPR) curve, from the Transportation Research Board's Highway Capacity Model (HCM), TRB (2000) that requires several parameters. The equation for estimating speed is determined by:

Speed = Free-Flow Speed / (1 + 0.15*(v/c) ^10)

Where,

v = volume
c = "practical" capacity

The model calculated capacity, c, is the product of *Duration of Peak Period*, *Number of Lanes*, and *Capacity per Lane.* The Cal-B/C Development team calibrated the BPR curve to approximate the speed-volume relationship found in the 2000 Highway Capacity Manual (HCM) for urban freeways.[1] The BPR curves rely on an "a" parameter, which is the ratio of the free-flow speed to the speed at capacity, and a "b" parameter, which determines how abruptly speeds drop from free-flow speed.

The Cal-B/C development team has found through its research that separate BPR curves should be used in different contexts, such as for freeways/expressways and conventional highways. Using values obtained in Dowling, et al. (1997), Cal-B/C model parameters are added to the Parameters worksheet of the model rather than having them hard-coded in the model. The BPR parameters and capacity figures found in the latest Cal-B/C model are presented in Exhibit 4.

[1] Cal-B/C models have not been re-calibrated with any potential changes in the BPR curve since 2009 under the assumption that any changes in the BPR curve would have a minor effect on the calculations of net benefits.

Exhibit 4: BPR Parameters and Highway Capacities

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

CAPACITY PER LANE

Capacity per lane is one of several parameters that affect speed calculation using BPR curves. As a matter of policy, Caltrans has decided that Cal-B/C should not use different highway capacities for different parts of California. 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.

The Cal-B/C development team's research determined that separate capacities exist for freeways/expressways and other roadway types (see Exhibit 4). For instance, Cal-B/C uses 2000 vphpl capacity for freeways and expressways and 800 vphpl for other roadway types. At the same time, 800 vphpl may be low for some rural conventional highways and can be adjusted to 1000 vphpl, if the context is relevant. In addition, HOV and HOT lane capacity is suggested as 1600 vphpl and alternative "a" and "b" parameters specifically for HOV and HOT lanes are also applied.

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.

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 Cal-B/C development team determined a v/c threshold by reviewing the BPR curve, using the prior BPR coefficient (0.15) and exponent (10) and considering a previously established maximum v/c ratio of 1.4. Findings indicate that for most free-flow speeds, the 5-mph floor is not reached with a ratio of 1.4. Also, the v/c ratio needed to obtain a 5-mph speed on a facility with a

70-mph free flow speed is at 1.56. Accordingly, 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.

PERCENT AVERAGE DAILY TRAFFIC (ADT) IN AVERAGE PEAK HOUR

The current model reviewed data and literature to determine how to account for differentials in volume from day-to-day and hour-to-hour, and potentially in different regions. After an extensive data review, weekday travel was found to comprise roughly 70 percent of travel, while weekend travel accounts for the other 30 percent. This value is applied for all contexts.[2]

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 uses a statewide default value of 9 percent trucks, based on Departmental data on long-term comparisons of daily vehicle-miles traveled.

5. Benefits Parameter Discussion

TRAVEL TIME PARAMETERS

Cal-B/C draws principally from USDOT guidelines in valuing of travel time (VOT). The current Cal-B/C models are largely consistent with the latest guidelines from USDOT (see Exhibit 5). Cal-B/C and USDOT each use 50 percent of the median wage rate for local personal travel. However, while USDOT uses 70 percent and 100 percent for intercity personal travel and business travel, respectively, Cal-B/C uses the same 50 percent for all trip purposes. The rationale for the simplification in Cal-B/C arises from practical difficulties in estimating numbers of vehicles by trip purpose as well as the small number of potentially higher VOT trips.[3]

For truck travel, Cal-B/C and USDOT recommend using 100 percent of the wage rate for full-time operators in Transportation and Material Moving occupations and using a value that includes fringe benefits. Data on truck driver wages and benefits are included in the BLS Occupational Employment and Wage Estimates data. A weighted average of the median hourly wages for heavy-truck drivers and light-truck drivers is the basis for their VOT. Like passenger vehicles, a single VOT for trucks is established.

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[2] In case Caltrans chooses to make distinctions in the future, the model can differentiate percentages by location.

[3] Thus, Cal-B/C may underestimate general travel my only a small amount. The user can make adjustments. For example, if a project directly affects trips to an airport and there are estimated numbers of business travelers on the route, the user may want to use a higher value of time that reflects the different mix.

In past guidelines, USDOT has noted that VOT can change over time due to changes in labor productivity, which has led to an assumption of annually increasing VOT by 1.0 percent. This increase is above the effect of inflation since the values are already measured in real terms. The Cal-B/C model includes the option to increase the VOT over time with its travel time “uprater” or escalation parameter. The default for this parameter though is set to 0 percent to be consistent with USDOT guidelines of a fixed VOT.

Exhibit 5: VOT Parameters by Vehicle Type

Vehicle Type	VOT
Automobiles and Transit (in-vehicle time)	$13.65
Trucks	$31.40
Composite value of truck and automobile travel	$18.95

VEHICLE OPERATING COST PARAMETERS

Fuel Consumption

Cal-B/C values for fuel consumption are based on automobile and truck fuel consumption rates using data from the EMFAC2014 model (CARB, 2015). 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 and applies this for all project locations in the state. Idling fuel consumption cannot be extracted from EMFAC2014. To approximate fuel consumption and emissions during idling, Cal-B/C uses a 5 mph speed. A lookup-table on fuel consumption rates is found in the Parameters Worksheet of each Cal-B/C model.

Fuel Costs

Cal-B/C estimates fuel costs by multiplying the fuel consumption in gallons by the average fuel cost per gallon. The resulting value represents out-of-pocket fuel costs paid by consumers. The fuel cost calculations in Cal-B/C excludes federal excise, state sales and excise, and local sales taxes. These taxes are transfer payments and user fees for funding transportation improvements.

The Cal-B/C development team used the American Automobile Association (AAA) Daily Fuel Gauge Report as the source for fuel cost data (AAA, 2016). The Cal-B/C development team averaged fuel prices from the AAA website on two days (June 29, 2015 and June 29, 2016) to estimate fuel costs – the Daily Fuel Gauge Reports only limited historical data. 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 final fuel cost backs out the taxes from the two-day average price. 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.

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 estimates non-fuel costs separately to enable users to change fuel prices without re-estimating all vehicle operating costs.

For automobiles, Cal-B/C references AAA's driving cost estimates for three categories of sedans (small, medium, and large) and an average of the sedan categories. The resulting non-fuel costs for two categories include: (a) Repairs: 5.28 cents per mile; and (b) Tires: 1.00 cents per mile. AAA does not provide an estimate of depreciation by mile so Cal-B/C development team divided the cost of depreciation ($3,759) by an average annual mileage of 15,000 to determine a depreciation cost of 25.06 cents per mile. The total non-fuel cost per mile of 31.34 cents per mile is the per-mile sum of maintenance (5.28 cents), tires (1.00 cents), and depreciation (25.06 cents). Other fixed costs, such as insurance, license, taxes, and finance charges are excluded.

For trucks, the Cal-B/C development team applied data from American Transportation Research Institute (ATRI - the research arm of the American Trucking Associations Federation) (ATRI, 2015). 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. The resulting non-fuel cost for trucks is 42.9 cents per mile and consist of per mile costs for repair and maintenance (16.3 cents), tires (4.5 cents) and truck/trailer payments (22.1 cents).

ACCIDENT COST PARAMETERS

Many transportation agencies have adopted new terminology regarding safety. What USDOT calls "crashes," Caltrans 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 establishing 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.

Caltrans reports highway collision data in terms of both accidents and events. Transit agencies report only event data. For this reason, Cal-B/C uses 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). Cal-B/C uses the comprehensive (willingness-to-pay) methodology to estimate accident costs by type – an approach that is consistent with USDOT guidelines.

Passenger Vehicles and Trucks

Accident Rates by Severity

Cal-B/C has relied in the past on data from average statewide accident rates. The current models use average statewide accident rates computed from a special TASAS run titled 2013 Statewide Collision Total Check (TASAS, 2016). 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. Non-freeway accident rates are available in the 2009 Collision Data on California State Highways data. The accident rates (in Exhibit 6) are developed by dividing the number of incidents by 178,281.8 million vehicle-miles.

Exhibit 6: Average of Vehicle-Injury Accident Rates (in 2013)

Event	Number of Impacts	Rate per Million Veh-Miles (MVM)
Fatality	1,105	0.0062
Injury	51,378	0.2882
PDO Accidents	98,338	0.5516
Non-freeway accident rate		1.05

Accident Costs by Severity

There are two primary sources of comprehensive cost data: the National Highway Traffic Safety Administration (NHTSA, 2010) and the National Safety Council (NSC, 2016). The largest differences between NHTSA and NSC are the frequency of updates and the scale used to capture injury severity. USDOT values is based on a willingness to pay approach but unlike these NHTSA and NSC, they do not include direct, out-of-pocket costs. The Cal-B/C team adopted the USDOT values, even though they exclude these direct costs, because they are used for USDOT's competitive grant program, the parameters of which are updated annually. In addition, the injury values are consistent in magnitude with the injury values in the prior versions of the NSC reports. According to the 2016 guidance dated August 8, 2016 (USDOT 2016), the value of statistical life is $9.6 million in 2015 dollars. This value and others are adjusted to 2016 dollars with the GDP deflator. Costs per accident are used with personal vehicles and represent adjustments in cost per event that reflect accidents per event and injuries by type per accident.

Exhibit 7: Average of Cost per Accident Type

<table>
<tr><th>Event</th><th>Cost per Event</th><th>Cost per Accident</th></tr>
<tr><td>Death</td><td>$9,800,000</td><td>$10,800,000</td></tr>
<tr><td>Incapacitating Injury (A)</td><td>$466,400</td><td rowspan="3">$148,800</td></tr>
<tr><td>Non-Incapacitating Injury (B)</td><td>$127,000</td></tr>
<tr><td>Possible Injury (C)</td><td>$64,900</td></tr>
<tr><td>No Injury</td><td>$3,300</td><td>$9,700</td></tr>
<tr><td>PDO value (from NHTSA)</td><td>$2,700</td><td>$2,700</td></tr>
</table>

Transit

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 (USDOT, 2015). Data from Table 2-33 in that report provides transit safety data by mode for all reported accidents. Exhibit 8 shows the updated transit accident rates for Cal-B/C. The Cal-B/C development team used the average of 2003-2012 safety statistics.

Exhibit 8: Average of Transit Accident Rates for 2003-2012 (events per MVM)

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. Bus accident data do not include intercity or school buses. Data for these statistics are from the online FTA document “Transit Safety & Security Statistics & Analysis Annual Report.”

Cost of Transit Accident Events

Cal-B/C uses the cost per event data for transit accidents instead of costs per accident used by highway safety assessments. 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 highway average.

Estimates of transit property damage due to accidents are developed from data in the FTA “Transit Safety & Security Statistics & Analysis Annual Report”. 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. Property damage values for Cal-B/C (Exhibit 9) 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 9: Cost of Transit Accident Events (2011)

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

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

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 costs for criteria air contaminants and greenhouse gas emissions. The distinction between the emissions and greenhouse gas emissions 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.

Criteria Air Contaminant Pollutants

Emissions Rates

The Cal-B/C development team updated the emissions factors in Cal-B/C using EMFAC2014 (CARB, 2015). Consistent with previous Cal-B/C versions, the Cal-B/C development team used EMFAC2014 to generate emissions factors for 2016 and 2036 EMFAC estimates. 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.

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 changes in emissions on new trips. The model assumes that each new trip results in a start, which may overestimate emissions if trip chaining occurs. Idling emissions are included but diurnal and resting loss emissions are excluded because they are not impacted by project types 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.

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. 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. Exhibit 10 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. Note that these values differ from those established by USDOT in its BCA guidelines, they are reported here for reference only.

Exhibit 10: 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
USDOT (not used)	---	*$8,137*	*$372,215*	*$48,091*	*$2,064*

Source: Adapted from Delucchi and McCubbin (1996).

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 any 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.

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 and active transportation 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.

Emissions Rates

Cal-B/C reports greenhouse gas emissions in terms of the amount of CO_2 emissions saved because of project construction. 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, EMFAC2014 reflects 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 as a difference in emissions between the Build and the No Build cases.

Emissions Costs

The US Interagency Working Group on Social Cost of Carbon (2015) 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. The guidance has since been removed by the federal government, but Caltrans continues to use this guidance for Cal-B/C, since it is consistent with international guidance.

The US Interagency Working Group guidance provides values under four scenarios (average social carbon costs with discount rates of 5 percent, 3 percent, and 2.5 percent as well as 95th percentile social carbon costs at a 3-percent discount rate) for every five years between 2010 and 2050 in 2007 dollars. 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, and then uprated by 2.0 percent for one year, 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 (growth factor) of 2.0 percent per year. 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.

6. Model-Specific Parameters

This section provides summary tables of variables for each benefit category relevant to each of the tools in the Cal-B/C Framework. The parameters are organized by model and then benefit category.

CAL-B/C SKETCH

Travel Time Savings

For projects that reduce travel time through projects, operational improvements or transit expansion, the travel time savings can be a core source of benefits. Cal-B/C Sketch estimates delay reduction benefits for each mode and project type, as applicable, using standard valuation methods for time savings over the life of the project. Time savings are computed as the difference in travel time for all travelers between No Build and Build scenarios. Time savings for passenger vehicles and trucks differ from transit users since the number of roadway travelers includes the number of vehicles and average vehicle occupancy (AVO). The model calculates travel times for highway travelers based on estimates of roadway speeds and distances traveled. Since speeds vary over the course of the day separate calculations of travel time are conducted for peak and non-peak periods. Travel time savings for transit are calculated as the difference in the travel times supplied by the user. The value of time savings is assumed, as standard practice, to be derived from the median wage rate and differs between passenger vehicles and transit users, and truck drivers. A higher value of time is estimated for out-of-vehicle travel (such as during transit transfers). Cal-B/C calculates the value of induced demand as 0.5 multiplied by the reduction in travel time and the number of additional travelers.

Equations

Total Value of Travel Time Savings, by mode

$$VTT^{m} = N^{m} \cdot AF \cdot Dist \cdot VOT$$

Where for passenger vehicle travelers, the number of travelers adjusts the number of vehicles V^P by the AVO, average vehicle occupancy, as shown:

$$N^{P} = V^{P} \cdot AVO$$

As discussed above, AVO is an important parameter in estimating benefits of projects that convert lanes to HOV, HOT, or change the minimum of persons in a vehicle operating in a HOV lane.

For transit travelers, the model user enters a *total* number of transit travelers TN^T that is then adjusted by the percentage that travel in the peak (P_P) and off-peak period ($1-P_P$) to determine the numbers of transit travelers in each period. The peak transit travelers are determined as:

$$N_{P}^{T} = TN^{T} \cdot P_{P} \text{ [Peak Period Travelers]}$$

$$N_N^T = TN^T \cdot (1 - P_P) \text{ [Non-Peak Period Travelers]}$$

In addition, to account for the value of new transit travelers who shifted from a highway facility, the model computes the number of mode shift users in both the peak (N_P^{TS}) and non-peak periods (N_N^{TS}). The number of mode shift transit travelers is computed as the difference in transit trips between No Build (N) and Build (B) scenarios ($N_{B,P}^T$ and $N_{NB,P}^T$, respectively), multiplied by the percentage of travelers who shift from a parallel highway (P_S). For example, the number of mode shift transit travelers in the peak period is computed as:

$$N_P^{TS} = (N_{B,P}^T - N_{NB,P}^T) \cdot P_S$$

The model users has the control of whether to include this value or not. It is only applicable for certain types of improvements.

Model Inputs

Exhibit 11: Travel Time Savings - User Inputs and Parameters

Var.	Definition	Value	Unit	Source
V	Daily volume, by vehicle type (passenger vehicle, truck), period (peak, non-peak), facility (HOV, non-HOV, weaving)	#	Trips/Day	User Input
P_S	Percentage of travelers who shift from parallel highway	%	% of demand	User Input
Dist	Project length (distance traveled)	#	Miles per trip	User Input
AVO	Average Vehicle Occupancy	1.3 – Non-Peak; 1.15 – Peak; 2.15 – HOT Lanes	Persons / vehicle	1
P_P	Travel demand in peak period, by location, and roadway type and hours per day of peak period	Varies	% of demand	1
VOT	Statewide Average Hourly Wage	$27.34	$ per hour	3
	Automobile	$13.65	$/hr/per	5
	Truck	$31.40	$/hr/veh	5
	Auto & Truck Composite	$18.95	$/hr/veh	6
	Transit	$13.65	$/hr/per	5
	Out-of-Vehicle Travel	2	times	5
	Incident-Related Travel	3	times	7
	Travel Time Uprater	0.0%	annual increment	Caltrans

Sources: 1) CA Household Travel Survey (2012); 3) Bureau of Labor Statistics (BLS) OES, 5) USDOT Department Guidance (2016), 6) California Department of Transportation TSI and Traffic Operations, 7) IDAS model

Vehicle Operating Cost Savings

The methodology for computing operating costs in Cal-B/C Sketch is simplified and based upon the most recent, available data. The overall approach is similar to that found in other models where fuel and non-fuel operating costs are separated. An important feature in estimating the fuel component of VOC is the relationship between fuel consumption and speed. The model computes costs by looking up the appropriate fuel consumption rate per mile, for estimated speeds in the No Build and Build scenarios. Any difference in speed leads to differences in fuel consumption over the entire project length for each vehicle. In addition, if the model entails a change in pavement conditions, the model accounts for a change in vehicle costs under different pavement quality conditions. Overall, separate fuel consumption factors would be expected for passenger vehicles and trucks under peak and non-peak periods, as well as in highway, arterials and weaving lanes.

Non-fuel cost estimates are based upon factors similar to those found in other models plus an estimate for depreciation. These costs are applied to the change in vehicle-miles traveled (VMT) for each year of the project. VMT is calculated as annual traffic multiplied by the length of highway affected by the project.

Transit vehicle operating costs are not included since costs are borne by transit operators as a component of operation and maintenance costs. Since operation and maintenance costs are a component of total project cost, these are captured in the "cost" part of benefit-cost analysis. Therefore, reductions in transit vehicle operating costs are not counted as a benefit (i.e., cost savings) by the model. Any transit vehicle operating costs saving should be captured as cost reductions on the agency cost inputs.

Equations

Total Annual Value of Vehicle Operating Costs, by mode:

$$VVOC^t = [V^t \cdot AF] \cdot [Dist^t \cdot Fuel^t] \cdot VOC^t$$

Where VOC^t is the sum of fuel and non-fuel costs, depending on the vehicle type t.

Model Inputs

Exhibit 12: Vehicle Operating Cost Savings - User Inputs and Parameters

Variable	Definition	Value	Unit	Source
V	Daily volume, by vehicle type (passenger vehicle, truck), period (peak, non-peak), facility (HOV, non-HOV, weaving)	#	Trips/Day	User Input
Dist	Project length (distance traveled)	#	Miles per trip	User Input
S	Travel speed, by type, period, facility	#	MPH	Computed
Idling Speed	Speed lookup value for Operating Costs	5	mph	Caltrans

Variable	Definition	Value	Unit	Source
Average Fuel Price	Automobile (regular unleaded)	$3.18	$/gal	1
	Truck (diesel)	$3.00	$/gal	1
Taxes	State Sales Tax (gasoline)	2.25%	%	2
	State Sales Tax (diesel)	7.50%	%	2
	Average Local Sales Tax	0.50%	%	2
	Federal Fuel Excise Tax (gasoline)	$0.184	$/gal	2
	Federal Fuel Excise Tax (diesel)	$0.244	$/gal	2
	State Fuel Excise Tax (gasoline)	$0.278	$/gal	2
	State Fuel Excise Tax (diesel)	$0.160	$/gal	2
Fuel Cost Per Gallon	Automobile fuel cost (Excluding Taxes)	$2.65	$/gal	Computed
	Truck fuel cost (Excluding Taxes)	$2.40	$/gal	Computed
Non-Fuel Cost Per Mile	Automobile	$0.313	$/mi	3
	Truck	$0.429	$/mi	4

Sources: (1) AAA Daily Fuel Gauge Report (2016), (2) California Board of Equalization, (3) AAA Your Driving Costs (2016), (4) American Transportation Research Institute (2015).

Accident Cost Savings

Accident cost savings from transportation projects are computed by determining the difference in anticipated accident costs between the No Build and Build scenarios. Accident costs are associated with accident rates and costs per event over the lifetime of a project, which is 20 years in Cal-B/C Sketch. Individual projects may improve or adversely impact vehicle accidents, so the net result may be positive or negative. Based on the accident data available associated with each mode, highway costs are determined on a per accident basis, but transit costs are on a per event basis.

Equations

Total Annual Value of Accident Cost Savings Reduction:

$$VAR = [V \bullet AF] \bullet Dist \bullet ACC$$

Where ACC, accident costs per-mile, is derived using incident rates by severity (e.g., FatalAcc) and the respective cost by severity (e.g., CostFatal) and computed as a sum product of accident frequencies per mile and costs per accident, by severity

$$ACC \ (FatalAcc \cdot CostFatal + InjAcc \cdot CostInj + PDAcc \cdot CostPD)$$

Model Inputs

Exhibit 13: Accident Cost Savings - User Inputs and Parameters

Var.	Definition	Value	Unit	Source
V	Daily volume, by vehicle type (passenger vehicle, truck), period (peak, non-peak), facility (HOV, non-HOV, weaving)	#	Trips/Day	User Input
Dist	Project length (distance traveled)	#	Miles per trip	User Input
$CostFatal^{Tr}$	Cost per Fatality (Transit)	$9,800,000	$/event	1
$CostInj^{A,Tr}$	Cost per Level A Injury (Severe) (Transit)	$466,400	$/event	1
$CostInj^{B,Tr}$	Cost per Level B Injury (Moderate) (Transit)	$127,000	$/event	1
$CostInj^{C,Tr}$	Cost per Level C Injury (Minor) (Transit)	$64,900	$/event	1
$CostPD^{Transit}$	Cost per Property damage (Transit)	$2,700	$/event	2
$CostFatal^{t,d}$	Cost per Accident Fatality (Highway)	$10,800,000	$/accident	1
$CostInj^{t,d}$	Cost per Accident Injury (Highway)	$148,800	$/accident	1
$CostPD^{t,d}$	Cost per Accident PDO (Highway)	$9,700	$/accident	1
CostAVG	Average Cost per Accident (Highway)	$185,600	$/accident	1
$FatalAcc^{t,d}$	Fatal Accident Rate	0.006	per mil veh-mi	3
$InjAcc^{t,d}$	Injury Accident Rate	0.29	per mil veh-mi	3
$PDAcc^{t,d}$	PDO Accident Rate	0.55	per mil veh-mi	3
$NFAcc^{t,d}$	Non-Freeway Rate	1.05	per mil veh-mi	4

Sources: (1) USDOT VSL (2016), (2) NHTSA (2010), (3) TASAS summary 2013 (2016), (4) TASAS summary 2009

Emissions Cost Savings

Transportation investments also have external consequences on people, whether they use the facility or not, and the natural environment. Cal-B/C Sketch focuses on the environmental impacts associated with result of commuters using the facility itself. Travel changes related to travel speeds, vehicle trip-making, or diversion of trips all have implications for air pollution and greenhouse gas emissions. Vehicle emissions generally fall into two categories:

- Air Pollutant Emissions: Motor vehicles emit pollutants, such as carbon monoxide (CO), oxides of nitrogen (NOX), volatile organic compounds (VOC), particulate matter (PM), and oxides of sulfur (SOX).
- Greenhouse Gas Emissions (GHG): Fuel consumption releases gases that trap heat within the Earth's atmosphere, of which carbon dioxide is the most important.

For highway projects, Cal-B/C Sketch incorporates separate analyses for peak and non-peak periods because emission rates vary with vehicle speeds, and the relationship is non-linear. Separate emission rates were developed for automobiles, trucks, and buses using the California Air Resources Board, EMFAC 2014 emissions model. The emission rates for automobiles, trucks, and buses are based upon composite emission rates across vehicle classes (as required), for several pollutants: CO, NOX, VOC, and PM10 from vehicle exhaust, and brake and tire wear.

The Caltrans Cal-B/C uses a simplified approach to address emission rate changes: current emissions rates are used for the first seven years of project benefits, and a twenty-year forecast is used for remaining 13 years. Cal-B/C uses separate values for starting and running emissions.

For transit projects in areas with no existing transit service, No Build emissions are zero, and the change in emissions is just equal to the new project's emissions. It is necessary to examine the emission levels with and without the improvement project in order to assess the incremental emissions associated with the improvement. The calculations vary with the emission characteristics and rates for different transit modes. Emissions for buses are based on rates by vehicle speed from EMFAC. Flat emission rates per vehicle-mile are used for other transit modes.

Equations

Total Value of Emissions Cost Savings, by vehicle type (t):

$$VER^t = [V^t \cdot AF] \cdot Dist^t \cdot EC^t$$

Where, total emissions costs are the sum product of each pollutant's emissions ($pollutant^m$) rate per mile by mode (m), and costs per pollutant ($VPP_{pollutant}$)[4]:

$$EC = (CO \cdot VPP_{CO} + CO_2 \cdot VPP_{CO_2} + NO_X \cdot VPP_{NO} + PM_{10} \cdot VPP_{PM_{10}} + SO_X \cdot VPP_{SO} + VOC \cdot VPP_{VOC})$$

Model Inputs

Exhibit 14: Emissions Cost Savings - User Inputs and Parameters

Var.	Definition	Value	Unit	Source
V	Daily volume, by vehicle type (passenger vehicle, truck), period (peak, non-peak), facility (HOV, non-HOV, weaving)	#	Trips/Day	User Input
Dist	Project length (distance traveled)	#	Miles per trip	User Input
O	Average vehicle occupancy	1.5	Persons per vehicle	1
Pollutant Emissions	Pollutant emissions per ton, by vehicle, pollutant type, given an average vehicle speed	Varies by pollutant, See Cal-B/C Model	Tons / mile	2
VPP	Value per pollutant	Varies by pollutant, See earlier section on emissions	$/ton	3, 4

Sources: (1) Computed from CHTS (2012), (2) CARB (2015), (3) McCubbin and Delucchi (1996); (4) US Interagency Group on Social Cost of Carbon (2015)

[4] Emissions rates are a function of vehicle speed, which is a user input.

CAL-B/C CORRIDOR

Travel Time Savings

Reductions in travel time through projects, operational improvements or transit expansion, can be a core source of travel time savings benefits. Cal-B/C Corridor estimates delay reduction benefits for each mode and project type, as applicable, using standard valuation methods for time savings over the life of the project. Cal-B/C Corridor allows the number of travelers in the No Build and Build scenarios to differ if the user has project-specific information that suggests travelers will make new trips (i.e., induced demand) as a result of the project.

Time savings are computed as the difference in travel time for all travelers between No Build and Build scenarios. Time savings for passenger vehicles and trucks differ from transit users since the number of roadway travelers includes the number of vehicles and average vehicle occupancy (AVO). The model calculates travel times for highway travelers based on estimates of roadway speeds and distances traveled. Since speeds vary over the course of the day separate calculations of travel time are conducted for peak and non-peak periods. Travel time savings for transit are calculated as the difference in the travel times supplied by the user.

The value of time savings is assumed, as standard practice, to be derived from the median wage rate and differs between passenger vehicles and transit users, and truck drivers. Travel time benefits are calculated for (a) existing users; and (b) new users. For new users, the benefit is calculated based on the travel time difference between the selected mode and the least cost alternative.[5] A higher value of time is estimated for out-of-vehicle travel (such as during transit transfers). Cal-B/C calculates the value of induced demand as 0.5 multiplied by the reduction in travel time and the number of additional travelers. Cal-B/C Corridor generally follows the U.S. DOT guidance for estimating the value of time for each mode. The value of time for trucks is estimated as 100 percent of the California average Transportation and Utilities wage rate plus benefits. The value of off-the-clock highway travel is calculated at 50 percent of the wage rate.[6] Also, U.S. DOT recommends using 50 percent of the wage rate for the value of in-vehicle travel time and 100 percent for walking and waiting time.[7]

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[5] Note that complications can arise if the difference in travel time is negative (i.e., the travel time is smaller on the least cost alternative compared to the new mode). In this unusual case, the benefit is assumed to be zero. Since the new users must have shifted modes for reasons other than travel time savings. Assuming that users are rational in their decision making, the sum of these benefits must be positive. Accordingly, since this model may not capture all potential benefits (e.g., the value of reducing ones stress by not having to drive, the improved reliability of transit, etc.), the model conservatively estimates that the new transit riders do not receive a benefit, not a negative one.

[6] Due to the difficulty in measuring the value of stress due to congestion, Cal-B/C Corridor follows the U.S. DOT methodology and ignores any potential difference in the value of time per individual between periods.

[7] However, the value of the disutility associated with transit travel is likely to be lower than that for private vehicles, because transit users may have the ability to spend their time doing something else, such as reading, while riding transit. Rather than require users to estimate in-vehicle time and waiting time separately for transit, Cal-B/C Corridor simplifies the methodology and uses 50 percent for all transit travel time (in-vehicle and waiting).

Travel time savings can be calculated only for travelers that had travel times before the project was built (i.e., existing travelers). Travel time savings are computed for existing travelers as a change in travel time multiplied by the number of travelers in the No Build scenario. Induced travelers do not have time savings because they were not making trips prior to the project being built. However, they do receive a benefit for making a trip or they would not be making the trips. The model values this benefit using a standard economic technique—consumer surplus theory. Cal-B/C Corridor calculates the value of induced demand as 0.5 multiplied by the reduction in travel time, the change in out of pocket costs and the number of additional travelers. The model uses travel time as the price of travel since most travelers are not likely to consider accidents, emissions, or operating costs when making decisions.

Computations of the value of travel time savings are presented in three parts: scale of impact, impact factors, and impact value. In each case, the computations show the value of travel time and the value of time savings are the difference between No Build and Build conditions. Discussion is generalized for all modes (passenger vehicle, trucks, and all types of transit). If variables or calculations differ among modes or context, additional notes are provided.

Equations

Total Value of Travel Time Savings, by mode for existing users

$$VTT_{e}^{m} = N^{m} \bullet (PHT_{NB}^{m} - PHT_{B}^{m}) \bullet VOT$$

Total Value of Travel Time Savings, by mode for new users

$$VTT_{n}^{m} = 0.5 \bullet N^{m,s} \bullet ((PHT_{LC}^{m} - PHT_{B}^{m}) \bullet VOT + (PCK_{NB}^{m} - PCK_{B}^{m}))$$

Where for passenger vehicle travelers, the number of travelers adjusts the number of vehicles V^P by the AVO, average vehicle occupancy, as shown:

$$N^P = V^P \cdot AVO$$

As discussed above, AVO is an important parameter in estimating benefits of projects that convert lanes to HOV, HOT, or change the minimum of persons in a vehicle operating in a HOV lane.

In addition, to account for the value of new transit travelers who shifted from a highway facility, the model computes the number of mode shift users in both the peak (N_P^{TS}) and non-peak periods (N_N^{TS}). The number of mode shift transit travelers is computed as the difference in transit trips between No Build (N) and Build (B) scenarios ($N_{B,P}^{T}$ and $N_{NB,P}^{T}$, respectively), multiplied by the percentage of travelers who shift from a parallel highway (P_S). For example, the number of mode shift transit travelers in the peak period is computed as:

$$N_P^{TS} = (N_{B,P}^{T} - N_{NB,P}^{T}) \cdot P_S$$

The model users has the control of whether to include this value or not. It is only applicable for certain types of improvements.

Model Inputs

Exhibit 15: Travel Time Savings - User Inputs and Parameters

Var.	Definition	Value	Unit	Source
V^P	Daily volume, by vehicle type, period	#	Trips/Day	User Input
P_S	Percentage of travelers who shift from parallel highway	%	% of demand	User Input
PHT^m	Vehicle travel time	#	Person-hours traveled	User Input
AVO	Average Vehicle Occupancy	1.3 – Non-Peak; 1.15 – Peak; 2.15 – HOT Lanes	Persons / vehicle	1
$PCK^{m,s}$	Out-of-pocket cost by mode (m) for modal diversion users (s)	$	$ / trip	User Input
VOT	Statewide Average Hourly Wage	$27.34	$ per hour	3
	Automobile	$13.65	$/hr/per	5
	Truck	$31.40	$/hr/veh	5
	Auto & Truck Composite	$18.95	$/hr/veh	6
	Transit	$13.65	$/hr/per	5
	Out-of-Vehicle Travel	2	times	5
	Incident-Related Travel	3	times	7
	Travel Time Uprater	0.0%	annual increment	Caltrans

Sources: 1) CA Household Travel Survey (2012); 3) Bureau of Labor Statistics (BLS) OES, 5) USDOT Department Guidance (2016), 6) California Department of Transportation TSI and Traffic Operations, 7) IDAS model

Vehicle Operating Cost Savings

The methodology for computing operating costs in Cal-B/C Corridor is relatively simple and based upon the most recent, available data. The accuracy of a more complex model would likely be offset by the resources needed for gathering and estimating data. The overall separates fuel and non-fuel operating costs. An important feature in estimating the fuel component of VOC is the relationship between fuel consumption and speed. Since fuel rates are separated from other costs, fuel prices (minus taxes) can be updated without altering consumption rates.

The model computes fuel costs by looking up the appropriate fuel consumption rate per mile, for estimated speeds in the No Build and Build scenarios. Any difference in speed leads to differences in fuel consumption over the entire project length for each vehicle. Overall, separate fuel consumption factors would be expected for passenger vehicles and trucks.

Non-fuel cost estimates are based upon American Automobile Association (AAA) estimates plus depreciation. These costs are applied to the change in vehicle-miles traveled (VMT) for each year of the project. VMT is input by the user for a base year and a forecast year.

Transit vehicle operating costs are not included since costs are borne by transit operators as a component of operation and maintenance costs. Since operation and maintenance costs are a component of total project cost, these are captured in the "cost" part of benefit-cost analysis. Changes in transit vehicle operating costs are not counted as a benefit (i.e., cost savings) by the model. The model accounts only for savings on the consumer side, and not on the operator side.

However, transit projects that generate induced travelers from a parallel highway would gain from a lower VOC. The potential decrease in highway VOC, caused by a reduction in buses, is negligible and, therefore, is not incorporated into the highway model. VOC savings for remaining highway motorists are assumed to come from the reduction in other vehicle (non-bus) traffic.

Equations

Total Value of Vehicle Operating Costs, by mode:

$$\mathrm{VVOC}^{t} = \mathrm{VMT}^{t}_{NB} \cdot \mathrm{VOC}^{t}_{NB} - \mathrm{VMT}^{t}_{B} \cdot \mathrm{VOC}^{t}_{B}$$

Where VOC^{t}_{P} is the sum of fuel and non-fuel costs, depending on the vehicle type t, in the No Build and Build scenarios. Note that the fuel costs are a function of fuel consumption rates, which are determined from a look-up table based on the vehicle speed.

Model Inputs

Exhibit 16: Vehicle Operating Cost Savings - User Inputs and Parameters

Variable	Definition	Value	Unit	Source
VMT	Daily vehicle miles traveled	#	Miles	User Input
VHT	Daily vehicle hours traveled	#	Hours	User Input
S	Travel speed, computed from VMT and VHT	#	MPH	Computed
Idling Speed	Speed lookup value for Operating Costs	5	MPH	Caltrans
Average Fuel Price	Automobile (regular unleaded)	$3.18	$/gal	1
	Truck (diesel)	$3.00	$/gal	1
Taxes	State Sales Tax (gasoline)	2.25%	%	2
	State Sales Tax (diesel)	7.50%	%	2
	Average Local Sales Tax	0.50%	%	2
	Federal Fuel Excise Tax (gasoline)	$0.184	$/gal	2
	Federal Fuel Excise Tax (diesel)	$0.244	$/gal	2
	State Fuel Excise Tax (gasoline)	$0.278	$/gal	2
	State Fuel Excise Tax (diesel)	$0.160	$/gal	2
Fuel Cost Per Gallon	Automobile fuel cost (Excluding Taxes)	$2.65	$/gal	Computed
	Truck fuel cost (Excluding Taxes)	$2.40	$/gal	Computed
Non-Fuel Cost Per Mile	Automobile	$0.313	$/mi	3
	Truck	$0.429	$/mi	4

Sources: (1) AAA Daily Fuel Gauge Report (2016), (2) California Board of Equalization, (3) AAA Your Driving Costs (2016), (4) American Transportation Research Institute (2015).

Accident Cost Savings

Accident cost savings from transportation projects are computed by determining the difference in anticipated accident costs between the No Build and Build scenarios. Accident costs are associated with accident rates and costs per event over the lifetime of a project, which is between two and fifty years in Cal-B/C Corridor. Individual projects may improve or adversely impact vehicle accidents, so the net result may be positive or negative.

Cal-B/C Corridor uses data on costs per accident and accident rates from the best available sources. The user provides data on accident rates by type (fatal injury, and property damage only) for highway modes. The data entered by the user reflects current rates per million vehicle miles traveled and crash modification factors if accident rates are anticipated to change in the build case.

The project may also impact the occurrence of accidents on transit. Cal-B/C Corridor calculates transit accident costs as a function of vehicle-miles operated. The model uses default accident rates based on U.S. DOT national averages. Since these statistics are tabulated by event (i.e., number of fatalities, injuries, and accidents), Cal-B/C Corridor calculates the value of transit accidents per event rather than by accident severity. That is, for rail modes, train-miles must be converted to vehicle-miles using the average number of vehicles per train.

Since some transit improvements may enhance safety, Cal-B/C Corridor allows the user to reduce accident rates. The user is asked to input the percent reduction in accidents anticipated as a result of the project. Since Cal-B/C Corridor calculates accident costs as a function of vehicle-miles operated, a transit project that increases vehicle-miles operated (either by extending the system or adding service), but does not improve transit safety will result in a dis-benefit for transit accident costs. However, such a project is likely to result in a decrease in accident costs on another route or mode.

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. Data to compute these benefits are described in Appendix C. Additional information on accident cost methodology are contained in the Cal-B/C Resource Guide. Additional information on valuation parameters is provided in the Cal-B/C Parameters Guide.

Total Value of Accident Risk Reduction, by mode and severity:

$$VAR^{t}_{sev} = VMT^{t} \cdot ACC^{t}_{sev} \cdot (1 - (1 - CRF^{t}_{sev})) \cdot VACC^{t}_{sev}$$

Where ACC^{t}_{sev} is the accident frequencies per mile and costs per accident, by severity (e.g., FatalAcc) and CRF^{t}_{sev} is the Crash reduction factor, by severity and vehicle type (t). $VACC_{sev}$ represents the costs per accident, by severity (e.g., CostFatal). Where ACC, accident costs per-mile, is computed as a sum product of accident frequencies per mile and costs per accident, by severity.

$$ACC = (FatalAcc \cdot CostFatal + InjAcc \cdot CostInj + PDAcc \cdot CostPD)$$

Model Inputs

Exhibit 17: Accident Cost Savings - User Inputs and Parameters

Var.	Definition	Value	Unit	Source
VMT^t	Project length (distance traveled)	#	Vehicle Miles traveled	User Input
CRF	Crash modification factor	#	Unitless	Based on project type
$CostFatal^{Tr}$	Cost per Fatality (Transit)	$9,800,000	$/event	1
$CostInj^{A,Tr}$	Cost per Level A Injury (Severe) (Transit)	$466,400	$/event	1
$CostInj^{B,Tr}$	Cost per Level B Injury (Moderate) (Transit)	$127,000	$/event	1
$CostInj^{C,Tr}$	Cost per Level C Injury (Minor) (Transit)	$64,900	$/event	1
$CostPD^{Transit}$	Cost per Property damage (Transit)	$2,700	$/event	2
$CostFatal^{t,d}$	Cost per Accident Fatality (Highway)	$10,800,000	$/accident	1
$CostInj^{t,d}$	Cost per Accident Injury (Highway)	$148,800	$/accident	1
$CostPD^{t,d}$	Cost per Accident PDO (Highway)	$9,700	$/accident	1
CostAVG	Average Cost per Accident (Highway)	$185,600	$/accident	1
$FatalAcc^{t,d}$	Fatal Accident Rate	0.006	per mil veh-mi	3
$InjAcc^{t,d}$	Injury Accident Rate	0.29	per mil veh-mi	3
$PDAcc^{t,d}$	PDO Accident Rate	0.55	per mil veh-mi	3
$NFAcc^{t,d}$	Non-Freeway Rate	1.05	per mil veh-mi	4

Sources: (1) USDOT VSL (2016), (2) NHTSA (2010), (3) TASAS summary 2013 (2016), (4) TASAS summary 2009

Emission Cost Savings

Transportation investments have external consequences on people, whether they use the facility or not, and the natural environment. Cal-B/C Corridor focuses on the environmental impacts associated with result of travelers using the facility.[8] Changes related to travel speeds, vehicle trip-making, or diversion of trips all have implications for air pollution and greenhouse gas emissions.

The adverse health effects of vehicle emissions are probably the most significant environmental costs of travel. Enough is known about these effects to incorporate them readily into benefit-cost analyses. Vehicle emissions generally fall into two categories:

- Air Pollutant Emissions: Motor vehicles emit pollutants, such as carbon monoxide (CO), oxides of nitrogen (NOX), volatile organic compounds (VOC), particulate matter (PM), and oxides of sulfur (SOX).
- Greenhouse Gas Emissions (GHG): Fuel consumption releases gases that trap heat within the Earth's atmosphere, of which carbon dioxide is the most important.

The physical volumes of air-pollutants and greenhouse gas emissions resulting from travel are readily quantified since emission rates are well understood.[9] In addition, monetized costs of specific pollutants per unit of measure are well-established. It is important to note that a transportation project could yield benefits or dis-benefits since air pollutant emissions are based on travel volumes and speeds. Cal-B/C Corridor computes emissions benefits separately for each vehicle type and determines net benefits by comparing the value of emissions in the No Build and Build scenarios.

Separate emission rates were developed for automobiles and trucks using the California Air Resources Board, EMFAC emissions model. The emission rates for automobiles and trucks are based upon composite emission rates across vehicle classes (as required), for several pollutants: CO, NOX, VOC, PM_{10}, and $PM_{2.5}$ from vehicle exhaust, and brake and tire wear. The emissions model provides default values for the percent of vehicles in each vehicle category (e.g., light-duty gas vehicles, light-duty diesel vehicles, light-duty gas trucks) for each year of analysis (the fleet mix assumptions change over time). Emission rates are expected to change over time as the vehicle fleet changes. Cal-B/C Corridor uses a simplified approach to address emission rate changes: current emissions rates are used for the first seven years of project benefits, and a twenty-year forecast is used for the remaining years, if applicable.[10] Cal-B/C Corridor uses separate values for starting and running emissions.

[8] Construction activity can affect the environment directly through equipment emissions and noise, or indirectly by causing increased traffic congestion and vehicle emissions during the construction period.

[9] Other environmental effects are less significant, less understood, or difficult to quantify and value. As a result, these effects tend to be excluded from benefit-cost models. Ignored effects include: noise, hazardous materials incidents, and upstream fuel effects.

[10] Each year that the parameters are updated changes the current and forecast year for the emissions rates.

Investment in transit projects may result in net emission benefits or dis-benefits, depending on whether the emissions reduction from new transit riders who shift modes from highway vehicles is sufficient to offset any new emissions generated by the transit project.

For a transit project in an area with no existing transit service, No Build emissions are zero, and the change in emissions is equal to the project's emissions. In the case of a transit improvement project, it is necessary to examine the emission levels with and without the improvement in order to assess the incremental emissions associated with the improvement. The calculations vary with the emission characteristics and rates for different transit modes. For example:

- **Passenger Rail** (e.g., commuter rail or other diesel-electric locomotive powered train service): Cal-B/C Corridor uses rates were derived from locomotive emissions per brake horsepower hour, horsepower ratings, load factors, and average speeds using CARB estimates. These rates are expressed in grams per train-mile assuming a single locomotive train set, and can be converted with a unit conversion to tons per vehicle-mile and by dividing emission rates by the number of vehicles or cars per train.
- **Light Rail** (e.g., electric-power generated trains): Cal-B/C Corridor recognizes that the pollution from these vehicles is emitted from power plants that generate electricity used by the trains. Power plant emissions have been converted to emissions per LRT vehicle-mile, based upon 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. Rates are expressed in tons per vehicle-mile as opposed to train-mile.
- **Bus**: Buses generally travel on roadways with other vehicles, and their average speeds reflect those of the surrounding traffic. In most cases, the bus speed is the same as that of prevailing traffic, to take into account congestion effects. However, the user must specify the passenger miles traveled and passenger hours traveled to generate for buses to calculate the bus speed. The calculated speed is used by the model to estimate the emissions.

Equations

Total Value of Emissions Cost Savings, by vehicle type (t):

$$VER^t = VMT^t \cdot EC^t$$

Where, total emissions costs are the sum product of each pollutant's emissions (*pollutant*^{m}) rate per mile by mode (m), and costs per pollutant ($VPP_{pollutant}$)[11]:

$$EC=(CO \cdot VPP_{CO} + CO_2 \cdot VPP_{CO_2} + NO_X \cdot VPP_{NO} + PM_{10} \cdot VPP_{PM_{10}} + SO_X \cdot VPP_{SO} + VOC \cdot VPP_{VOC})$$

[11] Emissions rates are a function of vehicle speed, which is a user input.

Also, emissions rates are a function of S^t **,** travel speed which is computed from VMT and VHT, for a given roadway and in No Build and Build scenarios, by vehicle type (t)

Model Inputs

Exhibit 18: Emissions Cost Savings - User Inputs and Parameters

Var.	Definition	Value	Unit	Source
VMT	Daily vehicle miles traveled	#	Miles	User Input
VHT	Daily vehicle hours traveled	#	Hours	User Input
AVO	Average vehicle occupancy	1.5	Persons per vehicle	1
Pollutant Emissions	Pollutant emissions per ton, by vehicle, pollutant type, given an average vehicle speed	Varies by pollutant, See Cal-B/C Model	Tons / mile	2
VPP	Value per pollutant	Varies by pollutant, See earlier section on emissions	$/ton	3, 4

Sources: (1) Computed from CHTS (2012), (2) CARB (2015), (3) McCubbin and Delucchi (1996); (4) US Interagency Group on Social Cost of Carbon (2015)

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Shipping Cost Savings

These benefits are computed with a number of user inputs on volumes, distances and shares of activity by mode. Not shown in these equations are the potential for separate levels of growth in costs, and operational metrics (see Exhibit 19).

Equations

Total Annual Value of Shipping Cost Savings Elements

a) Diversion, Network Improvements: $VDN = FV^T \cdot \frac{1}{AC^T} \cdot SC^T + FV^R \cdot \frac{1}{[AC^R \cdot ART]} \cdot [SC^R \cdot ART]$

b) Transload: $VTC = [FV^T \cdot FT^T + FV^R \cdot FT^R] \cdot TC^T$

c) Drayage: $VDC \; [FV^T \cdot [\frac{FD^T}{AC^T}] + FV^R \cdot [\frac{FD^R}{AC^T}]] \cdot DC^T$

d) Efficiency: $VEC = FV^T \cdot \left[\frac{FT^T}{AC^T} \cdot Del^T\right] \cdot OC^T + FV^R \cdot \left[\frac{FT^R}{[AC^R \cdot ART]} \cdot Del^R\right] \cdot [OC^R \cdot ART]$

Total Annual Value of Shipping Cost Savings Elements:

$$\mathbf{VSC = VDN + VTC + VDC + VEC}$$

Model Inputs

Exhibit 19: Shipping Cost Savings - User Inputs

Variable	Definition	Unit	Source
AC^T, AC^R	Average capacity per truck (T), rail (R)	short tons or TEUs	User Input
ART	Average number of railcars per train.	railcars / train	User Input
SC_1^T, SC_1^R	Truck (T), rail (R) shipping cost in project opening year.[12]	$ / truck	User Input
FV_t^T, FV_t^R	Volume transported by truck (T), rail (R) in a given year t.	Percentage, values between years 1 and 20 are computed from interpolation	User Input
FT_1^T, FT_{20}^T	Percent of total truck volume transloaded in years 1 and 20. Default value set to 100 percent.		
FT_1^R, FT_{20}^R	Percent of total rail volume transloaded in years 1 and 20. Default value set to 100 percent.		
FD_1^T, FD_{20}^T	Portion of truck shipment volume drayed in years 1 and 20. Default value set to 100 percent.		

[12]Shipping costs for containers are inputted as $/TEU per truck and the model calculates the $/truck

Variable	Definition	Unit	Source
FD_1^R, FD_{20}^R	Portion of rail shipment volume drayed in years 1 and 20. Default value set to 100 percent.		
Del_1^T, Del_1^R	Terminal delay per truck (T), rail (R) in project opening year.	minutes / truck	User Input
TC_1	Cost per volume transloaded.	\$ / short ton or TEU	User Input
DC_1	Drayage cost per movement by truck.	\$ / truck movement	User Input
OC_1^T, OC_1^R	Truck (T), rail (R) operator cost per hour of delay.	\$ / hour	User Input
g_{TC}	Growth rate of transload cost. Default value set to 0 percent.	percentage	User Input
g_{DC}	Growth rate of drayage costs. Default value set to 0 percent.		User Input
g_{OC}^T, g_{OC}^R	Growth rate of truck (T), rail (R) operator cost per hour of delay. Default value set to 0 percent.		User Input
g_{Del}^T, g_{Del}^R	Growth rate of truck (T), rail (R) terminal dwell time. Default value set to 0 percent.		User Input
g_{SC}^T, g_{SC}^R	Growth of truck (T), rail (R) shipping costs.		User Input

Accident Cost Savings

These benefits are computed using a number of user inputs on volumes, distances and shares of activity by mode. Not shown in these equations are the potential for separate levels of growth in costs, and operational metrics. The variety of user inputs are shown Exhibit 20, while model parameters are presented in Exhibit 21.

Equations

Total Annual Value of Accident Cost Savings Reduction:

$$VAR^T = [TotVMT^T + TotVMT^D] \cdot ACC^T + [TotVMT^R] \cdot ACC^R$$

Where, combining $Dist^m$, AC^m with FV^m results in estimates of annual long-haul vehicle-miles traveled (VMT^m)[13] by mode (m) using the equation below:

$$VMT^m = FV^m \cdot \frac{Dist^m}{AC^m}$$

[13] VMT is highlighted because it is a more direct measure of scale of impact for accident risk than FV^m.

VMT for drayage (VMT^{D}) are similarly computed for drayage:

$$VMT^{D} = Dist^{D} \cdot \left[FV^{T} \cdot \frac{FD^{T}}{AC^{T}} + FV^{R} \cdot \frac{FD^{R}}{AC^{T}} \right]$$

Also, note that this derivation of VMT does not account for return trips. Accordingly, $EHTrip^{m}$ is used to adjust total VMT. The resulting equation for total VMT by mode is:

$$TotVMT^{m} = VMT^{m} \cdot (1+EHTrip^{m})$$

ACC^{m}, accident costs per-mile by mode, is derived using incident rates by accident severity (e.g., $FatalAcc^{m}$) and the respective cost by severity ($CostFatal^{m}$). The general formulation for accident costs is similar for trucks and rail, but with a subtle difference for truck costs and train costs.[14] In each case, costs are multiplied by the accident rate per million VMT as a sum-product.

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

Model Inputs

Exhibit 20: Accident Cost Savings - User Inputs

Variable	Definition	Unit	Source
$TotalAcc^{T}$	Total truck accidents during a defined reporting period.	count of total accidents	User Input
$FatalAcc^{T}$	Total fatal truck accidents during a defined reporting period.	count of total fatal accidents	User Input
$InjAcc^{T}$	Total of truck accidents resulting in injuries only during a defined reporting period.	count of total injury only accidents	User Input
$PDAcc^{T}$	Total number of truck accidents resulting in property damage only during a defined reporting period.	count of property damage only accidents	User Input
VMTRP	Total vehicle-miles traveled by truck during a defined reporting period.	miles	User Input
$RFatalAcc^{T}$	Fatal accident reduction factor.	ratio	User Input
$RInjAcc^{T}$	Injury accident reduction factor.		User Input
$RPDOAcc^{T}$	PDO accident reduction factor.		User Input
$EHTrip^{T}$ $EHTrip^{R}$ $EHTrip^{D}$	Number of empty-haul trips returning to point of origin for every full truckload (T), Rail (R), Drayage (D). 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	User Input

[14] Truck accident costs, such as the cost of a fatal accident ($CostFatal^{T}$), combines fatalities, injuries and property damage events whereas the cost of a fatal accident by rail ($CostFatal^{R}$) is just the cost of a fatality.

Exhibit 21: Accident Cost Savings - Parameters

Variable	Definition	Value	Unit	Source
$FatalAcc^R$	Freight rail fatalities per million mile traveled.	0.992	incidents / million VMT	1
$InjAcc^R$	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)	2
$CostInj^T$	Cost of injury accident.	$148,800	$ / accident (truck)	
$CostPD^T$	Cost of property damage only accident.	$9,700	$ / accident (truck)	
$CostFatal^R$	Cost of fatality or value of life.	$9,800,000	$ / fatality (train)	3
$CostInj^R$	Cost of injury.	$180,500	$ / injury (train)	
$CostPD^R$	Cost of property damage.	$147,600	$ / property damage (train)	4

Sources:
(1) Calculated using data from the Federal Railroad Administration Office of Safety Analysis;
(2) Calculated using 3 sources: Source a: California Highway Patrol, 2013 SWITRS Annual Report. Source b: California Department of Transportation, TASAS Unit; 2010 to 2013 average. Source c: U.S. Department of Transportation, Value of Statistical Life;
(3) Calculated based on data from the U.S. Department of Transportation, Value of Statistical Life (2016); and
(4) Federal Railway Administration, Office of Safety Analysis, Table 3.16, 2014 to 2016 average.

Emissions Cost Savings

These benefits are computed with similar user inputs on volumes transported by mode and speed along with emissions rates and costs. These variables are not repeated in this section since the values are the same and to avoid repetition in the document. Not shown in these equations are the potential for separate levels of growth in costs, and operational metrics. The variety of parameters are shown Exhibit 22.

Equations

Total Annual Value of Emission Cost Savings:

$$VER^T = TotVMT^T \cdot EC^T + TotVMT^D \cdot EC^D + TotVMT^R \cdot EC^R$$

Where, $TotVMT^m$ is computed the same way as above. EC^T, EC^R = Emissions cost by mode (*m*) per truck (T) and railcar (R) is equal to the sum product of each pollutant's emissions ($pollutant^m$) rate per mile by mode (m), and costs per pollutant ($VPP_{pollutant}$).[15]

Total emissions costs for each mode is:

$$EC^m = (CO^m \cdot VPP_{CO} + CO_2^m \cdot VPP_{CO_2} + NO_X^m \cdot VPP_{NO} + PM_{10}^m \cdot VPP_{PM_{10}} + SO_X^m \cdot VPP_{SO} + VOC^m \cdot VPP_{VOC})$$

Model Inputs

Exhibit 22: Emissions Cost Savings - Model Inputs

Variable	Definition	Value	Unit	Source
RFE	Freight rail fuel efficiency	468	ton-miles / gallon	1
RFI	Fuel burned at idle for trains	4.00	gallon / hr	2
EC^m	emissions by pollutant from trucks (T), rail (R) depending on speed	#	g / mile	3
$VPP_{pollutant}$	Emission costs by pollutant	$	$ / ton	4, 5

Sources:
(1) Association of American Railroads, The Environmental Benefits of Moving Freight by Rail, June 2017
(2) California Environmental Protection Agency / Air Resources Board, Technology Assessment: Freight Locomotives, Nov. 2016.
(3) California Air Resources Board, EMFAC 2014 (CARB, 2015)
(4) McCubbin and Delucchi (1996); (5) US Interagency Group on Social Cost of Carbon

CAL-B/C PNR

Travel Time Savings

The value of travel time savings for each traveler is a straightforward calculation that combines the estimated time to reach a destination with a value of time. The potential for time savings occurs because a park-and-ride facility enables travelers, especially commuters, to join vehicles that can travel on lanes at higher speeds or are closer to their original departure point. A park-and-ride lot facilitates the use of commuter vehicles because it enables drivers to park and then join higher occupancy vehicles. In some cases, the lot size can be a limiting factor in the number of commuters who can effectively join vehicles. Projects that increase the number of parking spaces can increase the demand for using commuter vehicles. A project that facilitates reaching the lot by bike or on foot can increase overall demand without additional vehicle externalities.

[15] Emissions rates are a function of vehicle speed and accordingly, costs per mile differ for long-distance and drayage truck hauling.

Travel time savings for each destination from the park-and-ride facility is determined by differences in travel times on normal and express lanes, or for those that switch from a local to express bus. In addition, for projects that change the headways of buses, savings in waiting times could occur. Total time savings while traveling on faster lanes are reduced by waiting times to join a vehicle. Note that consistent with other Cal-B/C models, this difference is used to estimate benefits only if the project generates positive travel time savings.

Equations

Total Value of Time Savings, for all commuter types (t) per destination (d):

$$VTT^{d} = [N^{t,d} \cdot AF\ ] \cdot TotT^{t,d} \cdot VOT$$

Where, TotN, the total number of daily commuters covering all destinations is computed from:

$$TotN = S \bullet F \bullet AVO + WB$$

The numbers of commuter types to given destinations are computed as:

$$N^{t,d} = TotN \bullet Dest^{d} \bullet C^{t}$$

The total change in travel time combines travel and waiting times as:

$$TotT^{t,d} = T^{t,d} - WT^{t,d}$$

The model establishes conditions for computing travel and waiting times as per the commuter types listed in Exhibit 23.

Exhibit 23: Travel Time Savings by Commuter Type and Scenario

Commuter Type	Scenario	Travel Time ($T^{t,d}$)	Waiting Time ($WT^{t,d}$)
New – Bus	No Build	Time @ normal speed to destination	Time until next bus
New – Bus	Build	Time @ HOV speed to destination	Time until next bus
Existing – Bus (Local)	No Build	Time @ local bus speed to destination	0
Existing – Bus (Express)	Build	Time @ Expr. bus speed to destination	0
New – Carpool/Van	No Build	Time @ normal speed to destination	0
New – Carpool/Van	Build	Time @ HOV speed to destination	Time until next veh.
Existing – Carpool/Van	No Build	Time @ normal speed to next PnR	0
Existing – Carpool/Van	Build	Time @ HOV speed to next PnR	0

Model Inputs

Exhibit 24: Travel Time Savings - User Inputs and Parameters

Var.	Definition	Value	Unit	Source
S	# of additional spaces at a facility, either as a new or expanded facility	#	Total # of Spaces	User Input
F	the percentage of the spaces that are filled on average	%	Percentage of total	User Input
AVO	Average Vehicle Occupancy of lot users	1.0	Persons / vehicle	Caltrans Assumption

Var.	Definition	Value	Unit	Source
WB	the number of users who walk or bike to a PnR facility	#	# of people	User Input
$Dest^{d}$	the percentages of all users going to a specific destination	%	Percentage of total	User Input
C^{t}	the percentages of commuter types for a given destination	%	Percentage of total	User Input
$TotT^{t,d}$	Percentage of travelers who shift from parallel highway	%	% of demand	User Input
$T^{t,d}$	Travel times to reach a destination (d) by commuter vehicle type (t)	#	In minutes	User Input
$WT^{t,d}$	Waiting times for a commuter vehicle (t) doing to destination (d)	#	In minutes	User Input
VOT	Automobile	$13.65	$/hr/per	1

Sources: 1) USDOT Department Guidance (USDOT, 2016)

Vehicle Operating Cost Savings

The methodology separates fuel operating costs from non-fuel operating costs. A key factor in fuel costs is the relationship between fuel consumption and speed. Fuel consumption data are based on estimates of current average consumption rates. The fuel consumption rates used in Cal-B/C are discussed in the Cal-B/C Parameters Guide. The model determines an appropriate fuel consumption rate based on speed for each project year. Vehicle speed is computed by dividing project distance by travel time. Speed varies by facility type over time. Consumption rates are converted into the total fuel consumed using an estimated VMT based on the number of travelers to each destination. These daily estimates are converted into annual estimates by multiplying by an annualization factor. The result is multiplied by a fixed fuel cost per mile and added to non-fuel costs. Discussion on the costs of fuel and non-fuel usage are discussed in the Cal-B/C Parameters Guide. The estimate of vehicle operating costs are developed for each commuter type applies a similar set of computations as discussed for travel time savings. The difference for vehicle operating costs is that the valuation metric is instead based on distance traveled rather than time. Accordingly, the distance to each destination enters the computations.

Equations

Total Annual Value of Vehicle Operating Costs, by mode:

$$VVOC^{t,d} = [V^{t,d} \cdot AF] \cdot [Dist^{t,d} \cdot Fuel^{t,d}] \cdot VOC^{t,d}$$

Where, $V^{t,d}$, the daily volume of vehicles of commuter types (t) for each destination (d) is computed as:

$$V^{t,d} = N^{t,d} / AVO$$

The value, $N^{t,d}$, the daily volume of commuted types (t) for each destination (d), is computed the same way as described in the travel time savings benefits, above. The same variables are used and not repeated here in this table.

$VOC^{t,d}$ is the sum of fuel, non-fuel and other out of pocket costs, depending on the commuter type and destination. These costs relate to vehicle use, i.e., Fuel and Non-Fuel Costs, and other out-of-pocket costs by mode. Costs differ by commuter type and scenario, as shown in Exhibit 25.

Exhibit 25: Vehicle Operating Cost Savings by Commuter Type and Scenario

Commuter Type	Scenario	Highway Vehicle Use	Other Out of Pocket
New – Bus	No Build	0	Local Bus Fare
New – Bus	Build	0	Express Bus Fare
Existing – Bus (local)	No Build	Fuel @ normal speed + Non-Fuel	Parking
Existing – Bus (express)	Build	Fuel @ HOV speed + Non-Fuel	Express Bus Fare
New – Carpool/Van	No Build	Fuel @ normal speed + Non-Fuel	0
New – Carpool/Van	Build	Fuel @ HOV speed + Non-Fuel	0
Existing – Carpool/Van	No Build	Fuel @ normal speed + Non-Fuel	Parking
Existing – Carpool/Van	Build	Fuel @ HOV speed + Non-Fuel	Share of Parking by AVO

Model Inputs

Exhibit 26: Vehicle Operating Cost Savings - User Inputs and Parameters

Var.	Definition	Value	Unit	Source
S	# of additional spaces at a facility, either as a new or expanded facility	#	Total # of Spaces	User Input
F	the percentage of the spaces that are filled on average	%	Percentage of total	User Input
AVO	Average Vehicle Occupancy of lot users	1.0	Persons / vehicle	Caltrans Assumption
$Dist^{t,d}$	Travel distance to each destination by a commuter vehicle (t) is multiplied by 2 to reflect a roundtrip length	#	Miles per trip	User Input
$S^{t,d}$	Travel speed is computed by dividing travel distance ($Dist^{t,d}$) by travel time ($Time^{t,d}$) by mode and destination	#	MPH	Computed
$Fuel^{t,d}$	Fuel consumption rates depend on average vehicle speed, $S^{t,d}$	#	Gal / mile	Caltrans
Fuel Cost Per Gallon	Automobile fuel cost (Excluding Taxes)	$2.65	$/gal	Computed
	Truck fuel cost (Excluding Taxes)	$2.40	$/gal	Computed
Non-Fuel Cost Per Mile	Automobile	$0.313	$/mi	3
	Truck	$0.429	$/mi	4

Sources: (1) AAA Daily Fuel Gauge Report (2016), (2) California Board of Equalization, (3) AAA Your Driving Costs (2016), (4) American Transportation Research Institute (2010).

Accident Cost Savings

Reducing the risk of vehicle accidents is a primary motivation for many highway capital investments or improvement projects. For example, about one-third of total benefits on many projects can be related to a project's improved safety conditions. Benefits of improved safety are estimated from the estimated reduction in the number or severity of accidents with a project and comparing that number and severity without the project. The monetary values for each type of accident are used to determine a monetized total value of accident risk reduction over time. Data involved in accident risk reduction analyses principally entail estimating annual accident rates by type with historical data and assuming these rates are reasonable forecasts without a project. With a project, changes could occur with safer infrastructure, lower traffic volumes or both.

Cal-B/C PnR estimates the impact of a transportation project on accident costs by comparing accident costs under No Build and Build scenarios over a 20-year period. Additional information on accident cost methodology is contained in the Cal-B/C Resource Guide. Additional information on valuation parameters is provided in the Cal-B/C Parameters Guide.

Equations

Total Value of Accident Risk Reduction, by mode:

$$VAR^{t,d} = [V^{t,d} \cdot AF\ ] \cdot Dist^{t,d} \cdot ACC^{t,d}$$

Where $ACC^{t,d}$, accident costs per-mile, is derived using incident rates by accident severity (e.g., FatalAcc) and the respective cost by severity (e.g., CostFatal) and computed as a sum product of accident frequencies per mile and costs per accident, by severity

$$ACC^{t,d} = (FatalAcc^{t,d} \cdot CostFatal^{t,d} + InjAcc^{t,d} \cdot CostInj^{t,d} + PDAcc^{t,d} \cdot CostPD^{t,d})$$

$V^{t,d}$, the daily volume of vehicles of commuter types (t) for each destination (d) is computed the same way as described in the vehicle operating cost savings benefits, above. The same variables are used and not repeated here in this table.

$ACC^{t,d}$, accident costs per-mile by commuter vehicle, is derived using incident rates by accident severity (e.g., $FatalAcc^{t,d}$) and the respective cost by severity ($CostFatal^{t,d}$). Exhibit 27 shows how costs are incurred by commuter type. For instance, a new bus commuter would reduce accident risk for drivers. Existing bus commuters that switch from local to express buses have no change in accident risk. Carpool/van commuters represent a reduction in accident risk based on the lower miles driven in Build compared to the No Build.

Exhibit 27: Accident Cost Savings by Commuter Type and Scenario

Commuter Type	Scenario	Accident Costs
New – Bus	No Build	Highway Accident Costs per Mile – No Build
New – Bus	Build	0
Existing – Bus (local)	No Build	0
Existing – Bus (express)	Build	0
New – Carpool/Van	No Build	Highway Accident Costs per Mile – No Build
New – Carpool/Van	Build	Highway Accident Costs per Mile – Build
Existing – Carpool/Van	No Build	Highway Accident Costs per Mile – No Build
Existing – Carpool/Van	Build	Highway Accident Costs per Mile – Build

Model Inputs

Exhibit 28: Accident Cost Savings - User Inputs and Parameters

Var.	Definition	Value	Unit	Source
S	# of additional spaces at a facility, either as a new or expanded facility	#	Total # of Spaces	User Input
F	the percentage of the spaces that are filled on average	%	Percentage of total	User Input
AVO	Average Vehicle Occupancy of lot users	1.0	Persons / vehicle	Caltrans
$Dist^{t,d}$	Travel distance to each destination by a commuter vehicle (t) is multiplied by 2 to reflect a roundtrip length	#	Miles per trip	User Input
$CostFatal^{t,d}$	Fatal Accident Cost	$10,800,000	$/accident	1
$CostInj^{t,d}$	Injury Accident Cost	$148,800	$/accident	1
$CostPD^{t,d}$	PDO Accident Cost	$9,700	$/accident	1
CostAVG	Average Accident Cost	$185,600	$/accident	1
$FatalAcc^{t,d}$	Fatal Accident Rates	0.006	per mil veh-mi	2
$InjAcc^{t,d}$	Injury Accident Rates	0.29	per mil veh-mi	2
$PDAcc^{t,d}$	PDO Accident Rates	0.55	per mil veh-mi	2
$NFAcc^{t,d}$	Non-Freeway Rates	1.05	per mil veh-mi	3

Sources: (1) USDOT VSL (2016); (2) TASAS, 2016, (3) TASAS summary 2009

Emissions Cost Savings

Cal-B/C focuses on the environmental impacts associated with result of commuters using the facility itself.[16] Travel changes related to travel speeds, vehicle trip-making, or diversion of trips have implications for air pollution and greenhouse gas emissions. Vehicle emissions generally fall into two categories:

- Air Pollutant Emissions: Motor vehicles emit pollutants, such as carbon monoxide (CO), oxides of nitrogen (NOX), volatile organic compounds (VOC), particulate matter (PM), and oxides of sulfur (SOX).
- Greenhouse Gas Emissions (GHG): Fuel consumption releases gases that trap heat within the Earth's atmosphere, of which carbon dioxide is the most important.

The physical volumes of air-pollutants and greenhouse gas emissions resulting from travel are readily quantified since emission rates are well understood.[17] Cal-B/C PnR estimates the benefits of reduced pollutant emissions by comparing the value of emissions costs with and without the transportation project. Air pollutant emissions are estimated based on vehicle-miles traveled and a per-mile emissions rate, which depend on travel speeds. The emissions cost methodology is discussed further in the Cal-B/C Resource Guide. Additional information on emissions valuation parameters is provided in the Cal-B/C Parameters Guide.

Equations

Total Annual Value of Emissions Reduction, by mode:

$$VER^{t,d} = [V^{t,d} \cdot AF] \cdot Dist^{t,d} \cdot EC^{t,d}$$

Where, $V^{t,d}$, the daily volume of vehicles of commuter types (t) for each destination (d) is computed the same way as described in the vehicle operating cost savings benefits, above. The same variables are used and not repeated here.

Total emissions costs, $EC^{t,d}$ for each mode and destination, are the sum product of each pollutant's emissions ($pollutant^{m}$) rate per mile by mode (m), and costs per pollutant ($VPP_{pollutant}$)[18]:

$$EC^{m}=(CO^{m}\cdot VPP_{CO}+CO_{2}^{m}\cdot VPP_{CO_2}+NO_{X}^{m}\cdot VPP_{NO}+PM_{10}^{m}\cdot VPP_{PM_{10}}+SO_{X}^{m}\cdot VPP_{SO}+VOC^{m}\cdot VPP_{VOC})$$

Exhibit 29 shows how in-vehicle pollutant emissions costs are incurred by commuter type. For instance, a change in bus type would not result in a change in emissions costs. Carpool/van commuters represent a reduction in emissions costs based on the lower miles driven in the Build

[16] Construction activity can affect the environment directly through equipment emissions and noise, or indirectly by causing increased traffic congestion and vehicle emissions during the construction period.

[17] Other environmental effects are less significant, less understood, or difficult to quantify and value. As a result, these effects tend to be excluded from benefit-cost models. Ignored effects include: Noise, Hazardous Materials Incidents, and Upstream Fuel Effects.

[18] Emissions rates are a function of vehicle speed, which is a user input.

scenario compared to the No Build scenario. Any additional commuters who arrive by biking or walking to the PnR facility and switched from passenger vehicles would have higher "starting" emissions in the No Build case and zero emissions in the Build case, after they switch.

Exhibit 29: Emissions Cost Savings by Commuter Type and Scenario

Commuter Type	Scenario	Running (In-Vehicle) Pollutant Costs
New – Bus	No Build	Pollutant Costs per Mile – No Build
New – Bus	Build	0
Existing – Bus	No Build	0
Existing – Bus	Build	0
New – Carpool/Van	No Build	Pollutant Costs per Mile – No Build
New – Carpool/Van	Build	Pollutant Costs per Mile – Build
Existing – Carpool/Van	No Build	Pollutant Costs per Mile – No Build
Existing – Carpool/Van	Build	Pollutant Costs per Mile – Build

Model Inputs

Exhibit 30: Emissions Cost Savings - User Inputs and Parameters

Var.	Definition	Value	Unit	Source
$Dist^{t,d}$	Travel distance to each destination by a commuter vehicle (t) is multiplied by 2 to reflect a roundtrip length	#	Miles per trip	User Input
Pollutant Emissions	Pollutant emissions per ton, by vehicle, pollutant type, given an average vehicle speed	Varies by pollutant, See Cal-B/C Model	Tons / mile	1
VPP	Value per pollutant	Varies by pollutant, See Cal-B/C Model	$/ton	2, 3

Sources: (1) EMFAC 2014 (CARB, 2015), (2) McCubbin and Delucchi (1996); (3) US Interagency Group on Social Cost of Carbon (2015)

CAL-B/C AT

Cal-B/C AT calculates benefits for projects that impact active transportation modes such as cycling and walking. This section summarizes the active transportation parameters and their sources. More information can be found in the user's guide for Cal-B/C AT.

- **Annualization Factors (AF).** Cal-B/C AT 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 AT assumes that there are 180 school days per year when benefits occur.
- **Vehicle Statistics.** For estimating automobile emissions, Cal-B/C AT 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) and Broach et al. (2012). Cal-B/C AT uses an average walking speed of 3.0 mph based on 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.
- **Distance Traveled.** An important driver of user value is their distance traveled. Because this value is not necessarily known by tool users, standards for distance traveled are included (see Exhibit 31). These values average distance covered per trip for cyclists and pedestrians – both adults and children on route to school – is assumed to vary by region. These data were computed by evaluating data from the CA Household Travel Survey.

Exhibit 31: Average Distance for Active Transportation Trips by Mode and Location

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)

Journey Quality Benefits

Journey quality for cyclists is a direct function of their value of time and willingness to spend more time on a better or safer route. Cal-B/C AT uses the same value of time for pedestrians and cyclists as the other Cal-B/C tools do for other modes. 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 Caltrans choses to use a different value of time for children in the future.

Cal-B/C AT 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.

Equations

Total Annual Value of Journey Quality

Cyclists:

$$VJQC = [N \cdot AF] \cdot [Dist \cdot (1 - MRS) \cdot (1/ MPH_C)] \cdot VOT$$

Pedestrians:

$$VJQP = [N \cdot AF] \cdot Dist \cdot VPM$$

Model Inputs

Exhibit 32: Bike Journey Quality Benefit Inputs - User Inputs and Parameters

Var.	Definition	Value	Unit	Source
N	One-way daily trips, measured originally as bike facility counts and estimated on a daily basis	#	Trips/Day	User Input
Dist	Mean distance traveled per trip for cyclists, varies by location in CA (see Exhibit 31)	Varies regionally for cities in north, south of CA, and rural areas.	Miles per trip	1
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 Bike Class II: 0.49 Bike Class III: 0.92 Bike Class IV: 0.49	Ratio	2
MPH_C	Mean cycling speed, in miles per hour, per trip in CA	11.8	Miles per hour	3
VOT	Value of Time as 50% of CA Median Wage	$13.65	$ per hour	Caltrans

Sources: (1) Computed from CHTS (2012); (2) Hood et al. (2011); (3) Broach et al. (2012)

Exhibit 33: Pedestrian Journey Quality Benefit - User Inputs and Parameters

Var.	Definition	Value	Unit	Source
N	One-way daily trips	#	Trips/Day	User Input
Dist	Mean distance traveled per trip, varies by location in CA	Varies regionally for cities in north, south of CA, and rural areas (see Exhibit 31)	Miles per trip	1
VPM	Journey quality value per mile per pedestrian	Street lighting: $0.05 Curb level: $0.03 Crowding: $0.02 Pavement evenness: $0.01 Information panels: $0.01 Benches: $0.01 Directional signage: $0.01	Dollars per mile per trips; converted from estimated values in British pounds per km (2010), as reported in UK DfT TAG.	2

Sources: (1) Computed from CHTS (2012); (2) Heuman, D. (2005)

Accident Cost Savings – Facility Users

Cal-B/C AT estimates safety benefits if specific infrastructure or operational changes at intersections of existing facilities reduce risk of accidents. Data on three types of crashes 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

Equations

Total Annual Value of Intersection Safety Enhancements:

$$VIS = C \cdot CR \cdot ACC$$

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

ACC = (FatalAcc· CostFatal + InjAcc· CostInj + PDAcc· CostPD), ACC equals the sum-product of accident frequencies and costs per accident by severity per mile using incident rates by accident severity (e.g., FatalAcc) and the respective cost by severity (e.g., CostFatal).

Model Inputs

Exhibit 34: Safety Benefit - User Inputs and Parameters

Var.	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	User Input
CR(i)	Percentage reduction in the crash rate, by crash type	Signalized intersection, install pedestrian countdown signal head: 25%	%	1
		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%		
$CostFatal^T$	Cost of fatal accident.	$10,800,000	$ / accident	2
$CostInj^T$	Cost of injury accident.	$148,800	$ / accident	
$CostPD^T$	Cost of property damage only accident.	$9,700	$ / accident	

Sources: (1) Caltrans, Local Roadway Safety Manual for California Local Road Owners; (2) USDOT VSL Guidance (2016)

Travel Time Savings - Intersection Delay Reduction Benefits

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 AT estimates delay reduction benefits for each mode where applicable using standard valuation methods for the value of time savings.

Equations

Total Annual Value of Intersection Delay Reductions:

$$VID = [N \cdot AF] \cdot [Dist \cdot N / L \cdot S] \cdot VOT$$

Model Inputs

Exhibit 35: Intersection Delay Benefit Inputs - User Inputs and Parameters

Var.	Definition	Value	Unit	Source
N	One-way daily trips, measured originally as bike facility counts and estimated on a daily basis	#	Trips/Day	User Input
Dist	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 31)	Miles per trip	1
N	Number of improved intersection along entire facility	Depends on project	#	User Input
L	Facility length	Depends on project	Miles	User Input
S	Time savings per intersection	Depends on project	Minutes	User Input
VOT	Value of Time as 50% of CA Median Wage	$13.65	$ per hour	2

Sources: (1) Computed from CHTS (2012); (2) USDOT Guidelines (2016)

Reduced Absenteeism Benefits

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 found 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.

Equations

Total Annual Value of Health - Reduced Absenteeism:

$$VHRA = [N_I \cdot P_C / R \cdot AF] \cdot [S \cdot P_{SL} \cdot P_{SR}] \cdot VOD$$

Model Inputs

Exhibit 36: Reduced Absenteeism Benefits Inputs - User Inputs and Parameters

Var.	Definition	Value	Unit	Source
N_I	Induced one-way daily trips	#	Trips/Day	User Input
P_C	Percentage of users that commute to and from work	7% to 11% for cyclists and 4% to 9% for pedestrians, varies regionally	%	1
R	Number of unlinked trips per day	1.93 for cyclists; 2.38 for pedestrians	#	1
S_E	Average absence of employees	3.6	Days/ Year	2
P_{SL}	Percentage accounted for by short-term sick leave	95	%	3
P_{SR}	Percentage of sick days reduced by being active for at least 30 minutes a day	6	%	4
W_D	Average daily wage per worker (California)	207.28*	$/Day ($2014)	5

* Adjusted to $2016 in the model for consistency

Sources: (1) Computed from CHTS (2012); (2) 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); (3) U.K. Department for Transport. (2014). TAG UNIT A4.1 Social Impact Appraisal. Transport Analysis Guidance. (UK DfT TAG, 2014); (4) World Health Organization (WHO) (2003). Health and development through physical activity and sport. Geneva; (5) Occupational Employment and Wage Estimates for California, May 2014, Bureau of Labor Statistics.

Reduced Mortality Benefits

Cal-B/C AT 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 AT are from 2010-2014 Death Rates from the California Department of Health.

Equations

Total Annual Value of Health - Reduced Mortality:

$$VHRM = [N_I \cdot P_A / R \cdot AF] \cdot [Dist \cdot M \cdot (1\text{-}RR)] \cdot VSL$$

Model Inputs

Exhibit 37: Reduced Mortality Benefits - User Inputs and Parameters

Var.	Definition	Value	Unit	Source
N_I	Induced one-way daily trips	#	Trips/Day	User Input
R	Number of unlinked trips per day	1.93 for cyclists; 2.38 for pedestrians	#	1
Dist	Mean distance traveled per trip, varies by location in CA	Varies regionally for cities in north, south of CA, and rural areas. (see Exhibit 31)	Miles per trip	1
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 38)	% of users, by mode	1
M	Baseline annual mortality rate from all causes, by age cohort: Cyclists: Ages 20-64, Pedestrians: Ages 20-74	266 for cyclists 395 for pedestrians (see Exhibit 39)	# of deaths per 100,000	2
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	3
VSL	Value of a statistical life	10,800,000		4

Sources: (1) Computed from CHTS (2012); (2) CA Dept. of Public Health, Death Statistical Data Exhibit III-5-2; (3) WHO HEAT Tool (2016); (4) USDOT VSL Guidelines (2016).

Exhibit 38: Proportions of Bike Facility Users by Age Cohort

Age Cohorts by Activity Type	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)

Exhibit 39: Baseline All-Cause Mortality Risk by Age Cohort (2014)

Age Cohorts	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

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

Emissions Cost Savings

Reduced vehicle use, due a shift of travelers to active transportation, creates public benefits by reducing the externalities of air emissions from auto use. Changes in the value of air emissions would be associated with differences in VMT or vehicle speeds. Emissions rates per mile are determined by using lookup tables according to vehicle speeds. Pollutants evaluated include carbon monoxide (CO), oxides of nitrogen (NO_X), volatile organic compounds (VOC), particulate matter (PM), and oxides of sulfur (SO_X)) and greenhouse gases (CO_2). The value of pollutant emissions per mile are combined with VMT to determine a total value of emissions.

Equations

Total Value of Emissions Cost Savings:

$$VER = [N_I \bullet P_D / AVO \bullet AF] \bullet Dist \bullet EC$$

Where, total emissions costs are the sum product of each pollutant's emissions (*pollutant^{m}*) rate per mile by mode (m), and costs per pollutant ($VPP_{pollutant}$)[19]:

$$EC=(CO \cdot VPP_{CO} + CO_2 \cdot VPP_{CO_2} + NO_X \cdot VPP_{NO} + PM_{10} \cdot VPP_{PM_{10}} + SO_X \cdot VPP_{SO} + VOC \cdot VPP_{VOC})$$

Model Inputs

Exhibit 40: Reduced Emissions Benefits - User Inputs and Parameters

Var.	Definition	Value	Unit	Source
N_I	Induced one-way daily trips	#	Trips/Day	User Input
Dist	Mean distance traveled per trip, varies by location in CA	Varies regionally for cities in north, south of CA, and rural areas. (see Exhibit 31)	Miles per trip	1
O	Average vehicle occupancy	1.5	Persons per vehicle	1
Pollutant Emissions	Pollutant emissions per ton, by pollutant, given an average vehicle speed	Varies by pollutant	Tons / mile	2
VPP	Value per pollutant	Varies by pollutant	$/ton	3,4

Sources: (1) Computed from CHTS (2012); (2) California Air Resources Board, EMFAC 2014, (2015) (3) McCubbin and Delucchi (1996); (4) US Interagency Group on Social Cost of Carbon (2015).

Accident Cost Savings – Roadway Users

Accident rates may decline for road users when drivers shift to cycling or walking from motor vehicles simply because there are fewer cars on the road. Developing reasonable estimates of

[19] Emissions rates are a function of vehicle speed, which is a user input.

these benefits depends ideally on the availability of local data on accident rates in the corridor where an active transportation project is implemented. Relevant data would include numbers of motorized vehicle accidents per year by level of severity and total annual VMT. 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.

Cal-B/C AT compares accident costs with the project and without the project. Accident costs are summed over the lifetime of the project to derive the total impact. Individual projects may improve or adversely impact vehicle accidents, so the net result may be positive or negative. The estimation of the value of reduced accidents is presented in three parts: scale of impact, impact factors, and impact value per unit. Total benefits equal the difference in value between No Build and Build scenarios.

Equations

Total Annual Value of Accident Cost Savings Reduction – Roadway Users:

$$VAR = [N_I \cdot P_D / AVO \cdot AF] \cdot Dist \cdot ACC$$

Where ACC, accident costs per-mile is derived using incident rates by accident severity (e.g., FatalAcc) and the respective cost by severity (e.g., CostFatal) and computed as a sum product of accident frequencies per mile and costs per accident, by severity:

$$ACC = (FatalAcc \cdot CostFatal + InjAcc \cdot CostInj + PDAcc \cdot CostPD)$$

Model Inputs

Exhibit 41: Reduced Auto Accident Risk Reduction Benefits - User Inputs and Parameters

Var.	Definition	Value	Unit	Source
N_I	Induced one-way daily trips	#	Trips/Day	User Input
Dist	Mean distance traveled per trip, varies by location in CA	Varies regionally for cities in north, south of CA, and rural areas.	Miles per trip	1
O	Average vehicle occupancy	1.5	Persons per vehicle	1
C_S	Statewide crash rates for different levels of severity	Varies by type of accident	Crashes per million vehicle-miles	2
VPC	Value per crash, by severity	Varies by crash severity	$/incident, by level of severity	3

Sources: (1) Computed from CHTS (2012); (2) California Department of Transportation, TASAS Unit, 2007 to 2009 average; (3) California Department of Transportation, TASAS Unit, 2007 to 2009 average

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