

TRANSPORTATION BENEFIT-COST ANALYSIS: IT'S ALL ABOUT INPUTS!

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Chris Williges*
Vice President
System Metrics Group, Inc.
244 California Street, Suite 607
San Francisco, CA 94111
(415) 395-7000
chris_williges@sysmetgroup.com

Mahmoud Mahdavi
Senior Economist
California Department of Transportation
Office of Transportation Economics
Division of Transportation Planning, MS-32
1120 N Street
Sacramento, CA 95814
(916) 653-9525
mahmoud_mahdavi@dot.ca.gov

* Corresponding author

TRANSPORTATION BENEFIT-COST ANALYSIS: IT'S ALL ABOUT INPUTS!

Abstract

The California Department of Transportation (Caltrans) assesses over 100 transportation projects annually for its State Transportation Improvement Program (STIP), one of the largest such programs in the country. Caltrans relies on benefit-cost analysis as one factor in reviewing projects for inclusion in the STIP. Since all of the benefit-cost assessments need to be conducted over the span of just a few weeks, Caltrans developed a spreadsheet-based model to facilitate the analysis. The model relies on minimal data and incorporates simple rules of thumb to estimate benefits for several types of transportation projects. Despite the simplicity of the inputs, Caltrans has found that the need for accurate input data continues to frustrate “real world” benefit-cost analysis. This paper describes the motivation and structure of the California Lifecycle Benefit/Cost Analysis Model (Cal-B/C), recent applications, and its continued evolution.

TRANSPORTATION BENEFIT-COST ANALYSIS: IT'S ALL ABOUT INPUTS!

On two occasions, I have been asked [by members of Parliament], "Pray, Mr. Babbage, if you put into the machine wrong figures, will the right answers come out?" I am not able rightly to apprehend the kind of confusion of ideas that could provoke such a question.

- Charles Babbage (1791-1871), mathematician and inventor of the Difference Engine

INTRODUCTION

The California Lifecycle Benefit/Cost Analysis Model (Cal-B/C) offers a simple, practical method of preparing economic evaluations for prospective highway and transit improvement projects within the State of California. The California Department of Transportation (Caltrans) originally developed the Cal-B/C model in the mid-1990s to assess the cost-effectiveness of projects proposed for the State Transportation Improvement Program (STIP). The STIP is a multi-year capital improvement program that covers the majority of transportation projects on and off the State Highway System in California. Caltrans also uses the model to assess transit projects and address as hoc requests for analysis.

The model was developed in-house to address the need for assessing several projects in a short timeframe. After using the model for a few years, the Department decided to have the model reviewed by an outside consultant. This resulted in a new model that retained the simplicity of the original model, but added features such as calculating speeds, handling carpool traffic, and modeling peak versus off-peak travel.

The Cal-B/C model has evolved over the last decade. One of the first such changes was to handle projects that improve pavement. Although that capability has not been used extensively over the last few years, a recent emphasis on highway operations and system condition may change this. The most extensive update occurred a few years ago, when Caltrans added the ability to handle operational improvements and intelligent transportation systems (ITS). These types of public works projects do not significantly change the transportation infrastructure, but they do improve the way that the existing infrastructure performs.

In a November 2006 statewide election, California voters approved a large infrastructure bond package, of which \$4.5 billion was dedicated to funding performance improvements on the state highway system and major access routes (the Corridor Mobility Improvement Account, or CMIA). The California Transportation Commission (CTC) adopted guidelines that required a benefit-cost analysis for every

proposed project proposed. Caltrans needed to assess over 100 projects within a few weeks and chose to use the Cal-B/C model.

Caltrans also made the model available to other transportation agencies so their staff would understand how funding decisions were made and consider the relative merits of their proposed projects. This transparency also allowed many people to review the Cal-B/C model. For example, in the San Francisco Bay Area, the regional planning agency hired an outside consultant to help it assess projects before submission, so only the best projects went forward. At the same time, the local agencies hired their own consultants or conducted analyses in-house to consider the effectiveness of their projects before submitting them to the regional planning agency. Similar processes were followed in other regions of the state.

The use of Cal-B/C for the CMIA assessment brought planners and engineers at several agencies in contact with the model. At the same time, it exposed the model to a much wider range of projects than had been evaluated before and revealed limitations in the existing model. As an example, Cal-B/C had trouble evaluating the impacts of intersections, projects that solve queuing problems, and shifts in traffic that appeared instead to be new trips (i.e., induced travel).

Perhaps the biggest revelation was the sensitivity of transportation benefit-cost analysis to the input data. Despite relative sophistication in the way Cal-B/C models transportation projects, a handful of inputs (travel speeds and traffic volumes) tend to drive the results of the analysis. Caltrans is currently identifying ways to improve Cal-B/C based upon the lessons learned in the CMIA assessment. This includes providing guidance on appropriate input data and preferred sources, enhancing the model's capability to interface with regional travel forecasting models, and incorporating traffic micro-simulation to assess the impacts of proposed transportation improvement projects from a corridor perspective.

This paper discusses the general benefit-cost framework to analyze transportation infrastructure projects. We also present an overview of common transportation benefit-cost models and the Cal-B/C model. We subsequently describe the method California has used for soliciting data on transportation projects and for the CMIA analysis in particular. This paper ends with a brief summary and a discussion of findings.

TRANSPORTATION BENEFIT-COST ANALYSIS

Benefit-cost modeling provides an organized way of comparing the lifecycle cost of a project to the lifecycle benefits that result from the project. One of the first steps in conducting such assessments is to define the scope of the problem. For public policy projects, this decision is couched in terms of whether the analysis should be conducted from the standpoint of users of the system or society in general.

For transportation projects, the analysis typically focuses on the agency costs and the user benefits that accrue to the traveling public. Assessments may also consider impacts on society at large, but user benefits are the primary emphasis.

Most transportation benefit-cost assessments consider three types of user benefits:

- *Travel time savings*, which are defined as the difference in the time users spend traveling before and after construction of projects
- *Vehicle operating cost reductions*, which include fuel consumption, break wear, tire wear, and use-related vehicle depreciation
- *Safety improvements*, which reflect reductions in the number or severity of accidents after projects are built.

Some models also include societal impacts, such as air quality or noise. However, these societal impacts are hard to quantify since some of the basic research on vehicle emissions, noise propagation, and the monetary values of these impacts on society are generally lacking.¹

Most of these user benefits are direct functions of travel speed and traffic volume (i.e., the number of users benefiting from the facility). Speed, in turn, can often be reduced to a function of volume and the design of the transportation facility. This leads to the importance of having accurate volume data for transportation benefit-cost analysis – a subject to which this paper will return later.

The distinction between user and societal benefits becomes practically meaningless in most transportation applications. Transportation systems tend to operate as a network and most of society becomes a user of the network at one time or another. For highways, over 90 percent of California households have at least one vehicle available.² Households without available vehicles benefit from the cargo shipped on California highways and become indirect users of the highways as a result.

For transit projects, just over five percent of Californians travel to work by public transportation.³ However, this low percentage disregards cross-impacts between transit and highway usage. Transit vehicles often operate on highways. Also, transit and private vehicle can serve as near perfect substitutes for many trips. As a result of the near ubiquitous ownership of private vehicles and the substitution relationship with transit, the sum of user benefits are the societal impacts for most benefit categories.

¹ McCubbin and Delucchi (1996) provide one of the few reviews of the subject.

² US Census Bureau, Data Set: Census 2000 Summary File 3 (SF 3) - Sample Data, QT-H11. Vehicles Available and Household Income in 1999: 2000, Geographic Area: California.

³ US Census Bureau, Data Set: Census 2000 Summary File 3 (SF 3) - Sample Data, QT-P23. Journey to Work: 2000, Geographic Area: California.

Although benefit-cost analysis can be conducted without the use of a computer model, benefit-cost models have become much more common since the advent of personal computers. A computer model becomes particularly useful when multiple scenarios are being considered.

Transportation Benefit-Cost Models

A number of computerized benefit-cost models are available for analyzing transportation projects. Most of these models focus on specific transportation modes or applications. For example, the Federal Rail Administration (FRA) has a rail-only model called *RailDEC* (HLB, no date) and the Federal Aviation Administration (FAA) has a Microsoft Access application called *Airport Benefit Cost System (ABC)* that implements the Administration's procedures for State Airport System Plans (EDRG, no date). A few other models, such as the ITS Decision Analysis System, or *IDAS*, (Cambridge Systematics, no date) and SCReening for ITS, or *SCRITS*, (SAIC, 1999) estimate the benefits of intelligent transportation systems (ITS). For simplicity, this paper will focus on highway transportation models, although Cal-B/C incorporates aspects of both highway and transit benefit-cost models.

One of the major tradeoffs in developing highway benefit-cost models is simplicity (easy-to-use) and accuracy (flexibility to address multiple project types and their network effects). Transportation benefit-cost models typically manage this tradeoff in one of two ways:

- *Sketch planning approach*, which deals strictly with a single highway corridor and ignores benefits beyond the immediate project area
- *Network-based approach*, which estimates project benefits using the outputs of a network transportation model.

Sketch planning tools have the advantage of capturing the most direct project benefits without requiring extensive input data. For example, the Federal Highway Administration (FHWA) developed the Sketch Planning Analysis Spreadsheet Model (SPASM) as part of a National Highway Institute (NHI) course (FHWA, 1998). Figure 1 shows a snapshot of the facility information required. As is typical for a sketch planning model, very little information is entered about a limited set of transportation facilities. The model does not explicitly consider the impact of shifting traffic from one highway to another and the approach can fail to capture significant project benefits. These limitations make sketch planning models not very useful for network problems (e.g., a new highway interchange that provides local street access, but provides little benefit to the highway itself).

Network-based models address the limitations of sketch-planning tools by allowing users to consider entire highway systems. For example, the FHWA developed

Highway Economic Requirements System (HERS) to estimate the current condition and performance of the national highway system and the cost of the most effective improvements to bring the system to an established threshold (USDOT, 2004). The Administration uses the model to report to Congress the national highway needs biennially.

A few years ago, FHWA developed a state version of HERS called *HERS-ST* (FHWA, 2002). The model is intended to allow state departments of transportation (DOTs) to conduct analyses similar to those conducted by FHWA for Congress. The model can be used to assess statewide investments or the benefit of specific projects. The primary limitation of HERS and HERS-ST is that they are linked to the federal Highway Performance Monitoring System (HPMS).

These approaches are rarely satisfactory for state DOTs and regional planning agencies because the HPMS data and the forecasts are not consistent with up-to-date local traffic counts or more sophisticated models:

- Local agencies employ *traffic counts* to estimate the number of vehicles using a facility on a regular basis (e.g., annually) or on an ad hoc basis (e.g., for a specific transportation improvement study).
- *Regional travel demand models* incorporate traffic counts, travel and housing projections, as well as probability models to forecast travel on regional transportation networks. Regional planning agencies are required to use regional travel demand models in the preparation of their Regional Transportation Plans (RTPs).
- *Micro-simulation models* can employ a variety of modeling techniques and are favored by traffic engineers to model the impacts of changes in highway infrastructure on traffic behavior.

Each of these techniques provide speed and volume data that are necessary for benefit-cost analyses of transportation projects. A few benefit-cost models allow users to incorporate the output of regional travel demand models or micro-simulation models directly.

For example, the *NET_BC* model considers three primary user benefits: travel time, vehicle operating costs, and safety (BLA, 2004). The benefits are calculated directly from regional trip tables and account for differences in trip purpose and mode (automobile versus truck). The model functions as a post-processor – it can be attached directly to a modified travel demand model and run as each scenario is considered in the model. *NET_BC* calculates travel time benefits from the travel demand model trip tables. Many of the built-in parameters and assumptions are consistent with HERS.

Another model, the *StratBENCOST* model, was developed as part of National Cooperative Highway Research Project (NCHRP) 2-18(4). It incorporates methodologies from the earlier HERS and MicroBENCOST models (HLB, 1999). StratBENCOST allows users to estimate the benefits associated with: 1) single highway segments that do not involve traffic diversion, and 2) highway investments that impact networks. In this way, the StratBENCOST supports corridor and network analysis, depending on the level of the input data.

StratBENCOST incorporates a Monte Carlo simulation that allows the model to consider the uncertainty in input parameters explicitly. This is a useful feature that acknowledges the potential for “errors” in regional travel demand modeling. For network modeling, StratBENCOST relies on external estimations in travel demand models. StratBENCOST allows for the analysis of up to 20 scenarios.

The FHWA developed the Surface Transportation Efficiency Analysis Model (*STEAM*) to conduct corridor and network-level benefit-cost analyses (CS, 2000). The SPASM spreadsheet model is a predecessor of STEAM. Like StratBENCOST and NET_BC, STEAM can use network flows and trip matrices from travel demand models to estimate network impacts. However, multiple alternative analyses require multiple model runs, and the inputs must be entered manually into STEAM after each run.

Despite varying levels of complexity, all of these example transportation benefit-cost models share one common feature – the benefits are functions of travel speed and traffic volumes.

THE CAL-B/C MODEL

Cal-B/C Framework

The Cal-B/C model is an Excel workbook that supports economic benefit and cost analysis for a range of capacity-expansion and operational improvement transportation projects. The spreadsheet format allows the calculations to be shown as formulas, so the model does not appear as a “black box.”

Caltrans developed Cal-B/C to accommodate statewide variations in available transportation data. Some Caltrans districts have regional travel demand and micro-simulation models, which allow them to capture benefits, such as network and multi-modal effects. Similar to StratBENCOST, Cal-B/C provides the flexibility to estimate project benefits from a simple set of traffic data or from more complicated travel demand and micro-simulation outputs. Unlike StratBENCOST, Cal-B/C recognizes the importance of having consistent travel speed calculations across projects and allows users to estimate travel speeds from the traffic volumes.

The model consists of a cover page and ten worksheets. Users generally refer to only the first four worksheets (including one that provides instructions and reference materials) to conduct analyses. The remaining worksheets perform the detailed benefit calculations or store economic parameters and default transportation assumptions.

Cal-B/C requires relatively few user inputs. The first worksheet after the cover page provides instructions on each step involved in performing a basic analysis and hints on how to avoid problems in the analysis. Cells in the spreadsheets are color-coded. Green cells represent required data (i.e., values users must input for the model to work). Red cells provide default values, such as average vehicle occupancy (i.e., the number of people in each vehicle), that users can change if needed. Blue cells reflect data items calculated by the model, but can be changed if more detailed data are available.

Figure 2 provides an example of the project information sheet. This worksheet allows users to enter descriptive information, expected traffic volumes, accident rates, transit information (for transit projects), and expected project construction and operating costs. The project information sheet does not include an input for travel speeds. Instead, the speeds are calculated from traffic volumes to provide consistent estimations and to minimize “gaming” (people trying to exaggerate project benefits).

For a highway investment, the primary user inputs for the benefit calculations are:

- Highway design and traffic data:
 - Number of general traffic lanes
 - Number of carpool lanes
 - Estimated free-flow travel speed
 - Length of highway segment and affected areas
- Average daily traffic (ADT)
- Average hourly carpool traffic
- Three-year accident data
- Statewide average accident rates for the before and after highway facility type.

The Cal-B/C model then calculates the preliminary travel speed, traffic volume, and accident data that are the direct inputs to the benefit calculations. The model calculates speeds using speed/volume relationships found in the 2000 Highway Capacity Manual, which is a common rule of thumb used by traffic engineers to estimate highway speeds.

The next worksheet allows users to check and override the calculated values with project-specific information, if such information is available. Users can override the initial values with data aggregated from a network model. A travel demand model or a micro-simulation model can estimate shifts in travel speeds and traffic volumes over every portion of the transportation network.

Figure 3 shows an example of the benefit-cost results produced by the model:

- Lifecycle costs
- Lifecycle benefits
- Net present value
- Benefit/cost ratio
- Rate of return on investment
- Project payback period.

The sheet allows users to exclude the effects of vehicle emissions and induced travel,⁴ which Cal-B/C calculates using consumer surplus theory.

While the model requires inputs on only three worksheets, users can review the detailed calculations and change the model parameters. The final worksheet contains all of the economic values and rate tables used by the model. Adjusting the economic update factor⁵ changes the year of analysis in real dollar terms.

Other parameters and rate tables included in the model are:

General Economic Values

- Year of current dollars for model
- Economic update factor (using GDP deflator)
- Real discount rate

Highway Operations Measures

- Maximum volume-capacity (v/c) ratio
- Percent ADT in average peak hour
- Capacity per lane (general)
- Capacity per HOV lane

Travel Time Values

- Average hourly wage (for Transportation and Utilities industry and all industries statewide)
- Automobile, truck, and transit

User Operating Costs

- Fuel cost per gallon
- Non-fuel cost per mile (automobile and truck)

Highway Accident Costs

- Cost of a fatality
- Cost of an injury (Level A Severe, Level B Moderate, Level C Minor)
- Cost of a highway accident (fatal, injury, and PDO)
- Statewide hwy accident rates (fatal, injury, PDO)

Fuel Consumption Rates

- Gallons per VMT for autos and trucks

Passing Lane Accident Reduction Factors

Transit Accident Rates and Costs

- Fatality, injury, and PDO accidents
- Passenger train, light-rail, and bus

Highway Emissions Rates

- CO, NOX, PM10, SOX, and VOC
- Automobile, truck, and bus

Rail Emissions Rates

- CO, NOX, PM10, and VOC
- Passenger train and light-rail

Emissions Costs

- Urban Southern California, urban Northern California, and rural California
- Automobile, truck, and bus.

⁴ Induced travel refers to new trips that result from a transportation improvement. In this case, a transportation facility must accommodate demand in excess of the existing demand.

⁵ Based on the Gross Domestic Product (GDP) deflator

As this list indicates, the Cal-B/C model includes a number of detailed calculations in its estimation of user benefits.

Lifecycle Benefit and Cost Estimations

The lifecycle of transportation projects can vary considerably. For example, a transit vehicle may have an eight-year life, while pavement can last 30 or more years. The Cal-B/C model establishes a standard 20-year lifecycle to facilitate comparisons across projects with differing lifecycles.

Therefore, the project costs inputted in the model should reflect the full project costs to maintain a 20-year lifecycle. The project costs should include all of the initial and subsequent project costs:

- Right-of-way
- Construction
- Mitigation costs
- Project support
- Maintenance/Operation
- Rehabilitation.

Costs for a project are estimated on an annual basis from the beginning of construction to twenty years after the construction ends and benefits begin. The values inputted into the model must be denominated in the same real dollars as the benefit tables in the model.

Cal-B/C measures, in real-dollar terms, four primary categories of user benefits:

- Travel time savings
- Vehicle operating cost savings
- Safety benefits (accident cost savings)
- Emission reductions.⁶

Travel time savings are calculated as a function of the travel speeds and traffic volumes:

1. Based on the base and future-year traffic volume projections, the model estimates future annual average daily traffic (ADT), without and with the improvement project, assuming straight-line growth.

⁶ Emissions reductions are included even though they are societal benefits and the monetary value of the health impacts is less often studied. On a practical basis, Caltrans rarely includes emission reductions in an analysis. However, greenhouse gases are likely to be more important to measure in the future.

2. Annual ADTs are multiplied by the length of the area affected by the improvement and divided by the travel speed to find the total travel time, without and with the improvement.
3. Annual travel time savings are multiplied by the value of time and average vehicle occupancy for each mode to convert travel time savings into dollar values.
4. The dollar value of the travel time savings is discounted to estimate its present value.

Vehicle operating cost (VOC) savings (i.e., changes in fuel use, vehicle wear, etc. due to improved speed) are estimated from travel speeds and traffic volumes as follows:

1. Forecasted annual ADTs are multiplied by the affected segment length to find annual vehicle-miles traveled (VMT) with and without the project as well as the difference (VMT savings).
2. For each mode, annual VMT savings are multiplied by the fuel consumption (from look-up table based on average speed) and the unit fuel cost to find the dollar value for fuel VOC savings.
3. Annual VMT savings are multiplied by unit non-fuel VOC to find the dollar value of non-fuel VOC savings.
4. Future annual VOC savings are summed across modes and discounted to obtain their present value.

Safety benefits are a function of traffic volumes:

1. The aggregated accident cost is calculated by multiplying the accident rate by an average user cost for each type of accident and summing the result.
2. Annual VMT is multiplied by aggregate accident cost to estimate the annual cost of accidents without and with the projects.
3. The difference (change in accident cost) is discounted to find the present value of future safety benefits.

Emissions reductions are calculated from travel speeds and traffic volumes:

1. The aggregate emissions cost per mile is calculated by multiplying the emissions rate, which is a function of travel speed, by the emissions cost for each type of emission and summing the results.
2. Annual VMT is multiplied by the aggregate emissions cost to find the annual emissions cost with and without the project.
3. The difference (change in emissions cost) is discounted to find the present value of future emissions benefits.

Non-Linear Benefits

Most transportation user benefits are U-shaped functions of speed. For example, fuel consumption (one component of vehicle operating costs) and emissions obtain their maximum values at low and high speeds, while the lowest fuel consumption and emissions occur around 45 miles per hour (MPH). If one were to analyze a project that resulted in travel at 60 MPH during the off-peak and 30 MPH during the peak periods, the fuel consumption and emissions rates would be high. However, averaging the speeds for the two periods would result in an average speed near 45 MPH, which has low fuel consumption and emissions. Given their U-shaped functions, these benefits cannot be interpolated from Year 1 to Year 20 to estimate lifecycle benefits.

Instead, the Cal-B/C model interpolates the travel speed and traffic volume data and then estimates benefits for each year individually (an example is shown in Figure 4). An alternate approach would interpolate benefits on the basis of a few years chosen to mimic the U-shape of the speed-benefit function. This would not have a substantial impact on the accuracy of the benefit estimation, but it does make the communication of the results to decision-makers and the public more difficult.

Each user benefit is estimated separately for a peak and an off-peak period of travel. This captures the difference in user benefits during congested and free-flow conditions on highways by establishing two user groups, depending on the conditions they experience.

Speed and Volume Data

Travel speed and traffic volume data are critically important to estimating user benefits for transportation projects. The Cal-B/C model can calculate the necessary values from simple traffic volume inputs, or it can accept data from detailed transportation models, such as the travel demand models favored by transportation planners or the micro-simulation models favored by traffic engineers.

If detailed transportation models are available, one should aggregate the peak and off-peak speed and volume output from the models for three scenarios:

- Baseline (current conditions)
- Future with Project
- Future without Project.

The current year data approximate the year a project opens. A future scenario year should be chosen to be as close as possible to Year 20. The aggregate values across affected highway segments are needed for each input.

If detailed transportation models are not available, Cal-B/C estimates the necessary data using the seven inputs shown in Table 1. These inputs are readily available in the

project study reports conducted by Caltrans. Cal-B/C presents the resulting values, which can be overridden if detailed, project-specific data are available.

The model separates current and future ADT into peak and off-peak traffic volumes using the duration of the peak period (entered by user or 5-hour default value) and an estimate of the percentage of daily traffic during each peak hour. On the basis of data from the 1991 Statewide Travel Survey (Caltrans, 1991), Cal-B/C has a default of value of the transportation network carrying 7.8 percent of daily traffic during each peak hour. The model estimates the peak traffic volumes using the following formula:

$$\text{Volume}_{\text{Peak}} = \text{ADT} * 7.8\% * \text{Duration of Peak Period}$$

Off-peak volumes are calculated as:

$$\text{Volume}_{\text{Off-Peak}} = \text{ADT} - \text{Volume}_{\text{Peak}}$$

Cal-B/C calculates speeds using a standard capacity constraint function, which is calibrated to speed volume curves found in the 2000 Highway Capacity Manual:

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

The model calculates capacity, *c*, as:

$$\begin{aligned} \text{Capacity} &= \text{Duration of Peak Period} * \text{Number of Lanes} \\ &\quad * 2000 \text{ vehicles per hour} \end{aligned}$$

Travel demand models and traffic forecasts occasionally produce volume-to-capacity ratios (*v/c*) well in excess of 1.0. In practice, highways cannot support *v/c* ratios at this level. Cal-B/C constrains the *v/c* ratios so they do not exceed a defined maximum (default is 1.4). This ensures that inputs to the model are reasonable.

Taking into account the various combinations of time period, vehicle type, and year, Cal-B/C calculates 28 travel speeds and 28 traffic volumes. These are displayed for the model user to review. The user can choose to accept these values or enter their own, but it is unlikely that 56 travel speeds and traffic volumes will be available for a project.

Soliciting Project Data

In evaluating projects for the STIP, Caltrans provides its Districts and other agencies with "District input sheets" to use for submitting project information. Caltrans has developed seven different information sheets tailored to different project types:

- Highway Input Sheet: General highway, carpool lane, passing lane, and pavement rehabilitation projects
- Interchange/Connector Input Sheet: interchange, freeway connector, and carpool lane connector projects
- Bypass Input Sheet: bypass projects
- Transit Input Sheet: passenger rail, light-rail, bus, automatic vehicle location, transit signal priority, and bus rapid transit projects
- Ramp Input Sheet: auxiliary lane, carpool drop ramp, off-ramp widening, and on-ramp widening projects
- Highway TMS Input Sheet: ramp metering, signal coordination with ramp metering, incident management, traveler information, and arterial signal management.

These input sheets look similar (but are not identical) to the Cal-B/C project information sheet. The reasons for having separate submission sheets are:

- The information supplied by district personnel needs to be checked for consistency, which occurs as the data are transferred to the model.
- A tailored input sheet reduces the data supplied to just the information needed to calculate benefits for a particular project.

Since the Cal-B/C model calculates preliminary model inputs in terms of travel speeds and traffic volumes that can be checked before the final user benefits are calculated, the district input sheets add another level of data verification. Figure 5 summarizes this process.

A RECENT USE OF THE MODEL

A recent statewide analysis of transportation projects highlights the data verification process shown in Exhibit 6.

California voters approved a large infrastructure (\$19.9 billion) bond package, called the Highway Safety, Traffic Reduction, Air Quality, and Port Security Bond Act (Proposition 1B) in a November 7, 2006 statewide election. As part of Proposition 1B, the State established and voters approved the Corridor Mobility Improvement Account (CMIA) to provide \$4.5 billion in funding for performance improvements on or major access routes to the state highway system.

The California Transportation Commission (CTC) adopted guidelines for nominating projects to the CMIA program that included:

- A project fact sheet that describes the project scope, cost, funding plan, project delivery milestones, and major benefits.
- A description of the travel corridor and its function, and how the project would improve mobility, reliability, safety, and connectivity within the corridor.
- A description of project benefits, including how the project would improve travel times or reduce the number of daily vehicle hours of delay, improve the connectivity of the state highway system between areas, or improve the safety of a highway or roadway segment. The description also includes air quality benefits and other benefits.
- A description of how the project would improve access to jobs, housing, markets, and commerce.
- A description of the risks inherent in the nomination's estimates of project cost, schedule, and benefit.
- A description of the corridor management approach to preserving project mobility gains, which may include the corridor system management plan or the commitment of regional and local agencies to develop and implement a plan.
- Documentation of the basis for the costs, benefits and schedules cited in the project nomination (CTC, 2006).

As part of the guidelines, the CTC decided it would give priority to projects with the greatest benefits in relation to the project costs. The Cal-B/C model provided a convenient way to assess the measurable benefits, and the CTC adopted the model. The commission also required nominating agencies to provide a completed benefit/cost analysis input sheet (see Figure 6). This input sheet was modeled on the District input sheets used by Caltrans for STIP project nominations. Due to the nature of the CMIA program, the input sheet had to accommodate more project types than the individual District input sheets do.

As in the STIP programming cycles, Caltrans and CTC staff needed to assess hundreds of nominated projects quickly (within six weeks). Caltrans supported the effort by conducting a training session to familiarize staff at submitting agencies with the Cal-B/C model and the necessary inputs. Knowing that input data could vary considerably, Caltrans staff also developed a set of criteria that identified preferred project information sources and a method for validating the data submitted.

The data guidelines focused on the primary inputs that drive transportation benefit-cost calculations:

- Traffic volumes and speeds
- Accident data.

For traffic volumes and speeds, agencies were asked to obtain traffic volumes and speeds from regional travel demand models or micro-simulation models. Regional travel demand models were considered more applicable to capacity improvements and transit projects, while micro-simulation models were more applicable to ITS projects and operational improvements. If these were not available, agencies were to provide recently measured traffic volume data from traffic sensors (as reported in the Freeway Performance Measurement System, or PeMS) or traffic count programs (such as the Caltrans Traffic Volume Book). This information was used to estimate speeds within the Cal-B/C model.

The Commission received 149 nominations for over \$11.3 billion in project costs by the CMIA submission deadline of January 16, 2007 (CTC, 2007). Caltrans received over 200 project input sheets. In several cases, Caltrans received input sheets from multiple nominating agencies for the same projects. As may be expected, the input sheets reflected different data. These were just some of the problems that staff encountered, despite well-defined guidelines.

Other problems included:

- Missing data or unknown values
- Corridor level data for projects that have network impacts
- Differences in definitions of “capacity”
- Attempts at “gaming” that result in lower rather than higher benefits
- Projects thought to be beneficial, but with no quantified benefits.

Part of the data difficulties could be attributed to a steep learning curve. Many of the agencies submitting data were encountering benefit-cost analysis and Cal-B/C for the first time. The quick timeframe for the analysis also played a role.

In the end, fifty-five (55) projects qualified for the CMIA program with an average benefit-cost ratio of about 2.4 to 1. (Caltrans, 2007) Judgment was needed to determine the best input data, but the benefit-cost analysis served its purpose of proving a relatively unbiased platform for making project comparisons. The CTC used multiple selection criteria (in addition to benefit-cost) to take into account unquantifiable benefits and the need for judgment. This is reflected in a range of benefit-cost ratios from under 1.0 to over 8.0 for selected projects.

Some agencies did not like the use of benefit-cost evaluation once favored projects were not selected and the model was an easy culprit. However, the analysis also revealed cases where project planning occurred without consideration of the benefits.

THE FUTURE OF BENEFIT-COST ANALYSIS IN CALIFORNIA TRANSPORTATION PLANNING

Rather than the end of transportation benefit-cost analysis in California, the CMIA analysis appears to be the start of a renaissance. The CTC has decided to continue using benefit-cost analysis for the selection of other Proposition 1B projects and benefit-cost in other transportation programs is expected to expand.

Caltrans is convening a committee to guide further benefit-cost analysis for California transportation projects. One of the primary tasks of the committee is to develop guidance on how to use benefit-cost modeling in corridor analysis and to test the sensitivity of the Cal-B/C model to data inputs. The lack of consistent input data drives a fundamental decision in the model's evolution – should Cal-B/C remain an economic tool that can help quantify and summarize user benefits, or should Cal-B/C become planning/engineering judgment tool that replaces traditional analysis?

SUMMARY AND FINDINGS

The Cal-B/C model was developed to facilitate the rapid evaluation and comparison of multiple transportation projects. It considers a standard range of user benefits and incorporates simple rules of thumb that allow the model to evaluate projects with very little or detailed data. The model began as an economic model, but simple planning and engineering rules of thumb were incorporated to account for the limited speed and volume data available on many California corridors.

The development of Cal-B/C and its evaluation for the CMIA offers lessons for transportation benefit-cost analysis, but many of these lessons are also important to benefit-cost analysis in general once it enters the “real world:”

- *Practitioners need to scrutinize the input data.* During the CMIA analysis, economists often played the role of transportation planners and engineers. Despite upfront guidelines and safeguards built into the Cal-B/C model, Caltrans received multiple sets of information for the same projects. This required economists to decide which data were best.
- *Non-practitioners need training in benefit-cost analysis.* Transportation planners and engineers are the experts in modeling transportation projects. They need to understand how the input data will be used in

order to provide the best information. However, with greater knowledge comes the potential to “game the system.”

- *Practitioners need to be cognizant of the inputs that drive results.* For transportation benefit-cost analysis, every user benefit is a function of travel speed or traffic volume. The estimation of these values (which typically occurs outside benefit-cost models) have a greater impact on benefit-cost results than any of the assumptions inside transportation benefit-cost models – the value of time, the value of life, fuel and non-fuel vehicle operating costs, emissions tables, etc.
- *Academic research needs to provide guidance on important economic values.* About 60 to 80 percent of the user benefits of projects evaluated using Cal-B/C are due to travel time savings. As a result, the value of time is the most important factor after travel speeds and traffic volumes. Further research is needed on how the value of time differs with travel time, the time of day, goods moved, etc.
- *Guidelines on the appropriate input data are important.* Transportation professional need better methods and criteria for estimating the input data. Unfortunately, multiple methods exist for forecasting and estimating speeds and guidelines do not exist for the most appropriate method.

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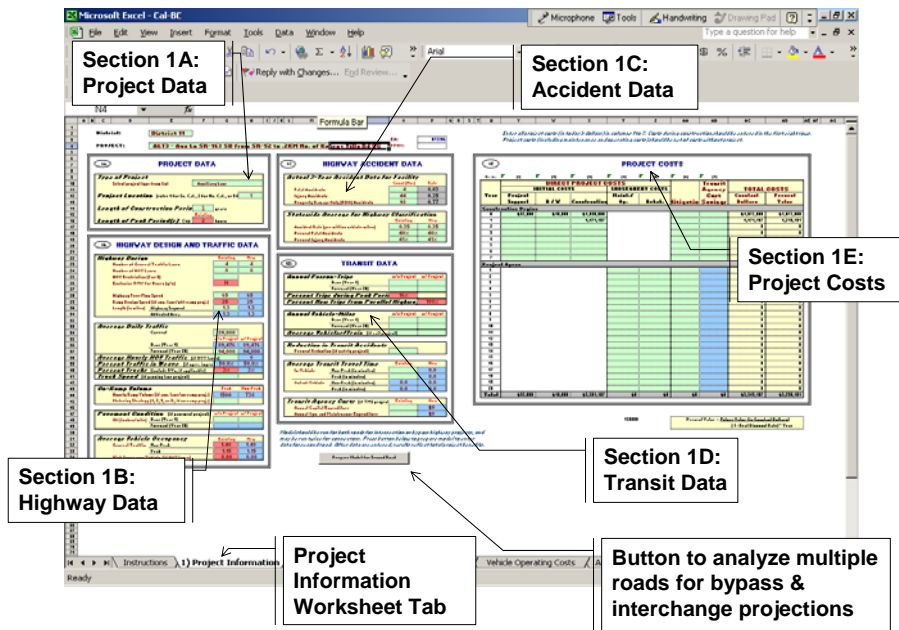
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Figure 1: SPASM Facility Information

BASE CASE			Free-Flow
	Length (miles)	Capacity (pce/hour)	Speed (mph)
Freeways			
1	10	12000	60
2			
3			
Arterials			
1	10		15
2			
3			
HOV			
Rail			
IMPROVEMENT CASE			Free-Flow
	Length (miles)	Capacity (pce/hour)	Speed (mph)
Freeways			
1	10	12000	60
2			
3			
Arterials			
1	10		15
2			
3			
HOV			
Rail			

Source: Federal Highway Administration, SPASM demand inputs worksheet, available at www.fhwa.dot.gov/steam/spasm.htm.

Figure 2: Project Information Worksheet



Source: System Metrics Group, Inc., 2004.

Figure 3: Cal-B/C Results Sheet

INVESTMENT ANALYSIS		
SUMMARY RESULTS		
3		
Life-Cycle Costs (mil. \$)	\$4.0	
Life-Cycle Benefits (mil. \$)	\$8.1	
Net Present Value (mil. \$)	\$4.1	
Benefit / Cost Ratio:	2.0	
Rate of Return on Investment:	15.8%	
Payback Period:	7 years	
ITEMIZED BENEFITS (mil. \$)	1st Year	20 Years
Travel Time Savings	\$0.5	\$7.1
Veh. Op. Cost Savings	\$0.0	\$0.7
Accident Reductions	\$0.0	\$0.2
Emission Reductions	\$0.0	\$0.1
TOTAL BENEFITS	\$0.6	\$8.1

Figure 4: Twenty-Year Benefit Estimation

Year	AVERAGE VOLUME (vehicles/yr)		AVERAGE SPEED (mph)		AVERAGE TRAVEL TIME (hours)		TIME BENEFIT (hours/yr)		Constant Dollars	Present Value
	Existing Facility	New Facility	Existing Facility	New Facility	Existing Facility	New Facility	Existing Users	New (Induced)		
1	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
20	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
2	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
3	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
4	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
5	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
6	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
7	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
8	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
9	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
10	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
11	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
12	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
13	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
14	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
15	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
16	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
17	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
18	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
19	0	0	55.0	55.0	0.00	0.00	0	0	\$0	\$0
Total										\$0

Table 1: Data Used to Estimate Speeds and Volumes

Input	Current	Year 20 with Project	Year 20 without Project
Average Daily Traffic (ADT)	X	X	X
Duration of peak period	X	Calculated	Calculated
Number of lanes	X	X	Same as current
Free-flow speed	X	Same as current	Same as current

Figure 5: Process for Cal-B/C Data Entry

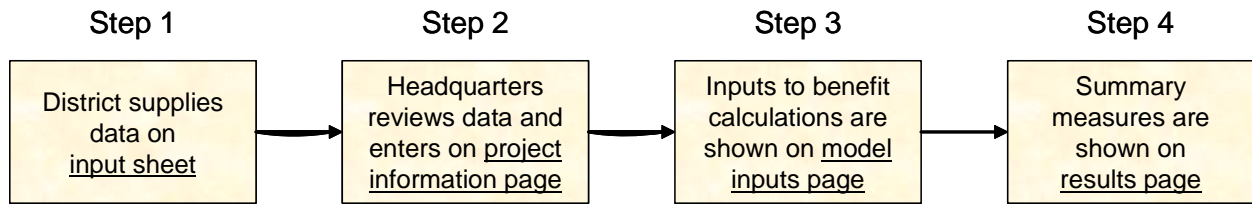


Figure 6: CMIA Benefit-Cost Analysis Input Sheet

California Transportation Commission APPENDIX B CMIA Guidelines

**CORRIDOR MOBILITY IMPROVEMENT ACCOUNT PROGRAM
BENEFIT/COST ANALYSIS: PROJECT INPUT SHEET**

Region/District: County: Route: EA:
 Describe Project: Post mile: PPNO:

PROJECT DATA

Type of Project	Enter "X"	
Hwy Capacity Expansion	<input type="text"/>	<input type="text"/>
Operational Improvement	<input type="text"/>	<input type="text"/>
Transp MGMT System (TMS)	<input type="text"/>	<input type="text"/>
Other (describe: _____)	<input type="text"/>	<input type="text"/>
Project Location (1 = So. Cal., 2 = No. Cal., or 3 = rural)	<input type="text"/>	
Length of Construction Period	<input type="text"/>	years
Duration of Peak Period (AM+PM)	<input type="text"/>	hours

HIGHWAY DESIGN AND TRAFFIC DATA

Highway Design			
	w/o Project	w/ Project	HOV Restriction
Number of General Traffic Lanes	<input type="text"/>	<input type="text"/>	
Number of HOV Lanes	<input type="text"/>	<input type="text"/>	
Highway Free-Flow Speed (in mph)	<input type="text"/>	<input type="text"/>	(2 or 3)
Project Length (in miles)	<input type="text"/>	<input type="text"/>	
Average Daily Traffic			
	w/o Project	w/ Project	
Current	<input type="text"/>	<input type="text"/>	
Forecast (20 years after construction)	<input type="text"/>	<input type="text"/>	
Average Hourly HOV Traffic (if HOV lanes)	<input type="text"/>	<input type="text"/>	
Percent Trucks (include RVs, if applicable)	<input type="text"/>	<input type="text"/>	
Truck Speed (if passing lane project)	<input type="text"/>	<input type="text"/>	

HIGHWAY ACCIDENT DATA

Actual 3-Year Accident Data for Facility		
	Count (No.)	
Fatal Accidents	<input type="text"/>	
Injury Accidents	<input type="text"/>	
Property Damage Only (PDO) Accidents	<input type="text"/>	
Statewide Average for Highway Classification		
	w/o Project	w/ Project
Accident Rate (per mil. veh-miles)	<input type="text"/>	<input type="text"/>
% Fatal Accidents	<input type="text"/>	<input type="text"/>
% Injury Accidents	<input type="text"/>	<input type="text"/>

TOTAL PROJECT COSTS (in escalated dollars)
From Project Nomination Fact Sheet:

Fiscal Year:

2007-08	\$ <input type="text"/>
2008-09	\$ <input type="text"/>
2009-10	\$ <input type="text"/>
2010-11	\$ <input type="text"/>
2011-12	\$ <input type="text"/>
2012-13	\$ <input type="text"/>

COMMENTS: _____

Prepared by: Phone No: E-Mail:

CONTACT: Mahmoud Mahdavi 916-653-9525 mahmoud_mahdavi@dot.ca.gov FAX: 916-653-1447

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Source: California Transportation Commission, 2006.