MINETA TRANSPORTATION INSTITUTE

Benefit-Cost Analysis for Transportation Planning and Public Policy: Towards Multimodal Demand Modeling

MTI Report 12-42

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REPORT 12-42

BENEFIT-COST ANALYSIS FOR TRANSPORTATION PLANNING AND PUBLIC POLICY: TOWARDS MULTIMODAL DEMAND MODELING

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16. Abstract

This report examines existing methods of benefit-cost analysis (BCA) in two areas, transportation policy and transportation planning, and suggests ways of modifying these methods to account for travel within a multimodal system. Although the planning and policy contexts differ substantially, this report shows how important multimodal impacts can be incorporated into both by using basic econometric techniques and even simpler rule-of-thumb methods. Case studies in transportation planning focus on the California Department of Transportation (Caltrans), but benchmark California's competencies by exploring methods used by other states and local governments. The report concludes with a list and discussion of recommendations for improving transportation planning models and methods. These will have immediate use to decision makers at Caltrans and other state DOTs as they consider directions for developing new planning capabilities. This project also identifies areas, and lays groundwork, for future research. Finally, by fitting the planning models into the broader context of transportation policy, this report will serve as a resource for students and others who wish to better understand BCA and its use in practice.

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EXECUTIVE SUMMARY

For much of the twentieth century, state Departments of Transportation (DOTs) were primarily highway-building organizations. Slowly, DOT responsibilities have shifted from highway building toward managing multimodal transport systems, as exemplified by California Department of Transportation's (Caltrans) new mission statement since April 2014: "Provide a safe, sustainable, integrated and efficient transportation system to enhance California's economy and livability."

Concurrent to any reorienting of goals must be a modification of the tools used to assess progress toward the goals. Benefit-cost analysis is one such tool. In the research described in this report, we aim to find ways of improving BCA tools to better account for system impacts that historically have been ignored.

Benefit-cost analysis (BCA) is a useful framework for helping state DOTs accomplish all aspects of their mission. Ideally, BCA takes into account all impacts of a decision – including safety, environmental, economic, equity, and other impacts – and provides a way of selecting investments that maximize social welfare. Of course, even the best BCAs measure only select impacts, but a good BCA can serve as a valuable performance measure for assessing organizational objectives.

Recent critics of Caltrans have said, "...Caltrans today is significantly out of step with best practice in the transportation field."[1] The results of our research suggest that the truth is more nuanced. For example, Caltrans has for decades supported the development of an elaborate set of spreadsheet-based BCA models (e.g. Cal-B/C). Caltrans has also supported the development of one of the most advanced statewide travel demand models (TDMs) in the US for simulation of multimodal interregional travel. But, although the spreadsheet BCA models are used on a routine basis, they are not used to their full potential. And the new statewide TDM is not routinely used to support the agency's BCA.

Our research has identified areas where there likely is room for improvement. This report makes four specific recommendations. These recommendations fall into two categories: those requiring changes to the Cal-B/C model or its use and those requiring better integration of BCA and TDMs. Within each category are two distinct recommendations.

With respect to changes to the agency's institutionalized BCA process, the primary BCA model that Caltrans uses – the Cal-B/C spreadsheet – is unimodal when evaluating highway and road investments. In addition, induced demand effects are routinely ignored when calculating traffic estimates with and without infrastructure projects. We therefore develop concrete proposals for modifying both the Cal-B/C model, and its method of use, to better account for multimodal and system effects.

- First, we suggest adding a function to Cal-B/C that accounts for induced demand when producing traffic estimates with and without the project;
- Second, we recommend better documentation and outreach to encourage the use of existing capabilities for modeling multimodal effects in the Cal-B/C spreadsheet.

With respect to better integration of BCA and travel demand modeling, if Caltrans is provided with the institutional support and incentives necessary to implement the statewide model, this will enable at least two improvements. This boils down to a general recommendation – implement the statewide model – which in turn will facilitate two specific recommendations for BCA:

- First, we suggest using the statewide TDM to help ensure demand is best accounted for in the Cal-B/C spreadsheet model;

- Second, we recommend Caltrans further develop a BCA post processor which can fully use the rich multimodal, geographic, and sociodemographic data available from activity-based TDMs for BCA and equity analyses.

We detail these and other recommendations throughout the report, and we list and summarize all of our recommendations in the conclusion. This report is organized so that readers who do do not need detailed data can proceed directly to the conclusion after reading this summary and refer back to the body of the report for more in-depth information on specific recommendations as needed.

In addition to focusing on models for planning, we also carry out an improved retrospective public policy analysis that assesses past investments in rail transit across the United States. While not directly relevant to most planners at DOTs, this analysis may be of interest to academics, public policy analysts, policy makers, students, and others. In our public policy analysis that integrates highway and transit data, we provide a stark example of how simple it can be to account for multimodal travel in BCA. Using this simple approach as inspiration, we turn to BCA for planning and find simple but powerful approaches hold promise for advancing practice at state DOTs as well.

I. INTRODUCTION: A STATEMENT OF THE PROBLEM

This project grew out of a research need communicated to the Mineta Transportation Institute (MTI), which was "…to review the activities of various Caltrans divisions that impact the planning, monitoring, and managing of the transportation system, to identify opportunities to increase the integration of transit."[2]

What evolved over the course of the research was a narrowing of the focus to a specific planning area – benefit-cost analysis (BCA) – but also a widening of the perspective to encompass not just transit, but multimodal system travel more generally.

This report focuses on benefit-cost analysis as a specific planning tool and develops methods for improving BCA for transportation planning and public policy. Our goal is to find practical ways of improving the accuracy of BCA models and methods by incorporating transit and other multimodal travel data, as well as induced demand and transport system effects more generally, to help Caltrans fulfill its mission.[3]

In writing this report, we made an effort to consider the political and institutional environment within which transportation planning operates so that our recommendations are more likely to have an impact. In the final analysis, we make four specific recommendations for improving models and methods that we think merit consideration by leaders at Caltrans. We hope that some of these recommendations are embraced, but we will consider this report a success even if it only sparks conversations that lead to smarter spending. With billions of dollars on the line, even a small success in improving BCA could add considerable value to society.

BCA is widely used in transportation planning and programming in California and elsewhere, and its role appears to be increasing, as exemplified by the federal government's TIGER grant program, which has allocated $8.3 billion in transportation funding since 2008. We profile the TIGER program in this report because one of its defining characteristics is that it has required BCA for all proposals.

This report focuses on models, but we present two new case studies on the use of BCA in transportation planning. In addition to the case study of the TIGER program, we also explore the role BCA played in allocating money from California's Proposition 1B, passed by voters in 2006, which authorized $20 billion in bond sales for transportation projects. These cases demonstrate how BCA is used in actual policy contexts, both in California and elsewhere.

The main body of the report consists of two subsections that present our modeling innovations in two contexts: public policy and planning. The public policy form of BCA is more likely to be encountered in academic settings, while the second form is more likely to be found in government agencies. Here we briefly describe our findings. Using basic applied econometric techniques and readily available data, multimodal data is added to a BCA of rail transit systems in order to more accurately predict demand characteristics across cities in a public policy analysis. This analysis finds that more rail transit systems are likely to pass the benefit-cost test compared to the less accurate rule-of-thumb method for estimating demand. However, a couple of systems are shown to have been somewhat worse investments when the more accurate multimodal demand model is used. This analysis demonstrates how simple techniques can enable BCA to better represent multimodal data, and that a bias results from failure to accurately represent demand.

With respect to planning, we find that both the methods and models used by Caltrans for BCA could be improved by incorporating induced demand and multimodal considerations. Improved analysis can also be realized with better use of existing model features. We also discuss the need to integrate BCA with travel demand models (TDMs).

We elaborate on these suggestions in the body of the report and in the conclusion, where we also briefly discuss the management practices of outsourcing and restructuring of the organizational hierarchy. Unlike our four recommendations for modeling, we don't offer specific recommendations. Instead, we lay out some of the general tradeoffs associated with status quo practices and urge decision makers to think hard about how best to develop state-of-the-art modeling capabilities.

Among the methods we employed in carrying out this research are statistical, Monte Carlo, and social welfare analysis. We also employed qualitative techniques. Indeed, our interviews and discussions with transportation professionals at Caltrans, Ohio DOT, and USDOT, along with consultants, and others, were among the most interesting and fruitful aspects of our research. These insights permeate the report and we are grateful to the many individuals who helped us during the course of our research.

The outline of the report is as follows. The next section presents background information on transportation planning and policy, and this provides the context for the models we discuss next. We then come to the main body of the report, which presents opportunities for better representing travel demand data in BCA for public policy and planning. The report concludes by summarizing the major results and recommendations arising from this research. Along the way, we consider the two case studies mentioned earlier.

II. TRANSPORTATION FUNDING, PLANNING, AND ECONOMICS IN THE UNITED STATES AND CALIFORNIA

This section presents background information on transportation funding and planning in the United States and in the State of California, which provides context for the technical analysis later in the report. Specifically, the first subsection briefly focuses on the history of federal-state transportation funding and the evolution of federal transportation policy. The next subsection describes the general transportation planning process in the United States, as well as the statutory transportation planning requirements for federal funding. The third subsection details California-specific policies towards transportation planning and project implementation. The final subsection presents a review of the economic underpinnings of this report.

FEDERAL TRANSPORTATION POLICY AND PLANNING EFFORTS IN THE UNITED STATES

Prior the 1960s, transportation infrastructure was funded on an ad hoc basis through a series of congressional acts. The Federal Aid Road Act (FARA) of 1916 was the first such act to be directed exclusively toward federal highway planning. The Act allocated $25 million for improvement of rural roads, with a federal contribution of at least 30% – but no more than $50 – per project. Funds were distributed to individual states to manage and implement projects, which were reviewed by federal authorities. By 1920, states receiving these funds were required to establish a state highway agency. A large portion was used to improve postal roads in rural areas of the country.[4] The 1921 Federal-Aid Highway Act (FAHA), also known as the Phipps Act, shifted the focus from postal roads to development of a national highway system. The FAHA appropriated $75 million in 50-50 matching funds for states to develop highways, but limited new construction to 7% of the state's total roadway miles.

Still, planning for long-term transportation needs was mostly a secondary concern of federal transportation policy in the first half of the twentieth century. Nearly all of the aforementioned funding was used for project implementation rather than long-term planning. The Hayden-Cartwright Act (HCA) of 1934 was one of the first federal efforts to encourage state transportation planning, allocating 1.5% of federal transportation funds to states for surveys, plans, economic analyses, and engineering investigations of projects for future consideration.[5] However, dramatic population shifts of the postwar era, in both population size and suburban migration, required a more systematic and comprehensive approach to transportation planning, making the 1950s a pivotal era for transportation in the US. Even though it was widely recognized that the US needed guiding legislation to expand such a large-scale and comprehensive transportation network, the logistics had yet to be determined.[6]

During the 1940s, transit ridership peaked at 23.4 billion trips per year (compared with 10.5 billion trips per year in 2012)[7] as rubber and fuel was conserved for the war effort. Once the war came to an end, however, both the refocused manufacturing ventures and the latent demand for cars and suburban homes resulted in a significant decline in transit use, dropping to nearly half its peak by the early 1950s. This major modal shift led to the

1956 FAHA that would provide 90% federal funding share for adding 41,000 highway miles to be implemented by state transportation agencies. Urban politicians supported a bill that would so generously transform statewide transportation infrastructure, and in June 1956 the FAHA passed, ushering in a new era of highway-focused, federally funded transportation initiatives.

By the early 1960s, there was a pressing need for permanent government agencies at the federal, state, regional, and local levels to manage such a large transportation network. In a special address to Congress, President Kennedy said: “An efficient and dynamic transportation system is vital to our domestic economic growth … Few areas of public concern are more basic to our progress as a nation.” Following this speech, Congress enacted the 1962 Federal-Aid Highway Act (FAHA) and the 1964 Urban Mass Transit Act, two critical new policies that provided funding and long-term structure for transportation planning. The 1962 FAHA brought the first true mandate for transportation planning to the nation’s states, requiring them to establish their own departments of transportation as a condition to receive federal funding. In addition, the act required urbanized areas with populations of greater than 50,000 to establish Metropolitan Planning Organizations (MPOs). The 1962 FAHA, in particular, established what would become known as the “3C” planning process, requiring a coordinated, comprehensive, and continuous approach to transportation led by state and MPO-level transportation plans. By the mid-1960s, all fifty states were in the process of establishing transportation agencies. In 1966, the federal government likewise established the US Department of Transportation, creating what is now a central pillar of transportation planning in the US.

By the 1970s and 1980s, the focus on highways started to lose traction. Public opinion about the social benefits of the interstate system slowly started to turn, and a movement for local control of transportation decisions took hold.[8] In a partial response to changing public opinion, the 1973 FAHA update funded mass transit and airport development in addition to highway building, signaling a slow transition toward a more diversified definition of transportation agency responsibility. Changing the substance of federal funding, however, was insufficient to address rising concerns that more local control in general was needed. With local or regional control, planners and engineers could use funds to build more nuanced transportation solutions specific to their region than could be achieved by participation in a national networking program. The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) marked the first transition of planning authority from federal and state agencies to regional Metropolitan Planning Organizations (MPOs). ISTEA dedicated 6% of highway funds to MPOs, which could be designated for regional projects without state approval. Though this change marked a significant step toward providing more local control over transportation planning, MPOs still had little authority, since they did not have the ability to generate revenue or control land use. The qualified progress of ISTEA continued with the 1998 Transportation Equity Act for the Twenty-First Century (TEA-21), legislation that secured and continued the funds allocated to MPOs for highway, transit, rail, bicycle, and pedestrian infrastructure.[9]

TEA-21 secured and continued the funds allocated to MPOs for highway, transit, and rail as well as bicycle and pedestrian infrastructure.[10] For the first time, federal legislation was embracing a truly comprehensive approach to municipal and interstate transportation, giving MPOs more tools to effectively reform transportation. During the 1990s, federal funding for bicycle and pedestrian infrastructure grew from a mere $7 million – hardly enough to make an impact in any one state, let alone the entire nation – to $222 million. Though a significant increase, this was still a modest amount that nevertheless reflected a symbolic shift of priorities in federal transportation planning. Likewise, transit experienced a funding boon from $3 billion per year to almost $6 billion[11] ISTEA and TEA-21 were now allowing states and metropolitan areas the financial security to invest in innovative transportation systems that could more specifically address the individual strengths and needs of each city. More recently, Congress passed the Moving Ahead for Progress in the 21st Century Act (MAP-21). Among other provisions, MAP-21 streamlines the National Environment Protection Act to help expedite the approval process for major transportation projects. In addition, the bill equally splits funding for pedestrian and bicycle projects between MPOs and state DOTs.

TRANSPORTATION PLANNING: THE PROCESS

Transportation planning plays a key role in fostering efficient, equitable, and environmentally sustainable economic growth. Consequently, its success depends heavily on how effectively it surfaces and addresses the views and concerns of involved stakeholders. This subsection will explore the general process of transportation planning in the United States.

As mentioned above, federal involvement in state and regional transportation planning is primarily through mandated establishment and distribution of federal transportation funds. The latter supports statewide and regional transportation projects from the Highway Trust Fund (HTF). Historically, HTF dollars come from the federal gas tax, currently 18.4 cents per gallon. At the sub-national level, federal mandates influence transportation planning by requiring each state to establish its own department of transportation (DOT) and regional metropolitan planning organizations (MPOs) as a condition for receiving federal funds for transportation projects.

State DOTs have two primary responsibilities: (1) to create a Long-Range Statewide Transportation Plan (LRSTP), and (2) to establish a Statewide Transportation Improvement Program. Content of each state's LRSTP vary but typically include twenty-year state transportation goals, projected statewide travel demand, transportation problems and preferred solutions, and sources of finance and capital investment. The STIP is similar to the LRSTP but is focused more specifically on a four-year time horizon, identifies individual transportation projects of critical importance to the state, and must include a financial plan for implementation. A key difference between the two, however, is the approving body. The USDOT approves each state's STIP, while states themselves are responsible for approving their own LRSTP.

MPOs also must undertake long- and short-term transportation planning. MPOs are responsible for three planning documents: (1) the metropolitan transportation plan (MTP), (2) a transportation improvement plan (TIP), and (3) a unified planning work program (UPWP). Like the LRSTP, the MTP establishes goals and priorities for a twenty-year period and includes regional visions for intermodal transportation systems; areas of concern; capital investment strategies; and coordination strategies for land use, employment, housing, and development. The TIP is similar to the STIP in that it is a four-year improvement plan that identifies specific projects the MPO would like to implement in the short-term. However, there are additional federal requirements for TIPs: They must be updated every four years, must include consideration of fiscal limitations, are subject to approval by the governor, and are included in the STIP. The UPWP is an even shorter-term planning document (one- to two-year horizon) that identifies funding sources, planning studies, implementation schedule, and responsible agencies for each project in the TIP. The UPWP is updated annually, and is approved by the MPO. State and MPO planning documents are summarized in Table 1.

Table 1. Federal Requirements for State and MPO Transportation Planning in the United States

Planning Document	Developing Authority	Approving Authority	Time/Horizon	Contents	Update Requirements
UWUP	MPO	MPO	1 or 2 Years	Planning studies and tasks	Annually
MTP	MPO	MPO	20 Years	Future goals, strategies and projects	Every 5 years (4 years for non-attainment and maintenance areas)
TIP	MPO	MPO/ Governor	4 years	Transportation investments	Every 4 years
LRSTP	State DOT	State DOT	20 years	Future goals, strategies and projects	Not specified
STIP	State DOT	US DOT	4 years	Transportation investments	Every 4 years

As shown in Figure 1, the process of creating these documents begins with establishing goals and general visions. Throughout the plan creation process, public engagement of stakeholders is common, and is typically facilitated by MPOs or state DOTs.

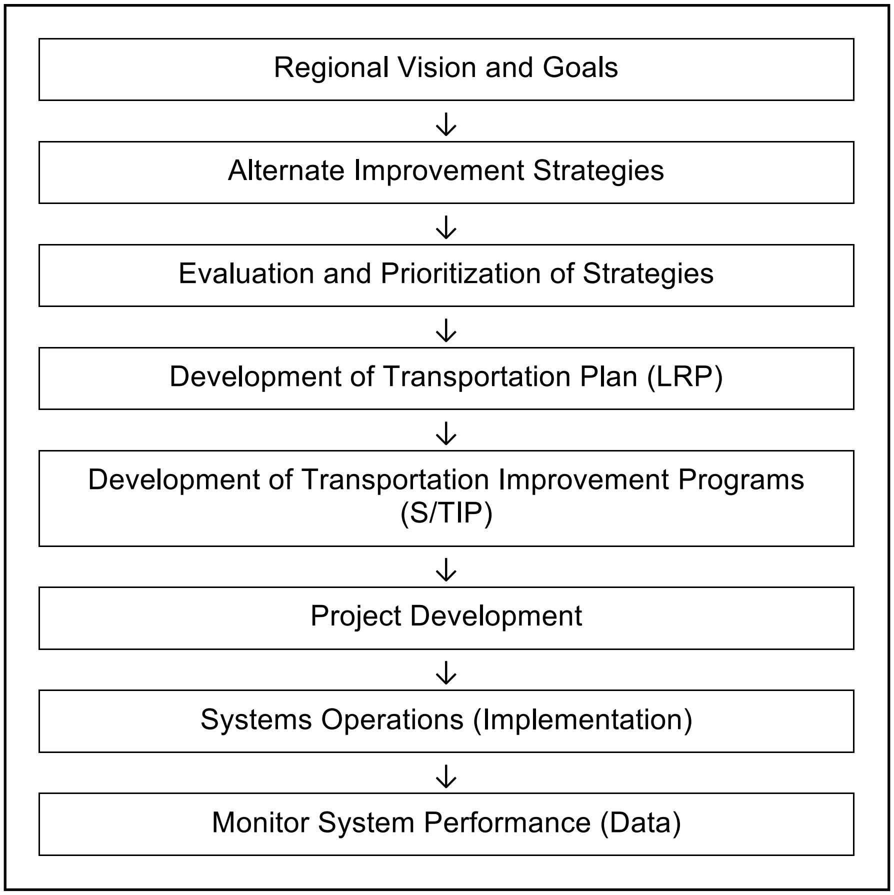


Figure 1. The Transportation Planning Process

Source: Federal Highway Administration, 2007.

TRANSPORTATION PLANNING AND POLICY IN CALIFORNIA

As demonstrated in Figure 1, transportation planning comprises a series of decision-making processes carried out primarily at the state and metropolitan level. For California, the process begins with the state adopting an LRSTP. Individual projects from TIPs that meet objectives of the LRSTP are then incorporated into the STIP, which is approved by USDOT. USDOT then distributes federal funds to Caltrans via the Federal Highway Administration. Caltrans allocates these funds, along with funds from other sources, to STIP projects based on decisions made by the California Transportation Commission (CTC).

As in other states, the responsibility for transportation planning in California varies according to mode type and location. The California Department of Transportation, Caltrans, manages 15,000 highway miles that account for 55% of the state's annual vehicle-miles traveled and is responsible for creating the LRSTP and compiling TIP projects for inclusion in the STIP. On the other hand, MPOs and local governmental agencies in California manage and plan for public streets in their jurisdiction that total nearly ten times the number of miles as the state-managed highways, but they account for only 45% of the state's vehicle-miles traveled.[12] In some circumstances, highways that run through MPO or local governmental jurisdictions are purchased from Caltrans so that those agencies can incorporate specific routes into their MTPs and TIPs.[13] However, it is typical for Caltrans to lead management of highways that run through MPO jurisdictions. Approximately 70 transit agencies operate throughout the state, working in conjunction with Caltrans, MPOs, and other agencies to coordinate the development of MTPs, TIPs, and UPWP. Though state legislation directs transportation policy and appropriates funding, the CTC – composed of nine governor-appointed members, plus one member appointed by the Senate Rules Committee and one appointed by the Speaker of the Assembly – provides oversight and approves funding for both Caltrans and MPO projects. However, Caltrans and the CTC are guided by state legislation – SB 45 passed in 1997 – that requires 75% of STIP funding to be allocated to TIPs and the remaining 25% to interregional projects. Since TIPs are created by MPOs and interregional projects are managed by the state, SB 45 significantly increased the influence of local needs on the California transportation planning process. In addition, a number of other state-level policies and legislation guide the allocation of federal and state transportation funding.

Following the directive of ISTEA and TEA-21, California has been a leader in adopting policies that encourage a shift toward multimodal planning. The California Environmental Quality Act (CEQA) has been a key element of transportation and land-use planning. Enacted in 1970 soon after passage of the National Environmental Policy Act, CEQA requires disclosure of the environmental consequences of proposed projects and recommendations for their mitigation.[14] In addition to impacts on the natural environment, CEQA also requires analysis and mitigation of impacts on the local transportation network. Such mitigation approaches include Transportation Demand Management techniques designed to encourage non-automobile travel.

Recently, several progressive laws have been adopted to provide further structure and incentives for sustainable transportation. In the mid-1990s, the California legislature passed AB 3152, the Transit Village Development Planning Act, which encouraged higher-density development near transit stations.[15] More recently, the 2006 Global Warming Solutions Act (AB 32) requires California to reduce its GHG emissions to 1990 levels by 2020, and the 2008 Sustainable Communities and Climate Protection Act (SB 375) sets regional targets for these GHG emissions reductions from passenger vehicles, specifically, and requires MPOs to develop transportation and land-use plans designed to meet these targets. As such, MPOs must include transportation projects in their TIP that help reduce GHG emissions.

Among other methods, the CTC uses the same BCA methods discussed later in this report to evaluate the merits of individual TIP and STIP projects and the tradeoffs involved in achieving the directives mentioned above. In the remainder of this report, we focus almost exclusively on how BCA is used in California at the state and MPO levels and suggest areas for improvement in the use of BCA models. Before analyzing BCA models, we first describe the economic underpinnings of BCA and how it is incorporated into the decision-making process.

ECONOMICS

Economic concepts such as welfare analysis and demand modeling are increasingly influencing the field of transportation planning. The former is used to examine the tradeoffs of investment benefits and costs, while the latter supports estimating current and future travel behavior. This section briefly reviews these two concepts.

Investments are ubiquitous in an economy and are made by households, private firms and governments. To analyze public sector investments, economists adopt the objective of *social welfare maximization*. The concept of social welfare is also a philosophical construct; its utilitarian notion can be summarized as – to paraphrase the British philosopher Jeremy Bentham – “maximizing the greatest happiness of the greatest numbers.” In practice, happiness is measured in dollars by willingness to pay (WTP). Monetization – that is, expressing all benefits and costs in dollar terms – is a key characteristic of BCA.

Given its reliance on WTP to measure benefits, one might think that BCA is limited in its ability to analyze questions of equity and sustainability. However the reliance on WTP need not impose these limitations. BCA can account for equity, for example, through the use of weighted social welfare functions. Likewise, given its insistence that all benefits and costs be expressed in dollar values, one might also think BCA is limited in its ability to handle the full diversity of impacts that transportation planners and policy makers care about – for example, injury and fatality reductions as well as health and environmental effects of pollution. However, economists have developed techniques for valuing benefits produced by these “nonmarket” and “external” impacts by using, for example, surrogate market approaches, survey methods, and statistical techniques.[16] Due to its anthropocentric nature, BCA remains open to what might be called the “deep ecological critique” – in short, that environmental benefits not valued by humans are ignored. While this is true, it is certainly not the case that BCA ignores equity and sustainability concerns altogether.

This is why in the introduction we proposed BCA as a useful tool for helping Caltrans achieve its mission, which encompasses the broad goals of safety, equity, efficiency, and sustainability. BCA promises to provide a useful tool for multi-goal pursuit. BCA has a firm basis in microeconomic theory. This theory provides the conceptual underpinnings for measuring social welfare; however the actual measuring – or valuation – of impacts is an empirical problem. Much attention in BCA is placed on valuing impacts, especially benefits (as reliable cost estimates are often available from engineers and thus do not need to be estimated). For example, what is the value of one less hour of time spent in traffic? Economists might use the driver’s hourly wage or an alternative measure.

The second of the methodologies from transportation economics that closely relates to the topics we study below is travel demand modeling. Advanced travel demand research in economics began in the 1970s. Nobel Laureate Daniel McFadden was a pioneer in this field, producing groundbreaking work in statistical methods and econometric theory. Today the multinomial logit developed by McFadden is a core of both traditional four-step and activity-based travel demand models, and microsimulation techniques used at State DOTs, MPOs, and other planning agencies. We describe travel demand modeling as practiced by planning agencies in detail later in this report.

Travel demand models provide important inputs to BCA models, but transportation demand theory also draws one's attention to situations where a lack of data may lead to biased results in planning contexts. In other words, concepts from demand theory provide additional motivation for this research. These concepts have been crystallized with names like "the Downs-Thompson paradox" and "Braess's paradox."[17] The first paradox describes a situation in which a highway parallels a rail line, the highway is expanded, travelers switch from the train to driving, and the transit agency then lowers train frequencies in response to the fall in demand. Highway speeds fall due to the induced demand from rail, and transit times increase due to the fall in train frequency. On the whole, society is worse off after the highway expansion. Braess's paradox describes a similar situation in which, again, induced demand causes a highway expansion to result in an overall increase in travel times. In this case induced demand comes from drivers migrating from other roads in the network to the improved road.

The Braess and Downs-Thompson paradoxes are theoretical possibilities, but recent empirical research confirms travel mode interrelationships. For example, a recent CBO study analyzed road sensor data and found that gas price elasticity is higher on roads near transit connections. When gas prices go up, some drivers on these roads can switch to the transit option.[18] One implication is that expanding road capacity is less likely to be efficient when alternative modes (transit) are available. We discuss more empirical studies of induced demand later in this report.

The branches of economics dealing with BCA and demand modeling for transportation provide important methodological guidance for this report. We conclude this section with a case study before turning to the next section, where we begin our original research of developing integrated BCA models for transportation planning and public policy.

CASE STUDY: CALIFORNIA'S PROP 1B AND THE ROLE OF BCA

Having completed our background review of economic theory and methods, and the public policy and planning processes, we now present a case study as a specific illustration of how BCA is used in an actual policy setting, namely California's Proposition 1B. In researching this policy setting, we reviewed documents; communicated with both Caltrans and CTC staff in person, by phone and by email; and analyzed data to learn about all stages of the proposition, from the election where it was approved by voters, to its execution by the State, where, as shall be seen, BCA played a key role.

Proposition 1B was a $20 billion state bond measure approved by 61.4% of California voters in 2006. Bond proceeds have been used to fund dozens of projects, which are listed on http://bondaccountability.ca.gov. Almost a quarter ($4.5 billion) of these bond revenues were deposited into a Corridor Mobility Improvement Account (CMIA). All projects submitted for CMIA funding were ranked by Caltrans using Cal-B/C, and selected by the California Transportation Commission. At least two published documents provide more information on the use of Cal-B/C in programming the CMIA component of Prop 1B funds.[19]

The California State Legislature voted to put Proposition 1B on the ballot via Senate Bill 1266 of the 2005–2006 Regular Session (Chapter 25, Statutes of 2006). The Assembly voted 61 in favor, with 10 opposed, while the Senate voted 37 in favor, with 1 opposed.[20] *PROP 1B: Highway Safety, Traffic Reduction, Air Quality, and Port Security Bond Act of 2006* is described in the 2006 Voter Information pamphlet as follows:

> *This act makes safety improvements and repairs to state highways, upgrades freeways to reduce congestion, repairs local streets and roads, upgrades highways along major transportation corridors, improves seismic safety of local bridges, expands public transit, helps complete the state's network of car pool [sic] lanes, reduces air pollution, and improves anti-terrorism security at shipping ports by providing for a bond issue not to exceed nineteen billion nine hundred twenty-five million dollars ($19,925,000,000). Fiscal Impact: State costs of approximately $38.9 billion over 30 years to repay bonds. Additional unknown state and local operations and maintenance costs.*

As this description reveals, Prop 1B spans projects from highways and local streets to security and public transit. It is possible that the broad appeal of this proposition was due to the wide range of projects it funded. As mentioned earlier, 61.4% of voters voted in favor. In addition, statistical analysis of the proposition revealed no particularly strong partisan effect.[21]

Following the election, the CTC had responsibility for programming transportation projects for the CMIA component of Prop 1B. The CTC assigned the Caltrans Office of Transportation Economics (now known as the Office of Economic Analysis) the task of applying Cal-B/C to all projects submitted for funding under the CMIA program budget line. Further information on how this process was carried out can be found in a *Transportation Research Record* article by Chris Williges and Mahmoud Mahdavi.[22]

The CTC provided us with the B/C ratios produced by Caltrans for each of the projects submitted by Caltrans districts. In addition, they shared the recommendations of the CTC staff regarding each project, as well as the ratings the staff assigned each project in various criteria.

The CTC staff evaluated proposals according to three criteria: value, deliverability, and appropriateness. The primary consideration for the "value" criterion was the B/C ratio produced by the Cal-B/C model, though the rating was adjusted upward or downward depending on other non-quantified benefits, including "how well the claimed benefits and costs are supported in the nomination" as well as risk considerations.[23] The deliverability category also included risk considerations, as well as the project's current stage of development, and the date on which the proposed project can begin construction. Finally, in the CMIA "appropriateness" category, analysts considered issues such as whether "project benefits match core intent of CMIA" and whether the project "relieves congestion [and] improves travel times, within high-congestion corridors."

These data allow testing of a variety of hypotheses regarding, for example, the importance of staff recommendations versus B/C ratios in CTC funding decisions; the relative importance of the value, appropriateness and deliverability categories; and other hypotheses of interest to political science and policy analysts. Although a rigorous analysis of these data is beyond the scope of this project, we have conducted some preliminary data analysis in order to lay some foundations for future research.[24]

In addition to the results of the BCA for CMIA projects, Caltrans provided a few of the actual spreadsheets that were used to produce the BCA results. Discussion of the spreadsheets is deferred until the model has been described in more detail. When the Cal-B/C model is explored later, it will be useful to recall the Prop 1B case just presented.

The next section contains the main body of the report, where we explore BCA for transportation planning and public policy.

III. TOWARDS MULTIMODAL DEMAND MODELING IN BCA FOR TRANSPORTATION PLANNING & PUBLIC POLICY

This section, the core of the report, contains two subsections – one on BCA for public policy and the other on BCA for transportation planning. Each of the two subsections could serve as a standalone study, but there are numerous parallels and substantial complementarity between them.

One parallel between the two studies is their structure. Each study is divided into three subsections. Each begins by describing the context-specific approach to BCA – public policy analysis or transportation planning – along with some of its limitations. Next comes a discussion of the role of travel demand modeling, an essential component of all types of BCA for transportation. Finally, each study concludes with a presentation of innovative solutions to the problems identified. Transportation planners, policy analysts and academics alike may benefit from the cross-pollination that will result from the parallel treatment of BCA in these two realms, though for the most part each can also be read in isolation.

The first study presents new retrospective BCA results for 23 rail transit systems in the United States. This is intended to inform policy making at a high level and is directed at politicians, policy makers, and also voters. The second study describes methods for prospective BCA. It evaluates methods used at state DOTs and offers suggestions for improvement.

PUBLIC POLICY ANALYSIS

In this first subsection we discuss a method of analysis that is useful for decision makers contemplating general directions in transportation policy – for example, deciding whether funding should be allocated to transportation or to other policy goals, such as hiring more teachers or police officers, pursuing carbon mitigation strategies, and so forth. This subsection provides an illustration of the basic microeconomic BCA framework. We also extend the policy-oriented academic literature by incorporating multimodal considerations into the demand-modeling component of the analysis, which leads to more accurate results and also serves as a concrete example of how easy it can be to incorporate multimodal considerations into BCA.

This subsection is divided into three sub-subsections. The first describes the textbook microeconomic method of BCA for policy analysis, the second discusses how travel demand modeling is used in this context, and the third presents the results of an original BCA for rail transit systems.

BCA for Retrospective Public Policy Analysis

In the previous section, we sketched the microeconomic foundations of BCA. We now elaborate on this and illustrate concepts graphically. In BCA (also sometimes referred to as cost-benefit analysis), all benefits and costs must be converted into monetary values. Of course any given policy or project will have numerous positive and negative impacts, and all BCAs need to determine which are the most important impacts to measure. In policy-oriented literature typically a small number of impacts are considered. For example, the study by John Harford included only user benefits and congestion reduction benefits. Similarly, the study by Clifford Winston and Vikram Maheshri included user and congestion reduction benefits only. Both studies also adjusted costs upward to account for a well-known effect, which, the Winston study referred to as "the excess burdens associated with taxes"[25] and the Maheshri study described as "the cost of raising public funds."[26] This effect can be thought of a negative external impact of the project, and it is a cost category separate from the more standard capital and operating costs.

Most recently, Erick Guerra has taken an even simpler approach. In his analysis the only benefit category was user benefits – specifically, benefits received by those who ride transit – and the only cost categories were operating and capital costs. Although this approach excludes some of the categories of benefits and costs captured in earlier studies, the impacts it does include are the primary ones. As a result, the main virtue of this approach is that it provides a valuable baseline BCA that is less controversial than other approaches. Our analysis builds directly on Guerra's study, by extending the demand modeling procedure to account for multimodal considerations, while keeping the simplicity and transparency of his "back-of-the-envelope" approach. Simplicity is preferred here because we are presenting this analysis primarily as an example of what a more integrated model – one that can facilitate rapid assessment of multiple projects – looks like.

Even if cost data is readily available, valuing even the one category of user benefits is not entirely straightforward. This is because we may observe, for example, that a transit system had 10 million riders (or trips; there are a variety of measures of the general concept of quantity that one could use here) who each paid a fare of $2, but this means only that they were willing to pay *at least* $2. To estimate their true willingness to pay, economists estimate a *demand curve*. In principle, demand curves can take many shapes, but the simplest form is a linear demand curve, which can be estimated by using the price-quantity point observed in the data (consisting of the average fare, and annual number of riders) and an assumed (or estimated) elasticity.[27]

An example will help clarify. Say a system had one million riders in a year, and the fare was $2. Assume the price elasticity of demand at this fare (denoted by P_d^e) is -1 (we will explain the concept of elasticity in a moment), then we can use three pieces of information to estimate the demand curve. The linear demand curve is given below in equation (1):

$$Q_d = a - bp \tag{1}$$

Here, Q_d is the quantity demanded, a is the constant term (to be calculated), b is the slope coefficient (also to be calculated; it is assumed negative given the law of demand – "as price increases, quantity demanded falls") and p is the price, which, like quantity, is given in the data. The concept of price elasticity of demand relates to how consumers respond to changes in price. From the Law of Demand we know that as price increases, quantity demanded falls, but by how much? Knowing the value of by P_d^e allows one to answer this question. It gives the percent reduction in quantity demanded resulting from a one-percent increase in price – so for example, if $P_d^e = -1.5$ then a 1% increase in price leads to a 1.5% decrease in Q_d, and if $P_d^e = -2.5$ then a 1% increase in price leads to a 2.5% decrease in Q_d. An expression for elasticity is given in equation (2):

$$P_d^e = \frac{\Delta Q}{\Delta p} \times \frac{p}{Q} \qquad (2)$$

Note that in equation (1), the slope coefficient b is the change in quantity resulting from a unit change in price, mathematically $b = -\frac{\Delta Q}{\Delta P}$. As mentioned above, for this hypothetical transit system we know that $p = \$2$, $Q_d = 1{,}000{,}000$, and, at this point, $P_d^e = -1$. Thus, we can solve for P_d^e which, as can be verified, is 500,000. Substituting 500,000 in for b, 1,000,000 for Q_d, and 2 in for p in equation (1), we can solve for a, which turns out to equal 2,000,000. Thus, given the fare and trips data for this system, and the assumed elasticity value of -1, we have solved for a linear demand function, which is $Q_d = 2{,}000{,}000 - 500{,}000p$. It is conventional to express price as a function of quantity demanded, as in:

$$p = \frac{a}{b} - \frac{1}{b} Q_d \qquad (3)$$

Plugging in the values of slope and constant solved for above, we see that

$$p = 4 - \frac{Q_d}{500{,}000}$$

This is the standard demand curve of introductory microeconomics. It is plotted in Figure 2. The curve shown reflects two assumptions: a linear shape – the actual fare and trip count – and an assumed elasticity of -1 at these fare and ridership levels.[28] Figure 2 contains a shaded region, equal to 2*1,000,000+2*1,000,000*0.5=3,000,000. The first term on the left side shows what riders pay, but the sum gives what they are collectively *willing* to pay; it includes actual expenditures, plus consumer surplus – the second term on the left side. Together, these are known as user WTP or *gross user benefits*.

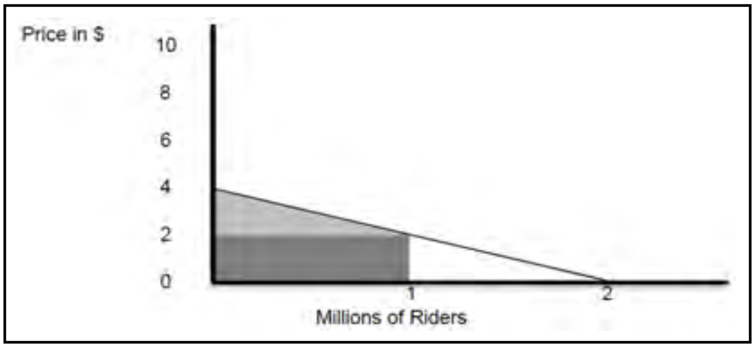


Figure 2. Demand Curve for Transit, Estimated Assuming Linear Form, and Price Elasticity of Demand Equal to -1 at Point of Observation

Note: Although the fare is $2, some riders are willing to pay up to $4. This means they are receiving a benefit that is not totally reflected in the price they pay.

We now consider the effect of changing the elasticity assumption. How would Figure 2 look if instead of $P_d^e = -1$ we had $P_d^e = -0.5$? Following the steps detailed above, we would find that the demand curve is as shown in Figure 3.

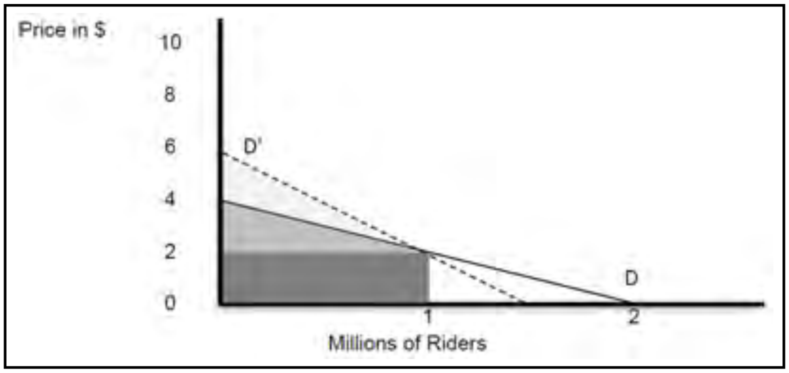


Figure 3. Two Estimated Linear Demand Curves for Transit, with Price Elasticity of Demand Equal to -1 and -0.5 at Point of Observation

Note: The lightest gray triangle, with a base of 6 minus 4 along the y-axis, is the addition to gross user benefits that results from D’ being less elastic than D.

The curve labeled D’ is less elastic than the curve labeled D. A rise in fare will not cause trips to fall as much with curve D’ as with curve D. For example, say that highway congestion is high in a city. If the transit fare increases, a transit rider will be less likely to switch to the congested roads. Thus D’ might represent transit demand in a city with more highway congestion than transit demand curve D which is in a city with less congestion. As shown, the area under D’, up to the number of trips taken (one million) is larger than D by the amount of the lightly shaded area.

We have now demonstrated one technique economists use to determine gross user benefits: find information on average fare and annual number of trips, estimate or assume a reasonable value of an elasticity, use this information to estimate a linear demand curve, and then calculate the area under this curve up to the number of trips taken. But what about costs? Fortunately, oftentimes cost data is readily available, especially for retrospective analysis. In his recent study discussed above, Erick Guerra used data from the 2008 National Transit Database to determine annual operating costs for rail transit systems. He also collected data from various sources on capital costs, for 24 heavy and light rail systems in the United States. This study also used data from the 2008 National Transit Database (NTD) to determine trips (quantity) and revenue, from which average fare is calculated (by dividing revenue by trips). Using an assumed elasticity of -0.3, -0.6, and -1.0, the study reports annualized net present values (annualized NPV, or ANPV) for each system. It is important to recall that this analysis excludes all external effects – travel time reductions (or increases) to highway users, environmental benefits, and safety benefits. Although authors such as Jon Harford, Clifford Winston, Vikram Maheshri, and others have attempted to estimate these effects, doing so is difficult and controversial. As mentioned previously, the simplicity of this “back-of-the-envelope” method can be seen as a virtue in that it avoids controversy while still providing useful baseline information.

Take now a specific example from this study, Atlanta’s MARTA. The NTD reported that 82,984,000 unlinked passenger trips (a measure of quantity) were taken on this system in 2008, and total revenue was $49,242,000. The average fare (or, price per trip) is therefore $0.59. With this data on price and quantity, and the assumption that elasticity is -0.3, we can use the technique described above to determine that the consumer surplus is $82,070,750.

Given expenditures are equal to $49 million, gross benefits are $49 million plus $82 million. From this we subtract operating and annualized capital cost estimates of $158,545,000 and $239,874,000, respectively,[29] to arrive at annualized NPV of $-267,086,250.

Table 2 shows annualized NPV estimates for all cities for elasticity equal to -0.3.[30] Assuming fare elasticity of -0.3, two systems have positive net benefits, even without considering external effects. External effects, such as pollution reduction due to substitution of single-occupancy vehicles for transit travel, are real and ideally should be included, but this simplified analysis still provides useful information to policy makers. It tells policy makers what the value of external benefits must be for the other 22 systems to “break even” in the sense of having non-negative NPV. Guerra also presented estimates assuming elasticity was -0.6 and -0.9, but we do not present these results. Estimates produced assuming more elastic demand will necessarily produce lower estimates of NPV. Despite the fact that three elasticity values were used, it is still the case that the analysis restricted each system to have the same elasticity. In the remainder of this subsection, we demonstrate how to remedy this problem through integration of multimodal transportation data.

Table 2. Annualized NPV, Calculated with a Rule-of-Thumb Elasticity and NTD Data

Entity	Unlinked Passenger Trips	Fare Revenues	Implied Average Fare	Operating Expenses	Annualized Capital Costs	Annualized NPV
Atlanta - MARTA	82,984,033	49,242,449	0.59	158,545,028	239,874,000	-267,105,831
Maryland Transit Administration	21,809,865	19,175,848	0.88	92,433,305	94,194,000	-135,491,710
Massachusetts Bay	222,429,875	230,792,800	1.04	397,975,381	266,901,000	-49,428,914
Niagara Frontier	5,680,505	4,243,983	0.75	23,440,156	31,538,000	-43,660,868
Charlotte Area Transit System	2,262,631	1,622,813	0.72	9,495,402	14,214,000	-19,381,901
Chicago Transit Authority	198,137,245	203,809,557	1.03	439,880,792	433,735,000	-330,123,640
Dallas Area Rapid Transit	19,437,603	13,822,668	0.71	89,218,007	59,686,000	-112,043,559
Denver Regional	20,635,133	21,945,973	1.06	41,677,168	47,604,000	-30,758,573
Los Angeles County (LACMTA)	86,707,000	6,153,000	0.07	249,196,000	350,159,000	-582,947,000
Miami-Dade Transit	18,538,741	13,246,540	0.71	82,381,902	82,226,000	-129,283,795
Metro Transit (Minneapolis)	10,221,681	8,989,861	0.88	23,697,504	15,078,000	-14,802,541
New Jersey Transit Corporation	21,331,377	20,976,417	0.98	114,560,257	132,790,000	-191,413,145
MTA New York City Transit	2,428,308,510	2,176,131,206	0.90	3,250,031,137	2,446,748,000	106,237,412
Southeastern Pennsylvania	121,562,311	106,006,736	0.87	211,127,074	257,056,000	-185,498,445
Port Authority of Allegheny County	7,141,814	7,054,214	0.99	44,345,351	51,127,000	-76,661,114
Tri-County, Oregon	38,931,646	31,495,353	0.81	84,120,139	76,891,000	-77,023,531
Sacramento Regional Transit District	15,484,670	14,032,316	0.91	51,829,516	29,969,000	-44,379,007
Utah Transit Authority	14,752,512	9,796,589	0.66	27,382,554	24,614,000	-25,872,317
San Diego Metropolitan Transit	37,620,944	31,120,170	0.83	55,949,227	71,009,000	-43,971,107
San Francisco (BART)	115,227,684	308,852,291	2.68	478,986,881	321,281,000	23,338,228
San Francisco Municipal Railway	50,312,720	26,306,334	0.52	142,510,861	180,962,000	-253,322,637
Santa Clara Valley	10,451,136	8,597,620	0.82	55,544,365	82,582,000	-115,199,378
Washington Metropolitan Area	288,039,725	458,304,931	1.59	755,747,463	693,685,000	-227,285,980

Note: This table presents data from NTD, including unlinked passenger trips and revenue, which are used to calculate average fare per trip. Operating expense data also comes from the NTD, while annualized capital cost data were presented in “Valuing Rail Transit: Comparing Capital and Operating Costs with Consumer Benefits,” by Erick Guerra.

Estimating a Cross-Sectional Fare Elasticity Model

As we have seen, elasticities are critical inputs for transportation BCA. Here, we estimate a fare elasticity model to enable assigning a unique elasticity to each system. Assuming homogenous fare elasticities, as in the examples described above, is a common practice in the literature. The studies by both John Harford[31] and Erick Guerra[32] assumed homogenous elasticities.[33] Both also conjecture that relaxing the assumption homogeneity would not dramatically affect the results of the analysis. For example, Jon Harford writes:

> *It is likely that [demand would be less elastic in] larger cities with higher local price levels and greater traffic congestion. ... Thus, assuming the same [elasticity] for the demand curve for all urban areas will tend to bias the benefit–cost ratios...downward for more populous areas compared to less populous ones. However, since the results tend to show benefit–cost ratios that are positively related to the size of the population of the urban area, the relative ranking of benefit–cost ratios should not be significantly affected.*

Similarly, regarding this issue, on page 53 Erick Guerra writes:

> *Although fare elasticity and the shape of the demand curve vary by system, use of the same elasticity for each system prevents small measurement errors from creating large estimation errors. As this analysis finds, the large, congested cities expected to have the most inelastic transit demand already tend to outperform cities expected to have more elastic demand. Empirically estimated elasticities will likely increase the performance gap.*

Here, we estimate a fare elasticity model so that we can assign an individualized elasticity to each transit system. The rationale for doing this is that even if heterogeneous elasticity estimates do not affect the ranking of systems very much (which itself is a conjecture that we will test), the size of NPV estimates also matters.

Fare elasticities will differ across cities for a variety of reasons. Some cities contain a large transit-dependent population – elderly, low-income, immigrant, etc. Other cities are very dense, which imposes costs (in terms of parking, etc.) on even those with high incomes. Still other cities suffer from severe traffic congestion. Todd Littman describes various reasons why elasticity differs across time and place and provides extensive references to the literature.[34]

While many studies have presented fare elasticity estimates, we are only aware of one study that systematically estimated fare elasticity for a large cross section of cities. In a 1991 report published by the American Public Transit Association (APTA), J. Linsalata and L. H. Pham present transit fare elasticity estimates for 52 cities. They conducted a survey to obtain the ridership data for bus systems two years before and two years after fare changes took place for each transit system. They estimated an autoregressive integrated moving averages (ARIMA) model and found that, on average, a 10% increase in fare decreases ridership by 4%. The important virtue of this APTA study, for our purposes, is that it presented elasticity estimates for a fairly large cross section of transit systems. Their elasticity estimates for 50 systems are presented in Table 3. The average value of fare elasticity among these systems is -0.402.

We recognize that these elasticity estimates suffer from several limitations with regard to our objectives here. First, they are bus fare elasticities, but clearly it would be better for our purposes if we had rail fare elasticities. We assume rail and bus fare elasticities are highly correlated.[35] Second, the estimates are rather old, having been estimated using data from the mid-1980s. In fact, one of the findings of the APTA study was that transit demand became more elastic than had been previously found up until that time. However the difference was on the order of a 25% more elastic demand curve, which is not necessarily dramatic. We therefore assume transit fare elasticity has not changed dramatically since the APTA study was published, though highlight the tentativeness of this assumption.[36] Finally, a third possible limitation of these fare elasticities is that the APTA study only presents elasticity values for about half of the systems in Guerra's sample. Therefore, rather than plugging in elasticity values directly from the APTA study, which would require us to dramatically limit the number of systems we examine, we instead estimate a fare elasticity model to enable assigning unique fare elasticities for all rail transit systems in a way that is computationally simple. We estimate simple (binary) and multiple regression models, using the variables described below and in Table 4.

Table 3. Fare Elasticity Estimates for Select Cities

Entity	Fare Elasticity	Entity	Fare Elasticity
Albany, NY	-0.456	Lincoln, NE	-0.5
Alexandria, VA (DC)	-0.412	Los Angeles, CA	-0.231
Allentown, PA	-0.747	Madison, WI	-0.401
Appleton, WI	-0.255	Nashville-Davidson, TN	-0.527
Atlanta, GA	-0.277	Oceanside, CA	-0.35
Baltimore, MD	-0.495	Oshkosh, WI	-0.167
Binghamton, NY	-0.704	Phoenix, AZ	-0.321
Buffalo, NY	-0.503	Portland, OR	-0.387
Chattanooga, TN	-0.341	Richmond, VA	-0.624
Cincinnati, OH	-0.738	Riverside, CA	-0.119
Dallas, TX	-0.134	Sacramento, CA	-0.162
Daytona Beach, FL	-0.423	San Diego, CA	-0.27
Denver, CO	-0.562	San Francisco, CA	-0.151
Des Plaines, IL (Chicago)	-0.117	San Jose, CA	-0.46
Detroit, MI	-0.247	Sarasota, FL	-0.214
El Paso, TX	-0.294	Seattle, WA	-0.266
Eugene, OR	-0.184	South Bend, IN	-0.261
Everett, MA (Boston)	-0.429	Spokane, WA	-0.527
Flint, MI	-0.585	Springfield, MO	-0.481
Fort Wayne, IN	-0.116	St. Petersburg, FL	-0.478
Fresno, CA	-0.311	State College, PA	-0.642
Grand Rapids, MI	-0.43	Tacoma, WA	-0.432
Honolulu, HI	-0.652	Toledo, OH	-0.855
Kansas City, MO	-0.511	West Palm Beach, FL	-0.605
Lancaster, PA	-0.428	Williamsport, PA	-0.299

Table 4. Fare Elasticity Regression Model, Variable Descriptions

Variable	Description	Source
Fare Elasticity	Expected percent reduction in ridership from a 1% fare increase. Also denoted as P_d^e.	APTA, 1991
City Population	Population of the central city in which transit agency operates.	CCDB, 1988
Urban Population	Population of the wider urban area in which transit agency operates.	APTA, 1991
Density	Population of central city divided by its land area.	CCDB, 1988
Congestion	Roadway Congestion Index value for 1985.	TTI, 2013

Source: J Linsalata, LH Pham, 1991. *Fare elasticity and its application to forecasting transit demand*. American Public Transit Association, Table 2: Transit Fare Elasticity Estimates of 52 Transit Systems, p. xv. City and County Data Book, distributed by ICPSR; Texas Transportation Institute.

These variables come from three sources. Fare elasticity, denoted previously as , is obtained from the APTA study by Pham and Linsalata. We also obtained basic demographic and land-use variables from the 1988 City and County Databook (CCDB).[37] The CCDB also contains data on the wider urbanized area, but since this data was also reported in the APTA study, we use the values from that source instead.[38] Finally, the Texas Transportation Institute (TTI) produces a Roadway Congestion Index for the years 1982 to present.[39] We use values from 1985. We were able to merge data from the CCDB to all but two of the 52 cities in the APTA study. However, lack of TTI data for 18 cities left us with 32 observations in the final merged data set. Table 5 presents summary statistics for these variables.

Table 5. Fare Elasticity Regression Model, Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Fare elasticity	32	-0.373	0.175	-0.855	-0.117
City population	32	477,326	588,208	36,330	3,259,340
Urban population	32	1,518,619	1,982,378	170,749	9,479,436
Density	32	4,508	3,020	988	16,142
Congestion	32	0.837	0.189	0.450	1.250

Table 5 shows that average fare elasticity in our sample (which is a subset of the APTA sample) is -0.373, and ranges from -0.855 to -0.117. Population ranges confirm a broad cross section of cities are included in this sample, though the mean city population of nearly half a million shows the sample contains more large cities. Summary statistics for the density and congestion variables tell a similar story. We use these data to estimate statistical models to predict fare elasticity. Specifically, we regress fare elasticity for a transit system, P_d^e, on independent variables as shown in equation 4:

$$P_d^e = \beta_0 + \beta_1 * CONGESTION + \beta_2 * CITY\_POP + \varepsilon \qquad (4)$$

Here, P_d^e is fare elasticity (as above), β_0, β_1, and β_2 are parameters to be estimated, CONGESTION and CITY_POP are two of the independent variables described in Table 4, and ε is a catch-all "error term" assumed to have the usual statistical properties. We also estimate four modified versions of this model, one in which β_1 is constrained to zero, another in which β_2 is constrained to 0, and two additional versions of equation (4) both of which restrict β_1 to 0. CITY_POP is replaced with URBAN_POP in one and with DENSITY in the other. The rationale for these five model specifications is that, given the small sample size, only a small number of variables are likely to provide a parsimonious and intuitive model, and these independent variables are those most strongly suggested by theory. Table 6 presents the estimates of these bivariate and multivariate regressions.

Table 6. Fare Elasticity Regression Model, Estimation Results

Variables	Fare	Fare	Fare	Fare	Fare
CITY_POP	0.000671**				
	(0.000274)				
URBAN_POP		0.000351***			0.000215
		(0.000123)			(0.000155)
DENSITY			0.00000755		
			(0.000008)		
CONGESTION INDEX				0.387***	0.266
				(0.131)	(0.161)
Constant	-0.405***	-0.426***	-0.407***	-0.696***	-0.628***
	(0.038)	(0.038)	(0.051)	(0.118)	(0.131)
Observations	32	32	32	32	32
R-squared	0.051	0.158	0.017	0.174	0.216
Adjusted R-squared	0.0192	0.13	-0.0158	0.147	0.162

Note: *** denotes significance at below the 1% confidence level; ** denotes significance at below the 5% confidence level; standard errors are in parenthesis.

As can be seen in Table 6, of the five models, the adjusted R-squared (similar to the more familiar correlation coefficient) is highest in the multiple regression model in the last column, which estimates equation (4). However, the single best predictor of fare elasticity is the congestion index, with an adjusted R-squared of 0.147. While the adjusted R-squared is slightly higher in the multiple regression model, and while we do hope to be precise, another goal here is to illustrate as simply as possible what incorporated multimodal data looks like. Therefore, we present below an equation (5), taken from column 4 of Table 6. This equation uses the congestion index as a single explanatory variable to estimate fare elasticity results:

$$\mathrm{FARE\_ELASTICITY} = -0.696 + 0.387 * \mathrm{CONGESTION} \tag{5}$$

Since Texas A&M Transportation Institute (TTI) calculated a congestion index value for many areas for many years, using this model and the contemporaneous value of the TTI congestion index we can estimate fare elasticity over many years for many systems.[40] We therefore estimate values for 23 of the 24 systems in Guerra's sample (we could not estimate fare elasticity for Puerto Rico because the TTI congestion index did not measure congestion there.) The congestion index for systems in this sample ranges from 0.45 to 1.25; thus, equation (5) shows that estimated fare elasticity ranges from -0.52185 to -0.21225.

Illustrating Data Integration with a Retrospective BCA of Rail Transit Systems

As shown above, the TTI highway congestion index is a fairly powerful predictor of transit fare elasticity. We now use the value of the TTI index for 23 rail transit systems in the US in 2008 and the fare elasticity model presented above as equation (5) to conduct a BCA of US rail transit systems. This provides a concrete example of a rail transit BCA that integrates highway data. Here, we find that highway congestion data is a good predictor of transit demand. Thus, our analysis is integrated in that it takes into account multimodal considerations.

In what follows, essentially, Guerra's BCA described above is extended by using fare elasticity estimates that more closely correspond with demand conditions in each city. All other variables – trips, average fare, operating costs, and capital costs – remain unchanged. But by allowing fare elasticity to vary by city, we can explore the extent to which the results of this analysis change when highway data is incorporated into a BCA of transit systems. In the language of BCA, plugging in elasticity estimates from external sources is known as "benefits transfer."[41] Our approach here is a statistically adjusted benefits transfer.

Table 7 summarizes the results. For each transit system, we present the value of the TTI congestion index, the estimated fare elasticity – estimated by inserting the TTI congestion index value for a transit system into equation (3) – and the annualized net present value (ANPV) that results from using these elasticity estimates in the calculations described above. Finally, we also present in Table 7 the ANPV calculated by Guerra.

Comparing the results of our analysis with those from Guerra's analysis, we see that there is one major qualitative difference, which is that Washington, DC now has a positive ANPV. Overall, most system rankings did not change, but here again DC is an outlier. Table 7 shows that it was ranked nineteenth in Guerra's study but third in ours. Two systems changed rank less dramatically but noticeably: San Diego improved by moving from eighth to fourth, while Niagara Frontier fell from seventh to eleventh.

One additional system (Washington) is shown to have positive NPV (i.e., building the rail system is more efficient than not building it); most other systems come out better as well.[42] Specifically, in all but two cases (Niagara Frontier, and Port Authority of Allegheny County) the NPV is higher in our analysis than in Guerra's. Given that the average of the elasticities used in our analysis is -0.25 whereas the comparison results used an elasticity estimate of -0.3 for all systems, this is not necessarily a surprise. However, it was not predestined that the average of our elasticity estimates would be greater than -0.3. The average of all elasticities reported in the APTA study was below -0.3 (to be precise, it was -0.373, as shown in Table 4). It is just the case that the cities in our sample were larger, on average, than those in the APTA study. TTI congestion index values are not available for all smaller cities. Thus, when TTI congestion index values are used with equation (5), they produce, on average, a less elastic demand curve than in our comparison study. We have not performed a sensitivity analysis on these results by, for example, adjusting the fare elasticity model or by using an alternative fare elasticity model (e.g., the other candidate models shown in Table 6), and we leave this task for future research.

Table 7. Original and Updated NPV Estimates (Annualized)

Entity	Congestion Index	Fare Elasticity	Original NPV*	Updated NPV*	Original Rank	Updated Rank	Change in Rank
MTA New York City Transit	1.13	-0.26	106,237,412	685,411,843	1	1	0
San Francisco (BART)	1.34	-0.18	23,338,228	378,983,156	2	2	0
Washington Metropolitan Area	1.35	-0.17	-227,285,980	329,255,444	19	3	16
San Diego Metropolitan Transit	1.34	-0.18	-43,971,107	-8,136,079	8	4	4
Metro Transit (Minneapolis)	1.10	-0.27	-14,802,541	-13,156,229	3	5	-2
Charlotte Area Transit System	1.06	-0.29	-19,381,901	-19,247,319	4	6	-2
Utah Transit Authority	0.99	-0.31	-25,872,317	-26,543,959	5	7	-2
Denver Regional	1.09	-0.27	-30,758,573	-27,312,631	6	8	-2
Sacramento Regional Transit District	1.29	-0.20	-44,379,007	-32,109,555	9	9	0
Massachusetts Bay	1.04	-0.29	-49,428,914	-40,936,947	10	10	0
Niagara Frontier	0.68	-0.43	-43,660,868	-45,831,688	7	11	-4
Tri-County, Oregon	1.08	-0.28	-77,023,531	-72,877,617	12	12	0
Port Authority of Allegheny County	0.75	-0.41	-76,661,114	-79,725,329	11	13	-2
Santa Clara Valley	1.32	-0.19	-115,199,378	-106,312,014	14	14	0
Dallas Area Rapid Transit	1.17	-0.24	-112,043,559	-106,664,193	13	15	-2
Miami-Dade Transit	1.34	-0.18	-129,283,795	-114,030,340	15	16	-1
Maryland Transit Administration	1.18	-0.24	-135,491,710	-127,391,609	16	17	-1
Southeastern Pennsylvania	1.07	-0.28	-185,498,445	-174,161,127	17	18	-1
New Jersey Transit Corporation	1.13	-0.26	-191,413,145	-185,830,299	18	19	-1
San Francisco Municipal Railway	1.34	-0.18	-253,322,637	-223,030,764	20	20	0
Atlanta - MARTA	1.19	-0.24	-267,105,831	-244,614,535	21	21	0
Chicago Transit Authority	1.12	-0.26	-330,123,640	-281,686,268	22	22	0
Los Angeles County (LACMTA)	1.55	-0.10	-582,947,000	-561,205,120	23	23	0

Note: Congestion Index values are 2008 values from the Texas Transportation Institute’s 2014 Urban Mobility Report; Fare elasticity was produced with the Congestion Index values and our fare elasticity regression model (equation 5 in this report); Original NPV results are replicated results from Table 2 of Erik Guerra, “Valuing Rail Transit: Comparing Capital and Operating Costs with Consumer Benefits.” Transportation Research Record 2219 (2011): 50–58. Updated NPV results were produced using estimated fare elasticities for the individual systems. “ * ” denotes “Values presented in annualized form.”

Before concluding this analysis, it is of some importance for what follows to address a small technical point concerning the use of NPV (or the closely related concept of annualized NPV) versus a benefit-cost ratio (B/C ratio). Many BCAs report the B/C ratio, even though some authors – including Boardman and associates – have made a case against its use. This is because selecting projects based on a strict B/C ratio standard can lead to incorrect decisions.[43] However, the B/C ratio can prove useful information – for example, in ranking mutually exclusive projects under a constrained budget. In fact, this was precisely the situation for decision makers at the CTC during Prop 1B, as described in our case study above.[44]

We have taken a simple example of a BCA of rail transit systems and extended it by incorporating highway congestion data. This simple illustration integrating highway congestion and transit demand data not only shows what a multimodal BCA looks like, it also shows that data integration matters. While to some it may not seem very important that only one additional rail transit system is found efficient, with our BCA, the number of systems shown to return positive NPV increased by a substantial 50% compared to analysis using homogenous, rule-of-thumb fare elasticity.

Finally, we reiterate once again an important point: The annualized NPV estimates presented above do not factor in any external effects. It is possible that our use of a congestion index variable to estimate fare elasticity may incorrectly lead some readers to believe that we have incorporated the external congestion effects of the transit systems on highway users. In fact, we have not incorporated any external effects in this analysis. It is simply the fact that congestion in a city predicts transit demand, as one would expect it would; therefore, we have used highway congestion to predict transit demand. It is likely that congestion would be worse in these cities if these transit systems did not exist, in which case highway users do receive benefits from these systems. The NPV values would be higher if we included benefits to highway users, the value of improvements in air quality, and other external benefits, but they would be lower if we included external costs, such as cost of public funds.

It is important to keep in mind that this analysis ignores all external effects, as doing so may lead one to conclude that all but three rail transit systems in the US are inefficient compared to the status quo. We interpret these results as follows: In our improved BCA of rail transit systems, three transit systems are shown to have positive NPV, even when external effects are ignored. Determining whether more systems would be shown to be efficient if all external effects (both positive and negative) were included is a task for future research.

TRANSPORTATION PLANNING

In this subsection we move from retrospective BCA for policy analysis to prospective BCA for planning. While it is important to consider the efficiency of past decisions when evaluating public policy, state DOTs and other transportation planning agencies typically need to evaluate the efficiency of proposed projects. Therefore we now consider tools developed by state DOTs for BCA for proposed projects.

As a point of clarification, we note at the outset that planners at state DOTs conduct a variety of types of economic analyses in addition to BCA. For example, economic impact analysis (EIA) and cost-effectiveness analysis (CEA) are different methods of economic analysis which are often confused with BCA. We have found that BCA, CEA, and EIA all have been used, or are planned for use, in California transportation planning.[45] However, the focus of this subsection, as in the wider report, is on BCA.

This subsection also contains this report's second case study, which considers a nationwide grant program (TIGER) that was directed by the US DOT and in which, like California's Prop 1B, the tool of BCA played a key role in allocating funding. This case study provides a good platform for comparing Caltrans' BCA methods with methods used in other states. We focus especially on comparing Caltrans' methods with those used by the Ohio DOT (ODOT) in a recent TIGER grant application, and we also briefly discuss BCA methods used by local governments from around the country in this grant competition.

ODOT was selected for comparison with Caltrans for several reasons, the most important of which is that analysts at ODOT had provided useful information for previous research upon which our project was explicitly trying to build.[46] We shall see that the ODOT case does indeed provide ideas for Caltrans and other state DOTs. At the same time, we will see that some of Caltrans' models, in particular Cal-B/C, has served as an example for other states and transportation agencies.

In the remainder of this section, we describe the method of BCA for transportation planning, discuss how travel demand modeling is used in conjunction with it, and then discuss ways of improving BCA methods and models for transportation planning.

BCA for Prospective Investment Analysis

A large variety of BCA models have been and are currently used at state DOTs.[47] All of these models strive to maintain a firm grounding in applied welfare economics, but they are unique in combining transportation-engineering concepts with economic valuation techniques. Chapter 4 of a recent FHWA publication[48] provides short descriptions of various BCA models, including seven developed by FHWA (HERS-ST, IDAS, IMPACTS, SCRITS, STEAM, TOPS-BC and BCA.net); the COMMUTER Model developed by the US EPA; models developed by state DOTs, including EMFITS (New York DOT), FITSEval (Florida DOT), and Cal-B/C (Caltrans); and TRIMMS, developed by the University of South Florida.

Most of these models can be classified as either "sketch-planning" or "post-processing" methods.[49] These categories lie along a continuum from "low cost" (in terms of knowledge and effort required) to "high cost," and also in their ability to account for more impacts (with the more "costly" models able to account for more impacts). The FHWA document cited above places Cal-B/C into the sketch-planning category. An alternative categorization, presented in "Cal-B/C Technical Supplement Volume 1," was published in 1999.[50] The three categories presented here – route-based, extended-corridor, and network-based models – likewise differ according to how many impacts, such as induced demand and off-network roads, they can handle. The route-based category of models can be thought of as the FHWA document's "sketch-planning" category, while the "network-based" is very similar to the “post-processing” category. However, this second classification provides an additional, in-between category named “extended-corridor,” and it is this category into which this classification places Cal-B/C.[51] Neither the list of models nor the categorizations provided here are exhaustive but they illustrate the variety of BCA models that have been developed for use in transportation planning. The complexity/accuracy tradeoff is well recognized in transportation BCA.

At Caltrans, the most widely used model for BCA is Cal-B/C, short for The California Life-Cycle Benefit and Cost Analysis Model, which was developed by Caltrans and outside consultants. It is the authors’ view that Cal-B/C can be classified as either “sketch-planning,” “route-based,” or “extended-corridor,” depending on how it is used – in other words, the model itself is flexible enough to handle simple and more complex analyses. Since the first version of Cal-B/C was released in the 1990s, a suite of related tools have been developed, including Cal-B/C Corridor and Cal-NET_BC. As these names suggest, they are designed to facilitate evaluation of entire corridors and networks.

The emergence of network BCA models at Caltrans is a recent development. Our research suggests that problems implementing TDMs make Cal-NET_BC too costly to use.[52] Although we have not found examples of the use of corridor or network models at Caltrans headquarters, our research evidences use of some models by Caltrans districts. Many districts and MPOs have already implemented regional travel demand models, which provide necessary inputs to corridor and network models. Future research should focus on finding ways to further the development of network models use din conjunction with TDMs.[53] We have, however, seen a variety of actual projects that Caltrans headquarters analyzed using Cal-B/C, and we discuss these below.

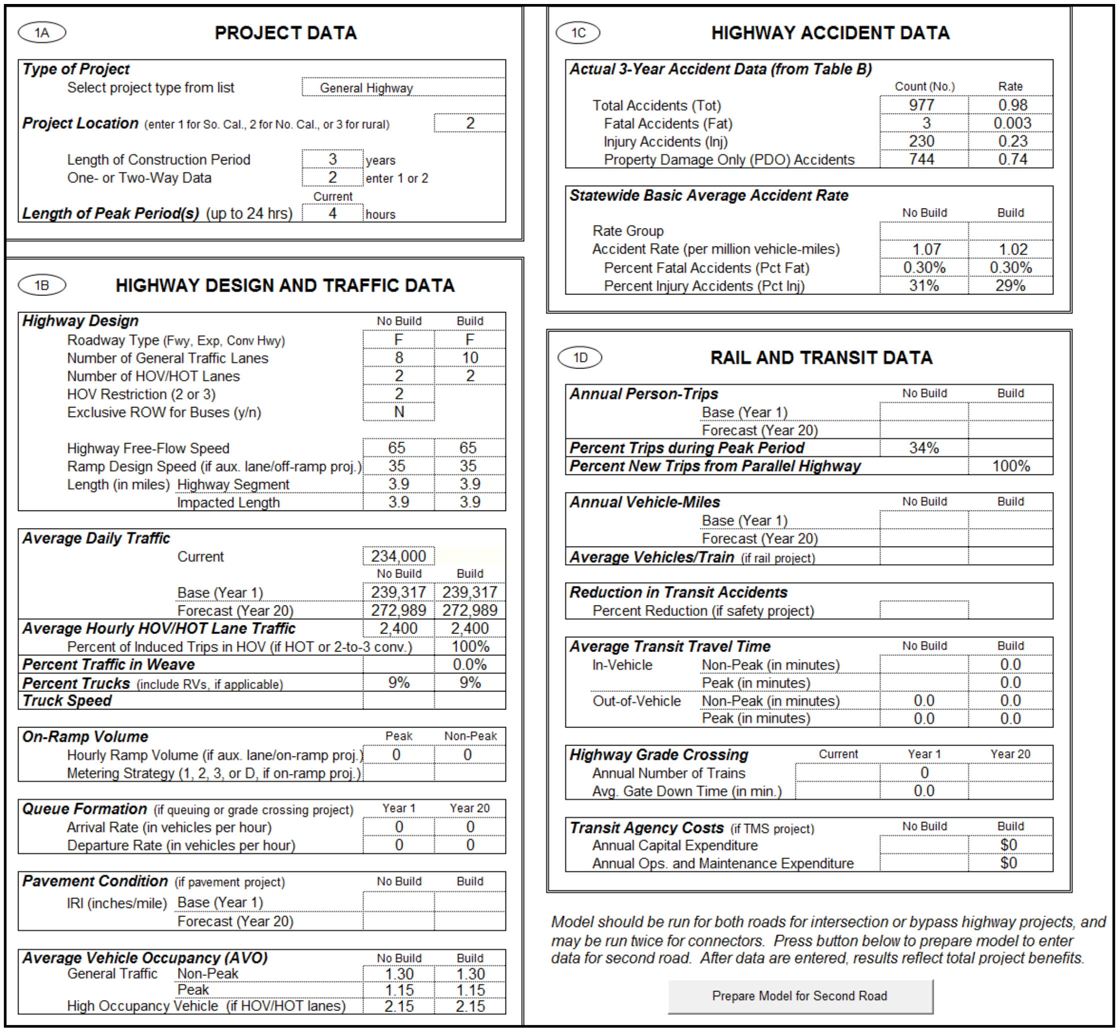
Cal-B/C is a spreadsheet model implemented in Microsoft Excel. “[Caltrans] uses Cal-B/C to conduct investment analyses of projects proposed for the interregional portion of the State Transportation Improvement Program (STIP), the State Highway Operations and Protection Program (SHOPP), and other ad hoc analyses requiring benefit-cost analysis.”[54] As Chris Williges and Mahmoud Mahdavi explain in an article for *Transportation Research Record*, Caltrans “...developed Cal-B/C in the mid-1990s to facilitate the assessment of many projects in a short time frame using a standardized approach,” and “Caltrans used Cal-B/C for the first time in evaluating capital projects for the 1996 State Transportation Improvement Program (STIP) … In 1998 Caltrans decided to have the model revised by an outside consultant … Cal-B/C is currently undergoing another revision.”[55] This revision was completed and released as Version 4, and since then another revision of the model (Version 5) has been released.

The Cal-B/C model is capable of analyzing an ever-expanding variety of project types. All projects (lane additions for highways, double tracking for commuter rail, etc.) use the same spreadsheet file, which contains eleven worksheets: Title, Instructions, Project Information, Model Inputs, Results, Travel Time, Vehicle Operating Costs, Accident Costs, Emissions, Final Calculations, and Parameters. The Title worksheet is simply a cover that denotes the version and identifies the file with Caltrans. The Instructions worksheet contains approximately 3,000 words describing basic requirements for analyzing projects.

For sketch-planning purposes, the most important worksheets are the three titled Project Information, Model Inputs, and Results. The Project Information worksheet is where the analyst enters all of the basic project-specific information required for analysis. Acting upon the information entered here the model applies a variety of engineering equations and outputs the results to the “Results” worksheet.[56] The Model Inputs worksheet can be ignored for many types of analyses, but if the user has more detailed information from a TDM it can be entered here, overriding the values produced by Cal-B/C. Likewise, the other worksheets are not required to obtain basic results, but they contain features useful for advanced analysis, such as the ability to incorporate benefits and costs to other roads, a feature we will return to later. Finally, Cal-B/C relies on a large number of user-configurable parameters, such as the discount rate, value of time, and others. These are adjusted in the Parameters worksheet.

The 2009 User Guide illustrates Cal-B/C through a highway lane addition. We will use this hypothetical example to help illustrate how Cal-B/C is used for sketch planning. Although this is a hypothetical example, we think it is quite representative of the actual project analyses Caltrans headquarters shared with us. This example will highlight some of the ways Cal-B/C, when used for sketch planning, fails to incorporate induced demand and multimodal travel. This will set the stage for the recommendations we offer at the end of this section.

This lane addition example begins with the Project Information worksheet. Figure 4 presents a view from this worksheet.[57]



1A **PROJECT DATA**

Type of Project		
Select project type from list	General Highway	
Project Location (enter 1 for So. Cal., 2 for No. Cal., or 3 for rural)	2	
Length of Construction Period	3	years
One- or Two-Way Data	2	enter 1 or 2
	Current	
Length of Peak Period(s) (up to 24 hrs)	4	hours

1B **HIGHWAY DESIGN AND TRAFFIC DATA**

Highway Design	No Build	Build
Roadway Type (Fwy, Exp, Conv Hwy)	F	F
Number of General Traffic Lanes	8	10
Number of HOV/HOT Lanes	2	2
HOV Restriction (2 or 3)	2	
Exclusive ROW for Buses (y/n)	N	
Highway Free-Flow Speed	65	65
Ramp Design Speed (if aux. lane/off-ramp proj.)	35	35
Length (in miles) Highway Segment	3.9	3.9
Impacted Length	3.9	3.9

Average Daily Traffic		
Current	234,000	
	No Build	Build
Base (Year 1)	239,317	239,317
Forecast (Year 20)	272,989	272,989
Average Hourly HOV/HOT Lane Traffic	2,400	2,400
Percent of Induced Trips in HOV (if HOT or 2-to-3 conv.)		100%
Percent Traffic in Weave		0.0%
Percent Trucks (include RVs, if applicable)	9%	9%
Truck Speed		

On-Ramp Volume	Peak	Non-Peak
Hourly Ramp Volume (if aux. lane/on-ramp proj.)	0	0
Metering Strategy (1, 2, 3, or D, if on-ramp proj.)		

Queue Formation (if queuing or grade crossing project)	Year 1	Year 20
Arrival Rate (in vehicles per hour)	0	0
Departure Rate (in vehicles per hour)	0	0

Pavement Condition (if pavement project)	No Build	Build
IRI (inches/mile) Base (Year 1)		
Forecast (Year 20)		

Average Vehicle Occupancy (AVO)	No Build	Build
General Traffic Non-Peak	1.30	1.30
Peak	1.15	1.15
High Occupancy Vehicle (if HOV/HOT lanes)	2.15	2.15

1C **HIGHWAY ACCIDENT DATA**

Actual 3-Year Accident Data (from Table B)	Count (No.)	Rate
Total Accidents (Tot)	977	0.98
Fatal Accidents (Fat)	3	0.003
Injury Accidents (Inj)	230	0.23
Property Damage Only (PDO) Accidents	744	0.74

Statewide Basic Average Accident Rate	No Build	Build
Rate Group		
Accident Rate (per million vehicle-miles)	1.07	1.02
Percent Fatal Accidents (Pct Fat)	0.30%	0.30%
Percent Injury Accidents (Pct Inj)	31%	29%

1D **RAIL AND TRANSIT DATA**

Annual Person-Trips	No Build	Build
Base (Year 1)		
Forecast (Year 20)		
Percent Trips during Peak Period	34%	
Percent New Trips from Parallel Highway		100%

Annual Vehicle-Miles	No Build	Build
Base (Year 1)		
Forecast (Year 20)		
Average Vehicles/Train (if rail project)		

Reduction in Transit Accidents	
Percent Reduction (if safety project)	

Average Transit Travel Time		No Build	Build
In-Vehicle	Non-Peak (in minutes)		0.0
	Peak (in minutes)		0.0
Out-of-Vehicle	Non-Peak (in minutes)	0.0	0.0
	Peak (in minutes)	0.0	0.0

Highway Grade Crossing	Current	Year 1	Year 20
Annual Number of Trains		0	
Avg. Gate Down Time (in min.)		0.0	

Transit Agency Costs (if TMS project)	No Build	Build
Annual Capital Expenditure		$0
Annual Ops. and Maintenance Expenditure		$0

Model should be run for both roads for intersection or bypass highway projects, and may be run twice for connectors. Press button below to prepare model to enter data for second road. After data are entered, results reflect total project benefits.

Figure 4. View from an Information Worksheet of Cal-B/C, Lane Addition Project

There are five sections on the Project Information worksheet: 1a.) Project Data, 1b.) Highway Design and Traffic Data, 1c.) Highway Accident Data, 1d.) Rail and Transit Data, and 1e.) Project Costs. Figure 4 shows only the first four sections due to space constraints. For lane addition projects (and all other project types) the user enters the number of years to build and the region into section 1a; in this hypothetical case the project requires 3 years to build and is located in Northern California. In section 1b we indicate characteristics of the freeway, such as the number of lanes and traffic estimates. Here we see the project will add two lanes to an eight lane freeway. In this example, we will assume that the current (base year) average daily traffic (ADT) is 234,000, and the 20-year ADT forecast for the no-build scenario is 272,989. Cal-B/C calculates the 20-year ADT forecast in the build scenario simply by using the no-build figure.[58] This of course means that both the current and future ADT estimates are identical in both the "no-build" and "build" scenarios – in other words, we assume for this example that this project *will not induce demand*.

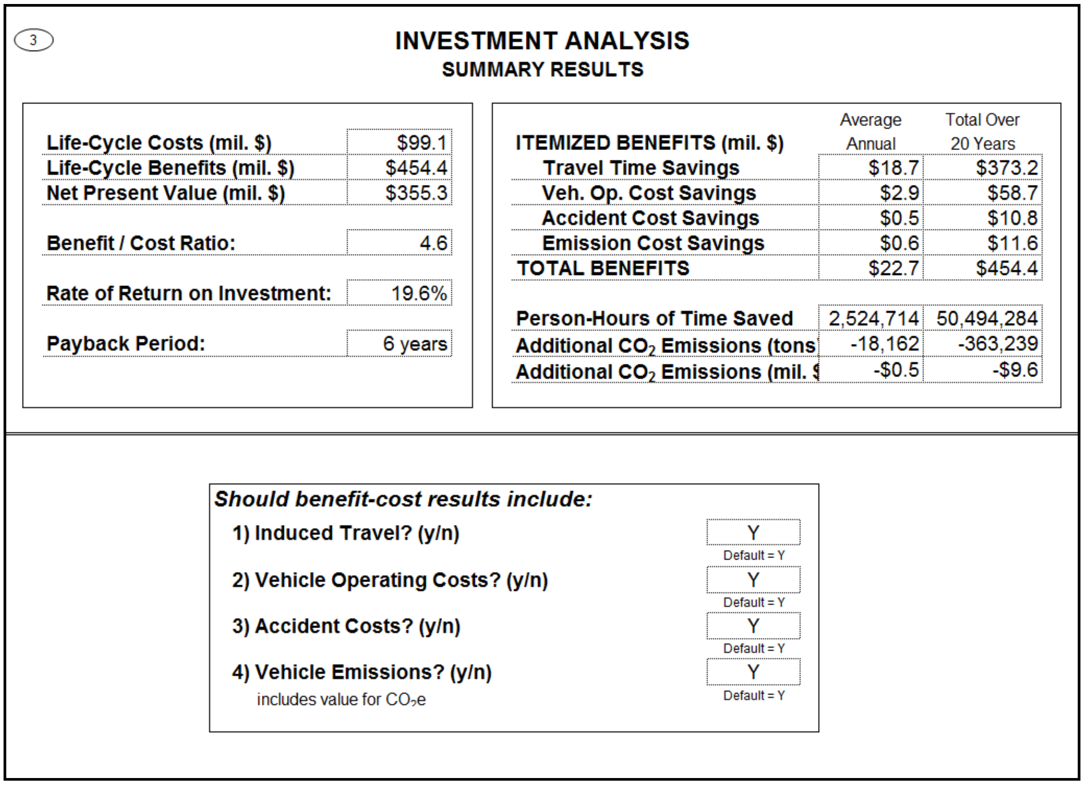
Section 3 in the Project Information worksheet contains accident data. For a quick appraisal, state averages can be used; when there is more time, project-specific averages can be entered.

Section 4, Rail and Transit Data, is ignored in this example. In fact, the documentation we consulted contains conflicting information as to whether or not, for a highway project such as a lane addition, Cal-B/C can accept rail and transit data. For example, the instructions worksheet of the Cal-B/C spreadsheet says, "This section [Section 4] is used for rail and transit projects only," and this is consistent with the approach taken in this lane addition example. However, Chapter 6 of the Cal-B/C Technical Supplement Volume 1 on Network Effects, says, "Information on transit from regional planning models can be inputted directly into the model."[59] In any case, this example ignores transit data, which would otherwise be entered into section 1D. In other words, this example is *unimodal*.

In addition, and as already noted, this example ignores induced demand, as indicated by identical ADT figures for both the build and no-build scenarios. These two criticisms – that Cal-B/C ignores multimodal considerations and induced demand – are weaknesses of the model when used for sketch planning.

As previously mentioned, due to space constraints Figure 4 does not show the fifth section of the Project Information worksheet, which is Project Costs. As long as reliable cost estimates (both dollar cost and timing) are available, entering project costs is a straightforward aspect of project appraisal. This section calculates the present value of costs.

Once general project characteristics are input, the Results worksheet displays the output, as illustrated in Figure 5.



INVESTMENT ANALYSIS
SUMMARY RESULTS

Life-Cycle Costs (mil. $)	$99.1
Life-Cycle Benefits (mil. $)	$454.4
Net Present Value (mil. $)	$355.3
Benefit / Cost Ratio:	4.6
Rate of Return on Investment:	19.6%
Payback Period:	6 years

ITEMIZED BENEFITS (mil. $)	Average Annual	Total Over 20 Years
Travel Time Savings	$18.7	$373.2
Veh. Op. Cost Savings	$2.9	$58.7
Accident Cost Savings	$0.5	$10.8
Emission Cost Savings	$0.6	$11.6
TOTAL BENEFITS	$22.7	$454.4
Person-Hours of Time Saved	2,524,714	50,494,284
Additional CO_2 Emissions (tons	-18,162	-363,239
Additional CO_2 Emissions (mil. $	-$0.5	-$9.6

Should benefit-cost results include:

1) Induced Travel? (y/n)	Y Default = Y
2) Vehicle Operating Costs? (y/n)	Y Default = Y
3) Accident Costs? (y/n)	Y Default = Y
4) Vehicle Emissions? (y/n) includes value for CO_2e	Y Default = Y

Figure 5. View from a Cal-B/C Results Worksheet, Lane Addition Project

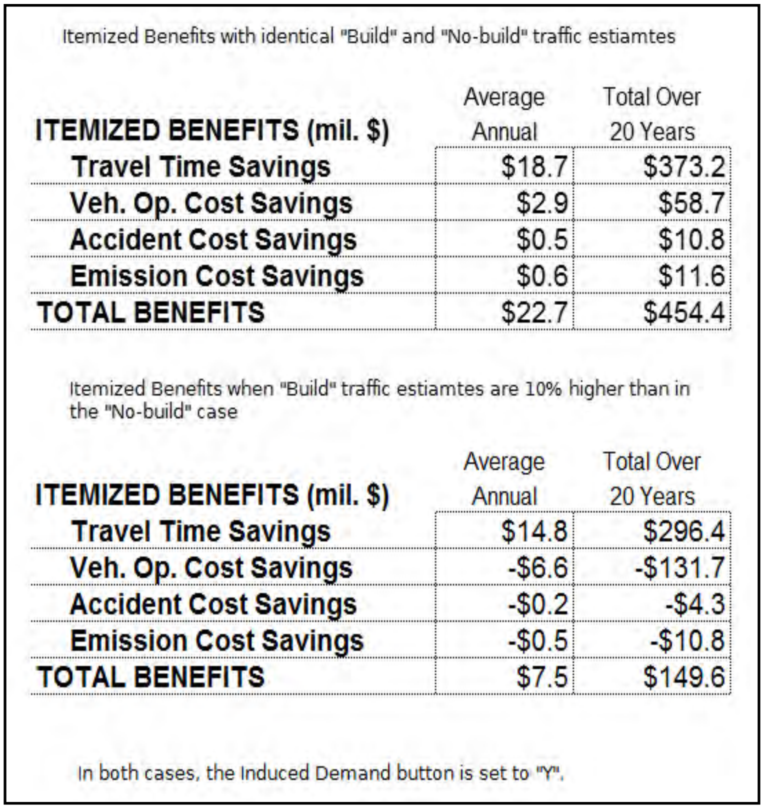
We see in Figure 5 that our example project generates a Net Present Value (NPV) of $355.3 million. This is the single most critical piece of information needed to determine how this project compares to other projects. It is also common to describe the results in terms of their benefit-cost ratios. This and other summary measures are shown on the left side of the upper box, while the right side shows benefits by category: travel time savings, vehicle operating cost savings, accident cost savings, and emissions cost savings. The lower box allows the user to exclude certain categories of benefits. For example, if the user enters “N” (for “No”) for “Vehicle Operating Costs?” the value for Vehicle Operating Cost Savings Over 20 Years (“Itemized Benefits,” line 2, column 2) changes from $58.7 million to zero. The same is true for accident costs and vehicle emission categories.

The final feature illustrated in this example is the induced demand toggle. We will spend some time here due to the importance of induced demand in building more integrated BCA models. Item 1) in the lower section of Figure 6 shows the Induced Demand toggle. In this example, entering “N” will not change the results of the analysis. To see why, recall that for this example we assumed no induced demand for the freeway, which is why traffic is identical in the build and no-build scenarios.

If the analyst were to assume that the lane additions *will* induce traffic, then a variety of effects would occur. If more people use the freeway due to its improvements, one effect may be slower speeds for existing drivers, and thus reduced benefits. On the positive side, benefits would rise for those newly induced to use the road, as long as the induced demand is toggled “on” (by entering “Y”).[60]

To further illustrate the role of induced demand, we now ask, “How would this project’s NPV change if the lane addition did induce traffic?” To answer this question, we assume the project causes traffic to increase by 10% in the build scenario. In particular, we consider how the NPV estimate changes when year-one traffic rises from 239,317 to 263,248, and year-20 traffic rises from 272,989 to 300,288. In this case, NPV falls to $50.5 million (this number is not reported in the figures.) This is a sizable reduction from the NPV of $355.3 million under the assumption of no induced demand.

To illustrate how the various categories of benefits change when build scenario traffic estimates are increased, Figure 6 shows the itemized benefits in two cases: the original case where traffic estimates are identical (previously reported in Figure 5, but reproduced here for comparison), and the second when year-20 ADT is 10% higher in the “build” scenario.



Itemized Benefits with identical "Build" and "No-build" traffic estiamtes

ITEMIZED BENEFITS (mil. $)	Average Annual	Total Over 20 Years
Travel Time Savings	$18.7	$373.2
Veh. Op. Cost Savings	$2.9	$58.7
Accident Cost Savings	$0.5	$10.8
Emission Cost Savings	$0.6	$11.6
TOTAL BENEFITS	$22.7	$454.4

Itemized Benefits when "Build" traffic estiamtes are 10% higher than in the "No-build" case

ITEMIZED BENEFITS (mil. $)	Average Annual	Total Over 20 Years
Travel Time Savings	$14.8	$296.4
Veh. Op. Cost Savings	-$6.6	-$131.7
Accident Cost Savings	-$0.2	-$4.3
Emission Cost Savings	-$0.5	-$10.8
TOTAL BENEFITS	$7.5	$149.6

In both cases, the Induced Demand button is set to "Y".

Figure 6. Comparing Benefit Categories With and Without Induced Demand

Here we see travel time savings fall from $373.2 million to $296.4 million, a reduction of about 25%. However, the other categories of benefits drop by much more. In fact, rather than producing savings, the project would actually *increase* costs of operating a vehicle, accidents, and emissions! In particular, vehicle operating cost “savings” fall from $58.7 million to -$131.7 million, a reduction of 324%, accident cost “savings” fall from $10.8 million to -$4.3 million, a reduction of 139%, and emissions cost “savings” fall from $11.6 million to -$10.8 million, a reduction of 193%.

In both cases shown in Figure 6, the Induced Demand toggle is active (set to “Y”); however this does not turn out to matter as much as the increase in ADT. Though not shown in the figure, if the toggle is set to “N”, (thus excluding the benefits received by the new highway users), the NPV falls even further. In the case when “Build” traffic estimates are 10% higher and the Induced Demand toggle is switched from “Y” to “N”, NPV falls from $50.5 million to $34.9 million.

This discussion of the highway example has illustrated a number of shortcomings of the way the Cal-B/C model is typically used. First, if induced demand is ignored when inputting ADT but the project will cause new traffic, Cal-B/C can significantly overstate project benefits. Second, the “induced demand” toggle on the Results worksheet accounts for induced demand effects in a very limited way. Third, when conducting sketch-planning BCA for roads, Cal-B/C does not account for multimodal considerations (i.e., rail and transit data is not used).

We hasten to add that although the highway example is not integrated in certain respects when used for sketch planning, this does not necessarily mean that the Cal-B/C model is not capable of taking into account multimodal and other network considerations; later we will discuss an example from the TIGER competition where Cal-B/C was used as an "expanded corridor" model, rather than "sketch-planning" model.

Although we have been considering a hypothetical sketch-planning example here, we also reviewed a number of actual projects analyzed by staff at Caltrans which used Cal-B/C, including seven of the project analyses used in the context of the CMIA component of California's 2006 Prop 1B. All seven had identical build and no-build ADT estimates. To explore the importance of induced demand, we performed a small-scale sensitivity analysis on the Prop 1B projects by increasing the 20-year "build" ADT estimate by 1% in each case and recording the resulting change in NPV. We found that the average NPV fell by 24.2%, with a standard deviation of 30.5%, and with NPV changes ranging from a low of -2.2% to a high of -100%. Although we are not sure our sample of Prop 1B grant projects is representative of all such projects, it seems safe to say that by ignoring induced demand in sketch planning, Caltrans' methods are potentially producing extremely biased results. We offer concrete solutions to this and other problems associated with the use of Cal-B/C for sketch planning at the end of this section, but due to the importance of TDMs for those recommendations, we first turn our attention to this area.

Travel Demand Modeling in California

Two of the most important inputs for benefit-cost models, such as Cal-B/C, are estimates of travel demand and travel speeds of a proposed project. Travel demand models (TDMs) in conjunction with other variables important for BCA, such as value of time, are the primary estimating tools used by transportation planners. In this section, we briefly review the history of travel demand modeling in California. We then provide a simplified discussion of how TDMs produce estimates of induced demand and describe how such estimates can provide useful data for improving the induced demand estimation in Cal-B/C.

Travel demand modeling in California began in the early 1920s and in its infancy consisted of rudimentary rule-of-thumb guidelines. These rule-of-thumb guidelines were based on past trends and future estimates of population growth only for the transportation link in question – effects on or from nearby transportation links were not typically considered. It was not until the 1950s – when population growth and automobile demand in California began to rapidly increase – that the Transportation Analysis Branch of the California Division of Highways (now the Office of Travel Forecasting and Analysis, or OFTA) began to comprehensively model travel demand using travel survey data and the so-called four-step modeling approach. From the 1950s to late 1980s, OFTA and its predecessor provided travel demand modeling for nearly all regions in the state. This was perhaps due as much to the complex computational requirements of the four-step model as to the availability of large mainframe computers needed to execute the models.

As the availability and cost of desktop computers came within reach of regional and local planning agencies in the late 1980s, so too did the desire for these agencies to conduct travel demand modeling on their own. At the present time, nearly all MPOs and regional planning agencies have developed their own travel demand models and, as such, are not reliant upon Caltrans' forecasting and modeling services. Caltrans' OTFA has since pivoted their role to provide statewide modeling of vehicle emissions and travel as well as to assist MPOs and regional agencies with software training and development.[61] For example, in 1984 Caltrans developed the Motor Vehicle Stock Travel and Fuel Forecast (MVSTAFF) that was used to predict statewide travel for both short- and long-term transportation planning and to estimate aggregate auto emissions. In 2009, Caltrans cancelled the MVSTAFF program in favor of the California Air Resources Board's model for estimating emissions and the 2006 Statewide Travel Model for estimating travel demand.

Also in 2009, HBA Specto, in partnership the Urban Land Use and Transportation Center at the University of California, Davis, developed California's first modern statewide demand model, the California Statewide Travel Demand Model (CSTDM09). The CSTDM09 is an activity-based TDM designed to estimate personal and commercial trips in the state, and is composed of five submodels: the Short-Distance Personal Travel Model, the Long-Distance Personal Travel Model, the Short-Distance Commercial Vehicle Model, the Long-Distance Commercial Vehicle Model, and an External Vehicle Trip Model for trips with an origin and/or destination outside the state. The CSTDM includes the following modes of travel: auto (single-occupant, as well as two- and three-occupant and high-occupancy vehicles); bus; rail; bicycle; walking; air; light commercial vehicles; and single- and multiple-unit trucks.[62]

In our interview with the Office of Travel Forecasting and Analysis, Caltrans staff told us that the CSTDM09 has not been used by *any* Caltrans division for travel demand estimation or planning. We were not able to determine the precise reason behind the failure to implement the model. For the purposes of this report, it is sufficient to note that Caltrans is not using a state-of-the-art statewide travel demand model as a matter of course in its BCA.

With respect to TDMs at Caltrans, the good news is that as of our interview with the agency in May 2014, Caltrans was in the process of implementing an updated TDM, referred to as CSTDM2.0. This model was recently recalibrated with a new statewide travel behavior survey and is being made available in the cloud for use by MPOs. These developments hold out the potential for Caltrans headquarters to pursue new avenues with regard to BCA.

For sketch-planning BCA, the most valuable element of TDMs is their ability to produce estimates of travel demand when an existing route (link) is expanded or a new link introduced. In principle, by incorporating a new or expanded link into the model, both induced demand and the source of induced demand can be estimated through comparing travel demand estimates by mode before and after the new link is added to the network. Of course the outputs of a model are only as good as the model itself, but over time TDMs have been improved to more fully account for induced travel (for example by including not only mode and route shifts causes by a new route, but changes in the number of trips and departure times as well.) However the promise of using TDM outputs as input in Cal-B/C is that its estimates can be added to the Cal-B/C model's required traffic inputs with and without the project, thus in principle accounting for both induced demand and multimodal considerations.

Next, a case study of projects from the USDOT's TIGER grant program provide a recent example of BCA use by state and local transportation agencies.

CASE STUDY: USDOT'S TIGER GRANT PROGRAM AND THE ROLE OF BCA

The federal Transportation Investment Generating Economic Recovery (TIGER) grants program provides a useful case through which to consider integrated approaches to BCA since BCA was required for each project application, grants were open to both state and local governments, and preference was given to multimodal projects. Our main approach here is to compare BCA methods used by Caltrans with methods used by other transportation agencies. We reviewed documents that describe the program, BCA guidelines disseminated by the USDOT, and we interviewed USDOT staff and staff at state DOTs and local agencies. We begin by describing key features of the TIGER program and then provide detailed descriptions of BCA methods used by Caltrans and the Ohio DOT in the 2013 TIGER grant application. We also briefly consider BCA methods used in the TIGER competition at two local transportation agencies: the city of Anaheim, and the Seminole Tribe of Florida. We conclude by comparing and contrasting all of these BCA methods.

The first TIGER grant program, known as TIGER I, was part of the American Recovery and Reinvestment Act (ARRA) of 2009. USDOT administered the TIGER I grants and has continued to administer TIGER II and subsequent rounds on a yearly basis, based on legislative appropriations. As described in the 2014 Notice of Funding Availability (NOFA), the ARRA has since expired. The current TIGER funding is part of the National Infrastructure Investments appropriation. "This appropriation is similar but not identical to the program funded and implemented pursuant to the [ARRA] ... Because of the similarity in program structure, DOT will continue to refer to the program as 'TIGER Discretionary Grants'."[63]

The following quotes taken from the USDOT website provide a good picture of the history and scale of the TIGER program:[64]

> *The Transportation Investment Generating Economic Recovery, or TIGER Discretionary Grant program, provides a unique opportunity for the US Department of Transportation to invest in road, rail, transit and port projects that promise to achieve critical national objectives. Congress dedicated more than $4.1 billion to the program: $1.5 billion for TIGER I, $600 million for TIGER II, $526.944 million for FY 2011, $500 million for FY 2012, $473.847 million for FY2013, and $600 million for the FY 2014 round of TIGER Grants to fund projects that have a significant impact on the Nation, a region or a metropolitan area.*
>
> *TIGER's highly competitive process, galvanized by tremendous applicant interest, allowed DOT to fund 51 innovative capital projects in TIGER I, and an additional 42 capital projects in TIGER II. TIGER II also featured a new Planning Grant category and 33 planning projects were also funded through TIGER II. In the FY 2011 round of TIGER Grants, DOT awarded 46 capital projects in 33 states and Puerto Rico. DOT awarded 47 capital projects in 34 states and the District of Columbia in the FY 2012 round. Last year the Department announced 52 capital projects in 37 states.*

A report published by the Eno Center for Transportation in April 2013, titled "Lessons Learned from the TIGER Discretionary Grant Program," describes a number of key features of the program.[65] For example, considering TIGER I through TIGER IV, most projects funded were road/bridge projects, though must funding went to freight/ports/rail projects. Transit projects also received nearly as much as road projects, while biking/walking and other multimodal projects together received less funding than transit projects. A study by the Reason Foundation from 2012 titled, "Evaluating and Improving TIGER Grants" considers the quality of economic analysis in the TIGER program, among other quality measures, and concludes that some problems with economic analysis had been remedied over the years since TIGER I, but the overall quality of analysis is still quite low.[66]

Although the Eno study classified a minority of the funded projects as multimodal, a focus on multimodal projects nevertheless is one characteristic of the TIGER program that makes it especially appropriate to study in this report. Citing again the USDOT website,[67]

> *Each project is multimodal, multi-jurisdictional or otherwise challenging to fund through existing programs. The TIGER program enables DOT to use a rigorous process to select projects with exceptional benefits, explore ways to deliver projects faster and save on construction costs, and make investments in our Nation's infrastructure that make communities more livable and sustainable.*

The most recent Notice of Funding Availability for the TIGER program describes the criteria used to evaluate proposals. There are five primary criteria corresponding to DOTs long-term goals and two secondary criteria corresponding to innovation and partnership goals. In addition, "DOT has a responsibility under Executive Order 12893, Principles for Federal Infrastructure Investments, 59 FR 4233, to base infrastructure investments on systematic analysis of expected benefits and costs, including both quantitative and qualitative measures." "The lack of a useful analysis of expected project benefits and costs may be the basis for not selecting a project for award of a TIGER Discretionary Grant. If it is clear to DOT that the total benefits of a project are not reasonably likely to justify the project's costs, DOT will not award a TIGER Discretionary Grant to the project." [68]

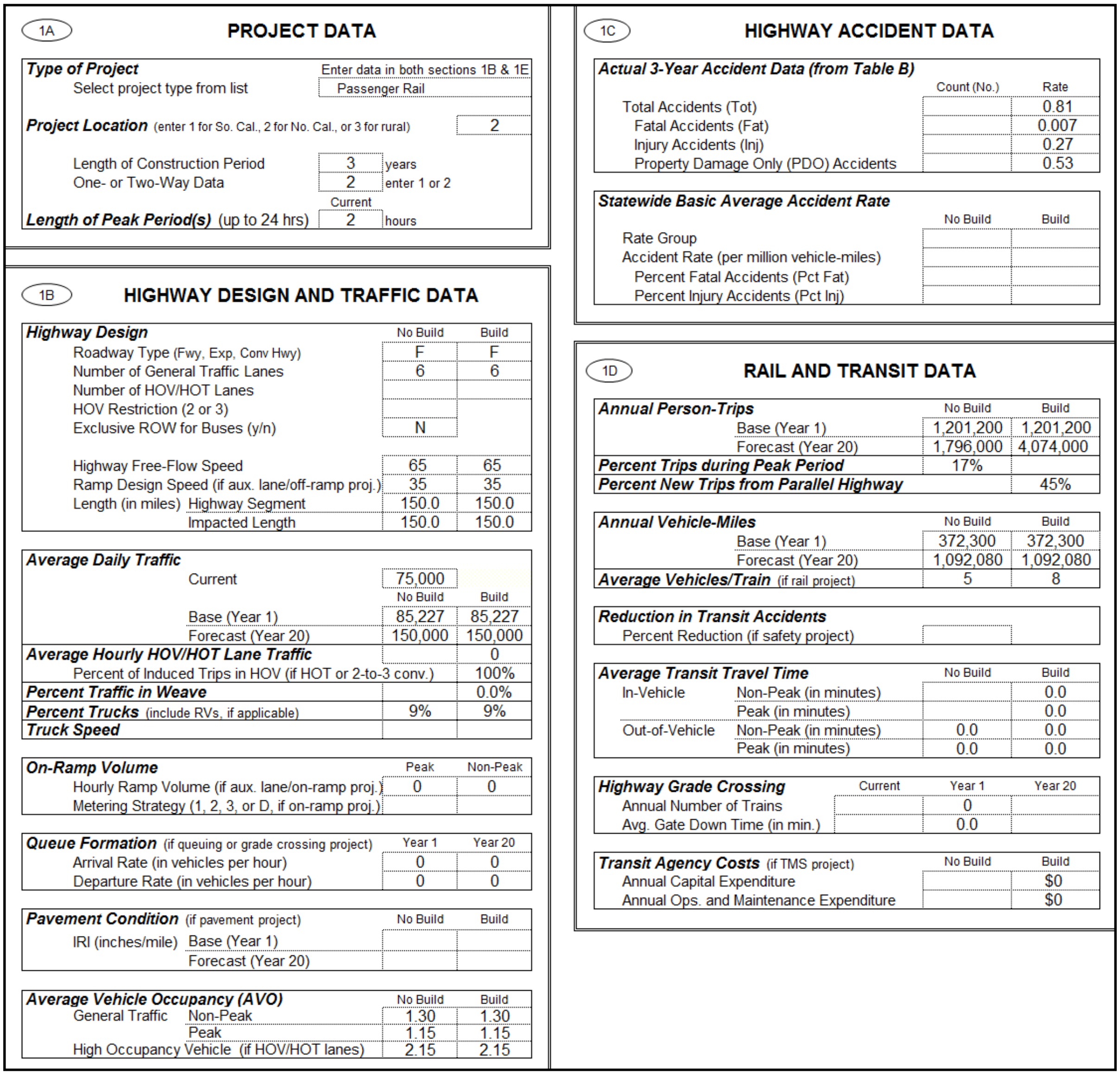
Unlike in our case study of Prop 1B, we were unable to obtain data on project NPV, B/C ratios, and measures of how projects scored according to these various primary or secondary criteria. We therefore turn our focus to actual BCA methods used in the TIGER competition.

Caltrans

We begin with the Merced to Le Grand double-track application submitted by Caltrans for the 2013 round of funding. This project proposed to double track portions of a train line that is used for freight and also by Amtrak on its San Joaquin route. Some of the application materials are published to the web,[69] while we obtained the complete application from Caltrans' Division of Rail, and the BCA spreadsheets from Caltrans' Office of Economic Analysis.

Given this application was submitted by the Division of Rail at Caltrans headquarters, it is not surprising that the main approach to BCA was Cal-B/C. Although portions of the application are publicly available on the Web, those portions only included the outputs from the model. Therefore, below we reproduce the data one must input to the Project Information worksheet to produce the published output. The only part of the project information worksheet we do not present in the figure is the costs, which, as before, we exclude to conserve space.[70] This analysis was carried out in the Cal-B/C version 4.0, modified for the TIGER grants. These modifications include changes to the discount rate, value of time, and other parameters required by USDOT.

What are the virtues of the approach to BCA taken by Caltrans? First, the approach is multimodal (or at least "bimodal"), as this analysis takes into account both rail and highway data. This can be seen in the Project Information sheet of Figure 7, which requires the user to enter information into section 1B, Highway Design and Traffic Data, and also, into section 1D, Rail and Transit data. We saw earlier with the hypothetical lane addition project that rail and transit data are *not* entered for a highway project. But here we see that highway data *is* entered for a *rail* project. Thus, in the case of a passenger rail project, we consider Cal-B/C to be a multimodal model. This illustrates an interesting divergence in the ways Cal-B/C handles highway and road projects versus rail and transit projects. The former are *unimodal*, while the latter, by including data from two modes, are *multimodal*.



1A **PROJECT DATA**

Type of Project	Enter data in both sections 1B & 1E	
Select project type from list	Passenger Rail	
Project Location (enter 1 for So. Cal., 2 for No. Cal., or 3 for rural)	2	
Length of Construction Period	3	years
One- or Two-Way Data	2	enter 1 or 2
	Current	
Length of Peak Period(s) (up to 24 hrs)	2	hours

1B **HIGHWAY DESIGN AND TRAFFIC DATA**

Highway Design	No Build	Build
Roadway Type (Fwy, Exp, Conv Hwy)	F	F
Number of General Traffic Lanes	6	6
Number of HOV/HOT Lanes		
HOV Restriction (2 or 3)		
Exclusive ROW for Buses (y/n)	N	
Highway Free-Flow Speed	65	65
Ramp Design Speed (if aux. lane/off-ramp proj.)	35	35
Length (in miles) Highway Segment	150.0	150.0
Impacted Length	150.0	150.0

Average Daily Traffic		
Current	75,000	
	No Build	Build
Base (Year 1)	85,227	85,227
Forecast (Year 20)	150,000	150,000
Average Hourly HOV/HOT Lane Traffic		0
Percent of Induced Trips in HOV (if HOT or 2-to-3 conv.)		100%
Percent Traffic in Weave		0.0%
Percent Trucks (include RVs, if applicable)	9%	9%
Truck Speed		

On-Ramp Volume	Peak	Non-Peak
Hourly Ramp Volume (if aux. lane/on-ramp proj.)	0	0
Metering Strategy (1, 2, 3, or D, if on-ramp proj.)		

Queue Formation (if queuing or grade crossing project)	Year 1	Year 20
Arrival Rate (in vehicles per hour)	0	0
Departure Rate (in vehicles per hour)	0	0

Pavement Condition (if pavement project)	No Build	Build
IRI (inches/mile) Base (Year 1)		
Forecast (Year 20)		

Average Vehicle Occupancy (AVO)	No Build	Build
General Traffic Non-Peak	1.30	1.30
Peak	1.15	1.15
High Occupancy Vehicle (if HOV/HOT lanes)	2.15	2.15

1C **HIGHWAY ACCIDENT DATA**

Actual 3-Year Accident Data (from Table B)	Count (No.)	Rate
Total Accidents (Tot)		0.81
Fatal Accidents (Fat)		0.007
Injury Accidents (Inj)		0.27
Property Damage Only (PDO) Accidents		0.53

Statewide Basic Average Accident Rate	No Build	Build
Rate Group		
Accident Rate (per million vehicle-miles)		
Percent Fatal Accidents (Pct Fat)		
Percent Injury Accidents (Pct Inj)		

1D **RAIL AND TRANSIT DATA**

Annual Person-Trips	No Build	Build
Base (Year 1)	1,201,200	1,201,200
Forecast (Year 20)	1,796,000	4,074,000
Percent Trips during Peak Period	17%	
Percent New Trips from Parallel Highway		45%

Annual Vehicle-Miles	No Build	Build
Base (Year 1)	372,300	372,300
Forecast (Year 20)	1,092,080	1,092,080
Average Vehicles/Train (if rail project)	5	8

Reduction in Transit Accidents	
Percent Reduction (if safety project)	

Average Transit Travel Time	No Build	Build
In-Vehicle Non-Peak (in minutes)		0.0
Peak (in minutes)		0.0
Out-of-Vehicle Non-Peak (in minutes)	0.0	0.0
Peak (in minutes)	0.0	0.0

Highway Grade Crossing	Current	Year 1	Year 20
Annual Number of Trains		0	
Avg. Gate Down Time (in min.)		0.0	

Transit Agency Costs (if TMS project)	No Build	Build
Annual Capital Expenditure		$0
Annual Ops. and Maintenance Expenditure		$0

Figure 7. View from a Cal-B/C Project Information Worksheet, TIGER Application

Our main criticism of this approach is the lack of discussion of the source of the traffic forecasts. USDOT is aware that project benefits are sensitive to traffic estimates,[71] which in large part determine the extent of travel time savings, safety improvements, and other impacts. The Merced to Le Grand double-track application does document that the estimate of the fraction of riders diverted from the highway is taken from rider surveys, and this is one of the key inputs to the model. However the source of the highway traffic estimates remains unclear.

Ohio DOT

Ohio DOT developed the Ohio Statewide Travel Demand Model (OSWTDM), and the full model has been in use for the last three years.[72] The OSWTDM incorporates an integrated econometric/land-use modeling, disaggregate microsimulation of passenger and business travel, and a commodity-based approach to freight shipment.[73] The Office of Statewide Planning and Research at ODOT uses the OSTDM for a variety of purposes, including to analyze major/new capacity projects. In 2013, this office conducted BCA for three projects submitted for TIGER grants. We profile one of these analyses here.

The Allen County I-75 improvement project proposed several upgrades (on/off ramp and other improvements) near Lima, Ohio (roughly halfway between Dayton and Toledo in the western portion of the state.) We obtained the internal ODOT report, “Benefit/Cost and Air Quality Analysis for Allen County IR 75” produced by the Office of Statewide Planning and Research in support of the TIGER grant application, who shared it with us. The BCA for this proposal was conducted with the OSWTDM and the Congestion Management/Air Quality Analysis (CMAQ) post processor.[74] ODOT typically uses the CMAQ process for planning-level congestion and air quality conformity analysis, though through a process called CMSCOST, it can be adapted to provide user benefits analysis. Categories of benefits considered in this process include travel time, vehicle operation, and accident cost savings. The analysis also estimated changes in vehicular emissions but these were not monetized.

This project provides a concrete example of something we have already referred to – integration of TDM with BCA post processor. There are several virtues of the BCA method used in the Allen County I-75 TIGER proposal, all of which stem from its use of a TDM. First, the approach is multimodal, as the OSWTDM considers travel on a variety of modes, including long-distance bus. Second, the approach could in principle incorporate other system effects such as induced demand. Finally, the use of a TDM can in principle enable consistent and transparent build-versus-no-build traffic forecasts across projects.

The main criticism one may have of this approach, however, is that the economic assumptions are not necessarily well documented. According to the USDOT publication offering guidance for TIGER grant applicants, “Applicants should make every effort to make the results of their analyses as *transparent and reproducible* as possible … It is inadequate for the applicant only to provide links to large documents or spreadsheets as sources.”[75] This criticism probably applies to most of the analyses that accompany TIGER grant submissions, but the virtues of methods such as those exemplified in this case may come at the cost of some transparency.

Comparing BCA Methods at Caltrans and ODOT

Studying the California and Ohio applications allows comparison of two rather different approaches to BCA. Caltrans' approach is spreadsheet-oriented, but it should not be classified as sketch planning; for example, the double-track project utilized rider surveys. ODOT's approach uses a BCA post processor in conjunction with a TDM.

What are the lessons for California? First, Caltrans can adopt the general BCA method ODOT used here. This is not to say that the ODOT method is strictly superior. However, if post-processor methods were developed, estimates of project benefits produced using multiple methods (Cal-B/C and the post processor) would help to provide a better sense of the robustness of the NPV estimates.

BCA Methods Used by Local Agencies in TIGER Applications

Before we turn to recommendations, we briefly comment on BCA methods used by local agencies in TIGER competitions. This is not a focus of our report, but in our review of the TIGER program, we found applications that demonstrate, first of all, a wide variety of approaches. In personal conversation, USDOT Chief Economist Jack Wells agreed with the sentiment that it is possible to conduct a good BCA using the methods exemplified in the Caltrans and ODOT case studies above, as well as with project-specific analyses and other forms. Our review of the TIGER program also found that while by no means in the majority, several applications from local transportation agencies use Cal-B/C. We briefly highlight two here, one from Florida, and one from Anaheim, California.

The Gene Autry Way application from Anaheim, which proposed to add an HOV drop ramp onto Interstate 5, is publicly documented online[76] and illustrates how Cal-B/C can be used to incorporate system effects. "The benefit-cost analysis considers the benefits of eliminating the weave across the freeway to access the HOV lanes using the standard HOV drop ramp weaving algorithms in Cal-B/C."[77] To do this, the analysis for Anaheim incorporated the results from two separate spreadsheets by adding the present value of benefits and costs from the first spreadsheet into the second on the "Final Calculations" worksheet. Although this was not a multimodal project, this technique nevertheless shows how Cal-B/C can incorporate impacts from other roads.

The example from Florida illustrates how Cal-B/C can be used successfully in competing for TIGER grants when induced travel is unlikely to be a significant factor in the analysis. The USDOT posted this example to the area of its website where it provides information on preparing a BCA for TIGER applications.[78] The Snake Road project submitted by the Seminole tribe proposed to improve 2.25 miles of road on the Big Cypress Reservation in Hendry County, Florida, by expanding lanes and building a median, a sidewalk and a 12-foot multi-use path. The BCA analysis was completed using Cal-B/C.

RECOMMENDATIONS: INTEGRATING BCA MODELS AT STATE DOTS

Earlier in this subsection, we considered a hypothetical lane addition example. This illustrated both the virtues and limitations of Caltrans' BCA methods. One limitation is that the required input for average daily traffic in the build scenario did not account for induced demand – the road is relatively more valuable after the project, but traffic remains the same as if the project were never built. The role out of CSTDM 2.0 is underway as of this writing. If the new model is successfully implemented, then one way of incorporating induced demand is to use TDMs to determine the build and no-build current and 20-year average daily traffic forecasts.[79]

An alternative approach for handling induced demand in BCA does not require use of a TDM but does involve modifying the Cal-B/C model. At the moment, Cal-B/C is designed to accept input for current and 20-year no-build ATD forecast. It then uses these same figures for "build" estimates and forecasts, unless this is overridden by the user. More specifically, in cell G39, the user enters the 20-year forecast for ADT in the no-build scenario. Entering a value of, say 272,989 (the number from the hypothetical lane addition example) assigns the value of the Cal-B/C variable "ADT20NB." Immediately to the right, in cell H39, the default syntax is "=ADT20NB." In other words, Cal-B/C automatically uses no-build forecasts for the "build" forecast, unless this is overridden by the user. We suggest modifying this so that instead the model estimates "build" forecasts based on characteristics of the project, and potentially on other variables.

Transportation researchers have empirically documented the role of induced demand resulting from highway capacity expansion. Kenneth Small and Erik Verhoef explain that congestion and the importance of the project relative to the network have been found to be two key factors influencing induced demand, and they provide references to the empirical induced demand literature.[80] These characteristics, as well as other characteristics of both the project and project areas, were also discussed in Cal-B/C Tech Supplement Vol. 1 (Chapter 6, pages 4-5).[81] This literature can be used to inform rule-of-thumb estimates of induced demand for sketch planning without the use of a TDM.

Our recommendation here boils down to modifying the syntax in cell H39 (the cell containing the figure for 20-year ADT in the build scenario). We have not formulated any specific syntax, but we have identified the relevant background literature that could inform future development on this aspect of the model. Future research could undertake retrospective empirical analysis to estimate the parameters of an equation that could be used to replace the syntax in cell H39. Equation (6) shows one possible form the updated syntax could take:

$$= \mathrm{ADT20NB} * (1+\propto) \tag{6}$$

where $\propto = \beta_0 + \beta_1 * CONGESTION + \beta_2 * IMPORTANCE$

In this equation, ADT20NB is 20-year forecast "no-build" ADT, CONGESTION is a measure of roadway congestion, such as the TTI congestion index (or other congestion index that has more extensive geographic breadth[82]) discussed earlier in the policy analysis subsection, and IMPORTANCE, a measure of the importance of project relative to network is another variable, an appropriate value of which could be calculated by the model (such as the length of the expanded/improved roadway, a value of which is already a required model input). Finally, β_0, β_1 and β_2 are parameters to be estimated (that is, calibrated) using historical data from past projects. When studying induced demand in Cal-B/C in the context of the hypothetical lane addition example, we arbitrarily chose $\propto=0.1$ or $\propto=0.01$, however equation (6) suggests a way of selecting more project-appropriate values. The choice of variables in equation (6) is inspired by the empirical induced demand literature cited above, and the linear form reflects a desire for simplicity; certainly in future research analysts could explore nonlinear functional forms and other modeling innovations.

A second shortcoming with Cal-B/C that we have identified is that other system effects, such as multimodal considerations, are ignored, may also be ameliorated with the use of TDMs. The short explanation of this is that BCA post processors for TDMs can be used as an alternative to Cal-B/C, as exemplified by the Ohio DOT's approach to BCA in its recent TIGER application. As we discussed earlier, Caltrans has already begun developing such a post processor, Cal-NET_BC, and although the most recent documentation suggests further development is not a priority, we have also seen evidence of some analysts, working in Caltrans district offices, who have attempted to advance the model.

As with our criticism related to induced demand where we offered a way of making BCA methods more integrated without the use of a TDM, we also suggest ways of handling multimodal considerations that do not require inputs from TDMs. However, instead of modifying Cal-B/C, as with our equation (6), here we suggest a non-technical solution, namely, to provide better documentation for methods that account for multiple modes. For example, it was unclear to us how multimodal data can be entered into highway analysis, and the documentation we consulted offered conflicting information. Two natural ways to use existing model capabilities to incorporate multimodal impacts include greater use of the "three roads" feature, a possibility exemplified in the Anaheim TIGER application, and directly entering transit data into the Project Information worksheet for highway and road projects. On this last point, what we are suggesting here is that Caltrans might be able to undertake more integrated analysis *by simply analyzing highway and road projects as transit projects*, as transit project analysis in Cal-B/C is already multimodal, while highway and road project analysis is not. This possibility should be explored, and if feasible, well documented.

In sum, for most highway and road projects, Cal-B/C does not measure either induced demand or multimodal impacts. For each factor, we have identified a way of making the BCA model more integrated that relies on a TDM, and also a way that does not. To account for induced demand, an analyst can use inputs from a TDM or, alternatively, the Cal-B/C model can be modified so it estimates induced demand. To account for multimodal considerations, a BCA post processor, such as Cal-NET_BC, can be used in conjunction with the CSTDM or, alternatively, better documentation can help users navigate existing features of the Cal-B/C model, such as the "three roads" feature, to incorporate system effects.

IV. CONCLUSIONS

In our study of BCA methods for policy analysis and transportation planning, we have documented biases that result from a failure to account for multimodal considerations and induced demand. Of course not all projects will result in significant induced travel effects or multimodal effects, but for those that do, current methods are likely distorting the efficient allocation of scarce transportation dollars.

We have also discussed a variety of ways of improving BCA methods. We conclude this report by listing all of the major recommendations that we have formulated during the course of executing this research. We have already discussed the first four of these recommendations. Therefore, after briefly summarizing each of them again below, we simply refer back to the relevant section of the report where we discussed the recommendation in detail. We have not discussed the last two recommendations yet, so we present and then spend more time elaborating on each.

RECOMMENDATIONS

Based on our research, we have identified six recommendations we believe worthy of Caltrans' consideration. We categorize these under three broad objectives. The first four recommendations were introduced earlier in this report; the last two are introduced in this section for the first time:

Improve the Cal-B/C model and the way it is used:

1. Add an induced demand function; we discussed this earlier in detail and presented the idea concretely as equation (6) in the "Recommendations" subsection of the last chapter.

2. Caltrans should encourage multimodal modeling and provide support for carrying it out. In the last chapter's "Recommendations" subsection, we discussed the need for documentation to guide analysts who wish to use Cal-B/C to measure multimodal effects.

Integrate Cal-B/C and TDMs:

3. Encourage users of Cal-B/C to incorporate build and no-build average daily traffic estimates from travel demand models (TDMs).

4. Use a BCA post processor for TDM (potentially one similar to Cal-NET_BC). We discussed both of these points in detail in the last chapter's "Recommendations" subsection.

We conclude with two suggestions not yet discussed regarding organizational and managerial practices. Instead of specific recommendations like those we made with respect to modeling, here we propose that consideration be given to some of the general tradeoffs associated with status-quo management practices affecting modeling. In general, we urge decision makers to think hard about how best to develop state-of-the-art modeling capabilities. The cost of model development is a tiny fraction of the cost of transportation projects, but model development does require resources (for example, flexible equipment, IT support, appropriate salaries) and attention.

Reconsider the structure and scope of Caltrans:

5. Consider formal structure changes, such as merging offices and branches, as well as informal approaches, such as facilitating knowledge-sharing meetings, to encourage closer collaboration between related offices.

6. Rethink relationships with external partners, such as outside consultants and universities, in order to fully exploit external expertise while ensuring in-house expertise is adequate to implement state-of-the-art models and methods.

One rationale for Recommendation 5 comes from an FHWA guide for BCA that was quoted in the last section: “In general, it is a good idea to conduct BCA in close coordination with planning offices.” Given the importance of accurate traffic estimates for BCA, the basis for this rationale should be clear. However, this guide does not address how to encourage this sort of coordination. Therefore, we are suggesting that Caltrans *consider* both formal and informal mechanisms to encourage closer coordination.

From our study of Caltrans, we have found that the organizational boundaries are rather fluid. For example, it was not until November 1, 2012 that the Traffic Forecasting Branch was added to the Planning Division. Before then, this function was part of the Division of Research and Innovation and Systems Information.[83] In our interviews, we learned senior managers at Caltrans have informally discussed a potential merger between three branches (Travel Forecasting and Analysis, State Planning, and System and Freight Planning) and a similar, though not identical thought occurred to us independently (our thought concerned the first two of these branches). Therefore, the first part of Recommendation 5 is to consider merging relevant offices.[84] At the same time, rearranging the formal structure of headquarters comes with its own, potentially large costs; moreover, it is not the only way to realize the intended goal of closer coordination.

Collaboration can also be fostered in informal ways, even when branches remain formally separated. For example, Caltrans has organized BCA conferences in the past that have brought together staff from around the agency; the conference described in Tech Supplement 3 included staff from headquarters and districts to exchange thoughts on the way Cal-B/C was used in programming Prop 1B projects.[85]

Recommendation 6 is that Caltrans should reconsider the “scope” of its operations, by which we refer not to its internal structure but to its relationships with outside consultants, university-based researchers, and others in the broader transportation community. In the past, Caltrans has relied on outside specialists to develop its BCA and TDMs, but, as we saw, the full potential of these models was not always realized. Caltrans has certainly benefited from outside expertise, but at the same time it must be careful not to outsource too much expertise. Caltrans must strike a careful balance between taking advantage of outside expertise and developing its own internal capabilities so it can fully implement this expertise.

Which of the six recommendations prove to be most beneficial remains to be seen. However, given the level of financing involved in transportation infrastructure, improved BCA models will lead to improved allocation of transport resources, and this in turn will lead to large gains for society.

ABBREVIATIONS AND ACRONYMS

AB1358	California Complete Streets Act of 2008
ADT	Average Daily Traffic
APTA	American Public Transit Association
ARRA	American Reinvestment and Recovery Act
ARIMA	Autoregressive Integrated Moving Averages
BCA	Benefit-Cost Analysis
Cal-B/C	The California Life-Cycle
CARB	California Air Resources Board
Caltrans	California Department of Transportation
CEA	Cost-Effectiveness Analysis
CEQA	California Environmental Quality Act
CMIA	Corridor Mobility Improvement Account
CSTDM	California Statewide Travel Demand Model
CTC	California Transportation Commission
CTIP	California Transportation Infrastructure Priorities (Workgroup)
CTP	California Transportation Plan
DOT	Department of Transportation
EIA	Economic Impact Analysis
FAHA	1962 Federal-Aid Highway Act
GHG	Greenhouse Gas(es) or Greenhouse Gas Emissions
HTF	Highway Trust Fund
ILG	Institute for Local Government
ISTEA	Intermodal Surface Transportation Efficiency Act
LRSTP	Long-Range Statewide Transportation Plan
MPO	Metropolitan Planning Organization
MTC	(Bay Area) Metropolitan Transportation Commission
MTI	Mineta Transportation Institute
MTP	Metropolitan Transportation Plan
MVSTAFF	(California) Motor Vehicle Stock, Travel, and Fuel Forecast
NB	Net Benefits
NEPA	National Environmental Policy Act
NPV	Net Present Value
NTD	National Transit Database
ODOT	Ohio Department of Transportation
OSWTDM	Ohio Statewide Travel Demand Model
RTIP	Regional Transportation Improvement Program
RTPA	Regional Transportation Planning Agency
SANDAG	San Diego Association of Governments
SHOPP	State Highway Operation and Protection Program

SRI	SRI International
SSTI	State Smart Transportation Initiative
STIP	State Highway Improvement Program
TDM	Travel Demand Model
TEA-21	Transportation Equity Act For The 21St Century
TIGER	Transportation Investment Generating Economic Recovery
TIP	Transportation Improvement Plan
TREDIS	Transportation Economic Development Impact System
TTI	Texas A&M Transportation Institute
UPWP	Unified Planning Work Program
VHT	Vehicle-Hours Traveled
VMT	Vehicle-Miles Traveled

ENDNOTES

1. *California Department of Transportation, SSTI Assessment and Recommendations* (Madison, WI: State Smart Transportation Initiative, 2014).

2. Mineta Transportation Institute, "*Request for Proposals*," http://transweb.sjsu.edu/MTIportal/research/RFPForms.html (accessed 2013).

3. The meaning of multimodal should be clear; it refers to non-single-occupancy-vehicle (SOV) travel, such as public transit and also other modes. By induced demand, we refer to what the literature has distinguished as both induced and latent demand. See, for example, Small and Verhoef, p. 173, who write, "...expansion [of highway capacity] reduces the ... price [of using the highway] and therefore attracts new traffic, known as induced traffic or induced demand …" The authors then clarify further; writing on p. 234: These terms, plus 'induced travel' and 'latent demand,' tend to be used synonymously. Lee, Klein and Camus (2002) suggest the following useful distinction: induced traffic is a change in traffic resulting in movement along a short-run demand curve, whereas induced demand is a shift in the short-run demand curve (perhaps also a movement along a long-run demand curve) ... Other authors, notably Cervero (2003), distinguish between the effects of a capacity expansion on traffic on the facility itself ("induced travel") and the effects on all traffic in the region ("induced demand"). We do not attempt here to maintain this distinction rigorously … Likewise, we also do not maintain a rigorous distinction between these nuanced concepts in this report. For more on the distinction between these two concepts, see Todd Litman and Steven B. Colman, "Generated Traffic: Implications for Transport Planning," *Institute of Transportation Engineers Journal* 4 (2001): 38-47.

4. Richard F. Weingroff, "Federal Aid Road Act of 1916: Building the Foundation," *Public Roads,* Summer 1996, http://www.fhwa.dot.gov/publications/publicroads/96summer/p96su2.cfm (accessed August 12, 2014).

5. Edward Weiner, *Urban Transportation Planning in the United States: History, Policy, and Practice* (New York, NY: Springer Publishing, 2013).

6. Marlon G. Boarnet, "National Transportation Planning: Lessons from the U.S. Interstate Highways," *Transport Policy* 31 (2014): 73–82.

7. American Public Transportation *Association*, *2013 Public Transportation Fact Book*, Washington, DC, October, 2013.

8. Mark H Rose et al., *Interstate: Highway Politics and Policy Since 1939* (Knoxville, TN: University of Tennessee Press, 2012).

9. Bruce Katz et al., *TEA-21 Reauthorization - Getting Transportation Right for Metropolitan America* (Washington, DC: The Brookings Institution, 2013).

10. *Ibid.*

11. Ibid.

12. *Transportation Funding in California* (Sacramento, CA: California Department of Transportation, 2011).

13. *Transportation System Analysis and Evaluation (TSAE) for the Relinquishment of SR 82 (US 101 to I-880) in San Jose* (Sacramento, CA: California Department of Transportation, 2010).

14. William Fulton, *Guide to California Planning* (Point Arena, CA: Solano Press Books, 1999).

15. Robert Cervero, "Growing Smart by Linking Transportation and Land Use: Perspectives from California," *Built Environment* 29 (2003): 66–78.

16. See Chapter 19 of Anthony E. Boardman et al., *Cost-Benefit Analysis: Concepts and Practice* (Upper Saddle River, NJ: Prentice Hall, 2011) on the topic of distributionally weighted cost-benefit analysis, which enables BCA to account for equity considerations. For empirical methods of measuring external impacts, see pp. 341-397.

17. For more information, see p. 95 of Kenneth A Small and Erik T. Verhoef, *The Economics of Urban Transportation* (New York, NY: Routledge, 2007), who write: Network equilibrium may sometimes lead to surprising and counterintuitive implications for public policy. A famous example is the so-called Braess paradox (Braess 1968): adding a new link to a congested network may cause equilibrium travel times to increase! Intuitively, this can happen if using a newly available route results in a lower average time but a higher marginal contribution to congestion than using competing routes … Another paradox, known as the Downs-Thompson paradox, occurs in a simple two-link, two-mode network in which one model (public transport) operates with scale economies. When the capacity of the other mode (a road) is increased, the average cost of both modes can go up!

18. *Effects of Gasoline Prices on Driving Behavior and Vehicle Markets* (Washington, DC: Congressional Budget Office, 2008).

19. These two documents are the Cal-B/C Tech supplement, volume 3, p. II-4; and Chris Williges and Mahmoud Mahdavi, "Transportation Benefit-Cost Analysis: Lessons from Cal-B/C," *Transportation Research Record* 2079 (2008): 79-87.

20. University of California, Hastings Scholarship Repository, "Proposition Summary: Highway Safety, Traffic Reduction, Air Quality, and Port Security Bond Act of 2006" (June 30, 2006), http://repository.uchastings.edu/ca_ballot_props/1260/ (accessed August 1, 2014).

21. In this analysis, the details of which are not reported here, precinct-level voting data was merged with block group-level data from the US Census. Vote-share multiple regression models were estimated, with ideology (as measured by precinct-level party

registration) as the main independent variable of interest. (A detailed description of the general methodology can be found in a July 2013 MTI report by Matthew J. Holian and Matthew E. Kahn.) In addition to estimating this vote-share model for Prop 1B, we also estimated identical vote-share models for two other recent transportation-related ballot propositions for comparison: Prop 87 (from 2006), which would have placed a tax on California oil producers to fund alternative energy projects, and Prop 1A (from 2008), California's well-known High-Speed Rail Bond of nearly $10 billion, which was passed by voters. This analysis showed that the ideology variable explained a lot in these two comparison projects, but not much for Prop 1B – again, suggesting the broad appeal of the bond reduced partisan opposition during the election. These and other results were presented in the March, 2014 TRF conference, slides from which are available at http://www.sjsu.edu/faculty/matthew.holian/pdf/Data_integration_TRF.pdf

22. Chris Williges and Mahmoud Mahdavi, "Transportation Benefit-Cost Analysis: Lessons from Cal-B/C," *Transportation Research Record*, 2079 (2008): 79-87.

23. CMIA Nomination Review (1/19/2007). Document provided by CTC staff.

24. The main results of this preliminary analysis can be summarized as follows: First, as expected, the B/C Ratio predicts the analyst's rating in the "value" category. For each category, CTC staff assigned each project a score of 0 to 5. A simple regression model estimated using data on 115 proposals had an R-squared value of 0.57 and the following form: VALUE = 1.34 + 0.71 * BCRATIO. Thus, for example, a project with a B/C ratio of 1 is predicted to have been assigned a rank of 1.34 + 0.71*1, which equals 2.05. Second, and in turn, the "value" rating predicted proposal funding in separate simple and multiple linear probability models that were estimated. Third, projects with high B/C ratios were not necessarily more likely to be funded (at least, the B/C ratio variable was not a statistically significant predictor in a simple linear probability model which predicted selection for funding. Future research should subject these data to more rigorous analysis to uncover the precise channels of influence of BCA on policy outcomes. These and other preliminary results can be found on slides from our presentation at the Transportation Research Forum conference; see pp. 28-38. http://www.sjsu.edu/faculty/matthew.holian/pdf/Data_integration_TRF.pdf

25. Page 50 of Jon D Harford, "Congestion, pollution, and benefit-to-cost ratios of US public transit systems," *Transportation Research Part D* 11 (2006): 45–58.

26. Page 375 of Clifford Winston and Vikram Maheshri, "On the social desirability of urban rail transit systems," *Journal of Urban Economics* 62 (2007): 362–382.

27. See Chapter 13 of Boardman et al., *Cost-Benefit Analysis: Concepts and Practice* (Upper Saddle River, NJ: Prentice Hall, 2009).

28. The demand curve depicted in Figure 2 is a straight line and thus has a constant slope. However, it is not true that the elasticity is constant along the curve. At higher fares, the elasticity will be smaller than -1 (more elastic), and at lower fares, the elastisticity will be larger (less elastic). Although we have opted to estimate linear demand curves

for conceptual clarity, one could alternatively estimate a constant elasticity demand curve. Again, see Chapter 13 of Boardman et al., *Cost-Benefit Analysis: Concepts and Practice* (Upper Saddle River, NJ: Prentice Hall, 2009).

29. Annualized capital costs represent the amortization of a fixed sum over a period of time. Usually the fixed sum is known to the analyst who must calculate annualized values. The choice of conducting an analysis in present-value or annualized terms (as here) is arbitrary and does not affect the results. To illustrate with an example, page 52 of Guerra's study notes, "For BART, amortizing the initial capital investment at 2.2% over 50 years gives an annual capital cost estimate of $321 million." The present value of any annual payment is given by the following formula: PV = (Annualized capital costs)*(annuity factor). One can calculate an annuity factor (also called a present worth factor) given data on the discount rate and time horizon; here the annuity factor = (1/0.022) – (1/0.022)/(1.022^{50}), which is equal to 30.14. Therefore, given annualized capital costs of $321 million, the present value of the investment must be $321 million multiplied by 30.14, or $9.68 billion. If the analysis is being done in annualized terms, the analyst typically will obtain this $9.68 billion figure, substitute it and the annuity factor into the formula shown above, and solve for annualized capital costs.

30. For the interested reader, we present detailed steps to estimate consumer surplus here: There are eight steps involved in calculating ANB for the systems shown in Table 1. They are as follows: There were 82,984,033 trips taken in Atlanta in 2008, and the revenue was $49,242,449. Hence the "average fare" is $0.59. Draw a demand curve such that at a price of $0.59, quantity demanded is 82,984,033. We need to calculate the intercepts. Use the formula (dQ/dP)*(P/Q)= -0.3, plug in what we already know, i.e. price and quantity, and solve for dQ/dP = -41,953,740.36. Write the demand function: Q = a - (41,953,740.36)*P. Plug in P and Q. (This yields 82,984,033 = a - 41,953,740.36 * 0.59). Solve for a =107,879,242.9. We now have solved for the demand function: Q = 107,879,242.9 - 41,953,740.36 *P. Rearrange to express it as an inverse demand function, i.e. P = 2.57 - (1/41,953,740.36)*Q. Go back to the demand curve you drew in Step 2. We now have a demand function with a y-intercept of 2.57 and an x-intercept of 107,879,242.9. The price is 0.59 and the quantity demanded is 82,984,033. All that is left to do is calculate the area of the consumer surplus triangle: (82,984,033)*(2.57-0.59)*1/2, which equals 82,070,748.33. This is equal to the value reported for Consumer Surplus for Atlanta. Consumer surplus plus expenditure gives gross benefits for transit users, and NPV is calculated by subtracting the present value of benefits from the present value of costs, or on an annualized basis as is done here, by subtracting annualized operating and capital costs from gross benefits. Repeat these steps for the rest of the transit agencies.

31. Jon D Harford, "Congestion, pollution, and benefit-to-cost ratios of US public transit systems," *Transportation Research Part D* 11 (2006): 45–58.

32. Erick Guerra, "Valuing Rail Transit: Comparing Capital and Operating Costs with Consumer Benefits." *Transportation Research Record* 2219 (2011): 50–58.

33. The study by Winston and Maheshri estimated a unique elasticity for only one system

– New York City.

34. Todd Litman, *Understanding Transport Demands and Elasticities: How Prices and Other Factors Affect Travel Behavior* (Victoria, Canada: Victoria Transport Policy Institute, 2013); Todd Litman, *Transit Price Elasticities and Cross-Elasticities* (Victoria, Canada: Victoria Transport Policy Institute, 2012).

35. It seems uncontroversial to us to say that bus and rail elasticites are positively correlated. Still, we ask an interesting related question: Is bus or rail demand likely to be more elastic? The best answer to this question is, “It depends.” According to Littman, 2012, p. 9: “Rail and bus elasticities often differ. In major cities, rail transit fare elasticities tend to be relatively low, typically in the –0.18 range, probably because higher-income residents depend on such systems (Pratt 1999). For example, the Chicago Transportation Authority found that bus riders have elasticities of -0.30 during peaks -0.46 during off-peaks, while rail riders have elasticities of -0.10 during peaks and -0.46 off-peak. Fare elasticities may be relatively high on routes where travelers have viable alternatives, such as for suburban rail systems where most riders are discretionary.”

36. It is likely that elasticities have continued to rise. Littman, 2012, p. 6, discussing the APTA estimates, writes, “Because they reflect short-run impacts and are based on studies performed when a larger portion of the population was transit-dependent, these values probably understate the long-run impacts of current price changes.” The study by Winston and Maheshri also presented evidence suggesting rail demand has become more elastic over the last few decades, e.g. on pp. 369-370.

37. *City and County Data Book* (Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 2009). Originally published by United States Department of Commerce, Bureau of the Census.

38. The APTA study used the population of urban area to conduct a “difference in means” test; they found statistically significant evidence that fares were less elastic in larger areas. The tests we conduct build upon this idea, with simple and multiple regression models.

39. Texas A&M Transportation Institute, “Annual Urban Mobility Report” (February 4, 2013), http://tti.tamu.edu/documents/ums/congestion-data/complete-data.xls (accessed September 25, 2013).

40. We acknowledge that our approach to modeling here is relatively simple. This is because offering a simple model that illustrates what data integration looks like is our primary goal in this section. We have posted our data to the Web and invite those who are interested to explore the consequence of alternate modeling assumptions. Our data (file name “holian_mclaughlin_data.xls”) can be found at https://sites.google.com/site/profholian/home/resources-for-sjsu-faculty. We also note here that the TTI congestion index is not without its critics; see, for example, Joe Cortright’s critique at: http://bettercities.net/article/focus-relieving-traffic-congestion-wrongheaded-says-

ceos-cities-13265. However whatever its drawbacks, a major virtue of the TTI index is that it has been collected for a long period of time, for a large cross section of cities. And, although it may not measure congestion perfectly, we feel it provides a good first approximation to measuring congestion differences across cities.

41. See Chapter 16 of Anthony E. Boardman et al., *Cost-Benefit Analysis: Concepts and Practice* (Upper Saddle River, NJ: Prentice Hall, 2011).

42. Given that economists use the term "efficiency" to refer to more than one concept, some explanation for our use of the term is in order here. One branch of the economics literature refers to "technical" (or "productive") efficiency, which has to do with getting the most output from a given amount of inputs. In contrast, allocative efficiency, which is what we refer to, has to do with choosing the type of output that society values most, in addition to producing it at lowest possible cost. Here, if a project "passes the cost-benefit test" it means the present value (PV) of project benefits is greater than the PV of project costs, and building the project was more efficient than not building it (although it does not mean the project was the most efficient out of all possible projects.)

43. Consider two projects: project A has benefits of $10 and costs of $1, and project B has benefits of $100 and costs of $20. The B/C ratio is 10 for Project A but only 5 for Project B. However if these are mutually exclusive projects, then Project B should be selected, because the net benefits are $80 versus $9. Thus, reliance on a strict B/C ratio standard to select mutually exclusive projects can lead to incorrect decisions.

44. For more on decision criteria for project, see pages 81-96 of Diana Fuguitt and Shanton J. Wilcox, *Cost-Benefit Analysis for Public Sector Decision Makers* (Westport, CT: Quorum Books, 1999).

45. These methods are often confused. See Glen Weisbrod, "Models to predict the economic development impact of transportation projects: historical experience and new applications," *Annals of Regional Science* 42 (2008): 519–543, especially pages 535-537. See also "Being Clear About Benefit/Cost Analysis and Economic Impact" by the same author, published in "Benefit/cost analysis for transportation infrastructure: a practitioner's workshop." US Department of Transportation, Washington (2010). http://tti.tamu.edu/group/tec/files/2011/09/benefit-cost10-proceedings.pdf. For an example of the use of CEA in the context of transportation planning in California, see http://www.arb.ca.gov/planning/tsaq/eval/eval.htm. An example of the use of EIA in California is on p. 72 of the California Interregional Blueprint Interim Report (December 2012) at http://www.dot.ca.gov/docs/CIB_Interim_Report_122012_FINAL.pdf, which notes that EIA will be used in assessing the CTP. This document also describes a variety of other models used in assessing the CTP. Page 13 of the following presentation slides identifies TREDIS as the model used for economic modeling: http://www.dot.ca.gov/hq/tpp/offices/owd/academy_files/D6_session_2/Presentations/Wednesday/California_Transportation_Plan.pdf

46. The document *Integrating Transit Data into State Highway Planning* (Madison, WI: CTC & Associates, LLC by request of the Division of Research and Innovation at the

California Department of Transportation, 2012) contains survey responses from state DOT professionals in various roles. Page 16 of that document contained the text of a survey response from an ODOT analyst, who provided concrete examples of how transit data is incorporated in ODOT's own planning models, as well as how this is done in Caltrans' models, thus suggesting to us a lucrative place to turn for insight into state-of-the-art practice. We corresponded with staff from ODOT via email and through an in-person interview in Columbus.

47. A now-defunct page on the Caltrans website (that we were able to access through the Internet Archive) provides a useful guide to BCA for transportation planning. It describes the following models: Cal-B/C, MicroBENCOST, STEAM, HERS-ST, StratBENCOST, and lists an addational 8: IDAS, NET-BC, RAILDEC, SPASM, IMPACTS, SMITE, SCRITS, ABC. This website also presents case studies and other valuable information: California Department of Transportation, "Benefit-cost Analysis" (July 21, 2004), https://web.archive.org/web/20070208163252/http://www.dot.ca.gov/hq/tpp/offices/ote/Benefit_Cost/index.html (accessed June 25, 2014).

48. Federal Highway Administration, "Operations Benefit/Cost Analysis Desk Reference: Providing Guidance to Practitioners in the Analysis of Benefits and Costs of Management and Operations Projects," (May 1, 2012) http://ops.fhwa.dot.gov/publications/fhwahop12028/fhwahop12028.pdf (accessed June 25, 2014). Although these are M&O projects the models can be used to analyze other types of transportation projects.

49. The FHWA report also considered a third category, "Multiresolution/multiscenario methods" but this category more closely represents a variant of BCA *methodology* rather than a category of BCA *models.*

50. See Chapter 6 of: *Cal-B/C Technical Supplement: Volume 1* (Sacramento, CA: California Department of Transportation, 1999).

51. Meanwhile, it classifies HERS into route-based category, and STEAM into the network-based category.

52. The Tech Supplement Vol. 1 published in 1999 concluded, "... the use of travel demand forecasting models is a natural step once it is determined that a network-based approach is appropriate …" It apparently was determined that a network-based approach is appropriate, as evidenced by the Tech Supplement Vol. 3 published in 2009, which describes the corridor and network models that had recently been developed: The Department and its partners are expected to use Cal-B/C and Cal-B/C Corridor as their primary benefit-cost tools going forward. Cal-B/C serves as a sketch-planning tool that supports benefit-cost analyses when potential project impacts are not yet fully known. Cal-B/C Corridor conducts benefit-cost analyses using the changes in vehicle-miles traveled (VMT) and vehicle-hours traveled (VHT) estimated in planning and simulation models. With regard to the network-level model: The Cal-B/C development team originally intended Cal-NET_BC to be used whenever detailed regional travel demand model or micro-simulation model data were available. However, the conversion of travel demand data into the appropriate format

is time consuming. Over the last several years, experience with Cal-B/C Corridor has demonstrated that the model is easier to use and can handle most of the analyses envisioned for Cal-NET_BC. As a result, the development of Cal-B/C Corridor has continued since the 2009 revision. Notably absent here is any statement about the continued development of the network model. From this we conclude that Caltrans has already begun development of a network (post-processor) model, though actively developing it is not a current priority.

53. An example may be found in the presentation titled "An Overview of the Application of NET_BC Software for Caltrans District 5's System Analysis Study" at TRB National Transportation Planning Applications Conference, May 17-21. 2009, Houston, Texas. http://www.trbappcon.org/2009conf/program.html

54. *Cal-B/C User's Guide: Version 8* (Sacramento, CA: California Department of Transportation, 2009): 1.

55. See page 79 of Chris Williges and Mahmoud Mahdavi, "Transportation Benefit-Cost Analysis: Lessons from Cal-B/C," *Transportation Research Record* 2079 (2008): 79-87.

56. These were described in the first five chapters of the *Cal-B/C Technical Supplement: Volume 1* (Sacramento, CA: California Department of Transportation, 1999).

57. Because *Cal-B/C User's Guide: Version 8* (Sacramento, CA: California Department of Transportation, 2009), refers to Cal-B/C version 4, and because Caltrans no longer distributes version 4 through its website, we provide the spreadsheet (file name "CalBCv40_worked_example.xls") featured in this example at the following link, to allow readers who are so inclined to work through this example in detail: https://sites.google.com/site/profholian/home/resources-for-sjsu-faculty.

58. "Cal-B/C assumes that the number of travelers with and without the project are the same, but users can enter different values if they have project-specific information that suggests travelers will make new trips (i.e., induced demand) as a result of the project." See Pages 2-12 of *Cal-B/C Technical Supplement: Volume 1* (Sacramento, CA: California Department of Transportation, 1999).

59. The quote from the instructions worksheet can be found in cell W42. The quote from the *Cal-B/C Technical Supplement: Volume 1* (Sacramento, CA: California Department of Transportation, 1999) can be found on page 6-11.

60. "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 See pages 2-13 of *Cal-B/C Technical Supplement: Volume 1* (Sacramento, CA: California Department of Transportation, 1999).

61. R. Leslie Jones, "Statewide Travel Demand Forecasting in California," *Transportation Research Circular*, E-C011 (1999): 76-82.

62. A succinct overview of the CSTDM can be found on p. 540 of the article titled "Achieving reductions in greenhouse gases in the US road transportation sector," by Kay, Andrew I., Robert B. Noland and Caroline J. Rodier (2014) *Energy Policy*, 69, 536–545.

63. United States Department of Transportation, "Notice of Funding Availability for the Department of Transportation's National Infrastructure Investments under the Consolidated Appropriations Act, 2014" (February 24, 2014), http://www.dot.gov/sites/dot.gov/files/docs/TIGER%202014%20NOFA_FINAL.pdf (accessed June 3, 2014)

64. United States Department of Transportation, "About Tiger Grants" (March 4, 2014), http://www.dot.gov/tiger/about (accessed April 20, 2014).

65. Eno Center for Transportation, "Lessons Learned from the TIGER Discretionary Grant Program" (April, 2013), https://enotrans.r.worldssl.net/wp-content/uploads/wpsc/downloadables/TIGER-paper.pdf (accessed May 17, 2014).

66. Reason Foundation, "Evaluating and Improving TIGER Grants" (April 2012), http://reason.org/files/improving_transportation_tiger_grants.pdf (accessed May 21, 2014).

67. United States Department of Transportation, "About Tiger Grants" (March 4, 2014), http://www.dot.gov/tiger/about (accessed April 20, 2014).

68. United States Department of Transportation, "Notice of Funding Availability for the Department of Transportation's National Infrastructure Investments under the Consolidated Appropriations Act, 2014" (February 24, 2014), http://www.dot.gov/sites/dot.gov/files/docs/TIGER%202014%20NOFA_FINAL.pdf (accessed June 3, 2014): The first quote comes from the note on page 20. The second quote comes from p. 21.

69. California Department of Transportation, "Division of Rail: Reports, Documents, and Maps" (2014), http://www.dot.ca.gov/hq/rail/Reports_Docs_Maps.htm (accessed June 5, 2014).

70. The project costs include, in the first year, project support of $2 million and construction costs of $25 million in the first year, construction costs of $25 million in the second year, and construction costs of $30 million in the third year, and finally $4 million of rehabilitation in the tenth year.

71. "Benefit-cost analyses of transportation projects almost always depend on forecasts of projected levels of usage (road traffic, port calls, etc.). When an applicant is using such forecasts to generate benefit estimates, it must assess the reliability of these forecasts. If the applicant is using outside forecasts, it must provide a citation and an appropriate page number for the forecasts. Applicants should incorporate indirect effects into their forecasts where possible (e.g., induced demand)." See page 13-14 of United States Department of Transportation, "Benefit - Cost Analysis Analyses Guidance for TIGER Grant Applicants" (May 3, 2013), http://www.dot.gov/sites/dot.gov/files/docs/TIGER%20BCA%20Guidance%202014.pdf (accessed May 11, 2014).

72. Recorded presentation by Rebekah Anderson on the Ohio statewide model, beginning at 39:49: TMIP Online, “ODOT Experience Using its Activity-Based Model” (No date), http://tmiponline.org/Clearinghouse/Items/20130409_-_ODOT_Experience_Using_its_Activity-Based_Model.aspx (accessed May 13, 2014).

73. More information on the OSWTDM can be found at: http://www.dot.state.oh.us/Divisions/Planning/SPR/ModelForecastingUnit/Documents/osmp.pdf

74. “Benefit/Cost and Air Quality Analysis for Allen County IR 75,” produced by Modeling and Forecasting Section, Office of Statewide Planning and Research. More information on the ODOT CMAQ process can be found at: http://www.dot.state.oh.us/Divisions/Planning/SPR/ModelForecastingUnit/Documents/cmaqr6_revised_jan_2012.pdf

75. See page 14 of United States Department of Transportation, “Benefit - Cost Analysis Analyses Guidance for TIGER Grant Applicants” (May 3, 2013), http://www.dot.gov/sites/dot.gov/files/docs/TIGER%20BCA%20Guidance%202014.pdf (accessed May 11, 2014).

76. City of Anaheim, “Gene Autry Way - TIGER Grant Application” (November 16, 2009), http://www.anaheim.net/article.asp?id=2002 (accessed May 20, 2014).

77. “Benefit-Cost Analysis for Proposed TIGER Projects” document shared with us by the Southern California Association of Governments, page 8.

78. United States Department of Transportation, “Benefit-Cost Examples” (March 6, 2012), http://www.dot.gov/sites/dot.dev/files/docs/TIGER-bca-examples-03-06-12.pdf (accessed May 25, 2014).

79. Caltrans has developed a BCA model – Cal-B/C Corridor – specifically designed to handle inputs from TDMs. So, if a TDM were available, it may make more sense to use this. However, there are some reasons one may still prefer to use Cal-B/C even if TDM is available; for one, the Corridor model does not estimate accident benefits.

80. See page 174 of Kenneth A. Small and Erik T. Verhoef, *The Economics of Urban Transportation* (New York, NY: Routledge, 2007).

81. This document noted that “Types of projects that are well suited to a network-based benefit-cost analysis include: ITS projects ... Most HOV projects ... Interchange additions or improvements ... Significant capacity improvements…” while “[a]rea or facility type characteristics that are well suited to a network-based benefit-cost analysis include: Relatively dense roadway networks … [and] ... [t]ransportation systems experiencing relatively high levels of congestion …” This passage suggests induced demand effects would be stronger in certain situations. See Chapter 6, pages 4-5 of *Cal-B/C Technical Supplement: Volume 1* (Sacramento, CA: California Department of Transportation, 1999).

82. Todd Litman, “Faulty Assumptions In The TTI Urban Mobility Report,” *Todd Litman’s Blog, Planetizen*, October 2, 2011, http://www.planetizen.com/node/51680.

83. The following passage from the Caltrans website describes the recent history of the Division of Transportation System Information: Division of Transportation System Information has merged with the Division of Research and Innovation (DRI) on November 1, 2012. The new division is the Division of Research, Innovation, and System Information (DRISI). We will continue to provide the same great services but under a different name. One of our offices, Office of Travel Forecasting and Analysis, will also be moving to Transportation Planning. We will try to make these changes as smoothly as possible. So, the structure of Caltrans is more fluid than is suggested by Caltrans organizational charts. One of our interviewees suggested this merger was caused by financial pressure, but the synergies across the activities of the Office of Travel Forecasting and Analysis and the Office of Economic Analysis are apparent, and this part of the merger seems to make good strategic management sense.

84. A study of merging these offices is a BCA in and of itself, which of course we have not undertaken in this report.

85. *Cal-B/C Technical Supplement: Volume 3* (Sacramento, CA: California Department of Transportation, 2012).

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