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Caltrans worked with the Mineta National Transit Research Consortium to explore methods of integrating multimodal data to improve BCA. The project evaluated past policy decisions and current planning and programming for future transportation investments. The researchers reviewed the activities of various Caltrans divisions that influence the planning, monitoring, and managing of the transportation system to identify opportunities for increasing the integration of public transit.

16. ABSTRACT

Federal, state and local governments allocate billions of dollars in transportation funds each year. One useful tool for helping to decide which projects are best investments is Benefit-Cost Analysis (BCA). Ideally, BCA takes into account all impacts of a decision, and provides a way of selecting investments that maximize social welfare. However, in practice even the best BCAs only measure select impacts. This project develops methods of improving BCA by better integrating data from multimodal transportation network..It considers both BCA for evaluating past policy decisions, and BCA for planning and programming future transportation investments. We identify shortcomings of existing models, and propose, implement and evaluate concrete solutions. Case studies in transportation planning focus on the California Department of transportation (DOT), but benchmark California's competencies by exploring methods used by other states and local governments. In addition, while the focus is on BCA output as a concrete example of the type of performance measure that may suffer from data integration problems, we also consider other important models used by DOTs, especially travel demand models. The conclusion lists all recommendations for improving transportation planning through more integrated models. These will have immediate use to Caltrans as it considers directions for developing new planning capabilities. In addition by fitting the planning models we explore in the broader context of transportation planning and policy, the report will also serve as a valuable resource for analysis, managers and others who are interested in better understanding BCA methods and their use.

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Integrating Multimodal Network Data into Benefit-Cost Analysis for Transportation Planning and Public Policy

Matthew Holian, Ph.D.
Ralph McLaughlin, Ph.D.

March 9, 2015

Abstract

Federal, state and local governments allocate billions of dollars in transportation funds each year. One useful tool for helping to decide which projects are best investments is Benefit-Cost Analysis (BCA). Ideally, BCA takes into account all impacts of a decision, and provides a way of selecting investments that maximize social welfare. However, in practice even the best BCAs only measure select impacts. This project develops methods of improving BCA by better integrating data from multimodal transportation networks.. It considers both BCA for evaluating past policy decisions, and BCA for planning and programming future transportation investments. We identify shortcomings of existing models, and propose, implement and evaluate concrete solutions. Case studies in transportation planning focus on the California Department of Transportation (DOT), but benchmark California's competencies by exploring methods used by other states and local governments. In addition, while the focus is on BCA output as a concrete example of the type of performance measure that may suffer from data integration problems, we also consider other important models used by DOTs, especially travel demand models. The conclusion lists all recommendations for improving transportation planning through more integrated models. These will have immediate use to Caltrans as it considers directions for developing new planning capabilities. In addition by fitting the planning models we explore in the broader context of transportation planning and policy, this report will also serve as a valuable resource for analysts, managers and others who are interested in better understanding BCA methods and their use.

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Executive Summary

For much of the 20th century, state Departments of Transportation (DOTs) were primarily highway building organizations. Slowly, DOT responsibilities have shifted from highway building towards managing multimodal transport systems, as exemplified by Caltrans' new mission statement since April of 2014: "Provide a safe, sustainable, integrated and efficient transportation system to enhance California's economy and livability."

One useful framework for helping state DOTs accomplish *all* aspects of their mission is Benefit-Cost Analysis (BCA). Ideally, BCA takes into account all impacts of a decision--including safety, environmental, economic and other impacts--and provides a way of selecting investments that maximize social welfare. However, even the best BCAs only measure select impacts. Many state DOTs have developed models for conducting BCA. California in particular has used a formalized BCA process for decades. However, some worry that Caltrans' methods reflect old ways of thinking.

In particular, recent critics of Caltrans have argued that, due to its institutional history as a highway building organization, Caltrans has developed planning models that under-emphasize public transit, walking and other modes of transportation, and local streets and "network effects" more generally. The fact that a lack of data integration in Caltrans' *models* may be causing California's transportation *system* to be less multimodal than optimal provides the motivation for this report. Thus in this report, we seek to find appropriate and feasible ways of incorporating more multimodal and network effects into BCA for transportation planning and public policy.

Caltrans' critics claim that, "...Caltrans today is significantly out of step with best practice in the transportation field."[1] Our research indicates that Caltrans staff until recently did not receive the resources necessary to implement the new statewide travel demand model (TDM). This, in turn, has closed off some avenues for making the agency's BCA process more integrated. Our first main recommendation is thus better integration of BCA and TDMs. And, in case Caltrans' implementation of a statewide TDM continues to stall, we also suggest ways to enable the agency's institutionalized BCA process to better capture multimodal and network effects.

- The primary BCA model that Caltrans uses—the Cal B/C spreadsheet—is unimodal when evaluating highway and road investments. In addition, important effects from induced demand are routinely ignored in analysis. We therefore develop concrete proposals for modifying both the Cal B/C model and method of use to better account for multimodal systems and network effects, especially induced demand.
    - First, we suggest adding a function to Cal B/C that estimates induced demand;
    - Second, we recommend better documentation and outreach to encourage the use of existing capabilities for modeling multimodal effects in the Cal B/C spreadsheet.
- Problems with implementing TDMs has held back Caltrans' full potential for integrated BCA. We therefore encourage Caltrans to hasten adoption of well-known methods of integrating BCA and TDMs.
    - First, TDMs can be used to help ensure induced demand is correctly measured in the spreadsheet model;
    - Second, BCA postprocessors can be used in conjunction with TDMs to enable an alternative approach to BCA.

We detail these and other recommendations throughout the report, and we list and summarize all of our recommendations in the conclusion. We wrote this report so that a reader not wishing to read all the details can proceed directly to the conclusion after reading this Executive Summary, and refer back for more information on specific recommendations as needed.

In addition to our focus 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 will be of interest to academics, public policy analysts, policy makers and others. We also hope that by combining the discussion of public policy analysis and transportation planning models in this report, we will facilitate cross-pollination of ideas for improving BCA across these areas of study. In our public policy analysis that integrates highway and transit data, we find that more rail transit systems are likely to be more efficient than has previously been shown, however, a couple of the worst systems are somewhat less efficient than has previously been found. These findings highlight the need for data integration, and provide a stark example of what a more integrated BCA model looks like.

Introduction: A statement of the problem

This project grew out of a double coincidence of research needs. The first research need was identified by the Division of Mass Transit at the California DOT (Caltrans), and communicated to the Mineta Transportation Institute (MTI), and 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." In addition, "a lack of accurate transit data" was cited as one reason "Caltrans has constantly struggled with fully integrating transit into existing processes and activities."[2]

In our roles as academic transportation researchers, we identified a closely related research need. Specifically, we were working to improve public policy-level BCA of rail transit systems.Could we use our academic research methods to improve planning models? Might there be gains for academia from cross-pollination of academic and governmental analyses?

In this report, we focus on developing integrated models for benefit-cost analysis for public policy and transportation planning. Model integration can take many forms in practice, but in this report, we focus on network effects, principally multimodal travel and induced demand.[3] Fully integrated transportation models will of course also incorporate land-use impacts, interactions between freight and personal transport, and other issues, and we admit that these are areas that require more attention in future research.[4] To fix ideas, in this report we present a stark example of data integration in the context of public policy analysis. Specifically, we estimate a statistical fare elasticity model for *transit* systems, where the model input is a measure of *highway* congestion. Thus we are able to better estimate demand for rail transit in different cities by integrating multimodal data. We then use these updated demand estimates in a BCA of these systems. Carrying out this analysis has use for public policy purposes but also provides a concrete example of what a "more integrated model" looks like.

Our academic research had been on BCA, and this is one reason for this choice of focus, but it is also true that BCA produces concrete examples of the very type of performance measures that the Division of Mass Transportation is concerned do not sufficiently integrate transit.[5] Moreover, BCA is widely used in transportation planning 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 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, from California, and around the United States. In addition to the case study of the TIGER program, we also explore the role BCA played in allocating money from California's Prop 1B, which was passed by voters in 2006 and authorized $20 billion in bond sales for transportation projects. Both of these cases demonstrate how BCA is used in actual policy contexts, both in California and around the country. 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. With respect to the BCA for policy, using basic economic theory and readilyavailable data, an improved (integrated) BCA model for rail transit systems finds more rail transit systems are likely to pass the benefit-cost test than has been previously found, however, a couple of systems are shown to have been somewhat worse investments than has previously been found. This finding highlights the importance of model integration.

With respect to planning, we find that both the methods and models Caltrans uses for BCA could be more integrated with model updates that place more attention on network effects including induced demand and multimodal considerations. More integrated 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). Integrating BCA with TDMs would provide analysts with another way to incorporate induced demand and multimodal effects.

We elaborate on these suggestions in the body of the report and in the conclusion, where we also detail suggestions that are outside the realm of modeling. For example, we discuss ways of achieving a more integrated transportation system that will require action on the part of academics, policy makers and many others in the transportation community.

Among the methods we employed in carrying out this research are statistical, monte carlo and social welfare analysis. We also employed qualitative techniques. Indeed, one of the most interesting and fruitful aspects of our research were our interviews and discussions with transportation professionals at Caltrans, the Ohio DOT, the US DOT, consultants and others.

Initially, we had planned to interview Caltrans staff to learn about their models, but about halfway through our research, we began to see how our project related to wider events at Caltrans. We began this project in June 2013 and held our first interview in February, 2014. There we learned about a recently published report by the State Smart Transportation Institute (SSTI). We were not aware of this report when we began our research, but it became clear that this report helped to create an environment at Caltrans in which we did not expect to find ourselves. For example, some of the Caltrans staff we met regarded the SSTI report as unfair, and perhaps worried we would describe their models and methods unfairly. Of course, the value we place on our reputations as academic researchers requires us to try our hardest to shine light on truth. In large part, we view our report as an attempt to constructively address some of the suggestions highlighted in the SSTI report, in two main areas: the need for benchmarking, and especially strengthening of the planning division.

Our focus is not limited to Caltrans, and we attempt to benchmark California's competencies against other state and local agencies. We find that Caltrans' BCA methods comparable favorably with those used by transportation agencies in other states. In fact, as we discuss in the TIGER case study, Caltrans methods have even been adopted by other agencies. That said, we believe there remains plenty of room to improve these BCA methods. In contrast, we find that other states and local agencies are noticeably ahead of Caltrans in implementing state of the art TDMs. This in turn has consequences for BCA, a point we elaborate on below.

The other major recommendation that came out of the SSTI report that we follow up on here was to "strengthen the planning unit." As we have already mentioned, BCA output is a concrete example of the type of performance measure that may suffer from data integration problems, and BCA is widely used in transportation planning and programming at state DOTs.

Caltrans is a large organization. It had twelve geographic divisions and 42 administrative and functional divisions identified on its October 2013 organizational chart. Some of these 54 divisions are massive—one division we profile, the Division of Transportation Planning itself has over 100 subdivisions. Given its sheer size, it may be easy to understand why Caltrans might suffer from data integration problems.

Although we strive to take a broad approach in this report, we do not inventory models used in all 54 of Caltrans' divisions. Depending on how one defines "model", there would easily be hundreds if not thousands of examples of how a transport datum was used to support planning, monitoring or management at Caltrans. Instead, we focus on the Planning Division where we think an in-depth analysis would be most likely to bear fruit. We even found it necessary to limit our focus to a few offices within the Planning Division, and to restrict our detailed attention to two of its offices: The Office of State Planning, especially its Economic Analysis Branch, and the Office of Travel Forecasting and Analysis, especially its Statewide Modeling unit.

The outline of the report is as follows. The next section presents background information on transportation planning and policy, and this provides the context in which the models we discuss next are used. We then turn to the main body of the report where we present opportunities for data integration in public policy and planning models. This report concludes by summarizing the major results and recommendations which have come out of this research. Along the way we consider case studies from the state of California and across the United States.

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 schemes 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 following 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 through a series of congressional acts that funded projects on an ad-hoc basis. The Federal Aid Road Act (FARA) of 1916 was the first of such acts to be directed exclusively towards federal highway planning. The act allocated $25 million for improvement of rural roads with a federal contribution of at least 30 percent but no more than 50 percent for each project. Funds were distributed to individual states to manage and implement projects, which were reviewed by federal authorities, and by 1920, states receiving these funds were required to establish a state highway agency. Much of these fund were used to improve postal roads in rural areas of the country.[6] The 1921 Federal Aid Highway Act (FAHA) brought a change to the focus on postal roads, and instead directed funding towards the development of a national highway system. Otherwise known as the Phipps Act, the 1921 FAHA appropriated $75 million in 50-50 matching funds for states to develop highways, but the total miles of new construction could not surpass seven percent of each state's total roadways.

Still, planning for long-term transportation needs was mostly a secondary concern of federal transportation policy in the first-half of the 20th 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, as it allocated 1.5% of federal transportation funds for states to conduct surveys, plans, economic analyses, and engineering investigations for projects of future consideration.[7] However, dramatic population shifts of the postwar era, both in population increase 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.[8]

During the 1940s, transit ridership peaked at 23.4 billion trips per year (compared with 10.5 billion trips per year in 2012, APTA 2013) 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 rate by the early 1950s. This major modal shift led to the 1956 FAHA that would provide 90% federal funding share for 41,000 highway miles to be implemented by state transportation agencies. Urban politicians "enthusiastically" 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, the need for permanent government agencies at the federal, state, regional, and local levels to manage such as large transportation network was pressing. In a special address to Congress on transportation, President Kennedy declared: "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 to transportation planning. The 1962 FAHA brought the first true mandate for transportation planning to US states, and required states to establish their own department of transportation in order to receive federal funding. In addition, the act required urbanized areas of greater than 50,000 persons to establish Metropolitan Planning Organizations (MPOs). The 1962 FAHA in particular established what would be 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.

The focus on highways started to lose traction as public opinion about the social benefit of the interstate system slowly started to turn throughout the 1970s and 1980s as the movement for local control over transportation decisions grew in strength.[9] In a partial response to changing public opinion, the 1973 FAHA update funded mass transit and airport development in addition to highway building, signaling the slow transition towards 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 highways funds to MPOs that they could designate to regional projects without state approval. Though this change marked a significant step towards providing more local control over transportation planning, MPOs still had little authority, since they did not have the ability to raise revenues 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.[10]

TEA-21 secured and continued the funds allocated to MPOs for highway, transit, and rail as well as bicycle and pedestrian infrastructure (Katz et al 2003). 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 sufficient funds to make an impact in any state let alone the 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 funding experienced a funding boon from $3 billion per year to almost $6 billion (Katz et al 2003). 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). Amongst other provisions, MAP-21 streamlines the National Environment Protection Act to help speed up 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 an important role in fostering efficient, equitable, and environmentally sustainable economic growth. Because of this, an effective transportation planning process incorporates 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 mandates establishment and distribution of federal transportation funds. The latter supports statewide and regional transportation projects from the Highway Trust Fund (HTF). Historically, HTF dollars are raised from the federal gas tax, which is currently at 18.4 cents per gallon. Federal mandates, on the other hand, have influenced transportation planning at the sub-national level by requiring states and metropolitan areas to establish transportation departments (DOTs) and metropolitan planning organizations (MPOs), respectively, as a condition to receive federal funding for transportation projects.

[Insert Table 1 about here: Federal Requirements for State and MPO Transportation Planning

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 transportation goals of the state, projected statewide travel demand, transportation problems and preferred solutions, and sources of finance and capital investment schemes. The STIP is similar to the

LRSTP, but is focused more specifically on a four-year time horizon and 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 US DOT approves each state's STIP, while states themselves are responsible for approving their own LRSTP.

In parallel, MPOs must also carry out long and short-run 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 is a plan that 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 that the MPO would like to implement in the short-run. However, there are additional federal requirements for TIPs: they must be updated every four years, must include consideration of fiscal limitations, is approved by the governor, and is included in the STIP. The UPWP is an even shorter term planning document (1-2 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. A summary table of state and MPO planning documents is shown in Table 1.

[Insert Figure 1 about here: The Transportation Planning Process]

As shown in Figure 1, the process of creating these documents begins with establishing goals and general visions, followed by discussions of existing conditions, and continuing with reports on issues such as environmental, land use, safety, and traffic considerations.[11] Throughout the plan creation process, public engagement of stakeholders is common, and is typically facilitated by MPOs or state DOTs.

Transportation Planning and Policy in California

As demonstrated above, transportation planning is comprised of a series of decision-making processes carried out primarily at the state and metropolitan level. For transportation planning in California, the decision making 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 the US DOT. The US DOT, via the Federal Highway Administration, then distributes federal funds to Caltrans. Caltrans then allocates these funds, along with 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 throughout the state that account for 55% of the 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 amount of miles as the state-managed highways, but they account for 45% of the total vehicle miles traveled in the state.[12] In some circumstances, MPOs or local governmental agencies purchase highways from Caltrans that run through its jurisdiction in order to incorporate specific routes into their MTPs and TIPs.[13] Usually, however, Caltrans leads 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 gubernatorial-appointed members and a member appointed each by the Senate Rules Committee and 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 percent of STIP funding to be allocated to TIPs, and the remaining 25 percent for interregional projects. Since TIPs are created by MPOs, and interregional projects are managed by the state, SB 45 significantly increased the influence of local project needs in 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 shift towards more multimodal oriented planning. The California Environmental Quality Act (CEQA) has been a key element of transportation and land use planning. Enacted in 1970, and following the National Environmental Policy Act, CEQA discloses the environmental consequences of planning and proposes mitigations.[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 to specifically come from passenger vehicle use, and requires MPOs to develop transportation and land use plans that are designed to meet these targets. As such, MPOs must include transportation projects in their TIP that help reduce GHG emissions.

Amongst other methods, the CTC uses the same BCA methods we discuss later in this report to evaluate the merits of individual TIP and STIP projects and the tradeoffs involved with achieving the directives mentioned above. In the remainder of this report, we focus almost exclusively on how BCA is used at the state and MPO levels in California, and suggest areas for improvement in the use of BCA models. Before we proceed to analyze 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 the examination by 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 the tradeoffs of public sector investments, economists adopt the objective of *social welfare maximization*. The concept of social welfare is also a philosophical construction; its utilitarian notion can be summed up by paraphrasing the British philosopher Jeremy Bentham as “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 happiness (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; equity can be accounted for in BCA, 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 all types of impacts that transportation planners and policy makers care about, from injury and fatality reductions, to health and environmental effects of pollution. However, economists have developed techniques for valuing benefits produced by these “external” impacts, for example, by using 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”—which is 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 includes safety, equity, efficiency and sustainability goals. 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 hence often times 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 path-breaking work in statistical methods and econometric theory. Today the multinomial logit developed by McFadden provides a core of the foundation of both traditional four-step as well as 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 data integration may lead to a failure to achieve optimality. 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 “Braees’ paradox”.[17] The first paradox describes a situation where 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, and transit times increase due to the fall in train frequency. On the whole, society is worse off after the highway expansion. Braees’ paradox describes a similar situation, where again induced demand causes a highway expansion to result in an overall increase in travel times; in this case induced demand comes from drivers substituting to the improved road from other roads in the network.

The Braees 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 of this is that it is less likely to be efficient to expand road capacity when alternative options (transit) exist. 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 we will see, 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 and 10 opposed, while the senate voted 37 in favor and 1 opposed to placing Prop 1B before the voters.[20] The 2006 Voter Information pamphlet describes, "PROP 1B: Highway Safety, Traffic Reduction, Air Quality, and Port Security Bond Act of 2006" 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 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 to local streets, to security to public transit. One possible result of the wide range of projects funded through this proposition was broad appeal to voters. As mentioned, 61.4% of voters were in favor of Prop 1B. In addition, statistical analysis of this proposition revealed that there was 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 an article by Chris Williges and Mahmoud Mahdavi.[22]

The CTC shared with us 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, Appropriateness. The primary consideration for the "Value" criteria 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 identified, "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 speed at which the proposed project can begin construction, and the project's current stage of development. 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 for testing a variety of interesting hypotheses, for example regarding 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 the current project, we have conducted some preliminary data analysis. Our preliminary results suggest that BCA did influence policy outcomes in the case of Prop 1B, but rather than influencing commissioner's directly, BCA seems to have had a more indirect effect on outcomes, but first influencing staff assessments of project "value." These staff assessments in turn affected CTC commission decisions.[24]

In addition to the results of the BCA for CMIA projects, Caltrans shared with us a few of the actual spreadsheets that were used to produce the BCA results. We defer a discussion of the spreadsheets until we have described the model in more detail. It will be useful to recall the Prop 1B case we have just presented when we do explore the Cal B/C model later.

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

Toward integrated BCA for transportation planning & public policy

This section constitutes the core of the report. It contains two sub-sections, one on BCA for public policy, and the second on BCA for transportation planning. Both of these sub-sections could serve as stand-alone studies, but there are numerous parallels and substantial complementarity between them.

One parallel between these two studies is that they are both divided into three sub-sub-sections. In both cases, the studies begin by describing the context-specific approach to BCA--public policy analysis or transportation planning--as well as some of its limitations. Next, each study turns to a discussion of the role of travel demand modeling, an essential component of all types of BCA for transportation. Finally, each study concludes by presenting innovative solutions to the problems identified. Transportation planners, policy analysts and academics alike may benefit from the cross-pollination that will result from our 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. As mentioned above, in both subsections, we begin by describing the approach to BCA, then analyze the way demand models are used in the approach, and finally present the results of our original, integrative analyses.

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, whether to allocate funding towards transportation, versus 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 what a more integrated BCA looks like.

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 the policy-oriented literature, typically a small number of impacts are considered. For example, the study by John Harford included only user plus 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, referred in each study as "the excess burdens associated with taxes"[25] and "cost of raising public funds,"[26] respectively. 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 were user benefits--specifically, benefits received by those who ride transit--and the only cost categories were operating and capital costs. Although this approach misses categories of benefits and costs captured in earlier studies, the impacts it includes are the primary ones. As a result, the main virtue of this approach is to provide 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 envelop" approach. Simplicity is especially preferred here, because a large reason we are presenting this analysis is as an example of what a more integrated model, 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 only means 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):

$$Q_d = a - bp \qquad (1)$$

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 one percent increase in price leads to a 1.5% decrease in Q_d, and if $P_d^e = -2.5$ then a one percent 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 $\frac{\Delta Q}{\Delta P}$ which as can be verified is 500,000. Substituting 500,000 in for b, 1,000,000 in 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-hand 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-hand side. Together these are known as user WTP or *gross user benefits*.

(Insert Figure 2 about here: Linear Demand Curve for Transit (Price Elasticity of Demand of -1 at Point of Observation)

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.

(Insert Figure 3 about here: Two Linear Demand Curves for Transit, (Price Elasticity of Demand of -1 and -0.5 at Point of Observation))

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, often times 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, and he collected data from various sources on capital costs, for 24 heavy and light rail systems in the United States. This study 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, 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 already 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 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 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.

(Insert Table 2 about here: Calculating annualized NPV with NTD trip and cost data, and an assumed fare elasticity of -0.3)

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 like pollution reduction due to substitution of single-occupancy vehicle 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.

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 does 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 differs 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 a fare changes took place for each transit systems. 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-1980's. 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.

(Insert Table 3 about here: Fare elasticity estimates for select cities)

(Insert Table 4 about here: Fare elasticity model, variable descriptions)

These variables come from three sources. Fare elasticity, denoted previously as P_d^e, 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 given this was also reported in the APTA study, we use the values from this 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 below presents summary statistics for these variables.

(Insert Table 5 about here: Fare elasticity model, summary statistics)

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:

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

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 two modified versions of this model, one each where β_1 and β_2 are constrained to be zero, respectively, as well as two versions of equation (4) where β_1 is restricted to be zero, and CITY_POP is replaced with URBAN_POP and DENSITY, respectively. 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.

(Insert Table 6 about here: Fare elasticity model, regression results)

As one can see 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 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 of our goals here is to illustrate, as simply as possible, what data integration 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:

$$\text{FARE\_ELASTICITY} = -0.696 + 0.387 * \text{CONGESTION} \quad (5)$$

Given TTI calculated a congestion index value for many areas for many years, we can estimate fare elasticity for many years for many systems, using this model and the contemporaneous value of the TTI congestion index.[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, and so, using equation (5), estimated fare elasticity ranges from -0.52185 to -0.21225.

Illustrating Data Integration with a Retrospective BCA of Rail Transit Systems

As we show 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 U.S. in 2008 and the fare elasticity model presented above as equation (5), to conduct a BCA of U.S. rail transit systems. This BCA 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.

Essentially, in what follows we extend Guerra's BCA, described above, 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 integrated 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 kind of statistical benefits transfer.

Table 7 summarizes our 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 that come out of our analysis with those from Guerra's analysis, we see that there is one major qualitative difference, which is that Washington, D.C. now has a positive ANPV. Overall most system rankings did not change, but here again D.C. is an outlier. Table 7 shows that it was ranked 19th in Guerra's study but 3rd in ours. Two systems changed rank less dramatically but noticeably. San Diego improved by moving from 8th to 4th, while Niagara Frontier fell from 7th to 11th.

(Insert Table 7 about here: Original and updated NPV estimates (annualized))

In addition to an additional system (Washington) coming out as more efficient than the status quo (i.e. building the rail system more efficient than note building it) most other systems come out better.[42] Specifically, in all but two cases (Niagara Frontier, and Port Authority of Allegheny County) the NPV is higher in our integrated analysis. Given the average of the elasticities used in our analysis is -0.25, whereas the comparison results used a 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 elasticites reported by APTA 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, for example, by 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.

Before concluding this analysis, 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), is of some importance for what follows. Therefore we note here that many BCAs report the B/C ratio, even though a case has been made by many, including Boardman and associates, against the use of the B/C ratio. This is due to the fact that selecting projects based on a strict B/C ratio standard can lead one to incorrect decisions.[43] However, the B/C ratio can prove useful information, for example, in ranking projects when selecting mutually exclusive projects from a project list, while simultaneously facing a constrained budget. In fact, this is precisely the situation facing decision makers at the CTC during Prop 1B when they made funding decisions, 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 integrating highway congestion data. This simple illustration of integrating highway congestion and transit demand data shows not only what a more integrated model looks like, but also that data integration matters. While to some it may not seem very important that one additional rail transit system comes out as efficient, the fact is, the number of more efficient systems (again, efficient relative to the status quo) increases by 50% in our integrated BCA, compared to the homogenous fare elasticity case. 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 has 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, and we have therefore 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 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 U.S. are inefficient compared to the status quo. We interpret these results as, in our integrated BCA of rail transit systems, three transit systems are shown to be efficient, even ignoring external effects. It is our conjecture that more systems would be shown to be efficient if all external effects were included, however analytical advancement on this front is left for future research.

Transportation planning

In this subsection we move from retrospective BCA for policy analysis to prospective BCA for planning. While considering the efficiency of past decisions is important for evaluating public policy, among other purposes, 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 have all been used, or are planning to be used, for transportation planning in California.[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 nation-wide grant program (TIGER) that was directed by the U.S. 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, most important of which is that our background research suggested to us that ODOT uses models that are relatively more integrated than those used by other states.[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, is and 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 tools and 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 these tools 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 tools, including seven developed by FHWA (including HERS-ST, IDAS, IMPACTS, SCRITS, STEAM, TOPS-BC and BCA.net), the COMMUTER Model developed by the U.S. 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 a "sketch-planning" or "post-processing" methods.[49] These categories lie along a continuum from low cost (in terms of capabilities and effort required) to high cost, and also in their ability to account for more impacts (of course, 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 the "Cal B/C Technical Supplement Volume 1," was published in 1999.[50] The three categories presented here likewise differ according to how many impacts, such as induced demand and off-network roads, can be handled; they include route-based, extended corridor, and network-based models. The route-based category of models can be thought of as essentially 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 it places Cal B/C.[51] The list of models and the categorization provided here is not necessarily exhaustive but illustrates BCA models 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. Our own view is that Cal-B/C can be classified as "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 integrated types of 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, these are designed to facilitate evaluation of entire corridors and networks.

The emergence of network models at Caltrans is a recent development. However, we have not seen examples of the use of corridor or network models at Caltrans headquarters. Both of these models require inputs from TDMs, and as we discuss in the next subsection, Caltrans has struggled to implement its statewide TDM for use in planning. We have seen evidence of the use of some of these models by Caltrans districts, however, and this makes sense as these staff are in a better position to use them, given their geographic specialization puts them closer to regional travel demand models that many districts have already implemented.[52] We have however seen a variety of actual projects that Caltrans analyzed using Cal-B/C, and we discuss these below.

When we asked staff at headquarters about the use of network models at Caltrans, they mentioned plans to use TREDIS,[53] and did not mention Cal-NET_BC. Our research suggested problems implementing TDMs make CalNETBC too costly to use.[54] Our impression is that Caltrans, at least headquarters, almost exclusively uses Cal B/C for economic analysis. Therefore in what follows we describe the main features of this model and highlight some of the ways it does and does not take into account multimodal considerations and induced demand when used for sketch planning.

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."[55] In an article by Chris Williges and Mahmoud Mahdavi in *Transportation Research Record*, they report 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."[56] This revision was completed and released as Version 4, and since then another revision of the model (Version 5) has been released.

All projects (lane additions for highways, double tracking for commuter rail, etc.) analyzed in Cal B/C use the same spreadsheet file. The variety of project types Cal-B/C is capable of analyzing has been constantly expanding. The spreadsheet has 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 just a cover and denotes the version and identifies the file with Caltrans. The Instructions worksheet contains about 3,000 words and describes to the user the basic requirements for analyzing projects.

The three worksheets titled Project Information, Model Inputs, and Results are, for sketch planning purposes, the most important. The "Project Information" worksheet is the place where the analyst enters all of the basic project-specific information required for analysis. The model takes the information entered here and produces the output in the "Results" worksheet, using a variety of engineering equations.[57] The worksheet titled "Model Inputs" can be ignored for many types of analyses, but if the user has more detailed information from a TDM they can enter it here and override the values produced by Cal-B/C. Likewise, the other worksheets are unnecessary for obtaining basic results, but contain features that are useful for advanced analysis, such as incorporating benefits and costs to other roads, a feature we return to later. Finally, Cal B/C relies on a large number of parameters, including the discount rate, value of time, and others, that can be modified by the user.

The 2009 User Guide illustrates Cal B/C through a highway lane addition. We will use this hypothetical example here 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 has shared with us. This example will highlight some of the ways Cal-B/C--when used for sketch planning--is not integrated. 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 present a view from this worksheet.[58]

(Insert Figure 4 about here: View from an Information Worksheet of Cal B/C, Lane Addition Project)

There are five boxes 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. To conserve on space, only the first four of these are shown in Figure 4. For lane addition projects (and all other project types) the user must enter in the number of years to build and the region into box 1a; in this hypothetical case it takes 3 years and is in Northern California. In box 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 (in this case, 272,989.)[59] 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, in this example, we assume that this project *will not induce demand*.

Box 3 in the Project Information worksheet contains accident data. For a quick appraisal, state averages can be used while with more time project-specific averages can be entered.

Box 4, rail and transit data, is ignored in this example. In fact, there is conflicting information in the documentation we have consulted regarding whether for a highway project such as a lane addition, Cal B/C can or cannot accept rail and transit data. For example, the instructions worksheet of the Cal B/C spreadsheet says, "This section [Box 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."[60] In any case, this example certainly ignores transit data, which can be seen by the fact that the box 1D has been left blank. In other words, this example is *unimodal*.

In addition and as already noted, this example ignores induced demand, as ADT is identical in 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, viz-a-viz the goal of this research report, which is to develop more integrated methods for BCA.

Returning to the example, to conserve on page space, Figure 4 does not show the fifth box on the Project Information worksheet, which is Project Costs. This is a straightforward component of the model; so long as reliable cost estimates (including their dollar cost and timing) are available, entering in project costs is a straightforward aspect of project appraisal. This box calculates the present value of costs.

After inputting general project characteristics into the Project Information worksheet, the final output of the model is given in a separate worksheet named "Results". We illustrate what the results look like with Figure 5.

(Insert Figure 5 about here: View from a Cal B/C Results worksheet, lane addition project)

We see in Figure 5 that this 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-hand side of the upper box, while the right-hand side of the upper box 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 turn off certain categories of benefits. For example, if the user entered "N" next to "2) Vehicle Operating Costs?" the value of $58.7 million, shown in the top right box, would become zero. The same is true for accident costs and vehicle emission categories.

The final feature we illustrate in this example is the induced demand button. We will spend some time here due to the importance of induced demand in building more integrated BCA models. Item 1) in the lower box in Figure 6 is the Induced Demand toggle button. In this example, entering in "N" will not change the results of the analysis. To see why, recall that earlier we found, or assumed, that traffic is identical in the build and no build scenarios. In other words, the analyst assumed there is no induced demand for the freeway.

If the analyst did assume that the lane additions will induce traffic, then a variety of effects would occur. If new users decide to use the freeway due to its improvements, one effect may be slower speeds for existing drivers and thus lower benefits. On the positive side, the benefit received by the new travelers who are induced to use the road would be added, so long as the induced demand button is toggled on.[61]

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 large reduction. Recall when build and no-build traffic estimates were identical, as in the original estimate, the NPV was $355.3 million.

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 (these were previously reported in Figure 5, but are reproduced here to ease comparison), and the second when year-20 ADT is ten percent higher in the "build" scenario.

(Insert Figure 6 about here: Comparing benefit categories with and without induced demand)

Here we see travel time benefits fall from 373.2 to 296.4, a reduction of about 25%. However, the other categories of benefits fall by much more. In fact, in the cases of vehicle operating costs, accident cost and emissions cost savings, the project actually makes these problems worse! In particular, vehicle operating cost savings benefits fall from $58.7 to -131.7, a reduction of 324%, accident cost savings benefits fall from 10.8 to -4.3, a reduction of 139%, and emissions cost savings fall from 11.6 to -10.8, a reduction of 193%.

In both cases depicted in Figure 6, the Induced Demand button is 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 this button is set to "N", (thus excluding the benefits received by the new highway users), the NPV falls even further in the case when ADT is 10% higher; when "Build" traffic estimates are 10-percent higher and benefits of new users is not taken into account (i.e. the Induced Demand button is set from "Y" to "N"), NPV falls from $50.5 million to $34.9 million (where the $50.5 figure is arrived at by subtracting costs of $99.1 from benefits of $149.6, and the $34.9 figure is arrived at by subtracting costs of $99.1 million from benefits of $134 million.)

This discussion of the highway example has illustrated a number of shortcomings of the use of the Cal B/C model with respect to handling multimodal and other network considerations. First, if induced demand is ignored when inputting ADT, but in fact the project will cause new traffic, then Cal B/C can significantly overstate project benefits. Second, the "induced demand" button 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 was 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, we have also reviewed a number of actual projects that Cal B/C was used to analyze, including 7 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. We performed a small scale Monte Carlo analysis on the Prop 1B projects to explore the importance of induced demand, 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 we have identified with the use of Cal-B/C for sketch planning at the end of this section, but due to the importance of TDMs for our recommendations, we next turn our attention to this area.

Travel Demand Modeling in California

Two of the most important inputs for Benefit-Costs models, such as Cal B/C, are estimates of travel demand and speeds of a proposed project. Travel demand models (TDMs) are the primary tools that transportation planners use to provide these estimates. 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

The State of California began modeling travel demand in the early 1920's, 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 (which now exists as 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, the 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 it was the availability of large mainframe computers needed to execute the models.

As the availability and cost of desktop computers became 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 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.[62] 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 emissions factors model for modeling emissions and the 2006 Statewide Travel Model for modeling 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 true statewide demand model, called 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 5 sub-models: the Short Distance Personal Travel Model, which estimates travel demand for tours less than 100 miles from home; the Long Distance Personal Travel Model, which models personal tours greater than 100 miles; the Short Distance Commercial Vehicle Model that models work-based tours with stops within 50 miles; the Long Distance Commercial Vehicle Model that models work-based tours greater than 50 miles, and the External Vehicle Trip Model for trips with an origin and/or destination outside of the state.

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, but no one we have encountered in the course of conducting this research has disputed the claim that Caltrans is not using a state-of-the-art statewide travel demand model as a matter of course in transportation planning. Quite to the contrary, our impression is that statewide TDMs are hardly used at Caltrans headquarters.

With respect to TDMs at Caltrans, the good news is, as of our May 2014 interview, Caltrans was in the process of implemeting an updated TDM, referred to as CSTDM2.0. If this implementation is successful, Caltrans will be able to pursue new avenues with regard to BCA.

For 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. By introducing a new or expanded link, both induced demand and the source of induced demand can be estimated by comparing travel demand estimates by mode before and after the new link is added to the network. These before-after estimates can then be added to the Cal B/C model in the trip-count estimates with and without the project. The benefits and costs of induced demand can then be accounted for.

While these before-after estimates of travel demand by mode and link provide useful inputs for generating the benefits and costs of induced demand in Cal B/C, in practice we have found few projects where practitioners have actually included induced demand estimates in Cal B/C spreadsheets. We posit two explanations for this: (1) either the "induced demand" button misleads users into thinking that it automatically generates induced demand when selected (which it doesn't), or (2) benefit-cost analysts are not explicitly using data generated from TDMs.

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

Case Study: U.S. DOT'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, because 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 guildlines disseminated by the US DOT, and we interviewed US DOT staff, 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. The U.S. DOT 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'."[68]

The following quotes, taken from the USDOT webpage, provide a good picture of the history and scale of the TIGER program:[69]

> The Transportation Investment Generating Economic Recovery, or TIGER Discretionary Grant program, provides a unique opportunity for the U.S. 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.[70] 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 multi-modal 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.[71]

Although the Eno study classified a minority of the projects funded 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 US DOT webpage,[72]

> Each project is multi-modal, 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 corresponding to DOTs long-term goals, two secondary 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." [73]

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,[74] 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 page space.[75] 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 the U.S. DOT.

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 box 1B, Highway Design and Traffic Data, and also into box 1D, Rail and Transit data. As we saw with the hypothetical lane addition project earlier, for a highway project, the user *does not* enter in rail and transit data, but we see here that for a rail project, the user *does* enter in highway data. Thus in the case of a passenger rail project, we consider Cal B/C to be a multimodal model. This illustrates an interesting divergence between 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*.

(Insert Figure 7 about here: View from a Cal B/C Project Information worksheet, TIGER application)

Our main criticism of this approach is the lack of discussion of from where the traffic forecasts came. The US DOT is aware that project benefits are sensitive to traffic estimates,[76] which in large part determine the extent of travel time savings, safety improvements, and so on. The Merced-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 it is not clear where the highway traffic estimates came from; the fact that ADT estimates are identical in the build and no build scenarios suggests they did not come from a TDM.

Ohio DOT

The Ohio DOT began developing the Ohio Statewide Travel Demand Model (OSWTDM), and the full model has been in use for the last three years.[77] The OSWTDM incorporates recent innovations including integrated econometric/land use modeling, disaggregate microsimulation of passenger and business travel as well as a commodity-based approach to freight shipment.[78] The Office of Statewide Planning and Research at ODOT uses the OSTDM for a variety of purposes, including for analysis of 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.[79] 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 postprocessor. 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 fully multimodal (or, integrated), as the OSWTDM considers travel on a variety of modes, including long-distance bus. Thus if the improvement in the highway was important enough to induce demand from neighboring transit lines, this would be reflected in the model outputs. Second, the approach incorporates other network effects such as induced demand. Finally, the use of a TDM implies build versus no-build traffic forecasts are estimated consistently and transparently 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 US DOT 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."[80] 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 enables comparing 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 estimates. It seems Caltrans is already moving down this path as it develops capabilities to use TREDIS with the updated CSTDM and this is encouraging.

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 several applications that demonstrate first of all a wide variety of approaches. In personal conversation, US DOT Chief Economist Jack Wells agreed with the sentiment that it is possible to conduct a good BCA using both 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 a majority, some 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,[81] and illustrates how Cal B/C can be used to incorporate network 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."[82] 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 network effects.

The example from Florida illustrates how Cal B/C can be used successfully in competing for TIGER grants. The U.S. DOT posted this example to the area of its website where it provides information on preparing a BCA for TIGER applications.[83] 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 by building a median, a sidewalk and a 12-foot multi-use path. The BCA analysis was completed using Cal B/C. A review of this analysis showed that traffic was assumed identical both in the build and no-build scenario, from which we can gather they did not use a TDM. Therefore, the fact that the US DOT featured it as an exemplary BCA suggests that Cal B/C has been used successfully by a variety of local transportation agencies.

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. We have also considered actual examples from Caltrans that were used to analyze Prop 1B and TIGER projects. From all of these we conclude that Caltrans' methods could be better integrated because network effects such as 1) induced demand, and 2) multimodal considerations and usually not addressed. In this section we detail our innovations for developing more integrated models and methods.
The lack of an operational statewide TDM at Caltrans seems to have slowed the development of integrated BCA methods. The BCA methods exemplified in the ODOT case suggests, at a minimum, that Caltrans headquarters has not adopted the state-of-the-art in TDM methods. Further evidence that Caltrans' lack of TDM capabilities limit development of BCA methods comes from an FHWA guide for BCA[85] that notes the following:

> Standard travel demand modeling, principally addressing trip diversion, is often sufficient for BCA of routine capacity projects. State or MPO planning offices often undertake such modeling as a matter of course in their preparation of transportation improvement plans. In general, it is a good idea to conduct BCA in close coordination with planning offices.

Our research does not suggest that Caltrans currently undertakes transportation demand modeling "as a matter of course," at least not for interregional trips. But this appears to be changing. The role out of CSTDM2.0 is underway as of this writing. If the new model is successfully implemented, then one way of incorporating induced demand is through integration of TDM outputs in BCA. Specifically, TDMs can be used to determine the build and no-build current and 20-year average daily traffic forecasts.[86]

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 in 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 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.[87] 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).[88] 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 (5) shows one possible form the updated syntax could take:

$$= \text{ADT20NB} * (1+\propto) \qquad (5)$$
$$\text{where} \quad \propto = \beta_0 + \beta_1 * CONGESTION + \beta_2 * IMPORTANCE$$

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[89]) 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, $\beta_1$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 (5) suggests a way of selecting more project-appropriate values. The choice of variables in equation (5) 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 network effects, such as multimodal considerations, are ignored, may also be ameliorated with the use of TDMs. The short explanation of this is that BCA postprocessors 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. Caltrans seems to be considering two main options, as we discussed in the opening part of this subsection, including but not limited to Cal-NET-BC and TREDIS (both models with which Caltrans has at least some experience.) Caltrans has plans to use TREDIS for economic impact analysis, but no plans, at least as far as we found, to use it for BCA.[90]

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 (5), 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 we have recommended ways of handling both of the factors that prevents Cal-B/C from being what we would call an integrated model, at least when it is used for sketch planning. Specifically, for most highway and road projects, it 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 postprocessor, such as Cal-NET_BC or TREDIS MBCA, 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 "3 roads" feature, to incorporate network effects.

Conclusions

We conclude this report by listing all six 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 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.

Throughout the course of our research, we have identified six recommendations that we deem to be worthwhile for Caltrans to consider. We categorize these six recommendations into three areas, with two recommendations in each area, as shown below:

1. Improve Cal B/C:
    a. Add an induced demand function; we discussed this in detail, and presented the idea concretely as equation (5) in the Recommendations part of the last section,
    b. Caltrans should encourage multimodal modeling and provide support for carrying it out. In the Recommendations part of the last section, we discussed the need for documentation guiding analysts who wish to use Cal B/C to measure multimodal effects.

2. Integrate Cal B/C and CSTDM:
    a. Encourage users of Cal B/C to incorporate build and no-build ADT estimates from the TDM,
    b. Use a BCA post-processor for CSTDM (potentially one similar to Cal NETBC, but the BCA component of TREDIS may also make sense to use, given Caltrans is planning on using this software in assessing the CTP.) We discussed both of these points in detail in the Recommendations part of the last section.

Finally, we consider organizational recommendations that we have not discussed yet and these are in our third category of recommendations:

3. Reconsider the structure and scope of Caltrans:
    a. Consider formal structure changes, such as merging offices and branches, as well as informal approaches, to encourage closer collaboration between related offices;
    b. Rethink relationships with external partners such as outside consultants in order to fully exploit external expertise, while ensuring the in-house expertise is adequate to implement state-of-the-art models and methods.

One rationale for recommendation 3a comes from a FHWA guide for BCA that we 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, this rationale should be clear. However, we admit we are not sure how best to encourage this sort of coordination. Therefore, we suggest that Caltrans *consider* both formal and informal mechanisms.

From our study of Caltrans, we have found that the organizational boundaries are rather fluid. For example, only on November 1, 2012 was the Traffic Forecasting Branch even added to the Planning Division; before then, this function was part of the Division of Research and Innovation and Systems Information.[92] We heard from a senior manager about plans to merge the branches of Travel Forecasting and Analysis, State Planning, and System and Freight Planning, and a similar thought occurred to us independently. Therefore, the first part of our Recommendation 3a is to consider merging these offices.[93] At the same time, rearranging the formal structure of headquarters is not the only way to realize the intended benefits. Collaboration can 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.[94]

Recommendation 3b 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 above six recommendations prove to be most beneficial remains to be seen. The development of integrated models for transportation BCA may yield large gains. Continued collaboration between transportation analysts from different walks of life will generate further insights.

Abbreviations

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 Lifecycle XXX YYY ZZZ
CARB: California Air Resources Board
Caltrans: California Department of Transportation
CEA: Cost-Effectiveness Analysis
CEQA: California Environmental Quality Act
CMIA: Congestion XXX YYY ZZZ
CSTDM: California Statewide Travel Demand Model
CTC: California Transportation Commission
CTIP: California Transportation Infrastructure Priorities work group
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

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Endnotes

[1] *The California Department of Transportation: SSTI Assessment and Recommendations* (Madison, WI: State Smart Transportation Initiative, 2014).
[2] *Request for Proposals* (San José, CA: Mineta Transportation Institute, 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; on p. 234 they write:

> 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] There is often a great deal of overlap between BCA models for personal travel and freight travel. For example, in our case study on the federal government's TIGER program, we discuss methods used by the State of Ohio, and these same methods are used in the state's Transportation Review Advisory Council scoring system, which defines evaluation criteria for large, new projects, giving equal consideration to road, transit, freight and intermodal projects. See "Multimodal freight project prioritization" for examples of challenges of using BCA in the area of freight for Ohio and eight other states.
http://www.oregon.gov/ODOT/TD/TP_RES/docs/Reports/2014/SPR759_FreightPrioritization.pdf
[5] BCA produces a variety of performance measures, the most important of which is net present values, which put simply is the present value of benefits minus costs. Transportation engineers and planners often refer to the B/C ratio, which is benefits divided by cost. Economists prefer the former, due to errors in judgment that can result when the B/C ratio is used in decision making in isolation. For more on this, see pp. 33-34 of Anthony E. Boardman et al., *Cost-Benefit Analysis: Concepts and Practice* (Upper Saddle River, NJ: Prentice Hall, 2011).
[6] 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).
[7] Edward Weiner, *Urban Transportation Planning in the United States: History, Policy, and Practice* (New York, NY: Springer Publishing, 2013)
[8] Marlon G Boarnet, "National Transportation Planning: Lessons from the U.S. Interstate Highways," *Transport Policy* 31 (2014): 73–82.
[9] Mark H Rose et al., *Interstate: Highway Politics and Policy Since 1939* (Knoxville, TN: University of Tennessee Press, 2012).
[10] Bruce Katz et al., *TEA-21 Reauthorization - Getting Transportation Right for Metropolitan America* (Washington, DC: The Brookings Institution, 2013).
[11] *The Transportation Planning Process – Key Issues: A Briefing Book for Transportation Decisionmakers, Officials, and Staff* (Washington, DC: Federal Highway Administration and Federal Transit Administration, 2007).
[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 U.S. Census and 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 ax 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 the 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 are other results were presented in the March, 2014 TRF conference, the slides from which can be found here: 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 to us 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 analysts rating in the "value" category. For each category, CTC staff assigned each project a score of 0 to 5. A simple regression model we estimated using data on 115 proposals had an R-squared value of 0.57 and the following form: VALUE = 1.34 + 0.71 * BCRATIO. So for example, a project with a B / C ratio of one 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 we 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 results can be found on presentation 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 payment, for example the initial and subsequent investments in the BART system, is given by the following formula: PV = (Annualized capital costs)*(annuity factor). One can calculate an annuity 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 30.51. Therefore, given Annualized capital costs of $321 mllion, the present value of the investment must be $321 million times 30.51, or $9.79 billion. Usually the analyst will obtain this $9.79 billion figure, and then perform the calculations shown above, if the analysis is being done in annualized terms.

[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: Step 1. 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. Step 2. Draw a demand curve such that at a price of $0.59, quantity demanded is 82,984,033. Step 3. 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. Step 4. 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. Step 5. 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. Step 6. 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. Step 7. (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. Step 8. 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, an interesting question related to this is, 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 fare elasticity was less elastic in larger areas. The tests we conduct below 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 our main goal in this section is to offer a simple model that illustrates what data integration looks like. We have posted our data to the web and we invite those who are interested to explore the consequence of alternate modeling assumptions. Our data can be found here: www.sjsu.edu/faculty/matthew.holian/misc/holian_mclaughlin_data.xls . 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 most values, 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 the project (though it does not mean the project 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. May 17, 2010. Workshop Proceedings, August 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) which notes that EIA will be used in assessing the CTP. http://www.dot.ca.gov/docs/CIB_Interim_Report_122012_FINAL.pdf 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] See *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), for interviews responses, including one from an analyst from ODOT on page 16, in which they provided concrete examples of data integration in their own models as well as Caltrans' models.

[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] An example we found is a presented 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
[53] TREDIS has a BCA tool called MBCA; the TREDIS website (http://www.tredis.com/mbca) claims, "MBCA is the first free tool that equally covers all forms of air, water, rail and road transportation, as well as non-motorized (pedestrian and bicycle) transportation." We have not evaluated this claim but as we noted earlier, Caltrans is planning on using TREDIS to conduct EIA as a part of the evaluation component of the CTP. As we noted, EIA is different from BCA, though given TREDIS contains the ability to conduct BCA with its MBCA component, and Caltrans has some experience with TREDIS already, it makes sense that Caltrans explore the possibility of using the TREDIS MBCA model.
[54] 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 Volume 3 published in 2009, which described 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.

This document from which these passages were taken was updated in February 2012. It now appears that Caltrans will use TREDIS not Cal-NET_BC, as we discuss in an earlier note.
[55] From page 1 of *Cal B/C User's Guide: Version 8* (Sacramento, CA: California Department of Transportation, 2009).
[56] 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.
[57] These were described in the first five chapters of the *Cal B/C Technical Supplement: Volume 1* (Sacramento, CA: California Department of Transportation, 1999).
[58] 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 model version 4 through its website, we provide the spreadsheet featured in this example at the following link, to enable a reader to work through this example in detail, should they wish. www.sjsu.edu/faculty/matthew.holian/misc/Cal-BC v40_worked_example.xls.
[59] "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).

[60] 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.

[61] "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).

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

[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)

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

[70] 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).

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

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

[73] 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.

[74] 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).

[75] 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.

[76] "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).

[77] 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).

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

[79] "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

[80] 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).

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

[82] "Benefit-Cost Analysis for Proposed TIGER Projects" document shared with us by the Southern California Association of Governments, page 8.
[83] 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).
[85] US Department of Transportation, "Forecasting Traffic for Benefit Calculations" (October 23, 2013), http://www.fhwa.dot.gov/infrastructure/asstmgmt/primer06.cfm (accessed July 15, 2014).
[86] Caltrans has developed a BCA model--Cal B/C Corridor-- that is 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.
[87] See page 174 of Kenneth A. Small and Erik T. Verhoef, *The Economics of Urban Transportation* (New York, NY: Routledge, 2007).
[88] 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 "Area or facility type characteristics that are well suited to a network-based benefit-cost analysis include: Relatively dense roadway networks…[and]...Transportation 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).
[89] Todd Litman, "Faulty Assumptions In The TTI Urban Mobility Report," *Todd Litman's Blog, Planetizen*, October 2, 2011, http://www.planetizen.com/node/51680.
[90] Planning tools are used for a variety of purposes at Caltrans. We have profiled two cases in this report: Prop 1B and TIGER which used BCA. A third case would be interesting to explore in future research. Here we say just a few words on the evaluation of the 2015 California Transportation Plan (CTP). Page 72 of the California Interregional Blueprint Interim Report (http://www.dot.ca.gov/docs/CIB_Interim_Report_122012_FINAL.pdf) includes the quote: "Caltrans plans to use a macroeconomic model for the CTP 2040...The model will link with the CSTDM and economic forecasts to generate estimates of economic effects." In addition, Section 4 of this report provides a good summary of all models that will be used in evaluating CTP 2015. Related documentation is included in slides on the CTP 2015: http://www.dot.ca.gov/hq/tpp/offices/owd/academy_files/D6_session_2/Presentations/Wednesday/California_Transportation_Plan.pdf On Page 13 of this document it identifies TREDIS as the model used for analysis of macroeconomic impacts. Estimating these "macroeconomic impacts" is the goal of EIA, but BCA methods have a firmer foundation in economic theory.
[92] The following passage from the Caltrans webpage described 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 in fact 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.
[93] A study of merging these offices is a BCA in and of itself, which of course, we have not undertaken in this report.
[94] *Cal B/C Technical Supplement: Volume 3* (Sacramento, CA: California Department of Transportation, 2012).

Figure 1: The Transportation Planning Process

Source: Federal Highway Administration, 2007

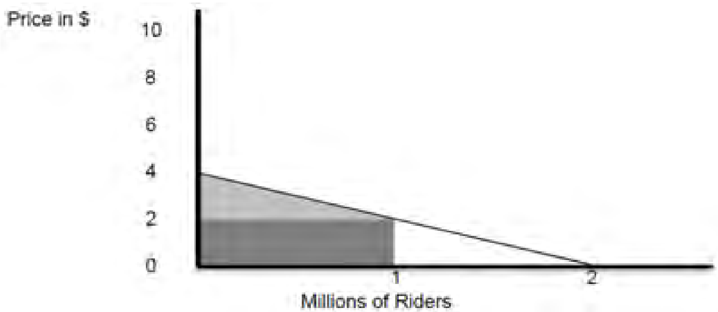

Figure 2: Demand Curve for Transit with a Price Elasticity of Demand of -1

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.

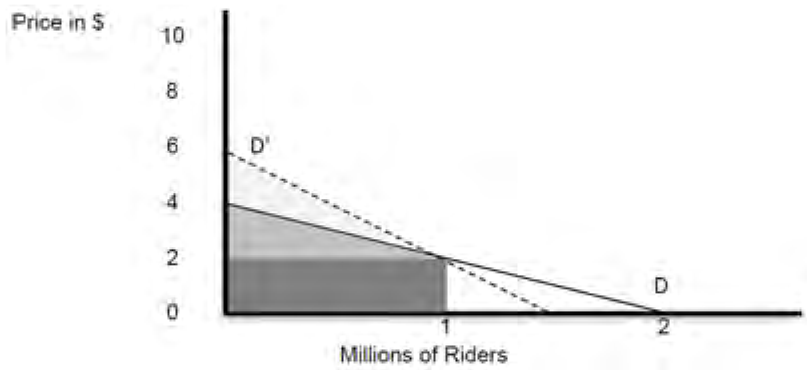

Figure 3: Demand Curve for Transit with a Price Elasticity of Demand of -1 and -0.5

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

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.

Prepare Model for Second Road

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

3

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

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

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

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

Source: Federal Highway Administration, 2007

Table 2: Calculating annualized NPV with NTD trip and cost data, and an assumed fare elasticity of -0.3

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.

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

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.

Table 4: Fare elasticity 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.

Table 5: Fare elasticity 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 6: Fare elasticity model, regression 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; standard errors are in parenthesis

Table 6: 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: Original results are from Table 2 of Erik Guerra, "Valuing Rail Transit: Comparing Capital and Operating Costs with Consumer Benefits." ***Transportation Research Record*** **2219 (2011): 50–58. *Values presented in annualized form.**