Cost/Benefit Analysis of Converting a Lane for Bus Rapid Transit—Phase II Evaluation and Methodology

DETAILS

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COST/BENEFIT ANALYSIS OF CONVERTING A LANE FOR BUS RAPID TRANSIT—PHASE II EVALUATION AND METHODOLOGY

This digest summarizes the results of NCHRP Project 20-65, Task 22, *Cost/Benefit Analysis of Converting a Lane for Bus Rapid Transit-Phase II Evaluation and Methodology.* The research was conducted by Jeffrey Ang-Olson, Principal, and Anjali Mahendra, Senior Associate, ICF International.

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SECTION 1 INTRODUCTION

Overview

Bus Rapid Transit (BRT) has emerged as a viable option to enhance transportation capacity and provide increased levels of mobility and accessibility. BRT systems vary from one application to another but all provide a higher level of service than traditional bus transportation. Service on BRT systems is generally faster than regular bus service because the buses make fewer stops and may run as often as comparable rail systems during peak travel times. BRT lines can transport large numbers of people efficiently and cost-effectively and can be an attractive way to get drivers out of their cars and onto transit.

BRT systems are characterized by a broad range of running ways which determine the speed and overall performance of the system. Table 1 shows the range of BRT facilities characterized by type of access control, ranging from grade-separated busways at one end of the spectrum to operation in mixed traffic at the other. BRT lanes that have a high degree of right-of-way segregation provide the fastest and most reliable BRT service and are most attractive for travelers. In addition to user benefits, they are likely to induce land and economic development benefits (Kittelson 2007). However, they cost more than BRT that operates in mixed traffic or reserved on-street bus lanes.

Levels of service vary for the different types of bus lanes on arterial streets. Bus lanes can help improve transit speed and reliability on urban streets. BRT lanes are most effective and reliable when the buses operate in conditions that are free from delays caused by other vehicles including autos and trucks. Separate bus lanes are also known to have a positive effect on ridership because they increase the visibility and identity of the BRT system. On an arterial street, bus lanes may operate in the same direction of general traffic (concurrent flow) or in the opposite direction (contraflow) along one-way streets.

While BRT in an exclusive ROW provides the highest level of service, such systems are often challenging to develop in urban areas. Yet BRT operating in mixed flow lanes may not be able to achieve the improvement in travel time and reliability necessary to attract significant new ridership. One solution is to convert a mixed flow arterial lane to exclusive BRT use. Such a conversion has pros and cons. While the exclusive bus lane helps to ensure a high transit level of service, the loss of capacity for mixed flow traffic could cause a significant increase in vehicle delay. This

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Table 1 Types of BRT facilities with level of access control.

Facility Type	Access Control	Examples
Busways		
Bus tunnel	Uninterrupted flow—full control of access	Boston, Seattle
Grade-separated busway	Uninterrupted flow—full control of access	Ottawa, Pittsburgh
At-grade busway	Partial control of access	Miami, Hartford, Los Angeles
Freeway lanes		
Concurrent flow lanes	Uninterrupted flow—full control of access	Ottawa, Phoenix
Contraflow lanes	Uninterrupted flow—full control of access	New Jersey approach to Lincoln Tunnel
Bus-only or bus priority ramps	Uninterrupted flow—full control of access	Los Angeles
Arterial streets		
Arterial median busway	Physically separated lanes w/in street ROW	Curitiba, Vancouver, Cleveland
Curb bus lane	Exclusive/semi-exclusive lanes	Rouen (France), Vancouver, Las Vegas
Dual curb lanes	Exclusive/semi-exclusive lanes	New York City (Madison Ave)
Interior bus lanes	Exclusive/semi-exclusive lanes	Boston
Median bus lane	Exclusive/semi-exclusive lanes	Cleveland
Contraflow bus lane	Exclusive/semi-exclusive lanes	Los Angeles, Pittsburgh
Bus-only street	Exclusive/semi-exclusive lanes	Portland (OR)
Queue jump/bypass lane	Mixed traffic operations	Leeds (UK), Vancouver
Transit signal priority	Mixed traffic operations	Los Angeles, Oakland

Source: *TCRP Report 118: Bus Rapid Transit Practitioner's Guide,* Transportation Research Board of the National Academies, 2007

study explores these trade-offs by performing a cost/benefit analysis for a hypothetical lane conversion BRT project.

Purpose of Project and Intended Audience

This research builds off NCHRP Project 20-65, Task 21, which focused on reviewing existing BRT projects and the methods used to evaluate their costs and benefits. NCHRP Project 20-65, Task 22 is intended to provide transportation agencies with a methodology and a guide for evaluating the potential benefits of converting a mixed-flow lane to exclusive BRT use.

The benefits and costs of converting a lane to a BRT lane will depend heavily on how such a project affects traffic speed, delay, and vehicle miles traveled, both in the mixed flow lanes and the BRT lane. The benefits will also depend on the extent to which improved transit service results in mode shift to transit. Thus, a critical section of the report is the description of the analytical methods and assumptions used for these calculations.

From a review of 11 models that can be used for cost/benefit analysis (see Appendix A), the research team found that most existing models do not allow consideration of both transit and auto modes at the same time in a single analysis. Therefore, analysts often need to apply alternative or off-model techniques to evaluate this special case.

This project required demonstration of a methodology that captures all the benefits (and disbenefits) across transit riders and auto drivers. The intended audience for this report includes transportation planners and modelers, consultants, professionals involved in economic, social, and environmental impact analysis, and others involved in evaluating projects, as well as decision makers who use the results of the analysis. The report is intended for those who have some knowledge of cost/benefit analysis and would like more information about how to apply it when converting a lane for the use of transit at a corridor, local, or regional scale.

How to Use the Illustrative Analysis

The illustrative analysis described in this report is intended as a reference for analysts considering the option of converting a mixed flow lane to a BRT lane. The hypothetical example involves an 8-mile long corridor with a BRT link to the central business district of a city, using assumptions for the peak hours and peak direction of traffic. It assumes a set of typical BRT features, including busway profiles, stations, vehicles, fare collection systems, and other safety and passenger information systems.

Accordingly, the costs of the hypothetical BRT system are calculated. The analysis assumes reasonable values for transit and auto modes shares, travel speeds, and vehicle occupancies on the corridor, and average values for traveler wage rates, auto operating costs, bus transit fares, and other conditions required to set up the scenario. These values can be altered to reflect locally-specific values. Net benefits and costs are calculated on an annual basis over the lifetime of the project. Also included is a sensitivity analysis that shows how the net benefits, costs, and final cost/benefit ratio of the project vary when the assumed values are altered. This report provides information on how the hypothetical analysis was conducted, thus providing a methodology that planners can use as a reference. Additionally, a sensitivity analysis shows the conditions under which converting an arterial lane to BRT may and may not be favorable.

A printout of the base case analysis spreadsheet is included as Appendix B.

SECTION 2 OVERVIEW OF COST/BENEFIT ANALYSIS

Cost/benefit analysis (also called benefit-cost analysis) is a method used to evaluate public expenditure decisions. The analysis involves identifying and quantifying all the benefits and costs that will accrue to society if a project is undertaken. Cost/benefit analysis thus helps determine the economically efficient investment alternative, i.e., one that maximizes the net benefit to society from an allocation of resources. For transportation projects, this involves estimating a dollar value for benefits to users of the facility, a value for social benefits, and comparing these benefits to project capital, operations, and maintenance costs. Total costs are subtracted from total benefits to calculate net benefit.

Purpose of Analysis and Steps

The purpose of a cost/benefit analysis is to determine the project alternative that would provide the greatest net benefit to the local area, region, or nation, by comparing the monetary value of benefits and costs of each alternative (U.S. GAO 2005). The benefits and costs will depend on the features of the project, estimates of future travel demand, and characteristics of the local area or region, such as the local economic and transportation conditions. Transportation agencies are typically required to do a detailed cost/benefit analysis to justify investment in a particular project. Such an analysis compares project alternatives with the "no build" base case, to determine a locally preferred alternative.

To enable comparison of alternatives, it is necessary to standardize the categories of benefits and costs that are considered and the methodology that is used to calculate them. Direct benefits to users of the transportation system include travel time savings, vehicle operating expenses and out-of-pocket expenses, and reduced crash costs. Other direct benefits can accrue to users and non-users, such as reductions in emissions, noise, and other environmental impacts. While these impacts can be relatively simple to estimate, much variation exists in how benefits are monetized. Indirect benefits can arise from increased economic development and land development; these are often difficult to estimate, and therefore are often omitted in transportation cost/benefit analyses. The costs against which these benefits are weighed are also similarly varied. The construction, operation, and maintenance costs of a project are relatively easier to estimate than the costs of traffic delays during construction or the costs of long-term environmental impacts.

The most critical component of a cost/benefit analysis for a BRT project is likely to be the estimation of impacts on vehicle delay and transit ridership. While the calculation of these impacts will differ with every project, it is possible to evaluate hypothetical projects using plausible ranges for key parameters (such as traffic volume and transit ridership) so as to illustrate how these parameters influence the outcome. The calculation of benefits is particularly important and will depend on assumptions about the study area of the project, the monetary values assumed for the benefits and costs, and the duration over which the different costs and benefits will occur (i.e., short term or long term). Costs and benefits are usually calculated cumulatively over a project period that represents some reasonable planning horizon, depending on the nature of the project; 10 to 30 years is most commonly used (ITE 2009).

Since benefits and costs often occur at different times over the lifespan of a project, they must be adjusted according to when they occur. Because many costs usually occur in the early stages of a project, while benefits are spread out over a number of years, discounting is used to bring all monetary streams (both costs and benefits) to the same year, i.e., usually the year in which the analysis is being done. Due to the time cost of money and the value placed on immediate consumption, future benefits and costs are worth less than those incurred immediately. To account for this, future benefits and costs are discounted and then summed to arrive at a present value. A project decision is then made by comparing the present value of the discounted stream of benefits to the present value of the discounted stream of costs. The discount rate is applied to the benefits and costs incurred in each year of the project's life cycle.

Cost/benefit analysis typically involves comparing project alternatives with a No-Build baseline scenario that assumes no action. The steps in conducting such an analysis include the following (ECONorthwest 2002):

1. Define the baseline and project scenarios in terms of facility features and operational characteristics
2. Set analysis period and define study area (single roadway segment or entire network)
3. Determine relevant categories of benefits and costs that will be measured or monetized in a way that avoids double-counting
4. Analyze changes in travel activity resulting from the project in terms of trips and vehicle miles traveled, by mode
5. Monetize travel activity impacts to estimate benefits and costs relative to the baseline scenario.
6. Decide on an appropriate discount rate and discount future steam of benefits and costs to present value
7. Estimate net benefits and cost/benefit ratios
8. Measure or discuss those project impacts that cannot be monetized due to uncertainties in monetary values or measurement
9. Conduct sensitivity analysis to assess changes in net benefits based on values of key input variables such as traffic volume
10. Evaluate and make recommendations to pursue project or not

Appropriate Measures for Cost/Benefit Analysis

There are several measures to compare benefits to costs in a cost/benefit analysis. The Federal Highway Administration recommends the use of either the Net Present Value (NPV) measure or the Benefit-Cost Ratio (BCR) to compare benefits to costs (FHWA 2003). These two most widely used measures have been used in the illustrative analysis in this project and are described herein.

NPV: All benefits and costs over the project's lifecycle are discounted to present values and the costs are subtracted from the benefits to obtain the NPV, which must be a positive number for the project to be justified. When multiple project alternatives exist, the alternative with the largest NPV of net benefits is typically the preferred alternative, though sometimes, other factors including project risks and funding availability may play a role in the selection of an alternative with a lower, positive NPV (FHWA 2003).

BCR: The BCR is a ratio where the present value of benefits (including negative benefits or disbenefits) is divided by the present value of the initial agency investment cost. When benefits exceed costs, the ratio is greater than 1 and implies that the project is worth pursuing.

Limitations of Cost/Benefit Analysis

Despite its many advantages, there are limitations to conducting a cost/benefit analysis in the context of converting a highway lane to a BRT lane. Transit projects often have several impacts that cannot be easily measured or expressed in dollars and are thus, omitted from the analysis. For example, future economic development impacts and spillover impacts in other jurisdictions are often not taken into account by an agency focusing only on local costs and benefits.

Additionally, the distribution of benefits may sometimes be as or more important than the actual values of calculated benefits. For example, transit projects often bring benefits by providing mobility to people with low incomes, disabilities, or with otherwise limited access to transportation options. The benefits to these groups may be as important to consider as travel time savings.

Another limitation is that the results of a cost/benefit analysis depend on assumptions for which justifiable alternative assumptions are always possible causing the final results to sometimes vary substantially. A sensitivity analysis must therefore always be done to illustrate the change in results with alternative values of inputs and assumptions.

SECTION 3 CATEGORIES OF BENEFITS AND COSTS CONSIDERED

This analysis includes the direct costs and benefits that will accrue to users of the corridor and to society at large. Commonly used measures of user benefit (or disbenefit) include changes in travel time, vehicle operating costs, fares for transit riders, and crash costs. The social benefits typically include reduction in damage costs caused by air pollutant emissions and changes in noise costs. Transit projects may also have indirect benefits that do not directly arise from travel activity but rather, arise from a redistribution of user benefits in the economy. The costs and benefits quantified in this analysis are listed in Table 2.

When enumerating benefits in a cost/benefit analysis framework, it is important to count only real increases in public welfare. Thus, reductions in travel time or crashes are counted as benefits because they are not offset by any losses elsewhere. The impact of construction on the local economy is not counted as a benefit because it does not change the underlying productivity of the local economy. Any increase in local economic activity would be considered a transfer, offset elsewhere by a reduction in economic activity due to the taxes necessary to fund the project. Similarly, the cost/benefit analysis does not explicitly count non-user benefits if they are assumed to be captured in the value of the user benefits. For example, the benefits to a business of reduced freight or commuter travel times are assumed to be captured in the commercial and passenger vehicle travel time benefits. Similarly, the increase in property values near BRT stations that may result from construction of a BRT project actually captures the benefit reaped from travel time savings to users and therefore, to avoid double-counting, must not be included in an analysis that already includes travel time savings.

Table 2 Categories of costs and benefits considered.

Benefits/Disbenefits	• Change in travel time for drivers, transit users • Change in vehicle operating costs for drivers, fares for transit users • Change in emissions of criteria pollutants and greenhouse gases • Change in crash costs
Costs	• Capital costs of materials, equipment, infrastructure construction, new buses • Operations and maintenance costs

Costs

Capital Costs

Capital costs include the one-time costs to the transit or funding agency of acquiring right-of way, constructing the BRT corridor and stations, procuring vehicles, and installing supporting systems such as fare collection, security, and passenger information systems. They include costs of design, engineering, and project management and exclude the out-year costs of reconstruction or replacement of facilities (ITE 2009).

Operation and Maintenance Costs

These are recurring costs related to the operations, maintenance, and administration of the BRT facility, stations, and service. Because these costs tend to rise over time, it is important to estimate them in constant or inflation-adjusted dollars. Since these costs are typically derived from historic data, they must be converted to current values (the research team reports costs in constant 2009 dollars using the Consumer Price Index for urban consumers from the Bureau of Labor Statistics).

Benefits and Disbenefits

The benefits of the BRT project can be categorized as direct and indirect. Direct benefits (and disbenefits) include changes in travel time, safety, and vehicle operating costs, as well as direct environmental impacts such as savings in costs associated with emissions. Indirect benefits can include benefits from increased economic activity, business agglomeration, higher property values resulting from transit investment, growth in employment, and savings to the transit agency from savings in transit operating costs.

Direct User Benefits or Disbenefits

Travel time changes: Travel time savings would arise from a project that converts an arterial lane to BRT due to the reduction in travel time for transit passengers who originally used the existing bus service. Auto drivers would also likely see a change in travel time due to a reduction in arterial capacity and also a reduction in traffic volume (due to some auto mode shift to transit). Travel time benefits are valued in terms of the hourly wage rate, under the assumption that time not spent in travel can be used for other activities having economic value.

Travel cost savings: Savings or increases in travel costs include out-of pocket vehicle operating and ownership costs and are directly related to the change in the number of vehicle miles traveled by auto drivers. Vehicle operating costs include the costs of fuel, oil, maintenance, insurance, and depreciation associated with vehicle wear. Travel costs also include the fares paid by transit riders on the existing bus service and the new BRT service.

Crash costs: If some auto drivers switch their travel mode to the new BRT service, costs related to vehicle crashes will decline. While some part of crash costs are perceived by travelers and included in their calculation of travel cost through insurance, the costs to other drivers and the costs to state and municipal governments of responding to crashes are typically not perceived by travelers when making travel decisions and must be calculated separately (ECONorthwest 2002).

Direct Social Benefits

Environmental impacts or externalities, including savings in emissions damage costs and noise costs experienced by those not using the BRT facility, are considered the direct social benefits of the project.

Emission reduction: The change in emissions cost damages are directly related to the change in the number of trips and vehicle miles traveled by auto drivers. To the extent that the new BRT corridor can encourage drivers to take transit, emissions are likely to decline. However, a BRT conversion could have a negative impact on total vehicle emissions if congestion on the remaining mixed-flow travel lanes increases significantly.

Noise Reduction: Motor vehicle noise imposes an economic cost on those living or working in close proximity to the facility. For this hypothetical project, noise impacts are likely to be insignificant because existing bus service is being replaced by a BRT service. Therefore, the research team ignores noise costs in this analysis.

Indirect Benefits

A BRT project is likely to have other benefits that are not directly related to the amount of travel on the facility, but arise as an indirect effect. These could include the following:

- Land development impacts involving a change in the use and value of properties located near the new BRT corridor.
- Savings in parking costs for drivers who switch modes from auto to the new BRT service and/or reduction in the need to provide vehicle parking in the CBD.
- Savings in reliability that would accrue to BRT riders.
- Economic impacts from enhanced accessibility to employment.
- Savings in operating costs for the transit agency due to the higher efficiency of the BRT service.

Quantification of indirect benefits is challenging for a cost/benefit analysis focused on a single BRT project. In this study, the research team does not quantify indirect benefits of the BRT project for two reasons. First, it would be difficult to isolate the impacts of the BRT project alone since these indirect benefits are influenced by several external factors. Second, the business and employment benefits are typically not included in project-level analyses since they are assumed to be transfers from other regions or from parts of the same region.

SECTION 4 ILLUSTRATIVE ANALYSIS

The most critical component of a cost/benefit analysis for a BRT project is the estimation of impacts on vehicle delay and transit ridership. While the calculation of these impacts will differ with every project, it is possible to evaluate hypothetical projects using plausible ranges for key parameters so as to illustrate how these parameters influence the outcome.

In this section we describe a cost/benefit analysis for a hypothetical BRT project to illustrate how the benefits of such a project are affected by key parameters such as traffic volume, change in travel time, and baseline mode shares. The results of this analysis are expected to help transportation agencies understand the types of conditions under which converting a lane to a BRT lane is likely or not likely to have net benefits.

Methodology

Our analysis compares a No Build baseline alternative with a BRT alternative that involves taking a mixed flow lane from a three-lane arterial and using it for dedicated BRT. The analysis involves defining a number of assumptions regarding the physical characteristics of the facility, its traffic controls, traffic volume, and baseline travel characteristics. We consider ranges of values for several key variables that would cover the range of conditions likely to be experienced by transportation agencies.

We begin with an assumption for baseline daily person throughput—equivalent to the number of persons traveling in the corridor by automobile or bus service. From this assumption we calculate peak hour and peak direction vehicle volume and transit riders. The total person throughput is assumed to remain constant. Benefits and costs accrue due to changes in travel time and mode shift.

We use the Highway Capacity Software to calculate automobile speed and delay for the No Build and BRT project, for each combination of input variables. To determine the likely change in transit ridership due to improved transit service, we used elasticity values from the literature to estimate the following:

- Ridership increase from travel time savings: range assumed is –0.5 to –0.7 for work trips and lower for general trips (Kittelson 2007, Cambridge Systematics 2009). To add in the effect of increased reliability, –0.1 may be added (Cambridge Systematics 2009). The research team used –0.6 in this analysis.
- Ridership increase from reduced transit headways (increased frequency): range assumed is –0.4 to –0.5 (TRB, 2005; Kittelson 2007). The research team used –0.4 in this analysis.

These additional riders are assumed to shift their travel mode from auto to transit, thus keeping the total number of travelers in the corridor the same before and after the BRT project. Based on the increase in transit ridership, the research team calculated the change in traffic volumes on the remaining general purpose lanes and the corresponding change in speed using the HCS. The research team also estimated the number of additional buses that would be required to accommodate the increased ridership from the mode shift. Using assumptions for transit and auto speeds before and after the BRT project, the research team estimated the change in travel time in vehicle hours traveled (VHT) for drivers and transit users, comparing No Build with a BRT Dedicated Lane Alternative. We multiplied that change by value of time parameters to monetize the delay benefit/disbenefit.

Based on the change in ridership and the number of auto drivers that shift to transit, we calculate the change in vehicle miles traveled (VMT) for the No Build case and the BRT case. This is used to estimate the changes in vehicle operating costs for users. Estimates of change in VMT were also used to calculate change in emissions damage costs and crash costs.

The research team used a discount rate of 7% to discount the costs and future stream of benefits, per guidance from the Office of Management and Budget (OMB 2003). The OMB guidance states that a real discount rate of 7% should be used as a discount rate "as a default position." The 7% rate is an estimate of the average before-tax rate of return to private capital in the U.S. economy. The guidance also recommends that analysts use other discount rates to show the sensitivity of the estimates to the discount rate assumption. For instance, lower discount rates are appropriate in cases where the project or policy does not primarily impact the allocation of capital, rather it directly affects private consumption. The alternative most often used is sometimes called the "social rate of time preference." This simply means the rate at which society discounts future consumption flows to their present value and has averaged around 3% in real terms on a pre-tax basis. The OMB therefore recommends providing estimates of net benefits using both 3% and 7% discount rates; the research team applied a 3% discount rate as part of the sensitivity analysis. Table 3 lists some of the fixed assumptions, variables, and calculated parameters in the analysis.

Finally, the research team conducted a sensitivity analysis by altering the values of key variables, including mode shares, average daily traffic, BRT headway, and BRT speed. Altering the user costs for autos and transit will also lead to a change in benefits; however, the research team did not include this in the sensitivity analysis. Fares on transit were assumed to be the same in the existing bus service and in the new BRT service.

Table 3 Assumptions, variables, and calculated parameters.

Fixed Assumptions	Variables	Calculated Parameters (both mixed flow and BRT lanes)
Capital, operating, and maintenance costs	Total auto and transit travel demand in a corridor (persons)	Average vehicle miles traveled (VMT)
Urban Street Class III	Mode shares	Vehicle delay, LOS
Discount rate	User costs for autos and transit	Person delay
Number of lanes	Average BRT speed	Average auto speed
Signal timing and spacing	Average BRT headway	Vehicle throughput
Average vehicle occupancy (autos and transit)		Person throughput
Transit ridership growth rate		
Auto ridership growth rate		
Transit ridership elasticity wrt travel time		
Transit ridership elasticity wrt bus frequency		
Average wage rates		

To assess the costs, the research team gathered data regarding assumptions for BRT costs as a function of physical characteristics of the facility and stations, vehicle type, and operational characteristics (Kittelson 2007). All costs and benefits are reported in constant 2009 dollars.

Assumptions and Sources for Data Inputs

Overall Assumptions

The cost/benefit analysis described in this report is for an urban BRT line created on a three-lane arterial by taking one lane, leaving two general purpose lanes in the corridor. The analysis considers traffic volumes and speeds in the peak periods and peak direction of traffic. The peak traffic period is assumed to be 6 hours in duration, including three AM and three PM hours. The percentage of traffic volume assumed to be in a single peak hour is 10% of the average annual daily traffic (AADT), with 60% of the peak volume assumed to be in the peak direction. Because we are considering a BRT line into the CBD, it is reasonable to assume that there is minimal traffic congestion and work travel in the reverse direction. Therefore, we do not calculate benefits in the reverse commute direction. The research team also assumed that benefits would be minimal during off-peak periods, and did not calculate any off-peak benefits. The research team assumed benefits occur for 300 days per year, based on a range of 250–365 as seen in the literature.

The analysis also assumes that all existing transit riders will transfer to the new BRT service, implying that all existing transit buses on the corridor will be replaced by BRT. For the Base Case analysis, the pre-project auto and transit mode shares in the corridor are assumed to be 85% and 15%, respectively. Examples of pre-project mode shares on arterial BRT corridors are difficult to find, but we believe this assumption for mode shares in corridors where BRT is being considered is likely to be conservative. For instance, the feasibility study for the proposed BRT corridor on Geary Boulevard in San Francisco estimates that buses serve as much as 25% of the trips made in the Geary corridor during the PM peak hour (SFCTA, 2007).

Arterial Speed and Volume Assumptions

The Highway Capacity Software, which applies methods defined in the Highway Capacity Manual (Transportation Research Board 2000), was used to estimate the relationship between hourly traffic volume and speed. As defined in the Highway Capacity Manual, the research team selected the Class III arterial for the analysis.

The research team made assumptions for roadway characteristics, signal characteristics, and traffic characteristics. Road characteristics include arterial class, free flow speed, number of through lanes, and median treatment. Signal characteristics include signal density, vehicle arrival type, signal type, signal cycle length, and green-to-cycle length ratio. Traffic

Table 4 Input assumptions for HCS arterial planning analysis.

Urban Street Class	III
Street Type	Urban Principal Arterial Intermediate Minor Arterial
Free Flow Speed (mph)	35
Left-Turn Bays	Yes
Median	Yes
Segment Length (mile)	8
Signals per mile	6
Arrival Type	5
Operational Characteristics	A highly favorable progression on an urban street, which receives high priority in signal timing.
Signal Type	Actuated
Cycle Length (sec)	80
Effective Green Ratio	0.5
Directional Distribution Factor	0.5
Adjusted Saturation Flow Rate (passenger cars per hour of green per lane)	1750
Planning Analysis Hour Factor	0.1
Peak Hour Factor	0.9
% turns from Exclusive Lanes	20

characteristics include the directional distribution factor, adjusted saturation flow rate, planning analysis hour factor, peak hour factor, and percent turns from exclusive lanes.

The input values for these characteristics were determined based on the range of values suggested in the Highway Capacity Manual, as well as professional experience and observation. The average travel speed during the peak hour was calculated based on the specified volume and road characteristics. Table 4 lists the assumptions used in the HCS analysis. The analysis was done for an 8-mile segment of the corridor; both transit riders and auto drivers are assumed to travel this length in a single trip.

Capital Costs

TCRP Report 118 presents a range of capital costs for BRT systems, depending on facility type, station type, vehicle type, fare collection system, and other information and safety systems. We used this source to estimate capital costs for the hypothetical example. For the illustrative analysis, the research team assumed the scenario of a lane within the existing roadway profile, at-grade typical stations (enhanced), standard vehicles, off-board fare collection, the availability of traffic signal priority, passenger on-board information, and other standard ITS, safety, and security systems. Table 5 shows the assumptions for capital costs that were used in the analysis, along with the full range of costs for different BRT features. Lane construction costs are for unfinished pavements and exclude right-of-way acquisition costs, but include engineering and design costs. Capital costs are assumed to be spent over 2 years, starting in 2011.

BRT Operations and Maintenance Costs

Annual BRT operation and maintenance costs were assumed to be $10,000 per lane mile (in 2004 dollars), assuming minor reconfiguration or widening of the arterial, based on figures provided in *TCRP Report 118.* These were converted to constant 2009 dollars for use in the analysis.

Table 5 Capital cost assumptions.

Capital Cost Assumptions	Value ($)	Notes/Units
Lane within existing roadway profile	2,700,000	Cost per lane mile
At-grade station with enhancements	30,000	per station
New Articulated Vehicles	675,000	average per vehicle
On-board fare collection	17,500	average per vehicle
Traffic Signal Priority	30,000	per intersection
Passenger on-board information	4,000	per vehicle
Other (ITS, safety, security systems)	90,000	70,000–120,000 per vehicle, depending on features

Source: *TCRP Report 118: BRT Practitioner's Guide,* 2007
Notes: All component costs reported above are in 2004 dollars and were converted to constant 2009 dollars for use in the analysis.

BRT Operational Characteristics

The results of the cost/benefit analysis are highly dependent on how the project changes travel time and wait time for transit riders. Numerous existing BRT systems have demonstrated substantial reductions in travel time and headways compared to conventional bus service. For the purposes of the base case example, the research team relied on the average bus speeds presented in the FTA's *Characteristics of Bus Rapid Transit for Decision-Making* (2009). We assume an average stop spacing of 0.2 miles and average dwell time of 30 seconds. In this situation, bus speeds on general purpose traffic lanes (No Build alternative) are estimated to be 7 mph. Bus speeds on dedicated arterial street bus lanes (BRT alternative) are estimated to be 11 mph. This reflects a 36% improvement in transit travel time.

The research team assumed an average bus headway of 10 minutes under the No Build alternative. Using 60-foot articulated buses with a maximum capacity of 80 passengers, this headway implies a maximum transit throughput of 480 riders per hour in the peak direction. For the BRT alternative, the research team assumed an average bus headway of 6 minutes, or a maximum transit throughput of 800 riders per hour in the peak direction. This capacity is sufficient to accommodate the transit demand under all the BRT scenarios analyzed in this report.

Value of Travel Time

The research team assumed value of time estimates of 50% of wage rate for in-vehicle time and 100% of wage rate for access, waiting, and transfer time (ECONorthwest 2002). The average wage rate in constant 2009 dollars was assumed to be $26.29 per hour for transit riders and auto drivers (U.S. DOT 2003).

Note that auto drivers who shift to BRT are likely to incur an *increase* in travel time, and thus an increase in travel costs. Therefore, these travelers would experience a net travel time disbenefit. Consistent with other literature, the travel time disbenefit to auto drivers is not assigned a negative cost, but rather is assumed to be zero. This is because, while auto drivers diverting to BRT experience this travel time disbenefit, it is clear there must be benefits other than travel time that cause drivers to switch to BRT. These can include benefits such as the convenience of not driving, increased productivity due to the use of travel time for doing other work, less stress, and so on. Since these benefits cannot be captured in this analysis, it is more realistic to assume a zero value for the change in travel time costs rather than a negative value.

Auto Operating Costs

These costs include ownership costs and were assumed to be 54 cents per mile using figures from the American Automobile Association (AAA 2009) that include costs of fuel, maintenance, tires, insurance, license, registration and taxes, depreciation, and financing and are based on an assumed 15,000 miles driven per year.

Transit Fare

The research team assumed the average adult single trip bus fare to be $1.30, based on statistics available from the American Public Transport Association (APTA 2007).

Vehicle Occupancies

Average auto occupancy during peak hours was assumed to be 1.2 and transit occupancy was assumed to be 80 passengers for both standard existing articulated buses and BRT buses.

Emissions Rates and Emissions Damage Costs

Emissions rates for light duty vehicles were available from the EPA (2005) and damage costs were EPA figures assumed in the National Highway Traffic Safety Administration's (NHTSA) *Corporate Average Fuel Economy for MY 2012-MY 2016, Passenger Cars and Light Trucks* (NHTSA 2009), reported in 2007 dollars (see Table 6). These costs were converted to constant 2009 dollars for calculating the cost/benefit ratio. The change in emissions for buses has not been taken into account. While the emissions per bus-mile will remain constant, bus emissions are likely to be higher in the BRT case

Table 6 Emission rates and emission damage costs assumed.

	Emission Rates (grams/mile)	Emissions Damage Costs ($/ton)
VOCs	1.36	1,300
NOx	0.95	5,300
SOx	0.008	31,000
Particulates	0.01	290,000
CO_2	369	20

because bus VMT will be higher. However, this increase in bus emissions due to increase frequency has a negligible effect on the net benefits of the project.

Crash Costs

Crash costs per vehicle mile traveled for light duty vehicles was available from the EPA and was assumed to be $0.023, as referenced by NHTSA (NHTSA 2009) and reported in 2007 dollars. These costs were converted to constant 2009 dollars for calculating the cost/benefit ratio.

Results

The research team calculated costs and benefits for all categories over a period of 22 years, assuming initial construction costs over a period of 2 years and discounting future benefits and Operation and Maintenance (O&M) costs over a period of 20 years after construction.

Table 7 shows the total capital costs under various cost categories and the O&M costs incurred every year over the life of the project in constant 2009 dollars. Costs of infrastructure and station construction, on-board fare collection, vehicles, traffic signal priority, as well as other on-board information, safety, and security systems constitute the total capital costs. The research team estimated these costs based on the assumption of a bus lane on an urban arterial constructed within the roadway profile. The largest proportion of costs (60%) is for construction of a BRT lane within the existing right-of-way, followed by purchase of new articulated buses (28%). Our analysis for the hypothetical case shows that fifteen new buses would be required to accommodate the increased ridership. The increase in ridership is within the bounds of the maximum peak hour peak direction BRT capacity in the assumed corridor.

Table 8 shows the different categories of benefits (and disbenefits) that accrue to users and nonusers of the arterial under in the base case scenario (40,000 daily person throughput). A project of this nature that involves reducing capacity for autos while creating a BRT lane is unique from other stand-alone transit projects in that it results in a substantial disbenefit to auto users, while bringing substantial benefits to transit riders. This reduces the net user benefit in terms of travel time and out-of pocket cost savings that can be expected from the project. Based on the research team's assumptions, the analysis shows that the benefits to transit riders exceed the disbenefits to auto drivers by a factor of approximately 3.5. Smaller savings occur due to the reduction in crash costs and emissions, which depend on the reduction in VMT by auto drivers diverting to BRT. The sensitivity analysis in the next section shows how these benefits vary under alternate assumptions.

Table 7 Costs of converting an arterial lane to a BRT lane for hypothetical corridor*.

Capital Costs	Constant 2009 $
Construction of lane within existing roadway profile for 8-mile corridor[1]	$24,531,494
At-grade stations[2]	$1,362,861
Articulated buses[3]	$11,499,138
On-board fare collection system[3]	$298,126
Traffic Signal Priority[4]	$1,635,433
Passenger on-board information[3]	$68,143
Other (ITS, safety, security systems)[3]	$1,533,218
Capital costs assumed over two years	**$40,928,413**
Annual O&M Costs[5]	**$90,857**

*Costs above based on unit costs in Table 5, converted to constant 2009 dollars.

1: Costs are for unfinished pavement, exclude right of way costs, and include engineering and design costs.

2: Total costs for 40 stations, assuming 5 stations per mile on 8-mile corridor.

3: Total costs for 15 vehicles.

4: Total costs for traffic signal priority on 48 intersections, assuming 6 intersections per mile on 8-mile corridor.

5: Includes costs of street lighting and routine maintenance.

Table 8 Annual peak period benefits of converting an arterial lane to BRT (40,000 daily person throughput).

Annual Peak Period Benefits	Constant 2009 $
Benefits for transit riders continuing to use transit	$4,107,426
Disbenefits for auto drivers continuing to drive	−$1,189,190
Savings in crash costs	$425,733
Savings in emissions damage costs	$321,014
Total Annual Peak Period (AM and PM) Benefits	**$3,664,982**

The above benefits were estimated for each of 20 years that the BRT project is expected to be in operation. The results of the analysis show that under our base case assumptions, converting an arterial lane to a BRT lane is likely to show a favorable cost/benefit ratio or a positive NPV, because the net benefits exceed the total costs of providing the BRT system. However, the results are highly sensitive to the assumptions for pre-project traffic volume and mode share, as well as the travel time and frequency improvements provided by the BRT system.

Table 9 shows the results for four values of daily person throughput, ranging from 20,000 to 50,000. These results illustrate that while the project shows a positive net benefit at 40,000 daily person throughput, the net benefits become negative at lower and higher volumes.

- At lower volumes (20,000 and 30,000), the number of transit riders is too low to generate sufficient travel time benefits to offset the project costs and the (small) travel time disbenefit experienced by auto drivers.
- At a daily throughput of 50,000 persons, the travel time benefit to transit riders is large, but the automobile volume is large enough that going from three mixed lanes to two results in a significant drop in automobile speed. The value of the travel time disbenefit experienced by auto drivers is nearly equivalent to the value of the benefit to transit riders. Thus, the net benefits are significantly less than project costs.

The next section presents a sensitivity analysis to better understand the effect of key variables on cost/benefit analysis results.

SECTION 5 SENSITIVITY ANALYSIS OF COST/BENEFIT RATIO

This section describes the results of a sensitivity analysis to show the effects of different assumptions for the following four key variables:

- Pre-project auto-transit mode share,
- Corridor length,
- Discount rate, and
- BRT speed improvement.

Figure 1 shows the effect of pre-project mode share on the resulting cost/benefit ratio for four levels of daily person throughput. All other variables are unchanged from the scenario presented in Section 4. The solid line with diamonds is the base case scenario presented in Section 4.

The dotted line with squares shows that a higher pre-project transit mode share (20%) leads to a favorable cost/benefit ratio for values of person throughput greater than 25,000. At very high levels of throughput (50,000 and more), the number of transit riders in the No Build alternative is too large to be served under our assumption of 60-foot articulated buses with 10 minute headways.

The dashed line with triangles shows that a lower pre-project transit mode share (10%) always results in a cost/benefit ratio less than one. In these cases, the number of transit riders is too small to generate travel time benefits sufficient to offset the project costs and the (small) travel time disbenefit experienced by auto drivers.

Figure 2 shows that the cost/benefit ratio is fairly constant in relation to corridor length. These calculations assume that all auto and transit users travel the

Table 9 Base case results for different values of passenger throughput.

Key Assumptions: Discount rate = 7%
BRT Speed = 11 mph; No Build Bus Speed = 7 mph
BRT Headway = 6 min; No Build Bus Headway = 10 min
Pre-Project Mode Share: Auto = 85%; Transit = 15%

	Peak-Hour Peak-Direction Auto Volume		Peak-Hour Peak-Direction Transit Riders			
Daily Person Throughput	No Build	BRT Project	No Build	BRT Project	NPV of Net Benefits (million)	B/C Ratio
20,000	850	772	180	273	−$13.7	0.6
30,000	1,275	1,159	270	410	−$3.3	0.9
40,000	1,700	1,545	360	546	$2.4	1.1
50,000	2,125	1,931	450	683	−$11.6	0.7

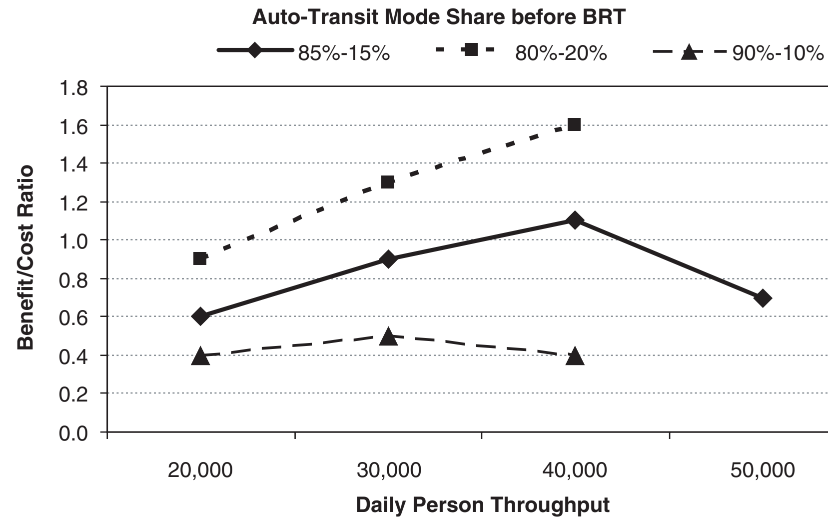

Figure 1 Sensitivity analysis for values of pre-project auto-transit mode share.

full length of the corridor, and all other variables are unchanged from the scenario presented in Section 4. Most of the costs and benefits are directly proportional to the corridor length, so the ratio does not change significantly. The disbenefit of transit wait time does not vary with corridor length, and its contribution to the total net benefit diminishes with trip length. This leads to a slight increase in the cost/benefit ratio for longer trips. At a corridor length of 17 miles, the cost/benefit ratio is 1.22.

Table 10 shows the results using a discount rate of 3% compared to 7%. Because most of the costs occur in the first 2 years while the benefits are spread over the subsequent 20 years, a lower discount rate has the effect of maintaining higher benefits relative to costs. Holding all other variables unchanged from the scenario presented in Section 4, these results show that, with a 3% discount rate, the hypothetical BRT project would achieve a positive net benefit if the daily person throughput is 30,000, 40,000, or 50,000.

Table 11 shows results for alternative values of BRT average speed. The base case analysis presented in Section 4 assumed a BRT speed of 11 mph, which results in a 36% reduction in transit travel time compared to the No Build alternative (with a bus speed of 7 mph).

If the BRT average speed was only 9 mph, resulting in a 22% transit travel time reduction, total costs exceed total benefits for all values of throughput (Cost/Benefit ratio is always less than 1.0). If the BRT average speed were 13 mph, resulting in a 46% transit travel time reduction, the project produces positive net benefits for a range of throughput values (30,000 to 50,000).

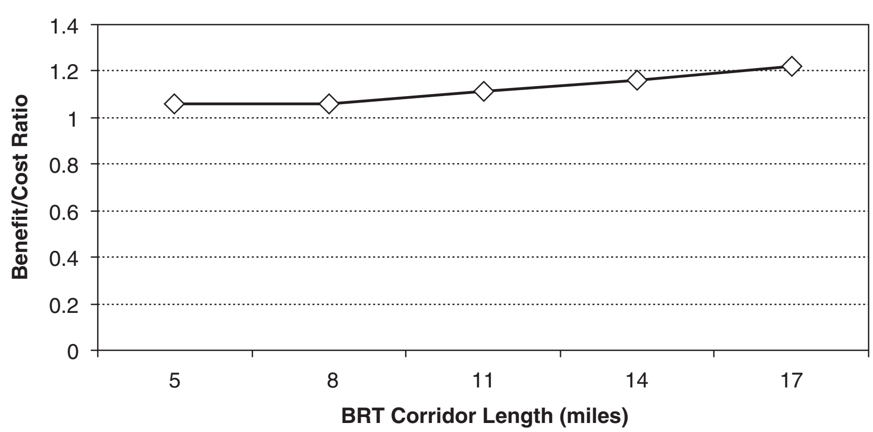

Figure 2 Sensitivity analysis for values of corridor length.

Table 10 Sensitivity analysis for alternative discount rate.

Key Assumptions: BRT Speed = 11 mph; No Build Bus Speed = 7 mph
BRT Headway = 6 min; No Build Bus Headway = 10 min
Pre-Project Mode Share: Auto = 85%; Transit = 15%

	7% Discount Rate		3% Discount Rate	
Daily Person Throughput	NPV of Net Benefits (million)	C/B Ratio	NPV of Net Benefits (million)	C/B Ratio
20,000	–$13.7	0.6	–$2.9	0.9
30,000	–$3.3	0.9	$13.2	1.3
40,000	$2.4	1.1	$22.0	1.5
50,000	–$11.6	0.7	$0.3	1.0

Figure 3 shows these results graphically. This analysis illustrates the importance of transit travel time savings to the calculation of BRT net benefits.

SECTION 6 CONCLUSIONS

This analysis of a hypothetical project shows that converting an arterial traffic lane for BRT can result in positive net benefits under certain conditions. The analysis also shows that the cost/benefit ratio and net benefits of this project are highly sensitive to the input assumptions. The net benefits expected from a BRT project are a function of multiple variables, including the following:

- Total corridor person throughput,
- Pre-project mode share,
- BRT travel time savings, and
- Discount rate.

There are trade-offs between these variables that affect the estimated net benefits. For instance, a higher than average BRT speed may result in a favorable cost/benefit ratio even with relatively lower passenger throughput, but if transit mode share is low, even a high BRT speed may not result in a favorable project. Table 12 summarizes the effect of the above key input variables that have a strong effect on the cost/benefit ratio, highlighting the conditions under which the ratio is likely to be greater than one.

As may be expected, the best corridors for converting a lane for BRT are those with relatively high person throughput (at least 40,000 per day) and relatively high pre-project transit mode share (at least 15%). In corridors with person throughput of 20,000 or less, or with a pre-project transit mode share of 10% or less, converting a lane to BRT is unlikely to result in positive net benefits.

Table 11 Sensitivity analysis for values of BRT speed.

Key Assumptions: Discount rate = 7%
No Build Bus Speed = 7 mph
BRT Headway = 6 min; No Build Bus Headway = 10 min
Pre-Project Mode Share: Auto = 85%; Transit = 15%

	BRT Speed = 11 mph (36% travel time reduction)		BRT Speed = 9 mph (22% travel time reduction)		BRT Speed = 13 mph (46% travel time reduction)	
Daily Person Throughput	Net Benefits (million)	C/B Ratio	Net Benefits (million)	C/B Ratio	Net Benefits (million)	C/B Ratio
20,000	–$13.7	0.6	–$22.0	0.4	–$7.5	0.8
30,000	–$3.3	0.9	–$16.4	0.6	$5.3	1.1
40,000	$2.4	1.1	–$15.3	0.6	$14.0	1.4
50,000	–$11.6	0.7	–$50.6	–0.3	$10.3	1.3

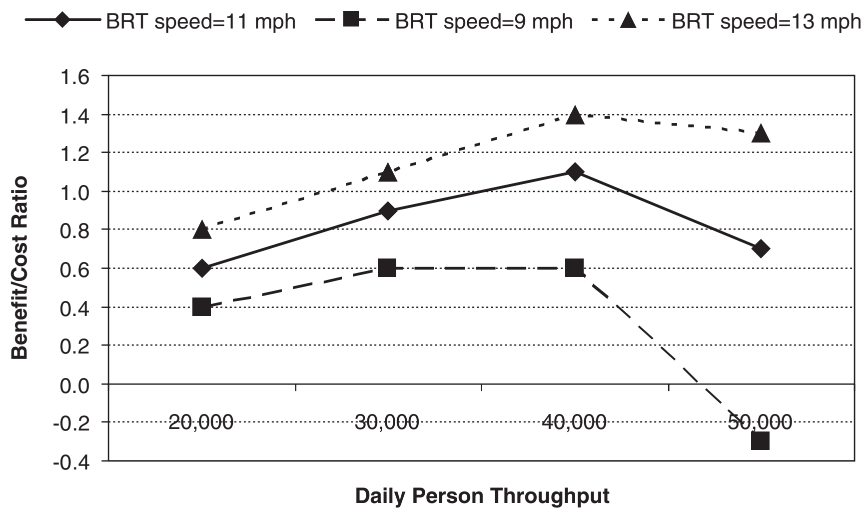

Figure 3 Sensitivity analysis for values of BRT speed.

Table 12 Conditions resulting in favorable cost/benefit ratio.

Variables	Daily Person Throughput	Cost/Benefit Ratio >1[1]
BRT Average Speed[2]		
9 mph (22% travel time reduction)	20,000	No
	30,000	No
	40,000	No
	50,000	No
11 mph (36% travel time reduction)	20,000	No
	30,000	No
	40,000	**Yes**
	50,000	No
13 mph (46% travel time reduction)	20,000	No
	30,000	**Yes**
	40,000	**Yes**
	50,000	**Yes**
Auto-Transit Mode Share Pre-Project[3]		
80%–20%	20,000	No
	30,000	**Yes**
	40,000	**Yes**
85%–15%	20,000	No
	30,000	No
	40,000	**Yes**
90%–10%	20,000	No
	30,000	No
	40,000	No
BRT Corridor Length[4]		
5 miles	40,000	**Yes**
8 miles	40,000	**Yes**
11 miles	40,000	**Yes**
14 miles	40,000	**Yes**
17 miles	40,000	**Yes**

Note 1: At 7% discount rate
Note 2: Assumes base case transit speed of 7 mph and auto-transit mode share (pre-project) of 85%–15%
Note 3: Assumes average BRT speed of 11 mph
Note 4: Assumes average BRT speed of 11 mph and auto-transit mode share (pre-project) of 85%–15%

The travel time savings for transit riders is a key factor driving the net benefits of a BRT lane conversion project. When new BRT service improves transit travel time by 40% or more, converting a lane for BRT is likely to product positive net benefits under a range of throughput values. Conversely, if BRT improves transit travel time by 20% or less, a project is unlikely to result in positive net benefits.

The length of the corridor does not make a significant difference to the resulting cost/benefit ratio. In the hypothetical example considered in this study, a relatively high person throughput of 40,000 per day is likely to result in positive net benefits, regardless of corridor length.

It should be noted that some benefits of a BRT project were not incorporated into this analysis because they are difficult to quantify. These include indirect positive impacts on land and economic development and savings associated with use and supply of parking for auto drivers. If these types of benefits were included, more of the scenarios analyzed in this study would produce a favorable cost/benefit ratio.

While cost/benefit analysis is a useful tool for public investment decisions, this study also highlights some of its shortcomings. The fact that the results are so sensitive to multiple input variables makes it challenging to draw conclusions about which types of projects are the best public investments. Although the research conducted a sensitivity analysis for a number of these input variables, there are many more variables that were not tested. Some of these other variables could significantly change the results if they differ from our assumptions. Thus, it is important to recognize cost/benefit analysis as just one tool to use in transportation decision making, to be complemented with other analyses and decision-making criteria.

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APPENDIX A: REVIEW OF RELEVANT COST/BENEFIT ANALYSIS MODELS

The research team reviewed 11 models that are used by agencies to conduct cost/benefit analyses for transportation projects.

1. California Life-Cycle Cost/benefit Analysis Model (Cal-B/C)
2. Highway Economic Requirements System for State Use (HERS-ST)
3. Transit Economic Requirements Model (TERM)
4. Florida Interstate Highway System: Multi-Modal Corridor Level of Service Analysis (MMCLOS)
5. StratBENCOST: Strategic Decision Support Tool for Highway Planning and Budgeting
6. MicroBENCOST
7. STEAM: Surface Transportation Efficiency Analysis Model
8. SPASM: Sketch Planning Analysis Spreadsheet Model
9. NET_BC
10. BCA.Net
11. IMPACTS

Summary

- Models either fall in the category of sketch-planning models or network-based models. Sketch-planning models are typically used to analyze a single corridor without considering impacts beyond the immediate project area; e.g., Cal B/C, SPASM and IMPACTS. Network-based models evaluate benefits and costs for the entire highway network, using outputs from a network travel demand model; e.g., HERS (national) and HERS-ST (state version), NET_BC, StratBENCOST, and STEAM. For our purpose, a framework that leads to the development of a sketch planning model is preferable since such models are more user-friendly, adaptable across agencies, and can be easily updated.
- Most existing models do not allow consideration of both transit and highway modes; the subset of models that can thus be used for analyzing conversion of a highway lane a BRT lanes is thus very small. STEAM, Cal-B/C, SPASM, and IMPACTS are the four models that allow this. Of these, the latter three are the more easily usable spreadsheet-based models that can inform the development of a framework. Cal-B/C is the most recent of these, although it is only applicable for California.
- Many of the models use economic values from very old data sources that have not been updated. Considering that about 60–80% of user benefits are due to travel time savings, the most recent data sources and methodologies for calculating value of time parameters must be used. Cal B/C is the most recent model in the list; however the parameters used are specific to California.
- Several existing models use default parameters from old sources, and user editing of parameters is often not available; if it is, it is difficult or not recommended because of complex relationships embedded in the model as a black box. Spreadsheet-based sketch planning models are more transparent and flexible because the user can enter all the input parameters; however, they can be limited in cases where detailed analysis is required and where impacts of improvements on one facility or on other parallel or surrounding facilities must be assessed.
- Benefit and cost categories are mostly common across models. Benefits typically include direct user benefits in the form of travel time savings, accident cost savings (safety benefits), and vehicle operating cost savings; social benefits include emissions and energy savings; costs include capital, O&M costs to the agency constructing the project. However, since several of the models do not consider multiple modes

simultaneously, additional benefit and cost categories may need to be considered for the specific case of lane conversion to BRT, where new users of the BRT are involved.

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

Model Purpose

Economic evaluation of prospective highway and transit improvement projects within the State of California. The model can handle specific highway projects such as HOV lane construction and new intersections and is capable of handling multiple modes, including transit.

Data Requirements

For highway projects, data required are highway design and traffic data including the number of general purpose and HOV lanes, estimated speed, length of highway segment, average daily traffic, and accident data for facility. For transit projects, data required are annual person trips, average travel time, annual passenger miles, percent trips occurring during peak periods, transit accident reduction, and the percent of trips occurring on a parallel highway

Format and Year

Microsoft Excel spreadsheet format; 2004

Timeframe of Evaluation

20-year project life cycle

Relevance to Project Objective

- Many input requirements related to new pavement construction can be reduced for the case of converting an existing lane for transit.
- Highway or transit components are separate, and it is not clear if both can be evaluated as part of a single project.

Cost and Benefit Categories Considered

Benefits: Travel time savings, vehicle operating cost savings, safety benefits (accident cost savings), and emissions reductions (CO, NO_x, PM_{10} and VOC).

Costs: Project-specific construction, operations and maintenance, and mitigation costs to the agency, entered for each year.

Noteworthy Features and Usable Parameters

- Rather than cross-sectional data for one year only, the model allows cost inputs for each year, based on analyses done by agencies using their own discount rates.
- The model can analyze benefits and costs even if the user does not have access to a regional travel demand model, as long as project-specific data are available.
- Excel worksheet with all inputs and parameters visible to the user; therefore not a "black box" model.

Limitations

- Only applicable to California, with use of statewide parameters.
- No consideration of transit user costs.
- Fixed real discount rate of 6%. Model should allow user to do a sensitivity analysis using different rates. Similarly, vehicle operating costs calculated in terms of fuel costs and non-fuel costs for autos and trucks are fixed values from the year 2004.
- Fixed values of time for auto, truck and transit passengers from 2004.
- Emissions factors used are from 2004.
- GDP deflator used to convert 2004 values to the year of analysis.
- Accident cost data is from the year 2000.

2. Highway Economic Requirements System for State Use (HERS-ST)

Model Purpose

The Federal Highway Administration (FHWA) developed the state-level HERS-ST model as a direct extension of the national-level HERS model. The model applies BCA to section-level highway data to predict the investment required to achieve certain highway system performance levels. HERS-ST considers capital improvements directed at correcting pavement, geometric, or capacity deficiencies.

Data Requirements

The agency must input highway capacity and traffic count records in the Highway Performance Monitoring System format at the state level. For each highway section, the model predicts future condition and capacity deficiencies based on section-specific information.

Format and Year

Microsoft Windows based application with built-in graphical mapping ability; 2000

Timeframe of Evaluation

Single year; cross-sectional

Relevance to Project Objective

- Not relevant because model provides a system-wide perspective of transportation improvements across the state; however, some background relationships for user costs may be useful.
- No capability to analyze transit investments

Cost and Benefit Categories Considered

Travel time, safety, vehicle operating, emissions, and highway agency costs

Limitations

- No local economic inputs accepted; state level highway inputs only

3. Transit Economic Requirements Model (TERM)

Model Purpose

TERM provides estimates of the total annual capital expenditures required in all urbanized areas by federal, State, and local governments to maintain or improve the physical condition of transit systems and the level of service they provide. TERM also determines the allocation of projected investment among transit asset categories over a 20-year period and the sensitivity of the investment projections to variations in the rate of future growth in the demand for transit services. The model also generates estimates of current transit conditions and evaluates the impact of varying levels and types of investment on future conditions and performance. Cost/Benefit analysis is one of four modules in the TERM model.

Data Requirements

The model uses data on transit fleet, track mileage, number of stations, and number of maintenance facilities from the 2002 National Transit Database and from surveys by the Federal Transit Administration. Asset data including useful life, condition, current age of the asset, and investments in transit enhancements must be input by each agency.

Format and Year

Unknown; 2004

Timeframe of Evaluation

20-year period

Relevance to Project Objective

- Not relevant because model primarily evaluates transit investments, not combined transit and highway investments as the project requires.

Cost and Benefit Categories Considered

Transportation system user benefits including travel time savings, reduced highway congestion, reduced automobile costs (fuel, insurance, maintenance, depreciation, and parking), and taxi expenses; social benefits including reduced air and noise emissions, roadway wear, and transportation system administration; and transit agency benefits including reductions in operating and maintenance costs.

Limitations

- No inclusion of transit supply and demand elasticities that translate transit service improvements into changes in transit ridership
- No linkage with the HERS model and no cross-elasticities to estimate the effects of highway investments on transit ridership.

4. Florida Interstate Highway System: Multi-Modal Corridor Level of Service Analysis (MMCLOS)

Model Purpose

The Multimodal Corridor Level of Service (MMCLOS) methodology was developed to enable FDOT planners to evaluate the impacts of projects and project alternatives on the quality of service perceived by users of all modes of travel in the corridor. The methodology was developed to provide the Department with a transportation corridor level of service analysis technique from a multimodal perspective that would reflect the automobile, bicycle, pedestrian, truck and transit modes in sufficient detail to allow the development of multimodal level of service (LOS) estimates.

Data Requirements

Data on corridor length, location, availability of auto and transit facilities, lanes, speeds, average annual daily traffic, and number of crossings must be provided by the analyst/agency.

Format and Year

Not a model but a step by step methodology of corridor definition, computation of modal LOS, and reporting of the results; 2001.

Timeframe of Evaluation

Single year; cross-sectional.

Relevance to Project Objective

- Not relevant because it is not a cost/benefit analysis methodology; only estimates Level of Service (LOS) for each mode. However, the methodology can provide guidance on how multiple modes are considered in performance evaluation.

Cost and Benefit Categories Considered

None specifically, though LOS may be considered an input to a cost/benefit analysis.

Noteworthy Features and Usable Parameters

- Performs analysis at the corridor level.
- Incorporates multimodal analysis into traditional highway LOS analysis.

Limitations

- No capability to estimate LOS separately for HOV lanes in the current version.
- LOS for non-auto modes currently unrelated to the volume or level of demand.
- Draws inputs from existing models used at the Florida Department of Transportation.

5. StratBENCOST: Strategic Decision Support Tool for Highway Planning and Budgeting

Model Purpose

StratBENCOST is designed for rapid preliminary analysis and comparison of a number of projects to facilitate strategic planning; the objective is to allow planners to select the most promising projects for more detailed analysis. The model is designed to support multi-year planning and budgeting. Default values for a number of variables are provided in the model so that a user needs minimal data for preliminary analysis of a set of projects. StratBENCOST uses the results of NCHRP Project 02-18 to provide a probability range for most of the economic and physical variables used in the analysis.

Data Requirements

Inputs include roadway physical characteristics (number of lanes, pavement surface characteristics, road grade, traffic capacity), operational characteristics (traffic volume and speed, traffic mix, peaking characteristics), and project characteristics (construction and right-of-way costs, maintenance costs, and project schedule). If available, the user may provide economic values such as values of time, accidents, emissions and vehicle operating costs; otherwise model defaults can be used.

Format and Year

Proprietary software; 1996.

Timeframe of Evaluation

Multi-year analysis using Net Present Values

Relevance to Project Objective

- Not relevant because the model evaluates only highway project alternatives and does not consider transit investments; however it can provide guidance on sources for economic parameters and methodology

Cost and Benefit Categories Considered

Travel time savings; vehicle operating cost reductions; accident-cost reductions; and reduction in emissions of HC, NO_X, and CO (emissions reduction benefits optional).

Noteworthy Features and Usable Parameters

- Performs analysis at the level of a single corridor segment or a regional network; the latter uses inputs from the regional travel demand model.

- Capability to do sensitivity analysis of model outcomes varying by user inputs such as average annual daily traffic on facility.

Limitations

- Default economic values are from old data sources; they can be modified by the user if data is available.

6. MicroBENCOST

Model Purpose

MicroBENCOST is a sister tool of StratBEN COST designed for in-depth economic analysis of detailed project options to facilitate operational planning as opposed to strategic planning as in StratBENCOST. It applies when specific design and engineering alternatives are at issue, rather than the strategic position of schemes and projects in a comprehensive, area-wide, and multiyear budget. MicroBENCOST is designed to analyze different types of highway improvement projects in a corridor. Benefits are calculated for existing and induced traffic, as well as for diverted traffic in the presence of a competing parallel route or when a bypass project is evaluated.

Data Requirements

Inputs include roadway physical characteristics (number of lanes, pavement surface characteristics, road grade, traffic capacity), operational characteristics (traffic volume and speed, traffic mix, peaking characteristics), and project characteristics (construction and right-of-way costs, maintenance costs, and project schedule). More engineering and design detail required than in StratBENCOST.

Format and Year

Windows-based software; early 1990s

Timeframe of Evaluation

Multi-year analysis using Net Present Values.

Relevance to Project Objective

- Not relevant because the model evaluates only highway project alternatives and does not consider transit investments.

Cost and Benefit Categories Considered

Benefits: Travel time savings, vehicle operating cost reductions, accident-cost reductions, and emissions reduction (optional).

Costs: Total initial costs, salvage (residual) value at the end of the evaluation period, rehabilitation and maintenance costs during the analysis period.

Limitations

- Substantial data requirements.
- No capability to analyze transit investments.
- Default coefficients are complex and the analysis is sensitive to these values; therefore user editing is not recommended.
- Default economic values are from old data sources and have not been updated.

7. STEAM: Surface Transportation Efficiency Analysis Model

Model Purpose

To facilitate detailed multimodal corridor and system-wide analysis, in the 1990s the FHWA developed the Surface Transportation Efficiency Analysis Model (STEAM). STEAM uses information developed through the travel demand modeling process to compute the net value of mobility and safety benefits attributable to regionally important transportation projects. The current version of this model, STEAM 2.02, is able to report mobility and safety benefits by user-defined districts and a new accessibility measure.

Data Requirements

STEAM 2.0 post-processes the traffic assignment volumes generated from conventional four-step planning models. Detailed outputs from travel demand models including in-vehicle travel time, out-of-vehicle travel time, fuel costs, non-fuel operating costs, out-of-pocket costs, and internal accident costs are thus required as inputs into STEAM. Inputs include detailed regional network tables, trip tables, and travel time matrices for the Base Case and the Improvement Case.

Format and Year

STEAM 2.0 free software package; 2000.

Timeframe of Evaluation

Single year; analysis of annual benefits and costs.

Relevance to Project Objective

- Relevant because the model considers all modes and can evaluate packages of transportation actions for a corridor or a region, involving transit and highway modes together.

Cost and Benefit Categories Considered

User benefits, emissions benefits, agency capital costs.

Noteworthy Features and Usable Parameters

- Benefits reported in aggregate or by zones.
- Model includes risk analysis.
- Model includes default input parameters that can be changed by the user if local values are available.

Limitations

- Extensive resources and data inputs required, programmed for input to STEAM.

8. SPASM: Sketch Planning Analysis Spreadsheet Model

Model Purpose

SPASM focuses on sketch planning analysis for screening purposes, in situations where running travel demand models to get output for use in STEAM is not possible or requires too much effort for the type of evaluation needed. It provides useful first cut estimates of annualized public capital and operating costs, other costs, system user costs and benefits, air quality and energy impacts, other external costs, and cost-effectiveness measures. SPASM allows analysis of transportation actions at the system and corridor level, including highway capacity improvements, transit improvements, HOV improvements, auto use disincentives or packages combining the above actions.

Data Requirements

User-specified inputs include unit costs and parameters for all modes analyzed, emission and energy consumption rates, agency costs, details about the project and facility including length, capacity, and speeds on all segments, and demand inputs including mode shares, user costs, travel times, trip lengths, and occupancies for the Base Case and Improvement Case.

Format and Year

Microsoft Excel and LOTUS 123; 1998

Timeframe of Evaluation

Single year; analysis of annual benefits and costs.

Relevance to Project Objective

- Relevant because the model considers all modes and can evaluate packages of transportation actions involving transit and highway modes together.

Cost and Benefit Categories Considered

Benefits: User benefits including travel time savings, safety benefits and operating cost savings; external benefits including energy savings, emissions savings, and public vehicle operating cost savings.
Costs: Costs to public agencies.

Noteworthy Features and Usable Parameters

- Induced travel impacts are taken into account.
- All economic parameters and inputs are user-specified; therefore high level of transparency.
- Model is customizable to any region/agency because all inputs and parameters are user-defined.
- Easy to use Excel spreadsheet-based format.

Limitations

- All agencies, specially small agencies may not have the required knowledge and local data to input all user-defined economic parameters.
- Relatively old model; therefore some relationships may need to be updated.
- SPASM cannot be used directly when detailed analysis is required because it makes several simplifying assumptions.
- It is difficult to do a system-wide analysis with SPASM.

9. NET_BC: Network Benefit Cost

Model Purpose

NET_BC is a post-processor cost/benefit analysis model that analyzes the output from regional travel demand models to generate monetary estimates of travel time savings, changes in vehicle operating costs, and reductions in costs associated with accidents over the entire transportation network.

Data Requirements

Requires inputs of network and trip tables and travel time matrices resulting from customized runs of the regional travel demand model for no-build base year, build base year, no-build forecast year, and build forecast year.

Format and Year

Coded in Visual Basic; year unknown.

Timeframe of Evaluation

User-specified.

Relevance to Project Objective

- More suited for evaluating the entire system-wide long range plan including groupings of improvement projects, rather than individual projects.
- Modes considered are autos and trucks, hence the model is not suitable for analyzing transit modes.

Cost and Benefit Categories Considered

Benefits: User benefits including travel time savings, vehicle operating cost savings, and accident cost reductions.

Costs: Project development costs, operations and maintenance costs.

Noteworthy Features and Usable Parameters

- Fully integrated with TransCAD software, allowing GIS analysis capability.
- Accepts user-specified assumptions for discount rate, construction assumptions, costs, mix of vehicle types, and analysis period.
- Time savings between build and no-build alternatives captured by time of day and trip purpose.
- Includes risk analysis component.

Limitations

- No capability to analyze transit improvements.

10. BCA.Net

Model Purpose

BCA.Net is the Federal Highway Administration's (FHWA) web-based cost/benefit analysis tool to support the highway project decision-making process. For a project evaluation, the user specifies strategies for highway improvements as part of scenarios and builds a Base Case and an Alternate Case for evaluation. BCA.Net calculates the traffic impacts and the present values of agency and user costs and benefits for each case and compares them to arrive at measures including the net present value, cost/benefit ratio, and internal rate of return for the Alternate Case relative to the Base Case.

Data Requirements

BCA.Net takes as inputs the capital costs, physical and performance characteristics, and forecast travel demand of the highway project in question. Inputs include details about the type of facility, number of lanes, pavement conditions, speeds, crash rates and average delays on facility, and details about strategy features.

Format and Year

Web tool available from FHWA website; last updated in 2007.

Timeframe of Evaluation

User-specified up to 35 years.

Relevance to Project Objective

- Not relevant because transit modes are not considered; model is only applicable for highway improvements.

Cost and Benefit Categories Considered

Travel time savings, vehicle operating cost savings, safety benefits, environmental benefits, project construction costs, and induced travel impacts.

Noteworthy Features and Usable Parameters

- Web tool that is available to users in the most updated version for free.

Limitations

- No capability to analyze transit improvements.

11. IMPACTS

Model Purpose

IMPACTS is a series of spreadsheets developed to help screening-level evaluation of multi-modal corridor alternatives, including highway expansion, bus system expansion, light rail transit investment, HOV lanes, conversion of an existing highway facility to a toll facility, employer-based travel demand management, and bicycle lanes. The impacts estimated include costs of implementation, induced travel demand, benefits including trip time and out-of-pocket cost changes such as fares, parking fees and tolls, other highway user costs such as accident costs, revenue transfers due to tolls, fares or parking fees, changes in fuel consumption and changes in emissions.

Data Requirements

The model requires as inputs travel demand estimates by mode for each alternative, including travel times, mode shares, occupancies, trip costs, trip lengths, and other information.

Format and year

Microsoft Excel and LOTUS 123; 1999.

Timeframe of Evaluation

User-specified.

Relevance to Project Objective

- Relevant because the model considers all modes and can evaluate packages of transportation actions involving transit and highway modes together.

Cost and Benefit Categories Considered

Benefits: Direct user and mobility benefits, emissions savings, fuel consumption savings, and safety benefits.

Costs: Annual costs to public agencies, including capital, operations and maintenance, and other costs.

Noteworthy Features and Usable Parameters

- Transparent, easy-to use spreadsheet-based tool.
- All parameters are user-defined, therefore the model has greater flexibility and can be updated easily with newer values.
- Model is customizable to any region/agency because all inputs and parameters are user-defined.

Limitations

- All agencies, specially small agencies may not have the required knowledge and local data to input all user-defined economic parameters
- Relatively old model; therefore some relationships may need to be updated
- The model makes several simplifying assumptions and uses aggregated average values; this does not allow a detailed analysis

Sources

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SPASM:
http://www.fhwa.dot.gov/steam/spasm.htm

IMPACTS:
http://www.fhwa.dot.gov/steam/impacts.pdf
http://www.fhwa.dot.gov/steam/impacts.htm

APPENDIX B: ANALYSIS SPREADSHEET

ASSUMPTIONS	Data	Units	Source/Notes
Fixed Assumptions			
General			
Analysis period	20	years	MnDOT BCA: typical planning timeframe: 20-30 years
Number of days in the year	300	days	Conservative estimate; could range from 250-365
Year operations begin	2011		
Benefits and costs reported in	2010	constant 2009 $	
Infrastructure			
No. of intersections per mile	6		HCS Analysis Assumptions
Number of bus lanes	1		
Lane width	11	feet	
No. of stations	5	per mile	
Variable Assumptions			
General			
Discount rate	7%		FHWA Economic Analysis Primer; Federal OMB guidance
Average wage rate of transit riders	$26.29	constant 2009 $ per hour; converted from original figure of $21.1 in 2000$ from source	Can be disaggregated for impacts by income group (assumes $40,000 per year)
Average wage rate of auto drivers	$26.29	constant 2009 $ per hour	http://ostpxweb.dot.gov/policy/Data/VOTrevision1_2-11-03.pdf
Pre-Project Mode Shares			
Autos	85%		
Bus	15%		
Average Vehicle Occupancy			
Auto	1.2		
Transit (60 ft articulated)	80		Source: TCRP 118
Annual Ridership Growth Rate			
Auto	2%		
Transit	2%		
Elasticities			
Transit ridership w.r.t travel time	-0.6	Source: TCRP 118 (p. 3-19) gives range of -0.5 to -0.7 for work trips and -0.3 to -0.5 for general trips; Levinson et al., TRB (2008) paper says -0.4, Moving Cooler Tech Appendix says -0.4 and can use -0.5 to add in the effect of increased reliability	
Transit ridership w.r.t bus headway (frequency)	-0.4	Source: Levinson et al., from TCRP Project A23A Report. Or -0.5 from "Traveler Response to Transportation System Changes", TCRP Report 95.	
Infrastructure and Travel conditions			
Length of arterial/corridor	5.0	miles	
Average headway of current bus service, during peak hours	10.0	minutes	
Current bus volume, bi-directional, peak hour	12	buses	
Maximum current transit riders in peak hour peak direction	480	riders	
Average headway of BRT (frequency), during peak hours	6.0	minutes	Typical 5-10 mins for peak hours, TCRP Report
BRT bus volume, bi-directional, peak hour	20	buses	
Maximum BRT transit riders in peak hour peak direction	800	riders	
Total daily passenger throughput, base case (trips)	40,000		
Percent of passenger trips in peak hour	10%		Assuming 10% peak hour trips
Percent of peak volume in peak direction	60%		Assuming 60% peak hour volume in peak direction
Daily peak hour passenger throughput, base case	4,000		
Daily peak hour pax throughput, base case, peak direction	2,400		
Auto volume, bi-directional, peak hour	2,833	cars	
Auto volume, peak direction	1,700	cars	
Average Base Case AUTO speed	21.8	miles per hour	HCS Analysis
Speed on GP lanes after BRT	20.3	miles per hour	HCS Analysis, based on new AADT calculated
Average Base Case Transit Speed	7.0	miles per hour	Source: FTA (2009)
Average BRT speed	11.0	miles per hour	Source: FTA (2009)
Change in transit travel time	-36%		

TRANSPORTATION IMPACT ANALYSIS	NO BUILD -- 3 LANES MIXED FLOW	BRT ALTERNATIVE	
		2 LANES, MIXED FLOW	1 LANE, BRT
Traffic volume during peak hours, in peak direction			
Auto	1,700	1,544	
Travel Demand (Person throughput) during peak hours, in peak direction			
Auto drivers and riders	2,040	1,853	`
Transit riders	360		547
Auto users diverted to BRT		187	
Increase in transit ridership due to decreased travel time			79
Increase in transit ridership due to increased frequency			58
Travel Data			
Average auto trip length on corridor (miles)	5	5	
Average transit trip length (miles)	5		5
Average auto travel time (minutes)	13.76	14.78	
Average transit travel time (minutes)	47.86		30.27
in-vehicle time	42.86		27.27
wait time	5.00		3.00
Average auto delay		1.02	minute per trip
Average transit time savings		17.58	minutes per trip
Average person delay for auto		1.22	minutes per trip
Average transit person time savings		1,407	minutes per trip
Daily VMT (trip length * trips)			
Auto	8,500	7,722	
Auto VMT savings	778		
Daily VHT (trip time * trips)			
Auto	390	380	
Auto VHT savings	9.5		
Daily person miles traveled			
Auto	10,200	9,267	
Change in auto daily person miles	933		
Daily person hours traveled			
Auto	468	456	
Change in auto daily person hours	11		

COST ASSUMPTIONS AND CALCULATIONS	Data	Notes/units	Source
Note: Multiple choices are provided under each category; options assumed in this hypothetical analysis are marked			
All component costs are in 2004 $ unless otherwise mentioned			
Infrastructure construction (capital costs below include engineering and design)			
Scenarios available for at-grade BRT from TCRP Report 118: BRT Practitioner's Guide, 2007, example BRT scenarios			
Bus lane -- new construction	25,000,000	Cost per lane mile	
Median arterial busway	4,000,000	Cost per lane mile	
Lane within existing roadway profile	2,700,000	Cost per lane mile	Assumption
Bus lane -- striping lane	100,000	Cost per lane mile	
Infrastructure construction cost	13,500,000		
Stations			
At-grade typical station costs (basic)	21,000	per station	TCRP report 118
At-grade typical station costs (enhanced)	30,000	per station	Assumption
At-grade major station costs	150,000	per station	
Station costs	750,000		
New Vehicles			
Number of new buses needed	10		
Standard	337,500	average per vehicle	Assumption
Articulated	675,000	average per vehicle	TCRP report 118
Vehicle costs	6,750,000		
Fare collection			
On-board	17,500	avg. per vehicle	
Off-board	62,500	avg. per vehicle	Assumption
Fare collection costs	175,000		
Other systems			
Traffic Signal Priority	30,000	per instersection	
Passenger on-board information	4,000	per vehicle	
Other (ITS, safety, security systems, etc.)	90,000	70,000-120,000 per vehicle, depending on features	
Other system costs	1,840,000	total	
TOTAL CAPITAL COSTS	**26,138,534**	over two years (assume)	Converted to $2009
Annual Operation and maintenance costs			
O&M Costs	$10,000	Cost per lane mile	Detailed calculation of O&M costs based on stations, vehicles, etc., see TCRP 118, pp. 4-90-91
TOTAL ANNUAL O&M COSTS	**$56,786**	Converted to $2009 -- most recent year for which CPI annual average is available	Assuming minor reconfiguration/widening of arterial
User Costs (Base Case)			
Auto drivers			
Auto operating costs	0.54	$ per vehicle mile	AAA, 2009 -- excluding ownership costs (15.42 cents/mile); 54 cents/mile with ownership costs at 15,000 miles per year
Auto operating costs per passenger mile	0.45	$ per passenger mile	
Tolls	0	$	
Value of in-vehicle travel time	13.14	$/hour	Assumes 50% of wage rate, TCRP 78, p. II-16
Cost of in-vehicle time	0.60	$/passenger mile	
Transit riders			
Single trip bus transit fare	1.30	$	Assumes average adult single trip bus fare = $1.30: source APTA statistics (see link)
Fare (per mile)	0.26	$ per passenger mile	
Travel time, in-vehicle	42.86	minutes/passenger	
Transfer time	0	minutes/passenger	
Value of walking, waiting, transfer time	26.29	$/hour	Assumes 100% of wage rate, TCRP 78, p. II-16
Value of travel time, in-vehicle	13.14	$/hour	Assumes 50% of wage rate, TCRP 78, p. II-16
Costs of wait time for transit riders	0.44	$/passenger mile	
Cost of in-vehicle time	1.88	$/passenger mile	
User Costs (BRT Case)			
Auto drivers			
Auto operating costs	0.54	$ per vehicle mile	
Auto operating costs per passenger mile	0.45	$ per passenger mile	
Tolls	0	$	
Value of in-vehicle travel time	13.14	$/hour	
Cost of in-vehicle time	0.65	$/passenger mile	
Transit riders			
Single trip bus transit fare	1.30	$	APTA Statistics; adult single trip bus fare
Fare (per mile)	0.26	cents per passenger mile	
Travel time, in-vehicle	27.27	minutes/passenger	
Transfer time	0	minutes/passenger	
Value of waiting time	26.29	$/hour	
Value of travel time, in-vehicle	13.14	$/hour	
Costs of waiting time for transit riders	0.26	$/passenger mile	
Cost of in-vehicle time	1.19	$/passenger mile	

BENEFIT ASSUMPTIONS AND CALCULATIONS			
Direct User Benefits or Disbenefits		BRT ALTERNATIVE	
	NO BUILD -- 3 LANES MIXED FLOW	2 LANES, MIXED FLOW	1 LANE, BRT
Total perceived daily user costs (includes time) per passenger mile:			
Auto	1.05	1.10	
Transit	2.58		1.72
Daily cost savings for transit riders continuing to use transit	309		
Daily cost savings for auto drivers continuing to drive	-83		
Daily cost savings for drivers switching to BRT(see note)	-124		Assumed zero if negative, otherwise assume calculated cost savings
	0		
Peak hour user cost savings	**$226**	$/passenger mile	
Daily peak period user cost savings	**$1,358**	$/passenger mile	Assuming 6 peak hours daily over AM and PM peak
Annual Savings in User Travel Costs	**$2,036,954**	peak period	Already in $2009; no conversion required
Social Benefits			
Emission damage costs		Source: Used CAFÉ DEIS estimates for all pollutants (see page 399 of DEIS_D document, 2009), except CO; reported in $2007	
Estimates from CAFÉ EIS, ICF, using EPA Data			
VOCs (HCs)	1,300	$/ton	
CO	0	$/ton	Impact ignored
NOx	5,300	$/ton	
SOx	31,000	$/ton	
Particulates	290,000	$/ton	
CO2	20	$/ton	$33/ton in WMATA analysis
Average 2005 emission rates for light duty vehicles		Source -- EPA, "Emission Facts: Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks," EPA Office of Transportation and Air Quality Document No. EPA420-F-05-022, August 2005 (saved on hard drive)	
VOCs (HCs)	1.36	grams/mile	
CO	12.4	grams/mile	
NOx	0.95	grams/mile	
SOx	0.008	0.17 grams of SO2 per gallon of gasoline -- DEIS p. 394; also 0.17 grams of SO2 per 20.3 miles (average mileage in MPG; see EPA); therefore, average grams/mile of SO2 = 0.17/20.3 = 0.008	
Particulates	0.01		
CO2	369.00		
Daily emissions for auto trips diverted to BRT			
VOCs (HCs)	1,269	grams	
CO	11,573	grams	
NOx	887	grams	
SOx	8	grams	
Particulates	9	grams	
CO2	344,393	grams	
Daily PEAK HOUR emissions damage cost savings for auto trips diverted to BRT			
VOCs (HCs)	$1.65		
CO	$0.00		
NOx	$4.70		
SOx	$0.24		
Particulates	$2.71		
CO2	$6.89		
TOTAL	$16.19	$/vehicle mile	
	$13.49	$/passenger mile	
Daily peak emissions cost savings, over 6 peak hours	**$80.93**	$/passenger mile	
Annual Emissions Damage Cost Savings for Auto Trips Diverted to BRT	**$125,608**	peak hour	in $2009
Crash cost savings			
Crash costs per VMT	$0.023	$/vehicle mile (2007 $)	Source: CAFÉ DEIS pp. 397-401(from FHWA source)
Daily savings in crash costs from auto trips diverted to BRT	$18	$/passenger mile	
Daily peak crash cost savings, over 6 peak hours	**$107**		
Annual savings in crash costs from auto trips diverted to BRT	**$166,583**		in $2009
TOTAL ANNUAL PEAK PERIOD BENEFIT	**$2,329,146**		
Benefit per existing rider	**$6,470**		

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