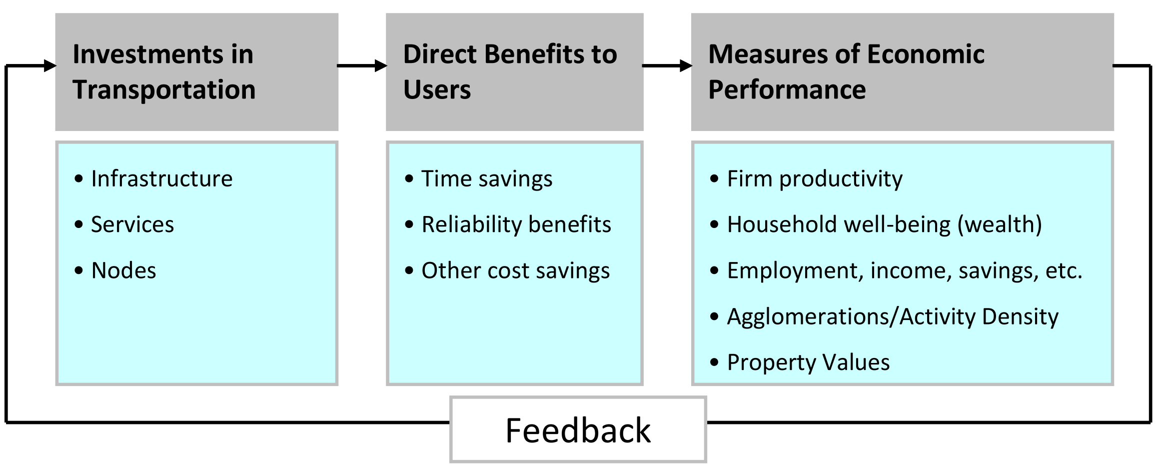
Puget Sound Regional Council 1011 Western Avenue, Suite 500 / Seattle, WA 98104 / 206-464-7090 / FAX 206-587-4825 / psrc.org

Benefit-Cost Analysis / OCTOBER 2009 /

The purpose of benefit-cost analysis is to compare the benefits associated with a policy or investment with the costs of implementing the policy or investment. If the sum of the benefits of the project or policy exceeds the costs, then there is a general economic argument supporting the action to make the investment or implement the policy. In its broadest form, benefit-cost analysis is a framework for social accounting, where any benefit or cost that can be measured and monetized is weighed against all other benefits or costs. In practice, benefit-cost analysis most often assumes a more limited scope of review due to limits on available information and methods for estimation and monetization of all consequences of the proposed investment or policy. Happily, economic analysis of transportation projects is a well developed field, where the primary benefits accrue to the users of the transportation system and yield well to established methods of estimation. There are also measures of economic performance that accrue over time for households or firms in the region that are accounted for indirectly by feeding back these measures into the travel demand models used to estimate direct benefits to users.



Transportation planning involves integration across a broad range of scales of analysis. Investment decisions can involve large up-front costs, with benefits that play out over time. The benefits of projects accrue across multiple types of system users and over a spatial scale as well, with both localized and broadly distributed effects. The complexity of these problems is recognized and accounted for in the travel demand modeling practices of regional planning agencies. A natural extension of these modeling practices is the accurate accounting of benefits and costs in a manner that can directly support decision-making. A dominant approach to this kind of accounting is benefit-cost analysis, and in Washington state these methods are a necessary part of fulfilling regional planning requirements set out in state law under the more general heading of "least-cost planning[1]."

An important element in project and program evaluation is the identification of two alternate states of the world: one state of the world in which the project, program or policy has been implemented, and one state of the world where the project, program or policy has not been implemented. In all other respects, these states of the world resemble each other. The objective is to isolate the consequences of the investments or change in policy. In this respect, there is a natural affinity between prospective benefit-cost analysis and models of systems change, like those employed for transportation planning. In a model framework it is possible to selectively represent a change in policy or investment while holding everything else constant.

Benefit-cost analysis can be used to guide decisions about the relative ranking, or prioritization, of numerous investment options or can be used to determine the economic usefulness of making any given investment in the first place. Like any analysis technique, benefit-cost analysis is subject to numerous constraints, from the accuracy of the data used in the estimation process to uncertainty about values to be employed in the analysis (either due to incomplete science or philosophical and ethical disputes). The purpose of analysis is not to resolve all such disputes, or eliminate uncertainty (and thus the need for judgment), but rather to provide a rich body of information assembled in a disciplined manner that can aid decision-makers faced with difficult investment or policy decisions. To this end, benefit-cost analysis must make key analytical assumptions clear and must be able to demonstrate the sensitivity of its findings to modifications to these key assumptions.

Overview

The Puget Sound Regional Council (PSRC) has developed a set of procedures and methods for project and program evaluation that fall generally into the category of transportation benefit-cost analysis. The purpose of these methods is to be able to produce information about project or program performance, relative to a baseline set of conditions where the project or program has not been implemented. Benefit-cost methods produce information about the relative magnitude of benefits and costs that accrue (over time) to society as a result of any given action.

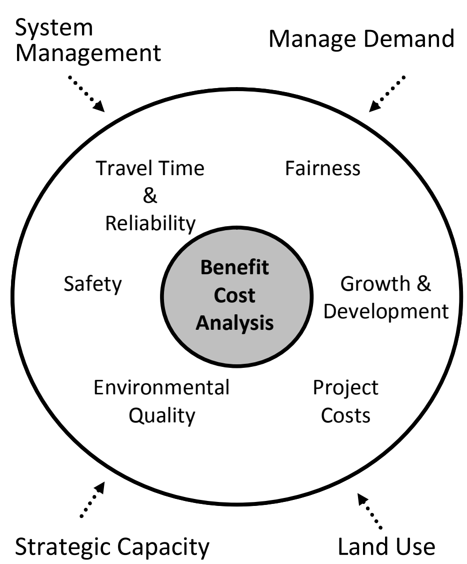
The logic of the benefit-cost framework follows naturally from the underlying economic principles of a private market-oriented economy, but also is widely accepted in the context of public project selection. Indeed, in the state of Washington, statutory requirements to evaluate project benefits and costs give additional weight to using benefit-cost analysis as the central, organizing principle of an evaluation methodology.

Benefit-cost analysis is clearly the dominant evaluation methodology in economics generally, and in transportation specifically. The reason is that benefit-cost analysis is an extension of the principle that the purpose of any system to select among project and program alternatives is to improve the well-being of the community net of any burden on society's scarce economic resources. However, there are challenges that need to be overcome when using benefit-cost analysis.

[1] See Appendix A in http://www.psrc.org/assets/2127/_09-45_BenefitCostAnalysisMethods.pdf for more details.

- **Equity:** Benefit-cost analysis theory does not offer good guidance on how to balance net gains to one part of the community that come at the expense of net losses to another part of the community.
- **Valuation:** The requirement that all benefits and costs be monetized can be a challenge to comprehensive benefit-cost analysis in settings where difficult-to-value benefits or resources (such as amenity values) dominate the decision context at hand.
- **Screening of Projects:** Project and program definition can be complex in a setting where project initiatives can be combined or staged in multiple ways.
- **Will the Tool be Used:** The evaluation framework must fit well operationally, and organizationally, within existing organizational parameters.
- **Programming with a Budget:** In an ideal world, all cost-beneficial projects would be implemented. In reality, budgetary, political, and organizational constraints limit the projects that may be implemented.

As a result, benefit-cost analysis can seldom be the sole means of assessing the usefulness of a project, program or policy. Such analysis can however significantly aid the evaluation process by integrating across multiple objectives and applying discipline to the accounting of benefits within a complex setting. And, when combined with analysis of other policy objectives (for example, those related to how benefits are distributed across members of society), benefit-cost analysis becomes an invaluable tool for project and program evaluation and the development of plans for investment.



What is the benefit-cost analysis used for?

Benefit-cost analysis is used to assess the performance of a project or program relative to a baseline set of conditions. At PSRC, this process can be applied to any project or program that can be represented in the regional travel demand forecasting model. To date, this has included evaluating a series of freight mobility projects and evaluating alternatives for the transportation plan update (Transportation 2040). In the Transportation 2040 process, there were different types of projects (system management, demand management, strategic capacity) and changes in land use for each alternative. Benefit-cost analysis was used to assess most of the performance measures in the evaluation of each alternative.

What are the advantages and limitations of the PSRC benefit-cost analysis tool?

Performing truly comprehensive benefit-cost analysis in a complex practical setting, however, introduces some empirical and policy advantages as well as challenges. From an equity standpoint:

- Benefit-cost analysis produces benefits across different segments of the population, which allows the decision-makers to understand how the benefits from specific programs or projects are distributed. There is, however, no clear way to balance net gains to one part of the community that come at the expense of net losses to another part of the community. PSRC has produced a series of equity measures to understand the allocation of benefits across different market segments, but did not establish any targets or goals to evaluate equity across these measures.
- The analysis is limited by aggregate market segments defined in the PSRC travel model, because the models produce only these aggregate segments. As PSRC develops new models which include individuals, user benefits reported by different person and household characteristics could improve equity analysis .
- It does not solve for "social weighting" of benefits/costs that accrue to specific segments of the economy (distributions among user groups). Since the relative importance of distributions of benefits to specific user groups cannot be observed directly, these judgments must be made and considered explicitly by those decision-makers who are charged with project and program selection.

The requirement that all benefits and costs be monetized is both an advantage and a challenge to comprehensive benefit-cost analysis:

- The advantage is that disparate data (such as safety and reliability) can be combined into a single measure.
- The challenge comes when difficult-to-value benefits or resources (such as health) contribute to the decision context at hand but are not monetized. Procedures such as contingent valuation or multi-criterion weighting methods were considered during the PSRC Transportation 2040 process but were not included in the benefit-cost analysis because there was a feeling that this may not adequately represent the relative importance of specific measures.
- There is limited knowledge about some long-run dimensions of costs (i.e., emissions). For example, in the case of the downstream consequences of CO2 emissions, there is agreement generally that there could be a wide array of economic and social costs, but notable uncertainty over the details and the magnitudes of these costs. This is not a limitation of the tools per se, but rather uncertainty over how best to apply them; a robust analysis will test the sensitivity of the results to various cost assumptions.
- It does not trace the "capitalization" of user benefits throughout the economy (it measures initial demand, not final demand). For the most part this is not a critical limitation as the initial direct benefits to transportation system users will be a good approximation of any benefits as measured in secondary markets (e.g., employment, firm productivity, etc.) as long as these secondary markets are open and competitive.
- It requires explicit treatment of a social discount rate that may not reflect all perspectives on inter-generational distribution issues. While there is general agreement that benefits that accrue today are more socially valuable than benefits that accrue in the distant future, this tradeoff in cases with very large but distant costs and benefits can take on ethical implications. In practice, using discount rates that represent the shadow price of capital (the after tax rate of return on safe investments as determined in private markets) represents a reasonable approach.

There are also some practical, logistical limitations in the use of the benefit-cost analysis tool at PSRC:

- Project and program definition can be complex in a setting where project initiatives can be combined or staged in multiple ways. Benefit-cost analysis works best in a setting where a project or program is compared against all reasonable alternatives. To the extent that project elements can be combined in multiple ways, the number of alternatives can proliferate. This can leave the analyst with an unreasonable evaluation burden. PSRC has defined program and project alternatives in a way that respects the tradeoffs between comprehensiveness and staff time availability.
- The evaluation framework must fit well operationally, and organizationally, within existing organizational parameters. In the PSRC context, for example, it was important to make the evaluation framework and assumptions consistent with the existing modeling resources of the organization, but to also be able to take advantage of newer modeling resources as they become available through the model improvement program.
- In an ideal world, all cost-beneficial projects would be implemented. In reality, budgetary, political, and organizational constraints limit the projects that may be implemented. Even if these constraints do not limit the set of projects perpetually, they impose timing or sequencing constraints that have the same conceptual effect.
- It does not explicitly treat seasonality of traffic. The PSRC travel models produce data for an average weekday and these data are annualized for reporting. Weekend travel and seasonal variations are not forecast directly.

How does the benefit-cost analysis operate?

The starting point for any analysis of transportation investments must involve a systematic means of estimating the project's effects on traffic and travel demand. The PSRC BCA tool was designed to make use of comprehensive databanks produced by the PSRC regional travel demand forecasting models. A project is characterized in the travel models' transportation networks for one or more analysis years. The models are run for both a build case (a network where the project has been implemented) and a base case (a network where the project has not been implemented). The PSRC BCA tool generates estimates of user benefits (travel time savings, travel reliability benefits, vehicle operating cost savings, and accident risk reduction benefits, and vehicle emission reduction savings) directly from mathematical transformations (consumer surplus calculations) of the differences between the build and base cases.

A number of complicating factors must be treated consistently in benefit-cost analysis. Typically, the benefits from transportation projects accrue over time, while the costs may be largely front-loaded. Any investment or policy where benefits and costs accrue over notably different time frames must explicitly treat the time value of money. This is done through the use of a social discount rate that reduces all future values to their present value equivalents. Also, travel models generally produce information about "average" conditions; PSRC models an average weekday condition for a particular future year. Since benefits from transportation projects will not be limited to a single weekday, expansion factors must convert the average weekday benefits to annual values.

Transportation investments provide benefits directly to users in the form of travel time savings, and reductions in other costs of travel. When the perceived costs of a trip are reduced, consumer surplus increases. As travel times are reduced between any origin and destination, users already making this trip enjoy lower costs while new users (for whom the willingness to pay was less than the old cost of the trip) now take advantage of a travel opportunity that was not attractive to them before. This leads to a simple approach to calculating the benefits of the improvement: subtract the consumer surplus without the improvement from the consumer surplus with the improvement. To do so, we need to know only two things:

- The willingness-to-pay (demand) relationship that is involved.
- The effect of the improvement on the users' perception of their costs of travel.

We don't have to know very much about the willingness-to-pay relationship to implement this procedure. All we need to know is the effect on additional travel of a change in travel costs. The calculation on willingness to pay is implemented by taking the area above the cost line and below the demand curve. Note that for the existing trips, all we need to know to calculate the change in consumer surplus is the difference in the cost without and with the improvement (i.e., 15.0 – 10.0 = 5.0 cents per trip). For new trips the benefit calculation is approximated by one-half the change in trip cost times the change in number of trips.

$$B = (U_0 - U_1)\frac{(V_0 + V_1)}{2} = \Delta U \frac{(V_0 + V_1)}{2}$$

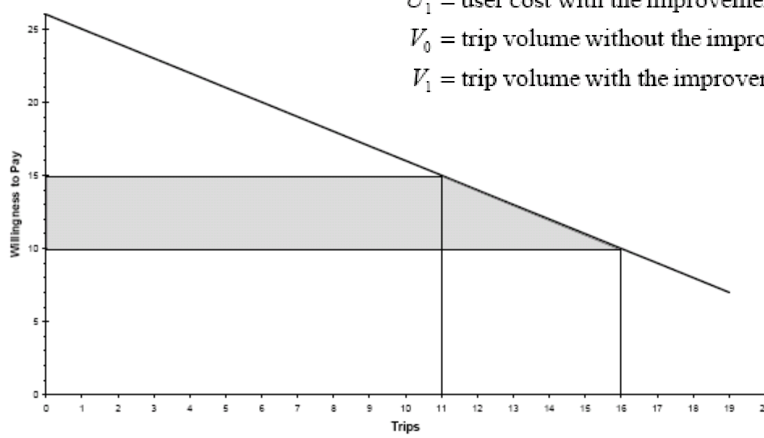
where:

U_0 = user cost without the improvement

U_1 = user cost with the improvement

V_0 = trip volume without the improvement

V_1 = trip volume with the improvement



This basic user benefit calculation can be made more detailed to recognize the major sources of user benefits: the savings in travel time, operating cost, reliability, and accident costs, and the consumer surplus that such savings generates. The user benefit calculation also incorporates induced traffic demand by incorporating traffic volumes with and without the project[2].

It is important to note that projects have more than one type of user. As such, the PSRC regional travel demand models and the BCA tool represent multiple user classes. Each of these user classes exhibits different values of time and is influenced by improvements in a different manner. In addition, the user benefits will vary with the time of day being modeled, the project year, and the segment or corridor affected by the project improvement. The proliferation of the number of user classes, facility segments, project years and travel times makes the accurate measurement of user benefits something that must be done using an organized accounting of all of the calculations, such as that which is implemented in the PSRC BCA tool.

[2] AASHTO; *A Manual of User Benefit Analysis for Highways*, 2nd Edition

The basic steps in the benefit-cost analysis process are as follows:

1. Define the Project Alternative and the Base Case.
2. Determine the level of detail (spatial, temporal, user segmentation, etc.) required.
3. Develop basic user cost factors (values of time, vehicle unit operating costs, accident rate and cost parameters, vehicle emission rate and cost parameters, etc.).
4. Select economic factors (discount rate, analysis period, evaluation date, inflation rates, etc.)
5. Obtain traffic performance data (for Project Alternative and Base Case) for explicitly modeled periods.
6. Measure user costs (for Project Alternative and Base Case) for affected link(s) or corridor(s)
7. Calculate user benefits.
8. Extrapolate/interpolate benefits to all project years (unless all time periods are explicitly modeled).
9. Determine present value of benefits, costs.

PSRC commissioned the development of custom benefit-cost accounting software from the consulting firm ECONorthwest. ECONorthwest was the prime author for the revised "A Manual of User Benefits for Highways, 2003," published by the American Association of State Highways and Transportation Officials (AASHTO) and referred to as the "Red Book."[3] The primary methods for estimation of user benefits that underpin the PSRC Benefit-Cost Analysis (BCA) tool are the same as those developed for the "Red Book," and those developed for a companion manual for estimation of transit user benefits[4].

In particular, the following project or program impacts lend themselves to monetization and are included in the PSRC BCA tool.

- **Travel time savings**. There have been many studies of travel-time savings that have established that the value of travel time saved is closely linked to the wage rate of passengers in autos and transit vehicles, and the wages paid to drivers plus the time cost of cargo inventory for commercial vehicles.
- **Accident cost savings**. The literature provides adequate guidelines on how to value mortality, morbidity and property loss consequences of accidents.
- **Vehicle operating and ownership cost savings**. There is an extensive literature, for vehicles of all types, which can be used to relate changes in network performance characteristics to vehicle cost savings.
- **Travel time un-reliability savings.** These are the value of the benefits of improved reliability associated with the policy or investment. Reliability is the degree to which facility performance (speeds) vary from the mean or typical condition. A high degree of variation implies that there is a higher risk of experiencing particularly onerous conditions; low variation implies lower risks. The risk is translated into a "certainty equivalent" or willingness-to-pay for the reduction in risk. This is implemented in the BCA tool by correlating speed variances with average speeds that are produced by the PSRC regional travel demand model.

[3] ASSHTO; *A Manual of User Benefit Analysis for Highways*, 2nd Edition, 2002

[4] Transit Cooperative Research Program Report 78, *Estimating the Benefits and Costs of Public Transit Projects: A Guidebook for Practitioners*, National Academy Press, Washington DC, 2002

- **Facility operating cost impacts.** Facility operating-cost impacts are quite idiosyncratic with respect to the type of facility, the local environmental conditions, local labor and materials costs, etc. However, the Highway Cost Allocation studies, performed both by states and the federal government, provide useful information and models (for pavement and bridge wear, etc.) of such cost impacts.
- **Facility capital cost impacts.** Ex ante costing of highway and transit improvements provides adequate information on the capital cost side of benefit-cost analysis. There is high uncertainty to these capital costs and, empirically, cost overruns have been common. However, benefit-cost analysis provides a means (through the use of sensitivity analysis and the use of risk premia incorporated in discount rates) to accommodate this uncertainty. In the state of Washington, this effort is aided considerably by the Washington Department of Transportation's (WSDOT) unique efforts to study construction cost variance on the highway side. The Transit Cooperative Research Program (TCRP) of the National Academy of Sciences (NAS) is soon to conduct a study of transit project cost variance.
- **Vehicle emissions costs**. There has been extensive study of the effects of various pollutants and noise emissions on the mortality and morbidity of populations, and the damage done to plants and property. In addition, there are engineering models of the effect of traffic conditions and vehicle vintage on emissions per mile. Therefore, air and noise pollution impacts generally can be monetized and directly incorporated in benefit-cost calculations.

What data inputs are needed in the benefit-cost analysis?

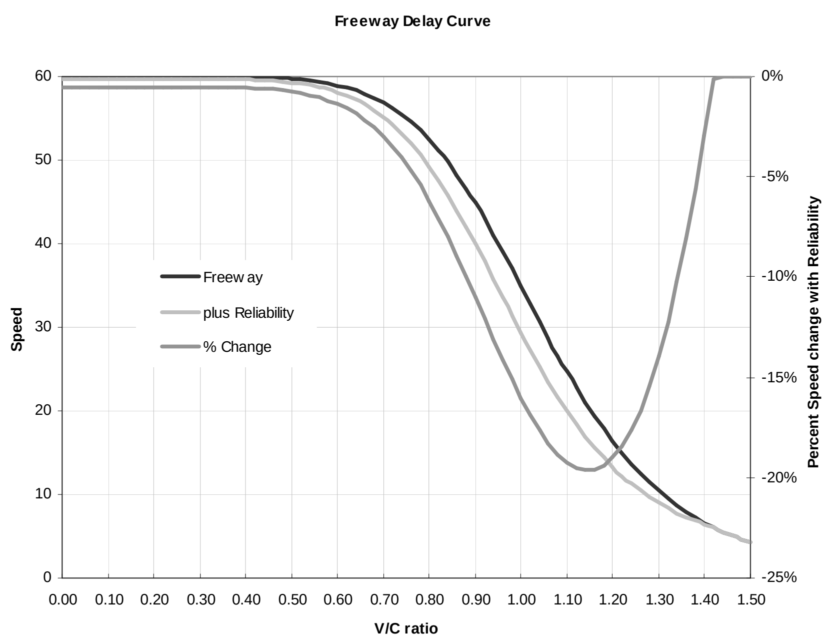
The primary inputs to the BCA analysis are of two kinds; 1) project or program performance information supplied by the travel models and, 2) unit cost and rate information supplied exogenously that constitute input parameters for the analysis. The field of economic analysis in general, and benefit-cost analysis in particular, has amassed an extensive literature regarding the costs associated with the consumption of various economic resources, including travelers' time, vehicle use, clean air and safe travelling. Where possible, economics tries to establish such values by observing consumption behavior directly in markets. This is not always possible, and, as a result, a range of advanced techniques have been established to develop estimates of costs of resources where no suitable market activity affords observations.

In practice, benefit-cost accounting makes use of this accumulated knowledge by representing unit costs for various resources as input parameters. As with any set of assumptions, the outcome of the analysis can be substantially influenced by the particular values that are employed. The "default" assumptions for a range of inputs to the analysis performed by PSRC are:

- **Travel Time Savings.** There have been many studies of travel-time savings that have established that the value of travel time saved is closely linked to the wage rate of passengers in autos and transit vehicles, and the wages paid to drivers plus the time cost of cargo inventory for commercial vehicles. Travel time savings are measures of consumer surplus that follow from changes in quantity (trips) and price (increments of travel time multiplied by values of time) for each class of transportation system users. In 2005, the Puget Sound Regional Council (PSRC) began collecting Global Positional System (GPS) data for 275 households to study the travel behavior in response to variable road charges as part of the

Traffic Choices Study. These data have been analyzed to identify the value of time for different auto market segments represented in the PSRC regional travel demand forecasting model. The value of time was computed for each household, vehicle, or worker unit of observation. The principle finding is that the value of commute (home-to-work tours) travel time appears to be closer to 75 percent of the wage rate for the greater Seattle metropolitan area. PSRC does not have an observed dataset to estimate truck values of time, so a national literature search of observed or estimated truck values of time was conducted to identify a reasonable estimate for values of time for trucks. This literature search identified a range of $28 per hour[5] up to $73 per hour[6] for trucks, with one additional source identifying the range as $25 per hour to $200 per hour[7]. This literature review, along with the knowledge that the observed auto values of time were 50 percent higher than previously expected, led us to increase the truck values of time to a range of $40 per hour to $50 per hour for light, medium and heavy trucks.

- **Travel Time Reliability Benefits.** In addition to travel time savings (measured as changes in time resources for an average weekday from the regional model), there are potential benefits from improved reliability associated with a policy or investment. Changes in risk can be translated into a "certainty equivalent," or willingness-to-pay for the reduction in risk. This is implemented in the BCA tool by correlating speed variances with average speeds that are produced by the PSRC regional travel demand model. The "certainty-equivalent" value concept says that variability in highway performance can be reduced to a single indicator equal to the certainty-equivalent value of the performance variability. This yields the following relationship between freeway link volumes and link speeds with and without the unreliability penalty.



[5] Kawamura, K. *Perceived Value of Time for Truck Operators*, Transportation Research Record 1725, Transportation Research Board, Washington, D.C., 2000

[6] *Freight Management and Operations: Measuring Travel Time in Freight-Significant Corridors*, accessed June 2005, http://ops.fhwa.dot.gov/freight/time.htm.

[7] U.S. Department of Transportation, Federal Highway Administration, *Freight Performance Measurement: Travel time in Freight-Significant Corridors*, December 2006.

- **Accident Cost Savings.** The literature provides adequate guidelines on how to value mortality, morbidity and property loss consequences of accidents. One such source is the U.S. Department of Transportation, National Highway Traffic Safety Administration's, T*he Economic Impact of Motor Vehicle Crashes 2000, Appendix A.* In the PSRC benefit-cost analysis tool, accidents are represented in three categories: property damage only, injury and fatality. Costs per accident are set as input parameters, with default values displayed below. These default values can be modified or overridden by the model user.

Accident Type	Cost per Accident
Property Damage Only	2600.0
Injury	75500.0
Fatality	2500000.0

- **Vehicle Operating and Ownership Cost Savings.** There is an extensive literature, for vehicles of all types, which can be used to relate changes in network performance characteristics to vehicle cost savings. In particular, PSRC had the consulting firm ECONorthwest prepare a forecast of vehicle operating costs. ECONorthwest was asked to provide short-run and long forecasts of the operating costs per mile for automobiles/light trucks and heavy trucks.

Auto:	0.15
Light Trucks:	0.15
Medium Trucks:	0.78
Heavy Trucks:	0.78

- **Vehicle Emissions Costs.** There has been extensive study of the effects of various pollutants and noise emissions on the mortality and morbidity of populations, and the damage done to plants and property. In addition, there are engineering models of the effect of traffic conditions and vehicle vintage on emissions per mile. Therefore, air and noise pollution impacts generally can be monetized and directly incorporated in benefit-cost calculations. PSRC is currently using a beta version of the MOtor Vehicle Emission Simulator (MOVES)[8] model developed by the U.S. Environmental Protection Agency to establish estimates of vehicle emission rates for the Puget Sound region vehicle fleet. Emission rates (grams per vehicle mile traveled at various speeds) are generated for various components of the vehicle fleet, given details of the vehicle fleet composition. These estimates are inputs to the benefit-cost analysis emission cost estimation process.

Pollutant	Ton
Carbon Dioxide	32.0
Carbon Monoxide	380.0
Nitrogen Oxide	9800.0
Volatile Organic Compound	7800.0
Particulate 2.5	6500.0

[8] http://www.epa.gov/otaq/models/moves/index.htm

Additional Information

There are three reports that the reader of this report may find particularly useful:

Benefit-Cost Analysis: General Methods and Approach
http://www.psrc.org/assets/2127/_09-45_BenefitCostAnalysisMethods.pdf

Transportation 2040 Draft Environmental Impact Statement
Appendix D: Policy Analysis and Evaluation Criteria Report
http://www.psrc.org/assets/1941/appd.pdf

Travel Demand Forecasting at PSRC
http://www.psrc.org/assets/2938/TDF_White_Paper_2009_final.pdf