Benefit-Cost Analysis: General Methods and Approach

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ABSTRACT

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ABSTRACT: 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. This report describes the purpose, approach, methods and assumptions that are part of this kind of appraisal. This report also contains a useful bibliography of reference materials relating to the general topic of benefit-cost analysis and to specific aspects of project evaluation.

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Executive Summary

Urban transportation systems involve large-scale investments of public resources with returns in the form of benefits to the system users that accrue over long time frames and broad spatial scales. Transportation is typically considered to be an intermediary good, or an input into firms' production activities and household utility. As a result, over the long-run, transportation investments influence other markets. Given the timing of benefits and costs and the interaction with other markets, making assessments about the suitability of investments in transportation is a potentially complex problem. Over many decades techniques for transportation project and program evaluation based on principles of economic analysis have been developed and refined. One class of analysis that is particularly suited to handle the temporal and network complexities of transportation project assessment is benefit-cost analysis.

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. See Appendix A for a discussion of benefit-cost analysis and least-cost planning.

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 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.

Benefit-cost analysis is clearly the dominant evaluation methodology in the 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.

- **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.

The rest of this report describes the purpose and approach (Chapter 1) to evaluation, the general analysis methods that are involved (Chapter 2), and some information about user defined inputs and assumptions (Chapter 3) that are inherently part of this kind of appraisal. This report also contains a useful bibliography of reference materials relating to the general topic of benefit-cost analysis and to specific aspects of project evaluation.

1. Purpose and Approach

Project and Program Appraisal: Compare Benefits with Costs

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.

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 investments 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.

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[1] See Appendix A for more details.

In this setting, the well-being of the community is used in the economic welfare sense, i.e., that the goal of human endeavor is to increase economic utility or welfare. These terms have formal, quantitative meaning in economic theory and are amenable to measurement, given appropriate data. In essence, the notion is that the economic welfare of the citizenry must be balanced against the burden placed on society's limited economic resources. In this use, the notion of economic resources includes not only human labor, energy, raw materials and man-made physical capital, but also the amenity value of natural resources such as clean air and water.

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 the evaluation methodology. Hence, the rest of this report proceeds with the assumption that benefit-cost analysis is the primary organizing principle of project and program evaluation and selection. This is appropriate given both the compelling case made by economic theory and the nearly-universal adoption of this concept in modern market and governmental decision processes.

Accepting comprehensive benefit-cost analysis as the appropriate analytical framework solves most, but not all, of the problems of practical implementation of a project and program evaluation framework. Accepting this framework has several numerous practical, as well as theoretical, advantages:

- There is a large literature on how to treat almost all of the elements of a benefit-cost analysis, such as calculation of transportation project benefits, adoption of appropriate discount rates, etc.
- The fact that benefit-cost analysis uses monetary measures dovetails well with budgetary and financing issues, which are also in monetary terms.
- Formal methods have been established to deal with uncertainty in the decision environment.
- Formal rules of project prioritization and selection follow naturally from the benefit-cost framework.

What Are Costs and Benefits

Most of the economic benefits of transportation improvements result from travel time and cost savings to transportation system users, such as reductions in travel time (time savings), vehicle operating costs, accidents, and improvements in the reliability of transportation systems or services, quantified as reductions in travel time. Most of the other benefits from transportation investments are indirectly a product of these primary user benefits. For example, changes in land values in close proximity to a new transportation project are largely the result of the "capitalization" of the future stream of travel time benefits in real estate. Counting these changes in land value in addition to the travel time benefits to transportation system users would result in the double counting of the initial benefit. The benefits of transportation projects may be either positive or negative, as would be the case if travel times were to increase as a result of some intended action. This is potentially confusing terminology, as a negative benefit seems like an oxymoron. By convention the results of the investment are captured as benefits (whether good or bad), while the accounting of costs of the investment is limited to the actual costs (capital, operating, etc.) associated with implementing the project or policy.

Limitations of Benefit-Cost Analysis

Performing truly comprehensive benefit-cost analysis in a complex practical setting, however, introduces some empirical and policy challenges. Specifically:

- **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. In technical terms, benefit-cost theory does not tell the analyst how to make inter-personal comparisons; it assumes that if there are net gains to the community as a whole, that the community will devise a means of balancing, or effecting compensation between, "winners" and "losers".
- **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. Procedures should be developed to introduce estimates of such benefits. These procedures, involving such techniques as contingent valuation or multi-criterion weighting methods, should be built into the evaluation framework if they are deemed generally to be important.
- **Project Screening:** 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 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. Hence, methods should be employed to define and configure project alternatives in a way that does not (a) leave out the most valuable alternative or (b) dissipate analyst resources on alternatives with low value. Candidate project screening methods thus need to be adopted which, while operating on benefit-cost principles, are less demanding than comprehensive benefit-cost analysis (BCA), yet respect the analytical and budgetary context of the framework.
- **Tool Use:** The evaluation framework must fit well operationally, and organizationally, within existing organizational parameters. In the PSRC context, for example, it is important to make the evaluation framework consistent with the existing modeling resources of the organization, because these are expensive to develop and are already embedded in other decision processes, and to take advantage of newer modeling resources as they become available through model improvement programs. This means that the evaluation framework should be adapted over time to make the most of available technical resources.
- **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. Even if these constraints do not limit the set of projects perpetually, they impose timing or sequencing constraints that have the same conceptual effect.

For the purposes of the PSRC application of the BCA tool, there are some general limitations in the application:

- 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 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.

- 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 specific limitations in the BCA tool:

- It is limited by the data produced by the travel models and modeling assumptions. For example, in the current PSRC travel model, user benefits are accrued to aggregate segments of the population because the models produce only these aggregate segments, but the PSRC model under development may be able to reflect user benefits to each person because the models include individuals. This could improve equity analysis because user benefits would be reported by different person and household characteristics.
- 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.
- 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 careful analysis will test the sensitivity of the results to various cost assumptions.

Benefit-Cost Analysis Approach

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. Appendix B describes the general mechanics of the data flow between the travel model and the benefit-cost accounting software. 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.

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.

The PSRC BCA tool is entirely consistent with the steps presented in the "Red Book" and outlined above, where steps 1, 2, and 5 are handled directly in the PSRC regional travel demand models; steps 3 and 4 are user defined parameters in the BCA tool; steps 6 and 7 are internal processes of the Benefit-Cost Analysis Tool program; and steps 8 and 9 are implemented in a standard spreadsheet software package. There are a few cases where assumptions (such as the value of time) are set in both the BCA tool and the regional travel demand model; the general practice for PSRC is to set these assumptions to match for consistency.

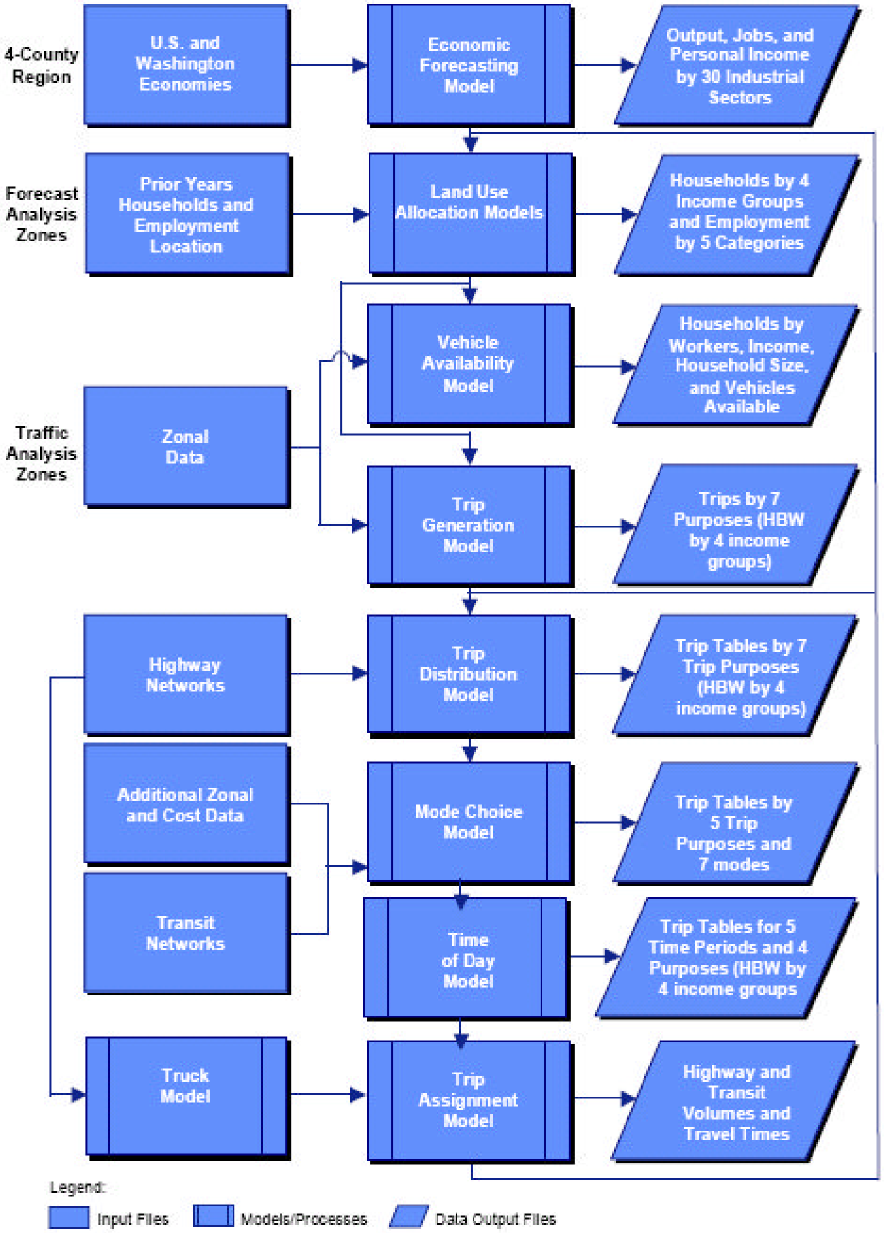
Regional Travel Modeling

The PSRC regional travel model is structured around theories of micro- and macroeconomics, economic geography, and sociology, and is therefore an appropriate modeling setting for generating transportation performance data that is a primary input to the benefit-cost analysis process. Travel models are supplied with economic conditions, land use distributions, transportation system user revealed preferences, and transportation supply conditions. The travel models incorporate a number of discrete choice models that represent utility maximizing behavior, and assignment and feedback procedures that ensure a demand-supply equilibrium condition.

For example, the probability of a trip maker choosing a mode of travel is a function of the "utility" of that mode versus the aggregate utility of all available modes. Borrowed from the microeconomics theory of consumer behavior, a utility function measures the amount of satisfaction one receives from the consumption of a certain good, in this case, the use of a particular mode of travel. The linear utility function of each mode is composed of variables describing the characteristics of the alternative and those of the decision-maker.

Assigning trips to transportation networks involves procedures that are likewise consistent with a framework for producing measures of user benefits. The highway assignment uses an equilibrium procedure to assign carpool and non-carpool trips to the roadway network for different time periods. This is a user optimal procedure that is based on the assumption that each traveler chooses a route that is the shortest time (and cost) path. See PSRC Travel Model Documentation (for Version 1.0) for more details on the PSRC Travel Models[2]. Figure 1.1 below displays the various elements of the PSRC Travel Models.

Figure 1-1. Land Use and Travel Demand Forecast Process



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[2] http://www.psrc.org/about/pubs/models

2. General Methods

Comparison Against a Baseline

The conceptual framework for estimating the economic benefits from transportation improvements is relatively straightforward. Measuring benefits requires that each project or policy being considered be compared against some alternative scenario. The alternative scenario, or counterfactual, is a state of the world without the improvement (that maintains current transportation system conditions into the future), or a state of the world with some alternate improvement project. To conduct the benefit-cost analysis, benefit and cost levels are estimated for the two different scenarios. The differences in costs and benefits are the economic impacts linked to the project.

It is very hard to measure the total benefits that a transportation alternative generates; in general, we must be content with measuring how it performs relative to some base case ("marginal analysis"). This seeming limitation is actually an advantage:

- Marginal analysis forces one to articulate the key, distinguishing features of the new policy or investment.
- Where alternatives cannot be distinguished from one another on a particular criterion, that criterion is irrelevant to policy choice and can be ignored.
- All behavioral models (such as those embedded in PSRC's regional travel demand models) are much more accurate if they report the effects of incremental changes rather than absolute values for a particular investment 30 to 40 years in the future.

The 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].

Measuring Costs and Benefits

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:

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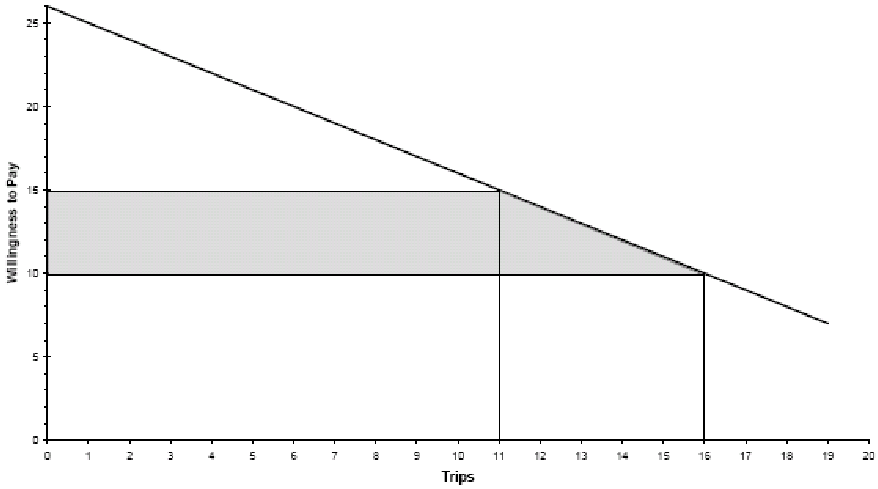
[3] ASSHTO; *A Manual of User Benefit Analysis for Highways*, 2nd Edition, 2002

[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

- 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. A simple example is illustrated in Figure 2.1. Figure 2 depicts willingness to pay at various trip levels and allows calculation of the consumer surplus without the project improvement (when the cost per trip is 15 cents per trip) and with the project (which reduces the cost per trip to 10 cents per trip). This calculation 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.

Figure 2-1. Stylized Calculation of Consumer Surplus



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

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[5].

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

$$B_{chst} = \Delta U_{chst}\left(\frac{V_{chst,0} + V_{chst,1}}{2}\right)L = (\Delta H_{chst} + \Delta OC_{chst} + \Delta AC_{chst})\left(\frac{V_{chst,0} + V_{chst,1}}{2}\right)L_s$$

where:

B_{chst} = user benefit to vehicle or user class c, at travel hour h, on link s, in project year, t

ΔU = change in per - VMT user cost

$\Delta H = H_0 - H_1$ = change in per – VMT (or per - user) valuer of travel time (without minus with)

$\Delta OC = \Delta OC_0 - \Delta OC_1$ = change in per - VMT (or per - user) operating costs (without minus with)

$\Delta AC = \Delta AC_0 - \Delta AC_1$ = change in per - VMT (or per - user) unreimbursed accident costs (without minus with)

V_0 = vehicles (or users) of class c in hour h without the improvement

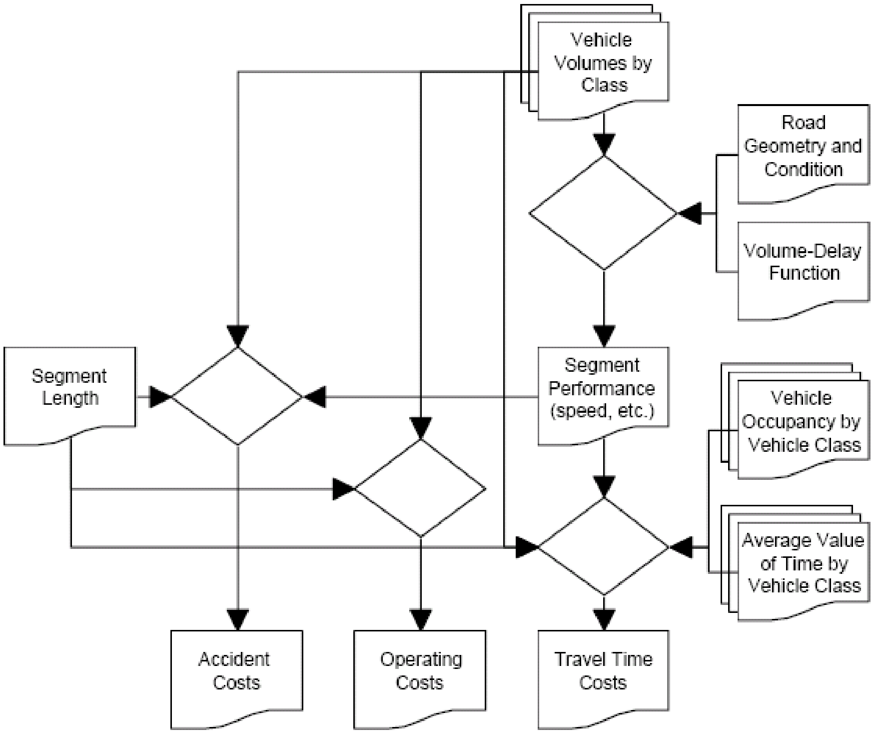
V_1 = vehicles (or users) of class c in hour h with the improvement

L = the segment or corridor length, in miles

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.

The formula above is a basic building block of user benefit analysis and therefore is simply referred to as the User Benefit Formula (UBF). The UBF is applicable to all user benefit calculations that involve changes in perceived user cost and play out over various origins and destinations or the various segments of travel corridors. It is general enough to be applied to analysis that is done by corridor, by road segment, by vehicle class or by user class. Figure 2.2 is a stylized representation of the relationships between dimensions of user costs and the segmentation of users and linkages to project characteristics (such as might be represented in the travel models).

Figure 2-2. Stylized Representation of the User Cost Linkages



In particular, the following project or program impacts lend themselves to monetization and are included in the PSRC BCA tool. Chapter 3 provides more detail about various cost input assumptions.

- **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.
- **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.

Estimating Streams of Annual Benefits and Costs

Analysis of user benefits relies upon the modeling of the project improvements and base case within the PSRC regional travel models. In general practice, the models will be used to analyze more than one analysis year both with the project and without the project being implemented. This results in user benefits that pertain to the specific years of analysis. For example, a project that is scheduled for implementation in the year 2018 might be included in a year 2020 and year 2040 model network. These networks, compared to the year 2020 and 2040 baseline, will yield benefits for each time period. For the purposes of benefit-cost analysis, these static benefits are then converted into streams of benefits over time, say for each year between the implementation year and some terminal year (e.g., 2018-2048). Various approaches to interpolation and extrapolation can be used to produce the necessary streams of benefits. Appropriate extrapolation methods depend upon the source of the single-year estimates of benefits that may or may not already include growth in all-day traffic, real income growth, and other factors that influence the growth of user benefits over time. For our purposes, where a sophisticated travel demand model is employed, simple interpolation and extrapolation rules are sufficient, and least subject to risks of unintentionally introducing estimation bias.

Discounting Benefits and Costs to Present Values

Streams of benefits, and costs, are needed in order to properly treat the time valuation of resources. Future benefits and costs must be converted into present value terms by applying an appropriate discount rate.

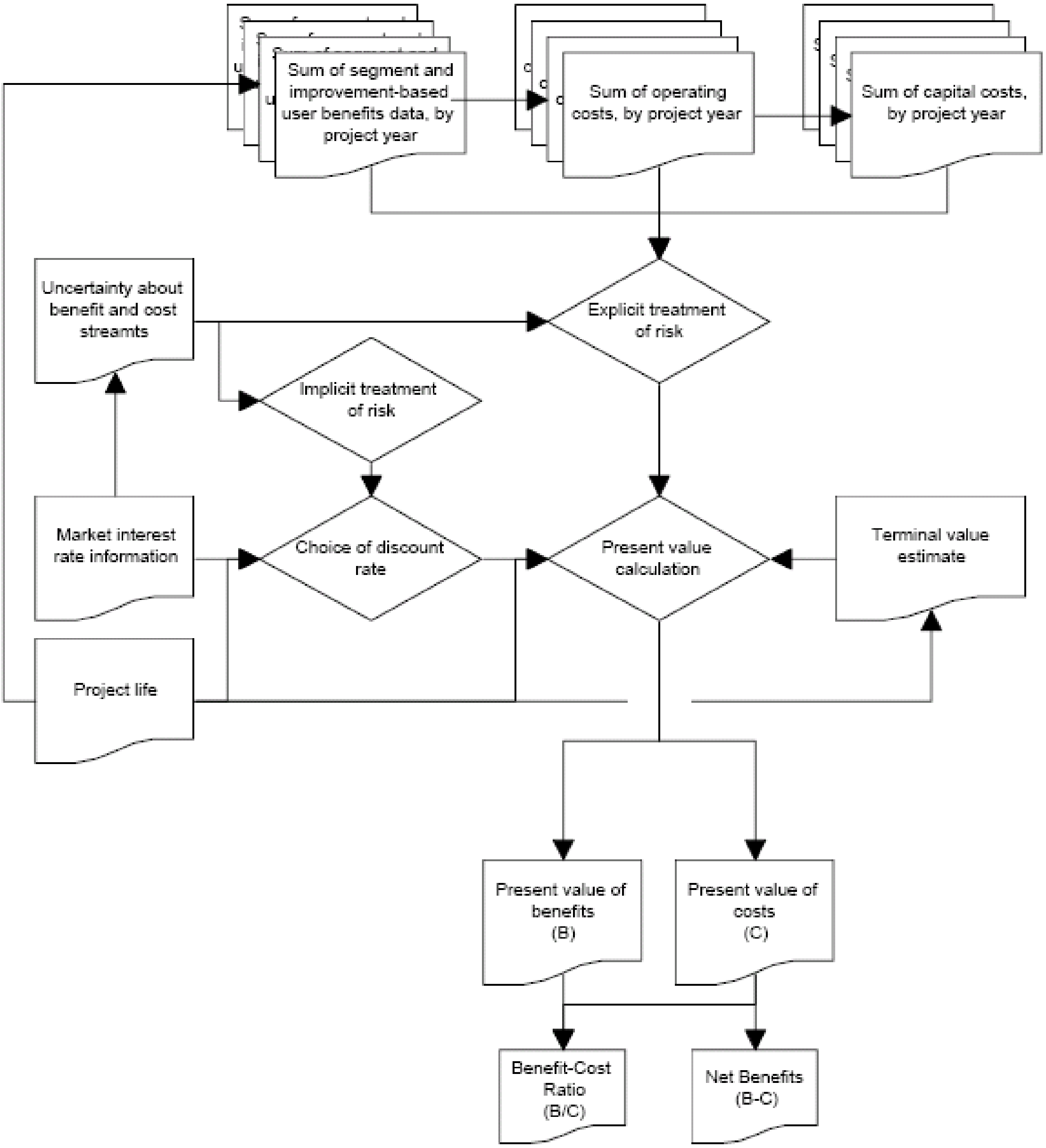
Present value calculations are important since society has the option of using the funds that are being dedicated to the project being evaluated for some other purpose instead. Spending resources on the project in question has an opportunity cost, which represent the benefits foregone by not making some alternative investment. Since financial markets tell us that we could always invest these resources with high probability of some known future returns on the investment (in a low-risk security), future benefits and costs should be discounted relative to benefits and costs experienced today. This is another way of saying that foregoing consumption today must be compensated with an opportunity for higher levels of consumption tomorrow.

The choice of discount rate, the factor applied to future benefits and costs in translating them to present values, is an important assumption in any benefit-cost analysis. The "Red Book" has the following to say about the choice of discount rates:

> *When there is no risk or uncertainty about the stream of future benefits and costs, and the social rate of time preference is the same as the private rate, transportation projects should be discounted using the riskless interest rates that prevail in private financial markets. The reason is that public projects are taking resources away from private projects, and they should be permitted to do so only if they offer a commensurate return. A good choice for the discount rate, thus, is the riskless rate of return that financial markets are currently offering over the same horizon as a cost or benefit element.*

Transportation forecasting analysis is subject to uncertainty and risk. In general, there will be 1) sources of forecast risk (e.g., regional growth and real income growth), 2) sources of uncertainty associated with elements of the traffic forecasts (e.g., values of time and other aggregation biases), and 3) sources of project financial risk (e.g., costs and timing). Ideally, explicit treatments of these factors are incorporated into the forecasting process. But, often, treating all important areas of risk would involve unreasonable analytical burdens. An alternative approach can involve the use of a risk adjusted discount rate. The methods involved are beyond this report, but are discussed in many of the reference documents cited at the end of the report. Figure 2.3 is a stylized representation of the present value calculation process.

Figure 2-3. Stylized Representation of Present Value Calculations



Unit Cost Inputs and Other Parameters

A number of key assumptions must be made in order to develop estimates of the user benefits from transportation projects and programs. Many of these assumptions are themselves estimated from observations about behaviors or about prices determined through market transactions. Examples of assumptions about behavior that are important to the benefit-cost framework are the values of time for users of the transportation system. These values of time are estimated from observations about users' choices in the face of time and cost tradeoffs. A key issue is to ensure that the assumptions that are incorporated into the travel demand modeling of the performance of the transportation project or investments (such as users' values of time) are consistent with similar assumptions employed in the benefit-cost analysis. This is true for the PSRC BCA tool, as these important assumptions are taken directly from the travel model used to generate the project performance information.

Other important assumptions include unit costs associated with required resources or expected damages for example, the costs of one ton of any given pollutant, where the pollutant may cause a range of damages including damages to structures, the environment, and human health. Chapter 3 includes a discussion of key assumptions that are included in the PSRC BCA tool, and their default values.

Reporting of Results

While benefit-cost analysis is a systematic and technical approach to evaluation, it is essentially a normative discipline. Values employed in benefit-cost analysis are determined in part by existing rights as determined under the law. These rights lead to current distributions of wealth and to the measures of willingness to pay and consumer surpluses that are at the heart of economic analysis. Recognizing known constraints and analytical uncertainties, benefit-cost analysis still aims to present information that is relevant to decisions about what actions should be taken in order to lead to improved outcomes for society. In this sense any specific benefit-cost analysis is only important in terms of its contribution to a decision process.

To be relevant to a decision process, benefit-cost analysis findings must be presented in a manner that can be readily used by those charged with making the decision. These results must also be supported by transparency of the analytical assumptions. Benefit-cost analysis tries to answer the question about the magnitude of the benefits associated with an action minus the costs of taking that action. Are these net benefits positive and by how much? In principle, this answer can come in the form of a single numerical value. This is rarely satisfying to any audience of decision-makers. Often the details behind the results (whether they be details of the timing, type, or recipient of benefits and costs) are of as great an interest to the audience. The reporting of results should be tailored to the audience, but must also conform to the underlying principles of the analytical approach.

Results should be reported in a comprehensive manner, taking care not to introduce bias in the communication of the findings. The present value of the benefits less the costs is the preferred approach to summarizing benefit-cost analysis results. Reporting on benefit-cost ratios or internal rates of return alone can mislead due to scaling problems.

In the end, people, and not analysis, make decisions. Benefit-cost analysis is designed to provide information that is relevant to the decision process and is not intended to substitute for human judgment. While this last point may seem obvious, it is an important tenet of a carefully designed analytical process.

3. User Inputs: Default Rate and Cost Parameters

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. This report contains an extensive, but not exhaustive, bibliography of reference materials regarding elements of this literature.

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. This chapter documents the "default" assumptions for a range of inputs to the analysis performed by PSRC.

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.

Value of Travel Time Saved

In 1992 Kenneth Small observed that there appeared to be sufficient consistency in the evidence to suggest that the value of time spent traveling to work could be approximated by 50 percent of the gross wage rate[6]. Small observed that this was a reasonable average that would vary considerably (between 20 percent and 100 percent) across regions and possibly even more among subgroups of a population. Recently Small and David Brownstone estimated values of time savings and improvements in travel time reliability for two California road pricing projects, the I-15 HOT Lanes in San Diego and the State Route 91 (SR91) facility in Orange County[7]. Their empirical results confirm original estimates and reveal values of time of $20-$40 per hour (50 percent-90 percent of area average wage rates) during the morning commute.

Common assumptions about values of time often focus upon the 50 percent of gross wage rate estimate, even through Small's original conclusion emphasizes the heterogeneity of value of time both across and within a given population. Often this simplifying assumption is a result of the lack of available local data about people's reveled behavior in the face of time-money tradeoff opportunities. As an example, the PSRC regional travel demand model has historically employed

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[6] Small, Kenneth, "Urban Transportation Economics", Vol. 51 of *Fundamental of Pure and Applied Economics*, Char, Switzerland, Harwood Academic Publishers, 1992.

[7] Brownstone, David and Small, Kenneth, *Valuing Time and Reliability: Assessing the Evidence from Road Pricing Demonstrations*, Transportation Research A, 39, 279-293, 2005.

value of time assumptions that are approximately 50 percent of average regional wage rates for each of four household income quartiles. With no tolling projects or demonstrations in operation, the region has had to adopt more global estimates and has only recently conducted stated preference experiments in an attempt to refine such estimates.

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 Traffic Choices Study provided the opportunity to observe value of time directly as a function of actual route choices made over the course of the experiment. Participants faced a financial incentive to avoid routes with high toll values. In many cases participants chose longer, more time-consuming routes that resulted in lower toll costs. These explicit decisions allowed the study team to estimate value of time across the study sample and over an extended period of observation.

The value of time was computed for each household, vehicle, or worker unit of observation. It is implicit in the observed rate at which participants demonstrated willingness to choose a longer path to reduce exposure to tolls (relative to the control conition.) 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. This is generally consistent with the range of findings of Small and Brownstone mentioned above.

Truck Values of Time

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[8] up to $73 per hour[9] for trucks, with one additional source identifying the range as $25 per hour to $200 per hour[10]. 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. These ranges for truck values of time were also discussed with the Washington State Freight Data System Working Group and there was a general consensus that the $50 per hour values of time for heavy trucks was reasonable.

Values of Time by Other Market Segments

The Traffic Choices observed data indicated that values of time were 50 percent higher than previously assumed in the PSRC regional travel demand forecasting model (Version 1.0) for all trip types. The Traffic Choices study was unable to identify any different values of time by vehicle occupancy (SOV and HOV) because these data were not collected as part of that study. Instead, we analyzed the 2006 PSRC household travel survey to identify the mix of trips by purpose (work and non-work) and time of day (am peak, midday, pm peak, evening and night) for carpool and

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

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

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

vanpool trips to generate weighted values of time for these trips. These take into account vehicle occupancy and so represent the cumulative value of time of all persons in the vehicle. For this purpose, a factor of 1.5, 2.0, and 6.0 was used to represent the conversion of vehicle values of time to person values of time for HOV2, HOV3+ and vanpools, respectively. The household survey was also used to identify the portion of non-work tours that are made for work and non-work purposes, by income group, to derive weighted average values of time for the non-work trips that comprise these tours. This accounts for the different definition of tours in the Traffic Choices Study and trips in the regional travel demand forecasting model. Truck values of time were specified from a review of national literature sources and discussed with the Washington State Freight Data System Working Group.

Figure 3-1. Default Values of Time in 2040 (2000 Dollars)

Field	AM	MD	PM	EV	NI
HBW Drive 1	9.57	9.57	9.57	9.57	9.57
HBW Drive 2	17.64	17.64	17.64	17.64	17.64
HBW Drive 3	25.71	25.71	25.71	25.71	25.71
HBW Drive 4	33.33	33.33	33.33	33.33	33.33
HBW Transit IVT 1	9.57	9.57	9.57	9.57	9.57
HBW Transit IVT 2	17.64	17.64	17.64	17.64	17.64
HBW Transit IVT 3	25.71	25.71	25.71	25.71	25.71
HBW Transit IVT 4	33.33	33.33	33.33	33.33	33.33
HBW Transit Wait 1	23.94	23.94	23.94	23.94	23.94
HBW Transit Wait 2	44.14	44.14	44.14	44.14	44.14
HBW Transit Wait 3	64.32	64.32	64.32	64.32	64.32
HBW Transit Wait 4	83.39	83.39	83.39	83.39	83.39
HBW Transit Walk 1	23.94	23.94	23.94	23.94	23.94
HBW Transit Walk 2	44.14	44.14	44.14	44.14	44.14
HBW Transit Walk 3	64.32	64.32	64.32	64.32	64.32
HBW Transit Walk 4	83.39	83.39	83.39	83.39	83.39
Heavy Trucks	50.0	50.0	50.0	50.0	50.0
Light Trucks	40.0	40.0	40.0	40.0	40.0
Medium Trucks	45.0	45.0	45.0	45.0	45.0
Other Driving	15.68	15.68	15.68	15.68	15.68
Other Transit IVT	10.0	10.0	10.0	10.0	10.0
Other Transit Wait	25.02	25.02	25.02	25.02	25.02
Other Transit Walk	25.02	25.02	25.02	25.02	25.02
SR2	30.14	19.29	22.91	20.5	26.52
SR3	38.09	21.28	26.88	20.5	26.52
Vanpool	101.73	37.19	26.88	21.28	87.38

HBW = Home-base Work Trips
IVT = In-vehicle Time
SR2 = Shared Ride (2 persons)
SR3 = Shared Ride (3+ persons)

Travel Time Reliability Benefits

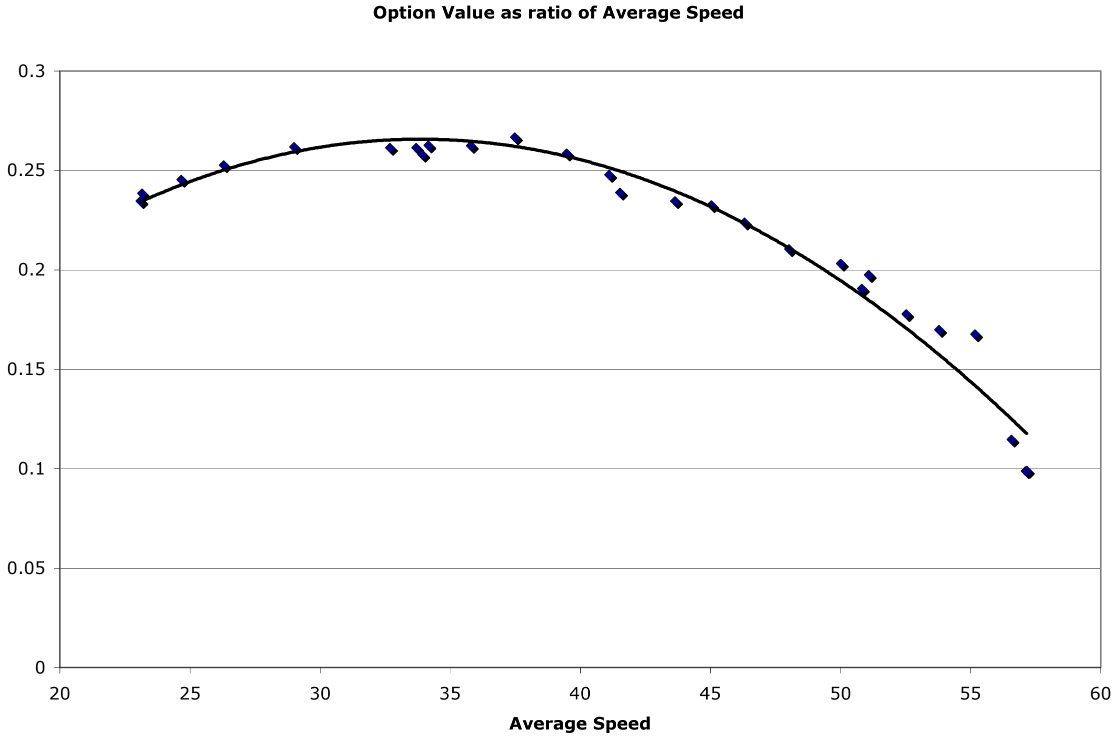
In addition to travel time savings (measured as changes in time resources for an average weekday from the regional model), there are potential benefits from improved reliability associated with a policy or investment. These concepts have been gaining greater attention in transportation project and program analysis. Reliability is the degree to which facility performance (speeds) vary stochastically from the mean or typical condition. Since the regional models represent an average weekday condition, the inclusion in the benefit-cost analysis tool of an accounting of benefits from improved reliability relies upon an observation of a more-or-less normal distribution of travel times around a time-, location-, and facility-specific average. A high degree of variation implies that there is a higher risk of experiencing particularly onerous conditions; low variation implies lower risks.

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.

Over several decades dealers in stocks, commodities, and insurance have developed methods for translating variability about a mean into a "value of certainty." For example, what amount (called a "put option") would a buyer be willing to pay for the option to purchase, at a future time, a stock at its expected price? This amount can be calculated from knowledge about the variability of the stock price around its mean. As applied to travel on roads, this method of analysis calculates, for a given facility, an "absolute certainty" speed which is equivalent in the traveler's mind to traveling on that same facility at a higher speed but with some positive risk of encountering a lower speed. For example, a traveler might be indifferent between travel on a congested freeway with an average speed of 45mph and a positive probability that the speed might drop much lower, and travel with an absolute certainty of maintaining an average speed of 40mph.

The data that permitted the estimation of this certainty equivalent already exist. For many years the Washington State DOT has collected five-minute vehicle counts and speeds at many locations on the region's highway network. The Puget Sound Regional Council hired ECONorthwest to analyze a subset of the data for the "certainty-equivalent value of unreliability." The analysis compared the lowest 1 percent speeds with the mean speeds at several locations for hundreds of time periods. The graph below displays the option value as a ratio of the mean speed condition for any link in the modeled network.

Figure 3-2. Travel Reliability Option Value



As a consequence for the benefit-cost analysis, mean travel time, or speed, conditions carry with them certainty equivalents (measured in time increments) of unreliability. These time increments are then valued for each highway user class according to their values of time described above. These can be included as consumer surplus calculations along with other user benefits. This certainty equivalent has also been implemented in the traffic assignment portion of the regional travel model in the form of a time penalty following a general link volume delay functional form as below.

$$\text{VDF delay} = t_1 = t_0 + t_0 a\left(\frac{V}{C}\right)^b$$

where

t_1 = delay in minutes per mile

t_0 = freeflow time in minutes per mile

V = total link volume in PCE

C = total link capacity in PCE

a,b = parameters of the BPR VDF formulation

$$\text{VDF delay under unreliability} = t = t_1 + U(t_1) = t_0 + t_0 a\left(\frac{V}{C}\right)^b + U(t_1)$$

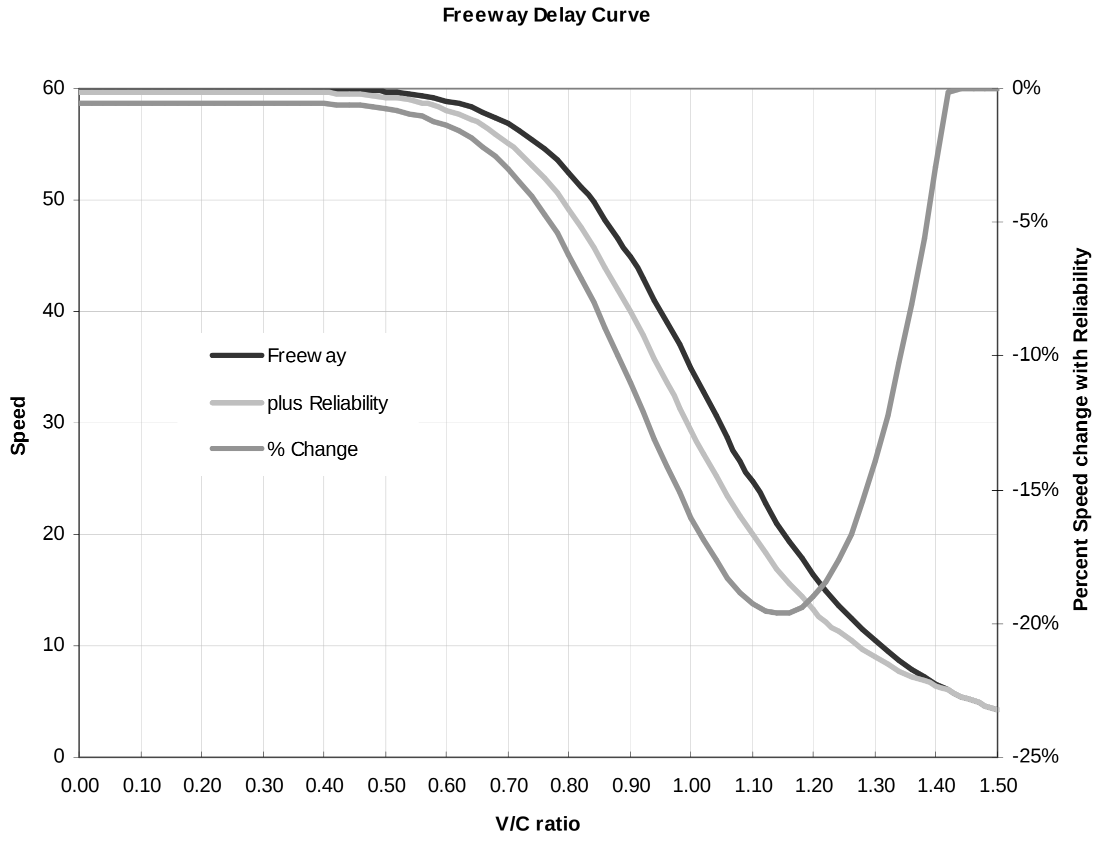
where

$U(t_1)$ = certainty - equivalent delay penalty (in min./mi.) from unreliability at t_1

$= c + et_1 + ft_1^2 + gt_1^3 + ht_1^4$

This yields the following relationship between freeway link volumes and link speeds with and without the unreliability penalty.

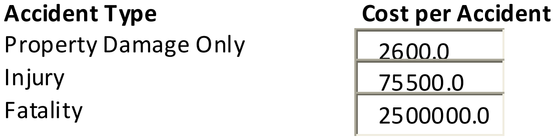
Figure 3-3. Freeway Delay with and Without Reliability Factor



Accident Cost Savings

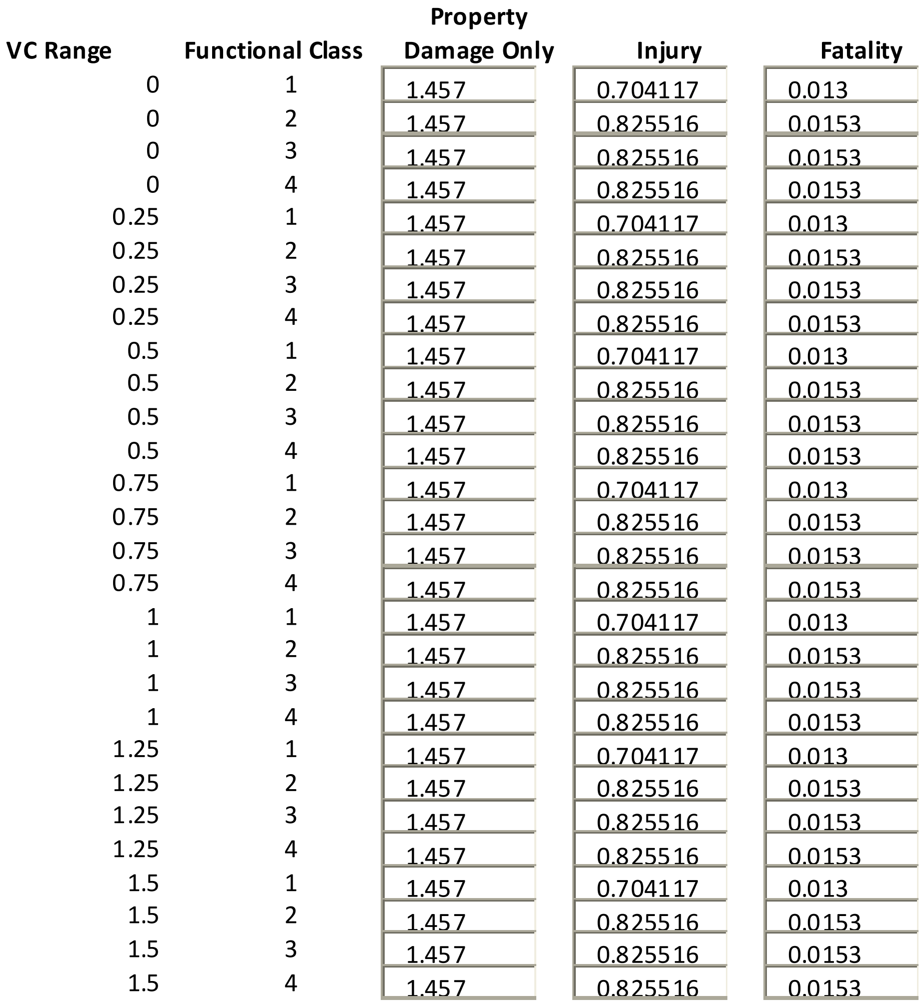
The literature provides adequate guidelines on how to value mortality, morbidity and property loss consequences of accidents. One such source is the U.S. Department of Transportation, National Highway Traffic Safety Administration's, T*he Economic Impact of Motor Vehicle Crashes 2000, Appendix A.* In 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.

Figure 3-4. Default Costs per Accident in 2040 (2000 Dollars)



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

Figure 3-5. Default Accident Rates (Accidents per Mile)



VC Range	Functional Class	Property Damage Only	Injury	Fatality
0	1	1.457	0.704117	0.013
0	2	1.457	0.825516	0.0153
0	3	1.457	0.825516	0.0153
0	4	1.457	0.825516	0.0153
0.25	1	1.457	0.704117	0.013
0.25	2	1.457	0.825516	0.0153
0.25	3	1.457	0.825516	0.0153
0.25	4	1.457	0.825516	0.0153
0.5	1	1.457	0.704117	0.013
0.5	2	1.457	0.825516	0.0153
0.5	3	1.457	0.825516	0.0153
0.5	4	1.457	0.825516	0.0153
0.75	1	1.457	0.704117	0.013
0.75	2	1.457	0.825516	0.0153
0.75	3	1.457	0.825516	0.0153
0.75	4	1.457	0.825516	0.0153
1	1	1.457	0.704117	0.013
1	2	1.457	0.825516	0.0153
1	3	1.457	0.825516	0.0153
1	4	1.457	0.825516	0.0153
1.25	1	1.457	0.704117	0.013
1.25	2	1.457	0.825516	0.0153
1.25	3	1.457	0.825516	0.0153
1.25	4	1.457	0.825516	0.0153
1.5	1	1.457	0.704117	0.013
1.5	2	1.457	0.825516	0.0153
1.5	3	1.457	0.825516	0.0153
1.5	4	1.457	0.825516	0.0153

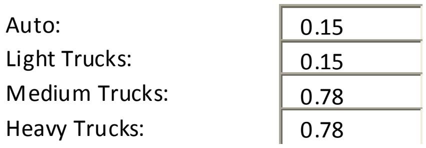
Vehicle Operating and Ownership Cost Savings

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, the 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. The approach taken employed a few basic assumptions

- Vehicle operating costs for the purpose of this effort were defined as fuel and maintenance costs.
- Forecasting motor vehicle operating costs requires forecasts of the cost of motor fuel. This is necessary both because motor fuel costs are the largest, single component of fuel and maintenance expenses, and because future trends in fuel costs will affect average fleet efficiency.
- What is relevant for travel modeling is the effective cost of operating a motor vehicle.

Although CAFE standards and other regulatory efforts will have an effect on fleet efficiency over time, their effect is only on new additions to the fleet. Household behavior causes the fleet average fuel efficiency to trail CAFE standards significantly. The higher purchase cost of more fuel-efficient vehicles, and the reduced primary- and secondary-market value of less efficient and older vehicles, causes less-fuel efficient vehicles to remain longer in the fleet. The interaction of these factors influences utilization of vehicles of various types and efficiencies and, hence, the effective fuel and maintenance cost of vehicles in the fleet. The approach taken, therefore, was to model the trends and influences of fuel costs on effective vehicle operating costs.

Figure 3-6. Default Vehicle Operating Costs per Mile in 2040 (2000 Dollars)



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)[11] 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.

Air pollution from vehicle emissions imposes a variety of costs including: human health, visibility, agricultural yields, ecosystem functions, damage to property. There are a range of methods available for estimation of these various costs. These methods can include estimating losses from the damages, or estimating costs to avoid damages in the first place. Given the wide range of potential costs and methods of estimation, and given that for many of these costs there are no markets in which transactions can be observed, it is not surprising that there is a broad range of estimates associated with the costs of vehicle emissions. For a comprehensive discussion of these issues and estimates of costs please see Delucchi (1996) in particular. Default unit costs for vehicle emissions were set to represent a middle of the range of available estimates.

Estimates of the unit cost of Carbon Dioxide are especially broad, ranging from as little as $1 per ton to over $150 per ton. Given the quantities involved, this variability in cost assumption could materially change the results of analysis. It is difficult to establish the long-run costs implications of carbon emissions as well as the proper approach to inter-temporal, or inter-generational, exchanges (discounting costs that accrue far in the future). As with other areas of uncertainty, it is

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

appropriate for the analyst to test the sensitivity of the results to alternate assumptions. The default cost per ton of Carbon Dioxide was set to be consistent with the maximal value of CO2 traded on the European Climate Exchange[12].

Figure 3-7. Default Vehicle Emissions Costs per Ton in 2040 (2000 Dollars)

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

Figure 3-8. Default Vehicle Emissions Rates in 2040 (Tons per Mile)

Pollutant	Speed Class	Car	Light Truck	Medium Truck	Heavy Truck
Carbon Dioxide	0	1367.87	1911.392	5260.83	5260.83
Carbon Dioxide	10	703.6223	979.6333	2604.637	2604.637
Carbon Dioxide	20	449.742	599.1229	1885.247	1885.247
Carbon Dioxide	30	375.1467	490.2579	1648.99	1648.99
Carbon Dioxide	40	353.9383	453.5595	1471.327	1471.327
Carbon Dioxide	50	347.6133	436.1347	1410.2	1410.2
Carbon Dioxide	60	356.3313	432.2829	1299.983	1299.983
Carbon Monoxide	0	21.28757	21.13314	9.160357	9.160357
Carbon Monoxide	10	13.9473	14.66225	5.04355	5.04355
Carbon Monoxide	20	12.4957	13.44995	2.91505	2.91505
Carbon Monoxide	30	12.26605	13.3525	2.08155	2.08155
Carbon Monoxide	40	12.8884	14.09565	1.86755	1.86755
Carbon Monoxide	50	13.7746	14.97025	2.14925	2.14925
Carbon Monoxide	60	14.61675	15.56575	2.675875	2.675875
Nitrogen Oxide	0	0.605071	0.692429	0.505643	0.505643
Nitrogen Oxide	10	0.43895	0.50575	0.40155	0.40155
Nitrogen Oxide	20	0.3965	0.4545	0.3406	0.3406
Nitrogen Oxide	30	0.3887	0.4427	0.32715	0.32715
Nitrogen Oxide	40	0.3973	0.451	0.3572	0.3572
Nitrogen Oxide	50	0.4163	0.46525	0.4501	0.4501
Nitrogen Oxide	60	0.431375	0.475625	0.565375	0.565375
Volatile Organic Compound	0	1.567786	1.702571	0.768643	0.768643
Volatile Organic Compound	10	0.71255	0.76925	0.4292	0.4292
Volatile Organic Compound	20	0.55125	0.6101	0.28695	0.28695
Volatile Organic Compound	30	0.49535	0.5578	0.2164	0.2164
Volatile Organic Compound	40	0.4657	0.5307	0.178	0.178
Volatile Organic Compound	50	0.45225	0.50985	0.15955	0.15955
Volatile Organic Compound	60	0.4585	0.498625	0.1555	0.1555
Particulate	0	0.0116	0.0113	0.0381	0.0381
Particulate	10	0.0116	0.0113	0.0381	0.0381
Particulate	20	0.0116	0.0113	0.0381	0.0381
Particulate	30	0.0116	0.0113	0.0381	0.0381
Particulate	40	0.0116	0.0113	0.0381	0.0381
Particulate	50	0.0116	0.0113	0.0381	0.0381
Particulate	60	0.0116	0.0113	0.0381	0.0381

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[12] http://www.ecx.eu/ECX-Historical-Data

Appendix A: Benefit Cost Analysis and Least Cost Planning

The Washington State law pertaining to regional transportation plans that are prepared by Regional Transportation Planning Organizations (RTPO) was amended in 1994 to require "least-cost planning." Specifically, the language states that the regional transportation plan must be "based on a least-cost planning methodology that identifies the most cost-effective facilities, services, and programs" [RCW 47.80.030(1)]. This amendment was sponsored by Senator Drew, who was asked on the Senate floor about his intention in requiring RTPOs to institute a least-cost planning methodology. Senator Drew responded:

> *I recognize that least-cost planning methodologies for transportation are just being developed, will need to be assessed and will take some time to validate. My intent with this amendment is for regional transportation planning organizations to incrementally implement these methodologies as they are developed, and to be at the forefront in developing and testing these least-cost planning methodologies. . . . Since regional transportation plans are to be reviewed at least every two years, there will be opportunity for least-cost planning methodologies to be implemented for future plan updates. It is my intent that the Department of Transportation should recognize this intent in implementing this bill.*
>
> *Journal of the Senate, p. 540.*

In accordance with this intent, the Washington State Department of Transportation (WSDOT) has adopted regulations pursuant to RCW 47.80.070 to establish minimum standards for development of regional transportation plans. WAC 468-86-030 defines least-cost planning as "a process of comparing direct and indirect costs of demand and supply options to meet transportation goals and/or policies where the intent of the process is to identify the most cost-effective mix of options".

In October 2009, WSDOT released Least Cost Planning Guidance[13] for Regional Transportation Planning Organizations. Within this guidance they define Least Cost Planning as follows:

> *A planning analysis that identifies the most cost-effective, multimodal project and program investment strategies, while taking into account supply and demand, full life cycle costs and project and program externalities.*

WSDOT recommends "treating least cost planning when applied to transportation, as a version of benefit-cost analysis. Benefit-cost analysis is a methodology long employed for evaluating transportation projects and strategies." Least-cost planning is a set of methods developed for resource planning in the electric utility industry. The planning procedures are designed to help identify new resource development to meet future demand loads through the most cost effective means. Typically, least-cost planning generalizes the investments in new power generating capacity, or demand side control programs, in order to identify the mix of strategies that offer a cost-effective approach to future demand conditions. Specific resource investments are then designed, or acquired as particular opportunities arise. There has been some considerable

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[13] *WSDOT Least Cost Planning Guidance*, accessed March 2010. http://www.wsdot.wa.gov/NR/rdonlyres/FDBC2704-7998-49D9-9F70-B16F5D1A0B2E/0/LeastCostPlanningexampledefinitionsfordiscussion.pdf

interest in applying these practices to transportation planning. However, some significant differences between transportation and energy resource planning have made such a simple application to transportation difficult. For example, in energy planning benefits can be expressed in a constant unit of analysis (kilowatt hour), while this is not possible for transportation analysis. It is possible to overcome some of these limitations in the transportation arena, by defining least-cost planning as essentially a strategic planning exercise with benefit-cost analysis at its core.

The WSDOT guidance states that "RTPOs applying a formal quantitative methodology are referred to the FHWA primer for methodology guidelines. For RTPOs wishing a simpler and more qualitative approach, WSDOT suggests using the following checklist to develop the transportation plan. The checklist questions are generally already part of the RTPO planning process.

This PSRC Benefit-Cost Analysis methods document describes in some detail the quantitative methods employed by PSRC during the development of the regional transportation plan Transportation 2040. A combination of this quantitative approach to benefit-cost analysis and the strategic planning framework used in the development, analysis and selection of plan alternatives fulfills the state least-cost planning requirements. The WSDOT least cost planning checklist and a corresponding discussion of the PSRC approach are reprinted below.

LEAST COST PLANNING CHECKLIST FOR USE IN PREPARING REGIONAL TRANSPORTATION PLANS

1. What are this Region's objectives for this transportation plan?

This information can be found within the Transportation 2040 Final Environmental Impact Statement[14] Appendix D: Policy Analysis and Evaluation Criteria Report and Appendix F: Public Scoping Process. A number of important objectives were addressed within Transportation 2040 and three of the most central issues related to 1) congestion and mobility, 2) environment, and 3) transportation finance.

2. What are the performance measures that indicate the RTPO has optimized its plan?

- *Region-wide*
- *In specific sub-areas, if appropriate*

This information can be found within the Transportation 2040 Final Environmental Impact Statement Appendix D: Policy Analysis and Evaluation Criteria Report and Appendix I: Transportation 2040 Alternatives Analysis Congestion Management Process Report.

3. What alternatives were developed initially for this plan?

This information can be found within the Transportation 2040 Final Environmental Impact Statement Appendix A: Alternatives Technical Report.

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[14] *Transportation 2040 Final Environmental Impact Statement and Appendices*, accessed March 2010. http://www.psrc.org/transportation/t2040/t2040-pubs/transportation-2040-final-environmental-impact-statement/

4. How were the plan's alternatives refined and evaluated?

This information can be found within the Transportation 2040 Final Environmental Impact Statement Appendix A: Alternatives Technical Report.

5. How were the following factors addressed in creating and evaluating these alternatives?
- *Life cycle costs*
- *Multiple modes*
- *Demand projections*
- *Supply side limitations*
- *Externalities*

A full treatment of these issues and more can be found in the materials published under the Transportation 2040 Final Environmental Impact Statement, and especially within Appendix A: Alternatives Technical Report, Appendix B: Regional Trends and Forecasts, Appendix D: Policy Analysis and Evaluation Criteria Report, Appendix E: Technical Description of the Modeling Framework, and Appendix K: Data Analysis and Forecasting at the PSRC, New Tools Within an Integrated Modeling Framework.

6. How were startup capital and lifetime operating costs weighed against results?

These project and program costs were compared directly to the benefits of the plan alternatives. Costs over the life of the plan were itemized at appropriate temporal detail, annualized and compared with annual benefits. In addition streams of annual benefits and costs were discounted to present value and summed. Details of the cost accounting can be found in the Transportation 2040 Financial Background Appendix. Details about the evaluation criteria employed in the planning process can be found in the Transportation 2040 Final Environmental Impact Statement Appendix D: Policy Analysis and Evaluation Criteria Report.

7. Did the planning process use benefit-cost analysis, and if so, what method(s) and what were the results?

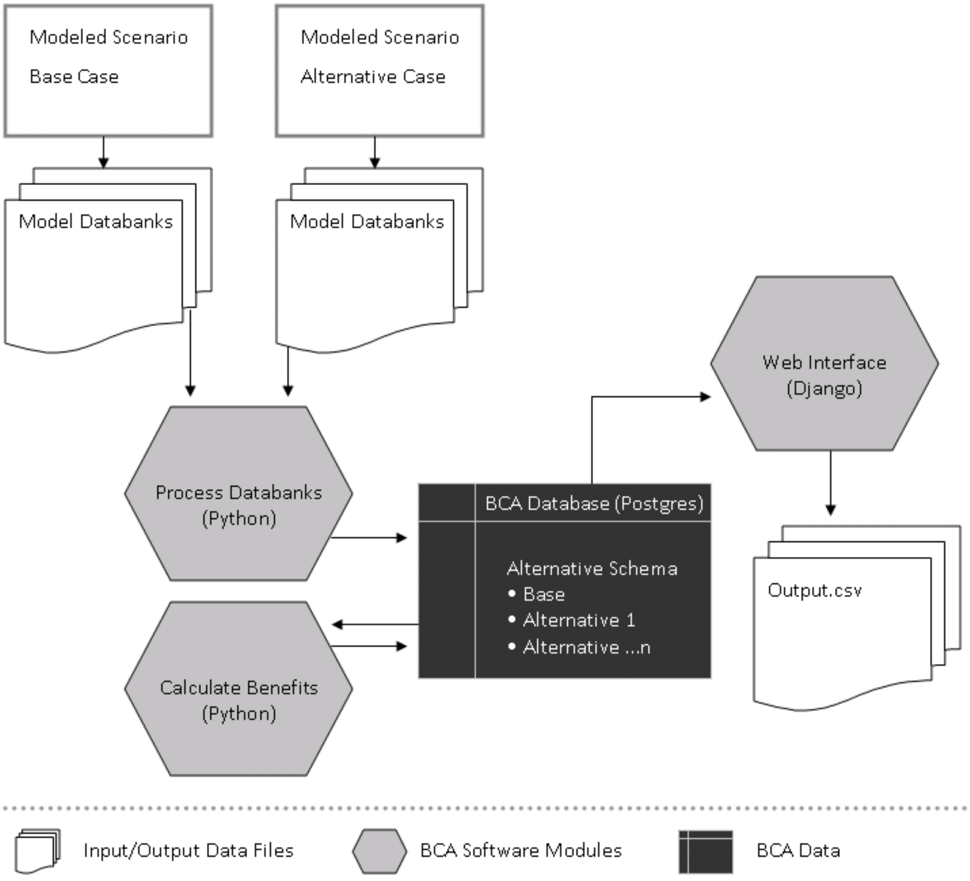
Yes, benefit-cost analysis methods were a central analytical element of the planning process. The analysis methods are outlined within this Benefit-Cost Analysis Methods documentation.

Appendix B: PSRC Benefit-Cost Analysis Tool

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 AASHTO and referred to as the "Red Book." [13] 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.

The software developed by ECONorthwest makes use of standard data available in specially prepared travel model databanks from the regional travel demand model software, EMME3. The databanks contain various trip cost, time, vehicle class and time of day information aggregated at either the origin-destination pair or links in the model network. This data is extracted and processed in a manner that permits consumer surplus and environmental benefit accounting when one model run is compared directly with another model run that is characterized as the base case scenario. The benefits-cost analysis tool consists of a number of software elements written in the Python programming language. Data is processed and stored as schema in a Postgres relational database. Results are then compiled through a web-based user interface (Django), with user programmable input parameters, and then tabulated in .csv output files that can be opened directly with standard spreadsheet software.

Figure B-1. Benefit-Cost Analysis Tool Flow Diagram



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

Bibliography

General References on Cost-Benefit Analysis

Adler, M. D., Eric A. Posner (Eds.) Cost-Benefit Analysis: Legal, Economic, and Philosophical Perspectives, 2001.

Boardman, A.E., Cost-Benefit Analysis: Concepts and Practice (2nd Edition), 1998.

Gal, Tomas (Editor), et al, Multicriteria Decision Making: Advances in McDm Models, Algorithms, Theory, and Applications (International Series in Operations Research & Management Science, 21), 1999

Doumpos, M. and Constantin Zopounidis, Multicriteria Decision Aid Classification Methods (Applied Optimization, V. 73) 2002

Londero, E., Benefits and Beneficiaries: An Introduction to Estimating Distributional Effects in Cost-Benefit Analysis, 1997

Layard, R. and Stephen Glaister (eds.), Cost-Benefit Analysis, June 1994.

Malczewski, J. GIS and Multicriteria Decision Analysis . 1999.

Panos M. Pardalos (Editor), et al, Advances in Multicriteria Analysis (Nonconvex Optimization and Its Applications ; V. 5), 1995

Puttaswamaiah, K. (Editor) Cost-Benefit Analysis: Environmental and Ecological Perspectives, 2002.

Saaty TL, The Analytic Hierarchy Process , NY, McGraw Hill, 1980

Zerbe, R. and Dwight Dively, Benefit-Cost Analysis in Theory and Practice, Harper Collins, New York, 1994.

References on Specific Topics in Project Evaluation

American Association of State Highway and Transportation Officials, Guide for the Design of High Occupancy Vehicle Facilities. Washington, DC (1992).

American Association of State Highway and Transportation Officials, Highway Safety Design and Operations Guide, 1997. Washington, DC (1997).

American Association of State Highway and Transportation Officials, A Policy on Geometric Design of Highways and Streets, 1994. Washington, DC (1995).

Apogee Research Inc., "Research on the Relationship Between Economic Development and Transportation Investment." NCHRP Report 418, Transportation Research Board, National Research Council (1998).

Arnott, R., and Small, K., "The Economics of Traffic Congestion." American Scientist, Vol. 82 (September–October 1994) pp. 446–455.

Arrow, K., “Essays in the Theory of Risk Bearing.” Markham Publishing, Chicago, IL (1970).

Bauer, K., and Harwood, D., "Statistical Models of At-Grade Intersection Accidents." No. FHWA-RD-96-125, Federal Highway Administration, Washington, DC (1996).

Bell, M., and McGuire, T., "Macroeconomic Analysis of the Linkages between Transportation Investments and Economic Performance." NCHRP Report 389, Transportation Research Board, Washington, DC (1997).

Blincoe, L., Seay, A., Zaloshnja, E., Miller, T., Romana, E., Luchter, S., and Spicer, R., "The Economic Impact of Motor Vehicle Crashes, 2000." DOT HS 809 446, National Highway Traffic Safety Administration, Washington, DC (2002).

Blincoe, L., "The Economic Cost of Motor Vehicle Crashes, 1994." National Highway Traffic Safety Administration, Washington, DC (1996).

Bonneson, J., and McCoy, P., "Capacity and Operational Effects of Midblock Left-Turn Lanes." NCHRP Report 395, Transportation Research Board, Washington, DC (1997).

Calfee, J., and Winston, C., "The Value of Automobile Travel Time: Implications for Congestion Policy." Journal of Public Economics, Vol. 69, (1998), pp. 83–102.

Cambridge Systematics, “Multimodal Corridor and Capacity Analysis Manual." NCHRP Report 399, Transportation Research Board, Washington, DC (1998).

Cambridge Systematics, "The Value of Travel Time” (Section 8.2) in Revisions to HERS. Federal Highway Administration, Washington DC (1997).

Cambridge Systematics, "Methods for Capital Programming and Project Selection." NCHRP Synthesis 243, Transportation Research Board, Washington, DC (1997).

Cohn, L., Watson, R., and Roswell, "Transportation Planning Handbook." Institute of Transportation Engineers (1992).

DeCorla-Souza, P. "Applying the "Cashing out" Approach to Congestion Pricing." Transportation Research Record, Vol. 1450, (1994), pp. 34–37.

DeCorla-Souza, P. "Comparing Cost-Effectiveness Across Modes." Federal Highway Administration, Metropolitan Planning Division, Washington, DC (1993).

DeCorla-Souza, P., and Cohen, H., “Accounting for Induced Travel in Evaluation of Urban Highway Expansion.” Federal Highway Administration, Washington, DC (1998).

DeCorla-Souza, P., Everett, J., and Gardner, B., "Evaluating the Options in Urban Areas with SOV Capacity Restrictions." Federal Highway Administration, Washington, DC (1994).

DeCorla-Souza, P., and Jensen-Fisher, R., "Comparing Multimodal Alternatives in Major Travel Corridors." Transportation Research Record, no. 1429, (1994), pp. 15–23.

Delucchi, M., "Emissions of Criteria Pollutants, Toxic Air Pollutants, and Greenhouse Gases, from the Use of Alternative Transportation Modes and Fuels." UCD-ITS-RR-96-12, Institute of Transportation Studies, University of California, Davis, Davis, CA (1996).

Delucchi, M., "Environmental Externalities of Motor-Vehicle Use in the U.S." Journal of Transport Economics and Policy, Vol. 34, no. 2, (May 2000).

Delucchi, M., "The Annualized Social Cost of Motor-Vehicle Use in the U.S. 1990–1991." Institute of Transportation Studies, Davis, CA (1996).

ECONorthwest and Parsons Brinckerhoff Quade & Douglas, “Estimating the Benefits and Costs of Public Transit Projects: A Guidebook for Practitioners.” TCRP Report 78, Transportation Research Board, Washington, DC (2001).

Eberts, R., McMillen, D., "Agglomeration Economies and Urban Public Infrastructure." In Handbook of Regional and Urban Economics, Volume 3, edited by Cheshire, P. and Mills, E., 1999.

Feldstein, M., “The Social Time Preference Discount Rate in Cost Benefit Analysis.” In Neoclassical Microeconomics, edited by Ricketts, M., Vol. 2, Gower, (1988), pp. 191–210.

Fuller, J., Hokanson, J., Haugarrd, J., and Stoner, J., “Measurements of Highway User Interference Costs and Air Pollution and Noise Damage Costs.” Final Report 34. DTFH61-80-C-00153, Federal Highway Administration, Washington, DC (1983).

Gillespie, J., “Estimating User Costs as a Basis for Incentive/Disincentive Amounts in Highway Construction Contracts.” FHWA/VTRC 98-R12, Virginia Transportation Research Council, Charlottesville, VA (1998).

Gluck, J., Levinson, H., and Stover, V., “Impacts of Access Management Techniques.” NCHRP Report 420, Transportation Research Board, Washington, DC (1999).

Gomez-Ibanez, J. "The Political Economy of Highway Tolls and Congestion Pricing." Transportation Quarterly, Vol. 46, No. 3, (1992), pp. 343–60.

Gomez-Ibanez, J., and O’Keefe, M., "The Benefits from Improved Investment Rules: The Case Study of the Interstate Highway System." DOT/OST/P-34/86-030, U.S. Department of Transportation University Research Program, Cambridge, MA (1985).

Gomez-Ibanez, J., Small, K., and National Research Council (U.S.). Transportation Research Board. "Road Pricing for Congestion Management : A Survey of International Practice." National Academy Press, (1994), 77.

Greene, D., Jones, D., and Delucchi, M., "The Full Costs and Benefits of Transportation: Contributions to Theory, Method, and Measurement." (1997).

Hallenbeck, M., "Choosing the Route to Traveler Information Systems Deployment: Decision Factors for Creating Public/Private Business Plans." Washington State Transportation Center, ITS America (1998).

Harwood, D., Council, F., Hauer, E., Hughes, W., and Vogt, A., "Prediction of the Expected Safety Performance of Rural Two-Lane Highways." FHWA-RD-99-207, Federal Highway Administration, Washington, DC (2000).

Hauer, E., “Observational Before-After Studies in Road Safety: Estimating the Effect of Highway and Traffic Engineering Measures on Road Safety.” Pergamon Press, Elsevier Science Ltd., Oxford, England (1997).

Hensher, D., "Value of Travel Time Savings in Personal and Commercial Automobile Travel." (May 1995).

Hicks, J., “The Valuation of Social Income.” Economica. (1939).

Institute of Transportation Engineers, "A Toolbox for Alleviating Traffic Congestion and Enhancing Mobility." ITE, Washington, DC (1997).

Jack Faucett Associates, "The Costs of Owning and Operating Automobiles, Vans and Light Trucks." Federal Highway Administration, Washington DC (1991).

Kaldor, N., “Welfare Propositions in Economics.” The Economics Journal, Oxford, England (1939).

Kittelson and Associates, "Roundabouts: An Informational Guide." Publication No. FHWA-RD-00-067, Federal Highway Administration, McLean, VA (2000).

Knudson, B., "The Value of Travel-Time: Estimates of the Hourly Value of Time for Drivers, Passengers, and Cargo in Oregon, 1997." Oregon Department of Transportation (1998).

Lee, D., "Full Cost Pricing of Highways." U.S. Department of Transportation, Research and Special Programs Administration, Cambridge, MA (1994).

Lee, D., "Uses and Meanings of Full Social Cost Estimates." Bureau of Transportation Statistics, U.S. Department of Transportation, John A. Volpe National Transportation Systems Center, Cambridge, MA (1995).

Lee, D., United States Federal Highway Administration, and Transportation Systems Center, "Methods for Allocating Highway Costs." U.S. Dept. of Transportation Federal Highway Administration; National Technical Information Service Distributor (1981).

Levinson, D., Gillen, D., Kanafan, A., and Mathieu, J., "Chapter 4: Highways." In The Full Cost of Intercity Transportation—A Comparison of High Speed Rail, Air, and Highway Transportation in California: Institute of Transportation Studies, University of California at Berkeley (1996).

Lewis, D., "Road User and Mitigation Costs in Highway Pavement Projects." NCHRP Synthesis 269, Transportation Research Board, Washington, DC (1999).

Litman, T., "Evaluating Public Transit Benefits and Costs." Victoria Transport Policy Institute, Victoria, BC (1999).

Litman, T. "Guide to Calculating Transportation Demand Management Benefits." Victoria Transportation Policy Institute, Victoria, BC (1999).

Lomax, T., Turner, S., and Shunk, G., "Quantifying Congestion: Volume 1." NCHRP Report 398, Transportation Research Board, Washington, DC (1997).

Lomax, T., Turner, S., and Shunk, G., "Quantifying Congestion: Volume 2—User's Guide." NCHRP Report 398, Transportation Research Board, Washington, DC (1997).

Louis Berger & Associates Inc., "Guidance for Estimating the Indirect Effects of Proposed Transportation Projects." NCHRP Report 403, Transportation Research Board, National Research Council, Washington, DC (1998).

MacKenzie, J., Dower, R., and Chen, D., "The Going Rate: What It Really Costs to Drive." World Resources Institute (1992).

McGee, H. W., Hughes, W., and Daily, K., "Effect of Highway Standards on Safety." NCHRP Report 374, Transportation Research Board, Washington, DC (1995).

Meyer, J., and Gómez-Ibáñez, J., "Autos, Transit, and Cities." Harvard University Press, Cambridge, MA (1981).

Meyer, J., Gómez-Ibáñez, J., Tye, W., and Winston, C., "Essays in Transportation Economics and Policy: A Handbook in Honor of John R. Meyer." Brookings Institution Press (1998).

Miller, T., Viner, J., Rossman, S., Pindus, N., Gellert, W., Douglass, J., Dillingham, A., and Blomquist, G., "The Costs of Highway Crashes. Final Report to the Federal Highway Administration." The Urban Institute, Washington, DC (1991).

Mitretek Systems Inc., "Intelligent Transportation Systems Benefits: 2001 Update." FHWA-OP-01-024, Federal Highway Administration, Washington, DC (1999).

Mitretek Systems Inc., "Intelligent Transportation Systems Benefits: 1999 Update." FHWA-OP-99-012, Federal Highway Administration, Washington, DC (1999).

Munnell, A., "How Does Public Infrastructure Affect Regional Economic Performance?" New England Economic Review (September/October 1990) pp. 11–32.

National Highway Institute, "Estimating the Impacts of Transportation Alternatives: Participant's Notebook." FHWA-HI-94-053, Federal Highway Administration, Washington, DC (1994).

National Highway Traffic Safety Administration, “Traffic Safety Facts 1999.” Washington, DC (2000).

Neuman, T., and Glennon, J., "Cost Effectiveness of Improvements to Stopping-Sight Distance Safety Problems." Transportation Research Record 923, Transportation Research Board, Washington, DC (1983).

Persaud, B., “Statistical Methods in Highway Safety Analysis A Synthesis of Highway Practice.” NCHRP Synthesis 295, Transportation Research Board, Washington, DC (2001).

Small, K., Chu, X., and Noland, R., "Valuation of Travel-Time Savings and Predictability in Congested Conditions for Highway User-Cost Estimation." NCHRP 2-18(2), Transportation Research Board, Washington, DC (1997).

Small, K. editor, "Congestion Pricing : Special Issue." Kluwer Academic, Norwell, MA (1992).

Small, K., and Kazimi, C., "On the Costs of Air Pollution from Motor Vehicles." Journal of Transport Economics and Policy, Vol. 29, No. 1 (1995), pp. 7–32.

Small, K., National Cooperative Highway Research Program, American Association of State Highway and Transportation Officials, and National Research Council (U.S.). Transportation Research Board, "Valuation of Travel-Time Savings and Predictability in Congested Conditions for Highway User-Cost Estimation." NCHRP Report No. 431, Transportation Research Board, Washington, DC (1999).

Small, K., Winston, C., and Evans, C., "Road Work : A New Highway Pricing and Investment Policy." Brookings Institution, Washington, DC (1989).

Tedesco, S., Alexiadis, V., Loudon, W., Margiotta, R., and Skinner, D., “Development of a Model to Assess the Safety Impacts of Implementing IVHS User Services.” Proceedings, IVHS America (1994).

Texas Transportation Institute. "Microcomputer Evaluation of Highway User Benefits." Program Report 7-12, Transportation Research Board. National Cooperative Highway Research, Washington, DC (1993).

Transcore, "Integrating Intelligent Transportation Systems within the Transportation Planning Process: An Interim Handbook." FHWA-SA-98-048, Federal Highway Administration, Washington, DC (1998).

Transportation Research Board, "Highway Capacity Issues: 1998." Transportation Research Record No. 1646, Transportation Research Board, Washington, DC (1998).

Transportation Research Board, "Highway Capacity Manual." Special Report 209, Washington, DC (2000).

U.S. Department of Transportation, "The Value of Travel Time: Departmental Guidance for Conducting Economic Evaluations." Washington, DC (1997).

Walls, J., and Smith, M., “Life-Cycle Cost Analysis in Pavement Design—Interim Technical Bulletin.” FHWA-SA-98-079, Washington, DC (1998).

Weinblatt, H., Stowers, J., Mingo, R., and Wheeler, P., "Alternative Approaches to the Taxation of Heavy Vehicles." Transportation Research Board Report 416, National Research Council, Washington, DC (1998).

Weisbrod, G., and Weisbrod, B. "Assessing the Economic Impact of Transportation Projects: How to Choose the Appropriate Technique for Your Project." Transportation Research Circular, Transportation Research Board Report 477, (October 1997) pp. 7–27.

Zegeer, C., Hummer, J., Reinfurt, D., Herf, L., and Hunter, W., "Cost Effective Geometric Improvements for Safety Upgrading of Horizontal Curves." FHWA-RD-021, Federal Highway Administration, Washington, DC (1991).

Zegeer, C., Hummer, J., Reinfurt, D., Herf, L., and Hunter, W., "Safety Cost-Effectiveness of Incremental Changes in Cross-Section Design Informational Guide." Report No. FHWA/RS-87-094, Federal Highway Administration, Washington, DC (1987).

Zegeer, C., Hummer, J., Reinfurt, D., Herf, L., and Hunter, W., "Safety Effects of Cross-Section Design for Two-Lane Roads, Volume I." Report No. FHWA/RD-87/008, Federal Highway Administration, Washington, DC (1986).

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