

TECHNICAL REPORT

Case Study:
**Testing Application of
Integrated Transportation Planning Methods on
System Level Evaluation**

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Preface *A Commentary*
Puget Sound Regional Council Staff

This case study offers a modest contribution to further the technical development and testing of a methodology to enhance the quality of information used by policy makers when evaluating major regional transportation system alternatives. The background to this effort was documented by the Regional Council in June 1995 with the publication of a report entitled Integrated Transportation Planning: A Primer for Policymakers. That primer described how the Regional Council was working to refine and adapt comparative system evaluation principles, referred to by the electric utility industry as "least-cost planning," for the evaluation of major surface transportation system alternatives.

Least-cost planning was used with some success by the electric utility industry in the Pacific Northwest in the 1970s, resulting in sound decisions to focus on renewable energy -- primarily conservation -- rather than invest in expensive new generating facilities. In that instance, the technical analysis was relatively simple; a kilowatt hour is essentially the same, regardless of how it is produced. The costs, benefits, and tradeoffs, were relatively clear and easy to quantify.

In transportation, however, the issues of "cost" and "benefit" are not so clear. For example, the perceived costs and benefits of trips on the regional transportation system vary greatly from person to person. For some, *access* -- the basic ability to just *make* the trip to a destination -- is a valued end in itself. Yet for others, the ultimate measure of the benefit of a trip is often *minimum travel time*, almost regardless of cost. How do current transportation planning practices try to accurately measure the costs and benefits of using the regional transportation system? Even using latest state-of-the-art transportation modeling tools and practices, the existing range of measurable benefits and costs is fairly limited as it relies heavily on "averaging" many complex travel elements such as trip length and trip travel time. These don't necessarily reflect the full range of benefits or costs associated with personal travel behavior.

Few individuals using the region's transportation system are aware of the ancillary costs of transportation related to accidents, air pollution, degradation of water quality, or even additional disposal requirements in land fills associated with many transportation related materials. Nor are people aware that there are direct relationships between the quality and accessibility of a region's transportation system and the resulting costs and benefits for many other *non-transportation* elements. Examples of a few of these other elements which have costs/benefits directly influenced by the quality and accessibility of the regional transportation system are the value of urban and rural land, affordable housing, and additional municipal services such as law enforcement or emergency services that are required to support travel on the transportation system. Should the public be aware of these costs or benefits? Should public officials consider these factors when making decisions on major transportation system investments? The premise of Integrated Transportation Planning is that better information and data on

direct and indirect benefits and costs of the transportation system should, to the extent possible, be identified and quantified for policy makers to improve the quality of public investment decisions.

This case study sought to advance the knowledge base of traditional transportation planning methodologies which, for the past three decades, have used variations of systems planning concepts. Under the banner of Integrated Transportation Planning (ITP), the Regional Council's case study provides initial insight into the potential merits and problems inherent with the application of broader economic benefit-cost concepts to traditional transportation planning practices. Though limited in the amount of resources able to be applied to the case study effort, the study does demonstrate improved results in the overall systems evaluation process. It also describes some significant data deficiencies and shortcomings that will require further attention before one should consider using these concepts ready for "real world" applications.

Summarizing a few lessons learned to date, the Regional Council suggests the following findings and caveats related to this particular case study effort:

- Additional research is needed to better understand and develop a more complete picture of the full costs and benefits of transportation systems for application to contemporary and future transportation decision processes. The need to better understand these issues in the transportation planning field is amplified when one considers how much "change" has already been found in personal travel behavior over the past several decades. Transportation modeling practices have been progressively changing to adapt and reflect significant economic and societal changes that impact personal travel patterns, many related to significant shifts in the economic landscape of urban and suburban areas, and with significant demographic shifts in the composition of the workforce. Fortunately, adequate documentation in professional literature is finally beginning to emerge describing the general nature and relationship of previously ignored "non-traditional" public, personal and societal costs of transportation systems. However, unlike "traditional" transportation modeling procedures, there is, as yet, no professional consensus or accepted standard for how to best measure or apply most of these non-traditional direct or indirect benefits or costs to the evaluation of transportation systems. In a like fashion, the probable effects (benefits) of improved system reliability and predictability (highway and transit) on an individual's choice of mode for personal travel (auto or transit) or on the freight industry's choices of routes or times of day for freight movement is not yet adequately understood or reflected in traditional travel models.
- Evaluating unrealistic modal extremes for transportation alternatives tends to yield unrealistic results. In seeking to identify significant differences in the application of the preliminary ITP methodology, the case study examined three extremes for modal alternatives -- a high cost *all* transit option with *no* highway improvements; a *no* transit improvements option with *major* highway improvements; and a *no* transit or highway improvements option with major systemwide transportation pricing and demand management applications. Given the further unlikely land use assumptions used in this case study to keep the costs down, i.e., that no land use changes would result from major structural transportation system changes, the specific conclusions one can draw

from the actual sample calculations provided in this case study remain only of academic interest for the direction of probable change. In the absence of more extensive data for a more complete and well rounded evaluation, the specific data results in the case study are not applicable to any real alternative situations.

- Lack of a level playing field for comparative benefit-cost data yields equally *uneven* results. This case study compared the monetized benefits and costs of transportation system alternatives using relatively traditional transportation benefits, mostly related to travel reduction or travel time savings. The methodology does include the cost of time and other traditional transportation capital, operating and maintenance costs. However, due to resource limitations, the methodology and its conclusions remain substantially incomplete as it does not yet clarify or define the full public, personal and societal/ environmental costs and benefits of transportation. The consequences of conducting an evaluation of potential alternatives with only partially complete benefit-cost data (especially if lacking non-traditional cost areas) tends to produce "least-cost" conclusions that ignore environmental and public policy objectives. For example, this refined evaluation methodology for ITP does not yet measure the probable respective benefits or costs associated with a given transportation system investment helping to achieve *or not achieve* adopted growth management or land-use plans for a desired quality of life and urban form.

For the hypothetical system alternatives used in this study, the very obvious gaps in non-traditional transportation data, weaknesses in assumptions (e.g., no changes in land use), and limitations in current modeling practices made it impossible to rigorously apply an integrated transportation system planning approach and come up with results that could be used for rational decision making. Nonetheless, one should remember that the limited resources applied to this study were not intended to result in the definitive answer to fully and accurately defining all costs and benefits. Rather, the intent was to at least determine whether there might be utility in pursuing a refined systems planning approach such as the one applied. The staff opinion of the Regional Council on this issue is a qualified "yes," there is merit in continuing to develop this methodology.

Those involved in this case study believe it is a positive step toward the practical application of an integrated systems approach to metropolitan transportation planning. Such an approach will improve the depth of technical knowledge available to assist decision makers as they deliberate major transportation investments. However, while Washington State law requires the application of least cost planning principles in developing future regional transportation plans, it is clear that before the presumed merits of this evaluation tool can be realized, considerably more research must be undertaken to more fully define the complete range of *costs* and *benefits* as applied to transportation. Much work is still needed to accurately quantify the many indirect or external costs and private costs inherent in travel by different modes. This case study is a step in the right direction and supplements the extensive technical improvements already underway and completed on the Regional Council's modeling programs. The Regional Council intends to undertake further steps in this ITP process to better refine

and interpret the complex data being examined to create a more user-friendly format for greater public understanding and deliberation.

The applications of improved transportation planning practices have had significant impacts on the nature and form of transportation system and land development over the past century, some good, some bad. The field of transportation remains a very complex subject with deep ties and relationships to many other areas of social and economic activity. Improving transportation systems planning should not be seen as an end in itself but rather as an effort to improve the ability to support and achieve other more noble public endeavors such as connecting human activity and sustaining essential economic and environmental vitality.

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EXECUTIVE SUMMARY

Purpose

Integrated transportation planning includes both analytic *methods* for evaluating transportation alternatives and a public planning *process* for making decisions. This case study focuses on just one element of the analytic side of integrated transportation planning, namely, the evaluation of long-term, large-scale system alternatives of the type contemplated in a metropolitan transportation plan. The study evaluates methods available for forecasting costs and benefits of major policy alternatives for the regional transportation network for the next twenty-five years. The goals of this study include the following:

- Demonstrating the application of integrated transportation planning analysis methods to the analysis and evaluation of several hypothetical system-level transportation plans.
- Identifying short-term and long-term changes to current transportation data collection and modeling techniques that would support integrated transportation planning.
- Identifying further refinements to integrated transportation planning analysis and evaluation methods.

The case study considered three hypothetical alternative transportation system plans for the central Puget Sound region relative to a base case:

- Additions to highway capacity
- Major additions to transit capacity
- Economically efficient pricing of transportation facilities.

The specific form of each alternative was chosen to be similar to a policy for which the Regional Council had already done most of the necessary modeling. This prototype analysis tested the application of integrated transportation planning across substantially different alternatives in order to reveal the strengths and weaknesses of the approach and the adequacy of the available data. The prototype analysis does not test the appropriateness of the different alternatives.

Findings

1. **The data used in current regional planning processes are sufficient to calculate some of the benefits and costs of alternative transportation policies.** Data from the regional travel forecasting models and other information collected by the Regional Council allow for a basic calculation of the benefits and costs of alternative transportation systems. But some of the subtleties in the calculations of full economic benefits are not possible because these models do not provide complete economic information. There is also considerable uncertainty about the value of some of the environmental and social costs of different alternatives.
2. **Current large-scale regional travel forecasting models cannot account for certain key aspects of travel behavior.** User benefit estimates based on outputs from these models may be distorted. Traditional models fail to account for key travel behavior decisions that can significantly affect user response to changes in travel cost, and therefore affect user benefit estimates. For example, the total number of trips within any time period is assumed to be constant, regardless of the cost of travel. This violates both economic theory and real-world observations of travel behavior which find increases in trip making for policies which reduce travel costs. Any errors in forecasting how travelers will actually behave result in errors in the calculations of costs and benefits. In particular, the models may

overestimate the user benefits due to increases in highway capacity, leading to analyses that unintentionally favor these types of policies.

Traditional models also do not estimate commercial vehicle travel at the same degree of detail and accuracy as passenger travel. Commercial vehicle travel has a very high time cost — typically several times higher than that for passenger travel. For some alternatives, benefits to commercial vehicle travel may be larger than benefits to passenger travel. Provision of good estimates of commercial vehicle travel is an essential part of applying integrated transportation planning.

3. **The limitations of the travel forecasting models constrain the range of alternatives that policymakers can consider.** Integrated transportation planning calls for analysis of a *full range* of alternatives. Current travel models are oriented toward analyzing only some types of policies, namely those that involve increases to transportation supply — highway capacity in particular. Current travel models are not well suited to analyzing demand-oriented policies such as pricing, urban designs aimed at reducing motorized travel, carpool programs, and flexible work hours. Without analytic methods for predicting the consequences of these policies it is difficult to evaluate them within the context of integrated transportation planning.

4. **Large-scale regional models may not be appropriate for analyzing all alternatives.** Running the regional models and working with the large data sets they generate is time-consuming and expensive. Generating and using the data from the regional models used the majority of resources for this case study. Analysis of more alternatives would not have been possible within the available time and resource limitations.

This is a significant finding for integrated transportation planning, which calls for the analysis of a full range of alternatives. This requirement would be prohibitively expensive if large-scale regional models were used to analyze each alternative. As pointed out in a previous study (ECONorthwest, 1995c), a more cost-effective approach to integrated transportation planning would be to use alternative methods such as sketch-planning techniques or reviews of previous project evaluations to screen out some of the initial alternatives, and to use the large-scale regional models to analyze those alternatives to which they are best suited.

It is not immediately clear that these models are the best tools for addressing broad, long-term, policy questions such as "Should the region adopt a rail or rubber tired transit system?" or "Is an HOV system with improved bus transit superior to more general purpose highway lanes?" Such questions may be more appropriately answered by analyses based on evaluations of actual projects rather than forecasts for a distant future.

5. **More complete analysis requires addressing a wider range of assumptions about the environment in which travel behavior changes occur.** This study used the population, land use, and economic assumptions that are part of VISION 2020. A different set of assumptions would have led to significant changes in the travel forecasts, possibly altering the benefit and cost calculations. A more complete analysis would include a range of scenarios about future employment,

socioeconomic, demographic, and land-use patterns that could affect the relative rankings of different transportation policies.

6. **Better estimates of costs, especially operating and maintenance costs, are needed.** This study used available data to estimate capital costs of the transit and highway alternatives; however, construction cost estimates are difficult to obtain for projects that involve expansion of existing facilities. Operating and maintenance costs, especially for highways, were also difficult to estimate because of insufficient data.
7. **Current and past policies and projects should be evaluated to the greatest extent possible in order to provide real-world information to inform future decisions.** As noted in the earlier reports on integrated transportation planning, monitoring is essential in order to determine the cost-effectiveness of previous decisions and to track current trends in the environment within which decisions must be made. Current decisions should be guided not only by long-range projections, which can have a high degree of uncertainty, but also by good information about what is happening as a result of decisions that have already been made.
8. **Corridor and subregional analyses provide opportunities for more detailed analysis.** The analytic principles involved in integrated transportation planning apply to corridor and subregional analyses as well as for region-wide studies. The federal requirement for major investment studies (MIS) provides an opportunity to develop more accurate demand and supply data within specific corridors or subregions. Integrated transportation planning may benefit from initial application at the MIS level; the analysis at this level could also be used for system-level planning.
9. **More research is needed on values of time.** For passenger travel, a usable working assumption is that the value of time is equal to half the wage rate. Some research indicates that the value of time depends on factors such as the user's income and the trip purpose. Sufficient data do not exist yet to provide reliable estimates of how the value of time varies across individuals and trip types. Values of time for commercial travel are particularly difficult to estimate given our lack of knowledge of the characteristics of this type of travel. For commercial trips, the value of time includes the driver's wages, overhead, and the time value of the goods carried. There remains a large degree of uncertainty associated with any estimates of these values.
10. **Better estimates of the costs of externalities are needed.** There are currently a number transportation costs for which there is no market mechanism to recover those costs: air pollution and accidents are particular examples. Although attempts were made in this study to estimate ranges of such costs, time and budget limitations precluded their inclusion in many of the study's benefit-cost calculations. To properly conduct such an analysis the full social costs of each of the alternatives must be reflected in the analysis.

The case study demonstrated that the conceptual framework for evaluating benefits and costs in the context of integrated transportation planning can work. The existing models and data are not yet fully up to the task. With further refinement of the models and data,

and with a comprehensive program of policy and project evaluation, planning agencies can present policymakers with better data on the benefits and costs of transportation policy alternatives.

1. INTRODUCTION

This case study tests the application of integrated transportation planning by applying it to the evaluation of several hypothetical transportation systems plans for the central Puget Sound region. The report *Integrated Transportation Planning: A Primer for Policymakers* (ECONorthwest, 1995a) describes integrated transportation planning and its potential to improve transportation decision-making. This case study is best understood within the broader planning context described in the *Primer* and detailed in two longer reports written for the Federal Highway Administration and the Regional Council (ECONorthwest, 1995b and 1995c). Readers are encouraged to review the *Primer* for a basic background on integrated transportation planning to assist with interpreting the findings of this study.

The *Primer* notes that integrated transportation planning includes both analytic *methods* for evaluating transportation alternatives and a public planning *process* for making decisions. This case study focuses on one element of the analytic part of integrated transportation planning, namely, the evaluation of long-term, large-scale system alternatives of the type contemplated in a metropolitan transportation plan. The emphasis here is on evaluating methods available for forecasting costs and benefits of major policy alternatives for the regional transportation network for the next twenty-five years.

Table 1 helps place the current study in the broader analytic context for evaluating alternatives in an integrated transportation planning process. Integrated transportation planning emphasizes monitoring and evaluation of past projects and policies as well as prospective analysis of policy options. To make informed decisions about future investments and policies, planners need to understand the performance of investments made in the past. Retrospective evaluation of existing projects and policies at a corridor or regional level can provide better data about what actually happens when certain policies are adopted. Prospective studies estimate what is likely to happen if certain investments are made or policies adopted in a corridor or within an entire region. This case study is focused entirely in the lower right-hand cell. Current regional travel demand models were used to estimate what would happen over the next twenty five years in the region if certain policies were adopted.

Table 1. Categories of Analysis for Integrated Transportation Planning

	Corridor or Subregional Analysis	Regional System Analysis
Retrospective evaluation	I. Project evaluation	II. Regional plan monitoring and evaluation Policy and program evaluation
Prospective studies	III. Major Investment Studies	IV. Regional transportation plans

With its emphasis on prospective analysis of system alternatives, this case study closely parallels the type of evaluation that would go into developing a metropolitan transportation plan if integrated transportation planning principles were adopted by the

planning agency. Quadrant III analysis corresponds to the federal requirements for Major Investment Studies. There are currently no federal mandates that correspond to quadrants I and II.

The objectives of this study were:

- Demonstrate the application of integrated transportation planning analysis methods to the analysis and evaluation of several hypothetical system-level transportation plans.
- Identify short-term and long-term changes to current transportation data collection and modeling techniques that are needed that would support integrated transportation planning.
- Identify further refinements to integrated transportation planning analysis and evaluation methods.

This case study evaluated three hypothetical alternative transportation system plans for the central Puget Sound region relative to a "do nothing" alternative: 1) additions to highway capacity, 2) major additions to transit capacity, and 3) economically efficient pricing of transportation facilities. The specific form of each alternative was chosen to be similar to a policy for which the Regional Council had already developed a representation of the transportation network and travel patterns. This prototype analysis was intended to test the application of integrated transportation planning across substantially different alternatives in order to reveal the strengths and weaknesses of the approach and the adequacy of the available data. It was not intended to provide an analysis of the appropriateness of the different policy alternatives.

Travel demand estimates for this study were developed with the same methods that were used for the 1995 *Metropolitan Transportation Plan*. Outputs from the regional travel model were used to calculate the dollar value of the improvements in mobility relative to the base case scenario. These user benefits were evaluated against capital and operating costs. The estimation of the net benefits and costs of each alternative were then tested for their sensitivity to key assumptions in the valuation of costs and benefits.

Readers should note that the purpose of this case study was to test the integrated transportation system planning approach and *not* to fully evaluate the hypothetical system alternatives on which the method was tested. The net benefit numbers for the alternatives that are presented in this report are preliminary and subject to change as the method is refined and better techniques are developed for forecasting travel behavior and evaluating a full range of social and environmental costs.

2. METHODS

The methods for the case study included the following steps:

1. Define system alternatives
2. Prepare existing data for analysis in an integrated transportation planning framework
3. Refine valuation methods
4. Compute benefit and cost measures
5. Analyze sensitivity of results to uncertainty in basic assumptions

2.1 Define System Alternatives

The initial project design called for evaluation of four alternative hypothetical transportation systems for the central Puget Sound region in the year 2020. Each alternative was intended to represent a policy that focused almost exclusively on a single modal or management direction, within reasonable policy bounds. Because travel demand estimates had to be readily available, the alternatives to be tested had to be close to the alternatives considered in the 1995 *Metropolitan Transportation Plan* (MTP) and in recent planning for a regional rapid transit system. The four alternatives chosen for this case study portrayed policy options that reflect current views about possible maximum scenarios in each policy direction. Hence, they would provide good test cases for the application of integrated transportation planning methods.

- **Base case ("no build").** This alternative included the existing highway network and level of transit service plus those highway and transit improvements currently scheduled and funded in the Regional Transportation Improvement Program for the region.
- **Highway intensive.** This alternative included the base case plus all of the highway improvements that were part of the preferred option under the 1995 *Metropolitan Transportation Plan*. These included completion of 5 miles of "missing links" in the regional freeway network, 468 lane miles of HOV lanes through either new construction or conversion of existing lanes, 12 miles of multi-lane highways and 71 miles of arterial streets. In addition, this alternative also included the addition of one lane in each direction on I-5 between the southern border of Pierce County and the northern border of Snohomish County. Between Southcenter and Lynnwood the lane would be added to I-405 rather than I-5.
- **Transit intensive.** This alternative was the base case plus a rapid rail transit system. The alternative includes 125 miles of rapid rail running on exclusive, grade-separated right-of-way and a 40 mile diesel-operated commuter rail line. The capital costs of the transit system were estimated at \$11.5 billion (1991 \$) and annual operating costs are \$492 million.

- **Pricing.** This alternative included the base case with the addition of economically efficient user charges that would be placed on all highway and transit systems. There would be no significant capital investment in expansion of highway or public transit systems beyond the base case.

A single set of population and land use forecasts was used for the alternatives; these were the VISION 2020 forecasts that were used for the MTP. Travel forecasts depend largely on population and land-use assumptions, which in turn impact benefit and cost assumptions. No attempt was made to estimate the effects of the policies on changes in population and land use, and the subsequent changes to the benefit and cost estimates.

2.2 Prepare Data

2.2.1 Data Received from the Regional Council

Outputs from the regional travel forecasting models were prepared to estimate the user benefits of the alternatives. The Regional Council ran their models for the base year and three alternatives to produce level of service and trip data. Table 2 shows the alternatives for which the regional travel forecasting models were run. The pricing alternative was modeled using the STEP micro-simulation model, which had been applied for an earlier study on congestion pricing in the region.¹

Table 2. Regional Travel Model Runs

Alternative	Years
Base case	1990
No build	2000, 2010, 2020
Highway intensive	2020
Transit intensive	2020

Table 3 lists the types of level-of-service data that were included in the data sets from the regional travel models. Transit data are only for the AM peak period and for offpeak. The analyses assumed that PM peak transit trips were the same as AM peak transit trips in reverse.

Table 4 lists the trip data produced by the regional travel models, and the trip types for which data were available.² The trip data were in the format of daily productions and attractions by zone pair. Conversion of these tables into origin-destination tables by time

¹STEP is a quick-response microsimulation travel model that applies a set of behavioral travel models to a sample of individual travelers. Results from the sample enumeration, when properly weighted, reflect changes in travel behavior due to changes in population, employment, transportation system level of service, and transportation costs. The STEP model is described in an earlier report on its application to the analysis of congestion pricing in southern California (Cameron, 1991).

²The Regional Council designates trip types as home-based work, home-based other, and non-home-based. Equivalent designations are home-work, home-other, and other-other.

of day is discussed below. Note that the carpool mode was available only for home-work trips. The analysis did not use school trip and through-trip data.

Table 3. Level of Service Data from Regional Travel Model

Data	Time periods
Highway <ul style="list-style-type: none"> Travel time - carpool Travel time - non-carpool Travel distance - non-carpool 	AM peak, PM peak, offpeak. PM peak travel distance not available for base year.
Transit (auto, walk access modes) <ul style="list-style-type: none"> Total time In-vehicle time Drive access time Total wait time First wait time Boarding time Number of boardings Fares (peak, offpeak) 	AM peak, day.

Table 4. Regional Model Trip Data

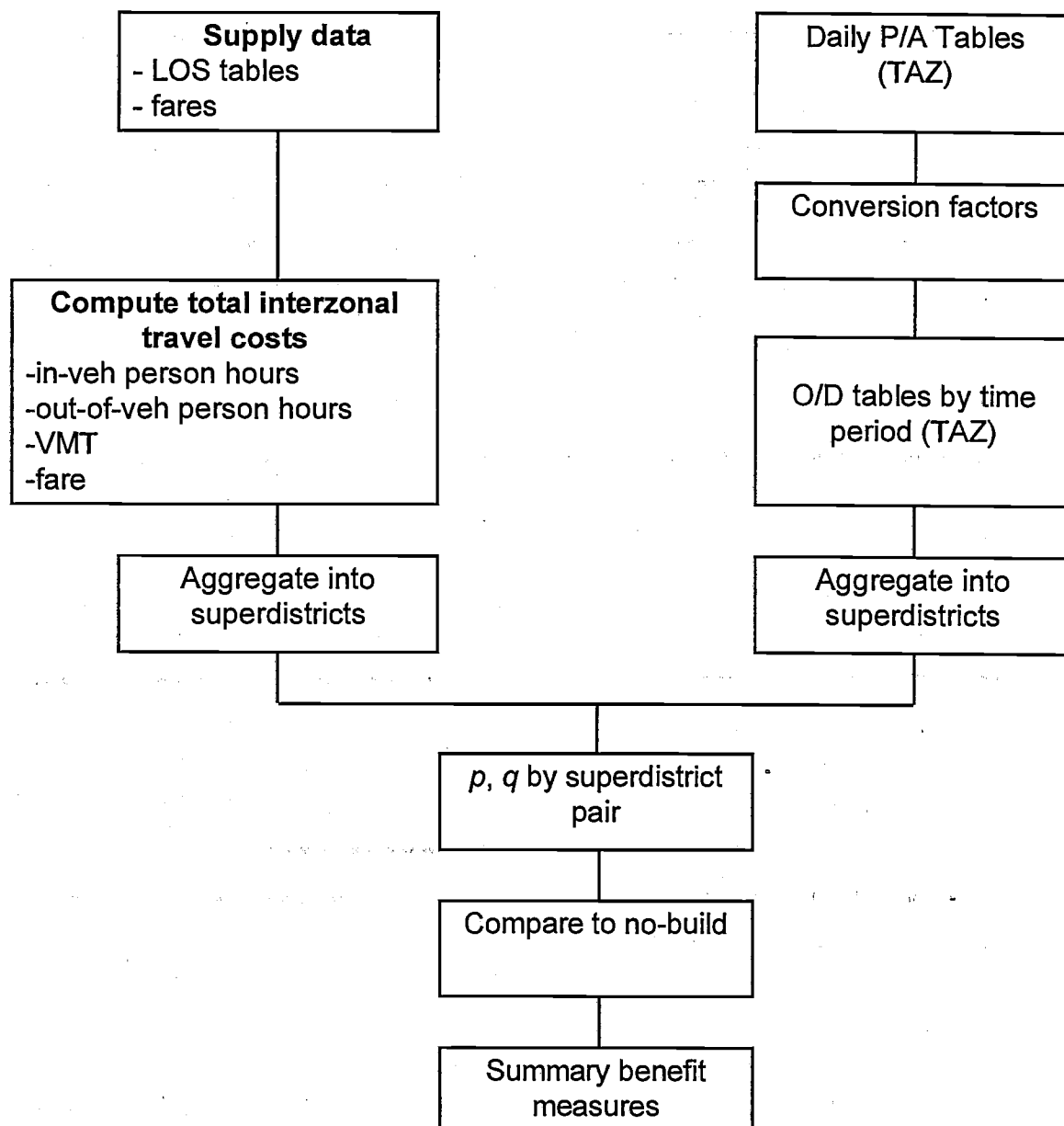
Mode	Trip purposes
Transit - auto access	Home-work, home-other, other-other
Transit - walk access	Home-work, home-other, other-other
Carpool - passengers	Home-work
Carpool - drivers	Home-work
Non-carpool - passengers	Home-work, home-other, other-other
Non-carpool - drivers	Home-work, home-other, other-other
Commercial vehicles	N/A
School (not used)	N/A
Through trips (not used)	N/A

Other data provided by the Regional Council included zonal data, which were used as inputs to the STEP model, and link data (lengths, numbers of lanes, facility type, vehicle speeds, and daily vehicle volumes), which were used to calculate lane-miles by facility type for the different alternatives. Regional Council staff also ran the link data through their air quality model to provide estimates of daily emissions for the no-build, highway, and transit alternatives.

2.2.2 Data Analyses

The data received from the regional model required additional analyses to carry out direct benefit calculations and for input to the STEP model. Figure 1 summarizes the process.

Figure 1. Data Analysis Procedures.



Level of Service Data

Table 5 shows calculations for additional level-of-service data. Most calculations were straightforward computations of data variables missing from regional travel model data sets.

Transit variables required some modification. By current convention, if the drive access time for transit auto access is zero between a pair of zones, then transit auto access is not available as a mode between those zones. Transit variables were set to zero in these cases. There were also zone pairs for which the transit in-vehicle time was zero, indicating that the minimum-time path between these zones was built entirely along the walk or drive access links. For these pairs transit variables were also set to zero.

Table 5. - Calculation of Additional Level of Service Variables

Variable	Calculation Method
<i>Highway</i>	
PM peak non-carpool highway distance (1990 only)	PM peak distance from i to j equals AM peak distance from j to i
Carpool highway distance	Assumed equal to non-carpool highway distance per Regional Council convention
Out of vehicle time (carpool and non-carpool)	Sum of terminal times at origin and destination zones
<i>Transit</i>	
Transit, auto access - all variables	Set to zero if drive access time is zero or in-vehicle time is zero
Transit, walk access - all variables	Set to zero if in-vehicle time is zero
Transfer wait time	Total wait time minus first wait time
Walk access time	Total time minus sum of drive access time, total wait time, and boarding time

Transit boarding times were not used in the user cost calculations. As defined by the Regional Council, these variables are surrogates for transfer penalties when calculating transit paths and mode split, but these do not represent actual physical times encountered by transit riders.

Trip Data

In order to calculate user costs, it was necessary to calculate person-hours and vehicle-miles of travel. These trip data were calculated by converting the daily trip production-

attraction table from the regional travel model into tables of trip origins and destinations by time of day: AM peak, PM peak, offpeak.³

Conversion of daily production-attraction trip tables to time-of-day origin-destination tables follows conventional practice by developing fixed factors that represent directionality and peaking characteristics for different trip types; these factors are derived from trip data in household travel surveys. AM and PM peak period factors are applied to get trip tables for these time periods; offpeak trips are calculated as the difference between daily trips and peak-period trips.⁴ Table 6 summarizes the factors used by the Regional Council.

Table 6. Conversion of Daily Trip Productions and Attractions to Trip Origins and Destinations by Time of Day

I -> j entry in origin-destination table	Factors applied to entries in production-attraction table	
	<i>i -> j</i>	<i>j -> i</i>
Transit, home-work - both peaks)	.3855	.3855
Transit, home-other - both peaks)	.1655	.1655
Transit, other-other - both peaks)	.0855	.0855
Carpool, home-work - AM peak	.6000	.1500
Carpool, home-work - PM peak	.1900	.6000
Non-carpool, home-work - AM peak	.3625	.0230
Non-carpool, home-work - PM peak	.0310	.2863
Non-carpool, home-other - AM peak	.1475	.0180
Non-carpool, home-other - PM peak	.0610	.2700
Non-carpool, other-other - AM peak	.0795	.0060
Non-carpool, other-other - PM peak	.0970	.2757
Commercial vehicles - AM peak	.0350	.0350
Commercial vehicles - PM peak	.0720	.0720

³The trip generation modeling step produces estimates of trip *productions* and *attractions*; the trip distribution phase then produces a trip table in production-attraction format. To calculate user travel times, however, it is necessary to have trip tables in origin-destination format by time of day. Consider a person who makes one round trip to work. That person is then said to have "produced" two home-work trips; the "production" end of each of these trips is the home location for the person, and the "attraction" end is the work location. If this person is a typical 9-to-5 worker, this will result in a trip from the home location to the work location in the AM peak origin-destination trip table, and a trip from the work location to the home location in the PM peak origin-destination trip table.

⁴Daily trips in origin-destination format from zone I to zone j are calculated as the average of the I-to-j and j-to-I entries in the production-attraction table. The daily origin-destination trip table is assumed to be symmetric.

The following are exceptions to the above :

- The PM peak transit trip table and travel time table were the transposes of the respective AM peak tables.
- Offpeak carpool trips were calculated as 2 times the total daily trips minus the sum of the peak period trips.

Preparation for Use in Benefit and Cost Calculations

In order to develop the benefit and cost measures for net economic benefit calculations, it is necessary to know the following:

- **User time costs.** These are directly proportional to total person-hours of travel for passenger trips. Commercial vehicles costs are proportional to vehicle-hours of travel, including driver wages and inventory costs of goods being hauled.
- **Other user costs.** These costs include transit fares paid by users and automobile operating costs. The analysis estimates automobile operating costs on the basis of a fixed unit cost per vehicle-mile of travel. Commercial user costs are estimated based on hourly operating costs.

Table 7 presents the specific measures and how they were calculated. The Regional Council makes special adjustments to transit level-of-service characteristics for ferry trips to reflect parking and other costs that do not appear in the mode choice model. The analyses did not account for this special treatment. All level-of-service variables were used as supplied by the regional travel model.

Table 7. Sources of Measures Used in Benefit/Cost Calculations

Measure	Calculation
<i>Transit</i>	
In-vehicle person hours	Transit person trips x (in-vehicle time + drive access time)
Out-of-vehicle person hours	Transit person trips x (walk access time + first wait time + transfer wait time)
Fare paid	Transit trips x fare
<i>Carpool</i>	
In-vehicle person hours	Carpool person trips x carpool interzonal travel time
Vehicle-miles of travel	Carpool driver trips x non-carpool interzonal distance
<i>Non-carpool</i>	
In-vehicle person hours	Non-carpool person trips x non-carpool interzonal travel time
Vehicle-miles of travel	Non-carpool driver trips x non-carpool interzonal distance
<i>Commercial movements</i>	
Vehicle hours	Commercial vehicle trips x non-carpool interzonal time

All measures were initially computed at the travel analysis zone level. The four-step modeling process typically does not estimate interzonal movements very well. To reduce variability in individual market calculations of benefit and cost measures, the interzonal measures were aggregated into the 20 superdistricts defined by the Regional Council. Each new superdistrict pair was treated as a separate travel market for purposes of the user benefit calculations.

Transit fares were calculated using the interzonal transit fare matrix developed by the Regional Council.

Automobile operating costs were defined as the *full* mileage operating costs of the automobile, including capital costs, insurance, fuel, maintenance, etc. There may be some objection to including the full operating cost of the automobile to estimate user costs. But given the nature of this case study, benefit and cost estimates were being developed for the long term. Future changes to the transportation system will influence not only vehicle-miles of travel, but, ultimately, the decision to purchase a car. Hence, it is assumed that *in the long run, the marginal costs of automobile travel are equal to the long-run average costs*. The analysis does not account for potential changes in automobile technology that might affect operating costs.

2.3 Refine Valuation Methods

Earlier reports on integrated transportation planning describe methods for estimating the net social benefits from transportation policies.⁵ Those reports focused on user benefits and describe general methods for estimating the changes in consumer surplus that occur with additions to transportation capacity or the introduction of pricing programs. This way of measuring changes in consumer surplus is consistent with generally accepted approaches to applying benefit-cost analysis to the evaluation of transportation policy. At the beginning of analyzing the output from the regional forecasting models and the STEP model for this case study, several issues arose that required conceptual clarification. Chief among these issues is how policy changes affect producers and consumers of transportation services. Ignoring the producer or supply side of the travel relationship can seriously bias the final evaluation of net social benefit. The discussion in Appendix A demonstrates the importance of considering how policy alternatives influence the marginal cost of supplying different modes of travel and why analysts must consider the interactions among related markets.

Unfortunately, current travel models make it difficult to specify some of the key supply required by theory. The volume-speed relationships imbedded in the travel demand models contain the travel time element of the supply curve but these relationships are difficult to extract at the zonal or district level. Furthermore, the models do not estimate

⁵ECONorthwest, (1995b and 1995c)

other elements of the supply costs. While other studies have estimated the supply cost relationships of different modes in other contexts⁶, it is difficult to integrate that information into the output of current regional travel models. Challenges in separating the primary and secondary market effects of policy actions compound the difficulties in specifying the supply relationships.

Table 8 gives examples of the types of primary and secondary markets affected by some of the policies considered in this study. When analyzing markets at the origin-destination level, output from current regional models makes it hard to distinguish between primary and secondary effects. For example, the highway-intensive alternative adds HOV lanes and general purpose lanes to competing routes in the network. One of the tests for the significance of secondary market effects is whether the generalized price per trip in the secondary market changes. Unfortunately, it is not possible to determine how much of the reduction in price per trip over a particular segment is a result of additional capacity in the primary market on that segment and how much is the result of secondary effects from capacity additions on a competing facility.

A similar argument can be raised for alternatives that involve additions to transit capacity. User costs for both transit *and* highway trips may decrease for some markets. For some transit trips, costs may decrease if capacity additions involve increased service frequencies, which would reduce transit waiting time costs; for some, highway trips, user costs will decrease to the extent that highway traffic is reduced as a result of trips being diverted to transit.

Table 8. Primary and Secondary Markets for Proposed Policies

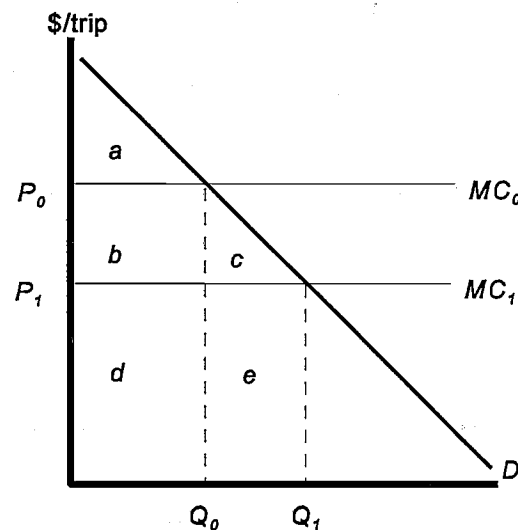
Policy	Primary Markets	Secondary Markets
Add general purpose freeway lanes over a congested segment	Peak SOV travel on segment Peak commercial travel on segment Peak HOV travel on improved segment Peak bus transit on improved segment	Peak SOV travel on alternative routes Peak commercial travel on alternative routes Shoulder SOV travel on improved segment Shoulder commercial travel on improved segment
Add HOV lanes to a congested highway segment	Peak HOV travel on improved segment Peak bus transit on improved segment	Peak HOV travel on alternative routes Peak bus transit on alternative routes Shoulder HOV travel on improved segment Shoulder bus transit travel on improved segment Peak SOV travel on improved segment Peak commercial travel on improved segment
Add rail transit capacity to corridor	Peak period rail Shoulder period Off peak period rail	Peak, shoulder, and off peak bus transit Peak period SOV Peak period HOV

The first approach to the problem of incomplete data on marginal supply costs and secondary market effects is to focus on calculating the *minimum consumer surplus benefit*. This benefit corresponds to the area *b* in Figure 2, and can be calculated by multiplying the change in price ($P_0 - P_1$) by the original quantity Q_0 . This estimate is

⁶Keeler, et. al. (1970) and Pozdena (1975)

considered a minimum benefit because any changes in the quantity of trips consumed due to price changes are presumably made because they increase gross consumer benefits. Because it is not known exactly how the demand curves change in each market, we cannot calculate the area *c* in Figure 2 without making unwarranted assumptions about the shape of the demand curves; but it can be assumed that any shifts in demand are made to increase net economic benefit. The total benefit increase is at least as large as the sum of the area *b* in all of the relevant markets. Calculating the minimum consumer benefit will give some insights into the *user benefits* of the policies. But it ignores the benefits from increased travel due to improved mobility; it is also likely to miss important effects on producers in the primary and secondary markets.

Figure 2. Benefit Measures



2.4 Compute Benefit and Cost Measures

2.4.1 Benefit Calculations

The regional level of service and trip data between 832 travel analysis zones were aggregated up into data for 20 superdistricts. These 20 superdistricts resulted in 400 origin-destination pairs that were analyzed on a spreadsheet. The spreadsheet kept data separate by mode, time of day, and trip purpose for each district O-D pair. Benefit calculations for this study were defined as minimum consumer benefits: i.e., the net change in cost per trip times the number of trips for the base alternative. The available data permitted development of benefit estimates for the year 2020. It was also necessary to estimate benefit *streams* to compute total net present value for each of the alternatives. The following assumptions were made:

- The transit-intensive, highway-intensive, and no-build alternatives would not begin to diverge until the year 2000.
- Benefits for years between 2000 and 2020 were estimated by linear interpolation. For example, the net benefits for the transit-intensive alternative for the year 2008 were estimated to be 8/20 of the difference between the year 2020 benefits for the transit-intensive and no-build alternatives.
- All benefits and costs were discounted to 1995, and expressed in 1995 dollars.

The benefit calculations also required assumptions about discount rates, values of time, mileage costs, and commercial vehicle operating costs. Appendix B gives the details of the values used.

One cost assumption may raise some questions, namely that the marginal cost of automobile operation (per mile) is equal to the average the full cost of ownership and operation; i.e., the costs of vehicle purchase and insurance are included with operating costs such as fuel and maintenance. The reasons for this assumption are as follows:

- This case study is looks at long-range policies and their long-range consequences. In the long run, increases or reductions in per household automobile travel will be reflected in increased or decreased automobile purchases at the margin.
- Even in the short run, it is reasonable to assert that at least some automobile costs regarded as “fixed” are in fact sensitive to the amount of travel. Automobile depreciation depends on the mileage driven as well as the age of the vehicle. To the extent that the owner keeps the vehicle to the end of its useful life, more and more of the vehicle depreciation can be regarded as due to vehicle mileage.

2.4.2 Cost Calculations

Capital and operating costs were calculated by five-year period for the highway and transit alternatives. Costs were assigned to the first year of each period and then discounted and summed to arrive at a total present value figure for each alternative. Appendix B summarizes cost estimates.

Capital cost estimates were based almost entirely on the existing planning documents prepared for the 1995 *Metropolitan Transportation Plan* (MTP). For the highway alternative, the MTP capital cost estimates for state highways and local arterials were used to estimate costs. To these were added the cost of an additional lane to I-5, which was estimated at 200 additional lane miles at a cost estimate of \$9 million per lane mile

(according to WSDOT estimates).⁷ This estimate does not include the costs of redoing the overpasses and therefore likely significantly underestimates the capital cost. The per mile operating costs for these new road facilities were estimated by finding the average maintenance, resurfacing, and public safety costs for both freeways and arterials. The total operating costs were partitioned among the five-year segments of the study period based on the number of lane miles constructed in each period. Each five-year segment was assigned a share of the total lane miles based on the share of total capital costs spent in that time segment. Maintenance figures were calculated using data from two WSDOT regional maintenance analysts. They provided figures on the existing maintenance costs per lane mile in the central Puget Sound region.⁸ WSDOT also calculated average yearly resurfacing costs for future roadways in the region.⁹ The Washington State Patrol estimated public safety costs from their current expenditures per lane mile in the region.¹⁰

RTA planning documents used for the MTP provided the transit capital and operating costs (Porter, 1995). The RTA planning documents state that these figures are preliminary and subject to change with more detailed engineering.

Benefits and Costs Not Included

The monetary costs of pollution were not included in the formal calculation because time and resource constraints prohibited the analysis necessary to refine their estimates for this study. Small and Kazimi (1995) provide a comprehensive review of attempts to value air pollution, and develop estimates of air pollution costs for the Los Angeles basin. But the degree to which these estimates are applicable to the Puget Sound area is uncertain. Lee (1994) has estimated the total amount of highway costs not recovered directly from users. Lee's estimates are not directly applicable because they are average, not marginal, costs; and they are for the nation as a whole rather than being specific to the central Puget Sound region. These limitations notwithstanding, a brief analysis was conducted to estimate what effects, if any, inclusion of estimates of these costs would have on the relative project rankings. As discussed in Appendix C, inclusion of these costs did change the alternatives relative rankings.

The analysis did not estimate a salvage value for the two capital intensive alternatives. The capital investment for the highway and transit alternatives was roughly comparable (\$5.1 billion and \$4.7 respectively). Assuming that they depreciate at the same rate they would have similar salvage values and including this in the analysis would not change their relative rankings. In cases where rankings of alternatives are close, more detailed evaluation of salvage values should be included.

⁷Frank Gililand, WSDOT, personal communication, September 21, 1995.

⁸Mel Courtney and Bob Lee, Regional Maintenance Analysts, WSDOT, personal communication, November 3, 1995.

⁹Robyn Moore, Pavement and Soils Engineer, WSDOT, personal communication, November 1, 1995.

¹⁰Ken Mitchell, Budget Officer, Washington State Patrol, personal communication, November 3, 1995.

Uncertainty Analysis

A full uncertainty analysis would have entailed simulating uncertainties in the inputs to the model system, then tracing these through to estimate the variances in the benefit and cost measures for each of the alternatives. This analysis was not feasible within the resources available to this study.

Instead, uncertainties in overall benefit and cost measures were postulated and simulated numerically. As stated in Appendix C, the estimated differences between the net benefits of the three alternatives were so large that the uncertainty analysis showed very low probabilities that the relative rankings of the alternatives would be different from the initial estimates.

3. RESULTS OF APPLYING INTEGRATED TRANSPORTATION PLANNING METHODS

One of the most significant results from the case study was the experience gained from going through the exercise of calculating benefits and costs. The data preparation phase of this project was much more time consuming and expensive than originally expected. The model output for each of the alternatives required half a gigabyte of data storage; even with a fast Pentium computer, the data proved very time consuming to manipulate and prepare. Some of these costs might have been avoided by using the matrix manipulation functions within EMME/2 to do the user benefit calculations rather than exporting the data to a standard database format so it could be manipulated with FoxPro. For this study, however, it was necessary to export some of the model output for input to the STEP model.

The models fail to capture some important transportation effects. Readers should not rely upon the results as definitive statements of the net social benefits of these projects. A key objective of this study was to identify the weaknesses in the existing data and modeling for application to integrated transportation planning. This analysis highlighted some of the areas where better data are needed while suggesting the type of results that a more complete analysis could provide.

The evaluation of benefits and costs yielded the following results:

- For all three alternatives, the estimated benefits for commercial vehicle travel dominates the benefit calculations, accounting for over half of the net user benefits. The estimates of net social benefits are highly sensitive to forecasts of commercial travel and to assumptions about value of time for commercial vehicles. Commercial vehicle benefits appear to depend most highly on the value of driver and vehicle time; inventory costs appear to account for only a small fraction of commercial vehicle costs.
- The transit-intensive alternative does not appear to have a net positive social benefit if only passenger travel benefits are included.
- The highway-intensive alternative appears to have a significantly positive net social benefit, even without consideration of benefits to commercial traffic. However, the cost figures used here are fairly soft and probably biased downward. The failure to account for environmental externalities and changes in producer surplus also tend to overstate the benefits for this alternative.
- The pricing alternative has the highest net benefits of any of the alternatives considered. Its net social benefits exceed the highway alternative by a factor of four. The analysis of pricing alternative assumed

that the revenue generated from pricing was returned to travelers through lower taxes.

The results and how they were estimated raise a number of issues on how well current planning analyses can meet the information needs of integrated transportation planning:

- Travel forecasts were available only for the final year. It was necessary to make assumptions about the shape of the benefit stream in order to estimate net present values. Also, the user benefits do not include the results of increased travel times due to construction, which occur earlier than the benefits from reduced travel times. *Omitting construction effects may lead to serious overestimation of benefits from alternatives that involve large-scale construction.* Lack of information about when significant changes in level of service occur gives rise to further errors in the benefit estimates.
- Commercial vehicle travel may in fact account for a significant portion of user benefits. But commercial vehicle travel is currently not estimated with the same degree of precision as passenger travel, primarily because there is little or no information on which to estimate current travel and to make forecasts. Improving on commercial travel forecasts should be a significant part of efforts to increase the application of integrated transportation planning to evaluating alternatives.
- Travel demand and level of service estimates from the regional models provide little actual data to estimate demand and supply curves; indeed, the models appear at times to generate results that appear inconsistent with economic logic. For example, there were a significant number of O-D pairs for which the generalized price *and* quantity of trips demanded were simultaneously greater for the alternative (compared to the base case). For alternatives that expand system capacity, one would expect lower generalized prices for almost all O-D pairs. In those instances where prices per trip do increase then the quantity demanded should decrease. These anomalous results undermine the credibility of other aspects of the model output.
- Total trip generation is inelastic with respect to level of service on the transportation system. Hence, travel speeds for the no-build alternative may have been underestimated. Consequently, net benefits of alternatives that involve large-scale capacity increases may have been overestimated.
- User benefits for the PM peak period appear to be significantly higher than for the other time periods; this holds across both carpool and non-carpool modes, and both alternatives. It is difficult to determine whether this is a real result, or whether it is an artifact of the process for allocating trips to

different times of day. If the latter case is true, user benefits to both automobile modes may be overestimated.

- Travel model outputs do not include weekends. To the extent that travel costs are reduced for weekend travelers, benefits of the alternatives will be understated.

4. EVALUATION OF APPROACH

This study can be regarded as a limited test case in which some aspects of integrated transportation planning were tested. Table 8 summarizes the key elements of integrated transportation planning and how this study addressed them. Important elements of integrated transportation planning were not part of this study such as engaging the public and monitoring and adjusting plans based on actual performance. The study focused on the analytic elements of estimating social costs and benefits and identifying the limitations in the data and techniques available.

Table 9. Case Study Coverage of Key Elements of Integrated Transportation Planning

Element of integrated transportation planning	Coverage in Case Study
Consider full range of alternatives	Wide range of alternatives considered, but did not cover full range of possibilities
Use cost-effectiveness as key decision criteria	Benefit-cost analysis used. Minimum consumer surplus changes estimated. Estimates of full consumer surplus and producer surplus not possible with existing data.
Consider all significant social costs	User and capital costs considered, including effects on commercial traffic. Consideration of some other costs (air pollution, accident costs, etc.) limited to estimating extent to which these might have affected rankings of the alternatives. Environmental effects such as noise, barriers, land use, and aesthetics not considered.
Uncertainty analysis	Limited uncertainty analysis based on assumed errors in aggregate benefit and cost estimates.
Engage the public in planning process	Outside case study scope.
Monitor and adjust depending on project performance	Outside case study scope.

Among the questions this case study was designed to answer is the following, "Can we use the existing data from the current analysis procedures used by the Regional Council to evaluate the net social benefits of system alternatives?" The preliminary answer is "Yes, but." We can use the data but they are less than ideal for answering some of the broad policy level decisions dealt with at the MTP level.

The case study does provide several important lessons to guide the future development of the integrated transportation planning method:

1. **The data used in current regional planning processes are sufficient to calculate some of the benefits and costs of alternative transportation policies.** Data from the regional travel forecasting models and other information collected

by the Regional Council allow for a basic calculation of the benefits and costs of alternative transportation systems. But some of the subtleties in the calculations of full economic benefits are not possible because these models do not provide complete economic information. There is also considerable uncertainty about the value of some of the environmental and social costs of different alternatives.

2. **Current large-scale regional travel forecasting models cannot account for certain key aspects of travel behavior. User benefit estimates based on outputs from these models may be distorted.** Traditional models fail to account for key travel behavior decisions that can significantly affect user response to changes in travel cost, and therefore affect user benefit estimates. For example, the total number of trips within any time period is assumed to be constant, regardless of the cost of travel. This violates both economic theory and real-world observations of travel behavior which find increases in trip making for policies which reduce travel costs. Any errors in forecasting how travelers will actually behave result in errors in the calculations of costs and benefits. In particular, the models may overestimate the user benefits due to increases in highway capacity, leading to analyses that unintentionally favor these types of policies.

Traditional models also do not estimate commercial vehicle travel at the same degree of detail and accuracy as passenger travel. Commercial vehicle travel has a very high time cost — typically several times higher than that for passenger travel. For some alternatives, benefits to commercial vehicle travel may be larger than benefits to passenger travel. Provision of good estimates of commercial vehicle travel is an essential part of applying integrated transportation planning.

3. **The limitations of the travel forecasting models constrain the range of alternatives that policymakers can consider.** Integrated transportation planning calls for analysis of a *full range* of alternatives. Current travel models are oriented toward analyzing only some types of policies, namely those that involve increases to transportation supply — highway capacity in particular. Current travel models are not well suited to analyzing demand-oriented policies such as pricing, urban designs aimed at reducing motorized travel, carpool programs, and flexible work hours. Without analytic methods for predicting the consequences of these policies it is difficult to evaluate them within the context of integrated transportation planning.
4. **Large-scale regional models may not be appropriate for analyzing all alternatives.** Running the regional models and working with the large data sets they generate is time-consuming and expensive. Generating and using the data from the regional models used the majority of resources for this case study. Analysis of more alternatives would not have been possible within the available time and resource limitations.

This is a significant finding for integrated transportation planning, which calls for the analysis of a full range of alternatives. This requirement would be prohibitively expensive if large-scale regional models were used to analyze each alternative. As pointed out in a previous study (ECONorthwest, 1995c), a more cost-effective approach to integrated transportation planning would be to use alternative methods such as sketch-planning techniques or reviews of previous project evaluations to screen out some of the initial alternatives, and to use the large-scale regional models to analyze those alternatives to which they are best suited.

It is not immediately clear that these models are the best tools for addressing broad, long-term, policy questions such as "Should the region adopt a rail or rubber tired transit system?" or "Is an HOV system with improved bus transit superior to more general purpose highway lanes?" Such questions may be more appropriately answered by analyses based on evaluations of actual projects rather than forecasts for a distant future.

5. **More complete analysis requires addressing a wider range of assumptions about the environment in which travel behavior changes occur.** This study used the population, land use, and economic assumptions that are part of VISION 2020. A different set of assumptions would have led to significant changes in the travel forecasts, possibly altering the benefit and cost calculations. A more complete analysis would include a range of scenarios about future employment, socioeconomic, demographic, and land-use patterns that could affect the relative rankings of different transportation policies.
6. **Better estimates of costs, especially operating and maintenance costs, are needed.** This study used available data to estimate capital costs of the transit and highway alternatives; however, construction cost estimates are difficult to obtain for projects that involve expansion of existing facilities. Operating and maintenance costs, especially for highways, were also very difficult to estimate because of insufficient data.
7. **Current and past policies and projects should be evaluated to the greatest extent possible to provide real-world information to inform future decisions.** As noted in the earlier reports on integrated transportation planning, monitoring is essential in order to determine the cost-effectiveness of previous decisions and to track current trends in the environment within which decisions must be made. Current decisions should be guided not only by long-range projections, which can have a high degree of uncertainty, but also by good information about what is happening as a result of decisions that have already been made.
8. **Corridor and subregional analyses provide opportunities for more detailed analysis.** The analytic principles involved in integrated transportation planning apply to corridor and subregional analyses as well as for region-wide studies. The

federal requirement for major investment studies (MIS) provides an opportunity to develop more accurate demand and supply data within specific corridors or subregions. Integrated transportation planning may benefit from initial application at the MIS level; the analysis at this level could also be used for system-level planning.

9. **More research is needed on values of time.** For passenger travel, a usable working assumption is that the value of time is equal to half the wage rate. Some research indicates that the value of time depends on factors such as the user's income and the trip purpose. Sufficient data do not exist yet to provide reliable estimates of how the value of time varies across individuals and trip types. Values of time for commercial travel are particularly difficult to estimate given our lack of knowledge of the characteristics of this type of travel. For commercial trips, the value of time includes the driver's wages, overhead, and the time value of the goods carried. There remains a large degree of uncertainty associated with any estimates of these values.
10. **Better estimates of the costs of externalities are needed.** There are currently a number of costs of transportation for which there is no market mechanism to recover those costs; air pollution and accidents are particular examples. Although some attempt was made in this study to estimate the ranges of these costs, time and budget limitations precluded the inclusion of many of these in the benefit-cost calculations noted. To properly conduct such an analysis the full social costs of each of the alternatives must be reflected in the analysis.

This case study has demonstrated that the conceptual framework for evaluating benefits and costs in the context of integrated transportation planning can be applied in practice. The current regional travel models and data are not yet up to the task of completely carrying out integrated transportation planning; monitoring and evaluation data in particular are lacking in the current repertoire of resources available to planning agencies. With further refinement and enhancement of the models and data, and with a comprehensive program of policy and project evaluation, planning agencies can present policymakers with better estimates of the relative net benefits of transportation policy alternatives.

APPENDIX A - ECONOMIC FRAMEWORK FOR EVALUATING TRANSPORTATION ALTERNATIVES

Least-cost planning in a transportation setting requires benefit-cost analysis. The simplicity of the underlying concept of benefit-cost analysis — that one just tallies economic benefits and costs — conceals the challenges in applying benefit-cost analysis in a practical, network setting. Because of the great confusion that exists concerning the process of calculating economic benefits, this appendix introduces benefit-cost measurement techniques for transportation networks.

What is benefit-cost analysis trying to measure? Economists evaluate economic policies based on their effects on economic welfare. Benefit-cost analysis is a practical way of measuring changes in economic welfare. Benefit-cost analysis measures two components: (1) the effects of a policy or project on consumers of goods and services and (2) the effects on producers of goods and services. There are also spillover or external effects, which are borne by those who are neither direct consumers nor producers of the affected transportation service. For the moment, this complication can be ignored. Changes in the prices and quantities of goods affect consumers. The demand curve measures these effects. It displays for every quantity the price consumers would be willing to pay for one more unit of the good.¹¹ Since willingness-to-pay is an expression by consumers of the value they place on the product, the demand curve measures the marginal benefit associated with various levels of consumption of the good. The total benefits to consumers of any given level of consumption, therefore, is the area under the demand curve up to the given quantity.¹²

A transportation project also has affects producers of transportation services. These effects also are caused by changes in the prices they enjoy in the marketplace, and the quantities they sell. The *marginal cost curve* measures producer effects. This curve displays for every quantity the additional costs the producer will incur in order to produce an additional unit. The total costs are represented by the area under the marginal cost curve, up to the given quantity produced.¹³

¹¹Technically, when described in this way, this is the inverse demand curve.

¹²In technical terms, the gross benefit or welfare, W , enjoyed by the consumer is

$$W = \int_0^{Q_0} B(Q) dQ$$

where $B(Q)$ is the inverse demand function, and Q_0 is the quantity consumed.

¹³In technical terms, the total costs (TC) experienced by the producer are

$$TC = \int_0^{Q_0} C(Q) dQ$$

where $C(Q)$ is the marginal cost curve, and Q_0 is the quantity produced. In short-run analyses, the marginal cost curve measures only variable costs. Fixed costs can be ignored since they are not subject to change in the short run, by definition. When performing benefit cost analysis over multiple time periods, however, either the long-run marginal cost relationship must be used, or a sequence of short-run cost curves is used. Changes in fixed costs (e.g., construction) are accounted for separately. The latter is the typical method in practice.

Typically, measures of interest are not total benefits and costs, but rather the *changes* in total benefits and costs that result from a change in the transportation network. The usual practice is to measure changes in the area under demand and marginal cost curves, rather than the areas themselves. This is fortunate, because we often do not know precisely what demand and cost curves look like over their full range, but only in an area around the current levels. As we will see, however, there are cases when the appropriate calculation requires more complete information about the supply curves than may typically be supplied by network modelers. In these cases, it is up to the benefit-cost analyst to provide the necessary information.

Measuring consumer surplus

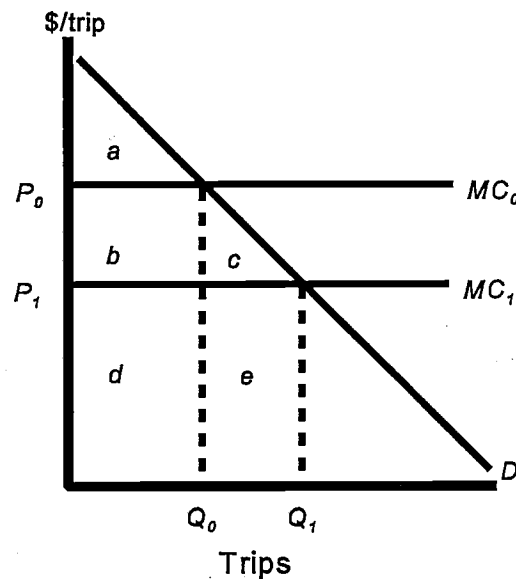
The welfare effects of changes in a market (like transportation) are accounted for by measuring consumer and producer surpluses. Surpluses are welfare gains enjoyed by the consumer or producer that are not offset by an obligation to pay someone else for resources used. An example illustrates the basic calculation from the consumer side. To make the example concrete, we assume that the service being examined is trips by a class of consumers along a particular link in the peak period, and that all prices and costs have been converted to dollars. Thus, for all the graphs that follow, the horizontal axis is scaled in trips per time period, and the vertical axis is scaled in dollars.

To introduce the concept of consumer surplus, we assume that consumers pay a price that is equal to the marginal cost of the services and, further, that marginal costs equal average costs.¹⁴ We assume also that the policy under study lowers marginal costs (and average costs), with a resulting decrease in price and increase in the number of trips consumed. In Figure A-1, marginal costs decline from MC_0 to MC_1 , resulting in a decline in price P_0 to P_1 , and an increase in consumption (of, say, trips per period) from Q_0 to Q_1 .

Consumer benefits are measured by the area under the demand curve (which is the same as the marginal benefits curve), policy effects are typically measured as changes to that area. The difference between gross consumer benefits (the entire area under the demand curve) and what consumers pay for those benefits (the area whose upper bound is the horizontal price curve) is termed *consumer surplus*. Prior to the improvement, total benefits to consumers were $a+b+d$ with $b+d$ being paid to producers. The consumer surplus prior to the improvement was the difference, or the area a . After the improvement, total consumer benefits are $a+b+c+d+e$, and $d+e$ must be paid to producers. Consumer surplus is now $a+b+c$, for a change of $b+c=(a+b+c)-a$. This latter measure that indicates the change in consumer surplus benefits per period in this case. Where this case applies, changes in consumer surplus can be estimated from the change in prices and the change in quantity, with the help of a little geometry.

¹⁴This will be the case when the cost relationship displays constant returns.

Figure A-1. Welfare Calculation, Marginal Cost Equals Average Cost

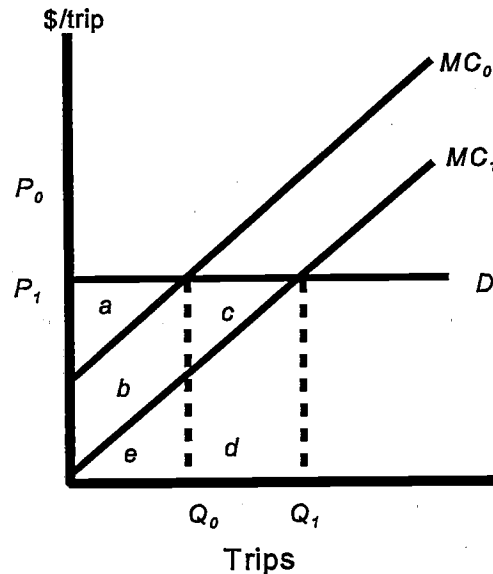


Measuring producer surplus

There is a concept analogous to consumer surplus on the producer side. *Producer surplus* is the difference between the revenue that the producer enjoys and his total cost, as measured by the area under the marginal cost curve. In the consumer surplus example, we assumed away any producer surplus. That is, producers got revenue from consumers that exactly equaled the costs of production incurred. This result follows from the assumption that average costs and marginal costs were equal, and prices equaled marginal costs. In typical transportation network contexts, however, this is not the case. (We will discuss the reasons below.) It is important to understand the notion of producer surplus. Changes in producer surplus are just as important to account for as changes in consumer surplus.

To avoid confusing consumer and producer surplus in this second example, we assume a demand curve that makes consumer surpluses impossible. This is the case where the demand curve is perfectly elastic — i.e., horizontal (usually the case under perfect competition). To allow for producer surpluses, we assume but that a producer experiences rising marginal costs as it tries to increase output. Figure A-2 illustrates this case.

Figure A-2. Welfare Calculation, Perfectly Elastic Demand



As in the first example, the policy under study involves reducing marginal costs. This reduction might occur, for example, because a more efficient roadway, with lower marginal costs of wear-and-tear, is introduced on the affected link. Put differently, for the same marginal cost (also equal to the price travelers are willing to pay), more trips can be produced. Specifically, the marginal cost curve shifts from MC_0 to MC_1 . Because of the shape of the demand curve, prices do not change, but the quantity of trips consumed (and "produced" by the roadway operator) increases from Q_0 to Q_1 .

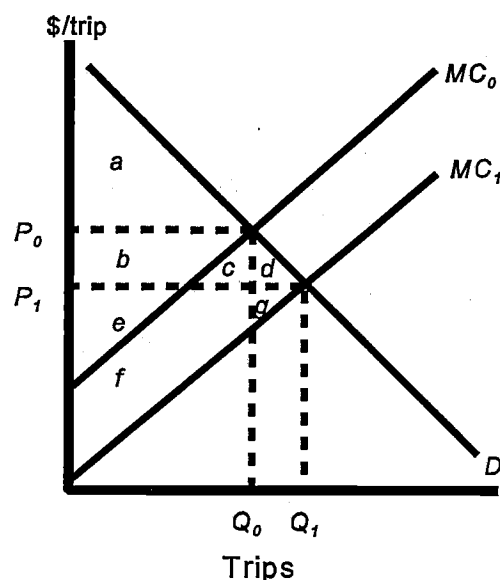
There is producer surplus in this case because there is a difference between what producers enjoy in revenue, and what it costs them to produce the desired level of trips — i.e., the area under the marginal cost curve. Prior to the improvement, revenue was $a+b+e$, and total costs were $b+e$ (i.e., the area under the marginal cost curve). Initial producer surplus is the difference, or a . After the improvement, the producer surplus is $a+b+c$, for a change equal to $b+c$. The latter quantity represents the benefits of the policy in this simple example. The calculation requires some knowledge of the shape of the marginal cost relationships: it is an easy calculation if they are straight lines, but can be more complicated if they are not (although the error introduced by linearizing the curves is usually not great).

Combining consumer and producer surplus calculations

Now combine these two simplified cases into a single case that generates both producer and consumer surpluses. Figure A-3, has both a sloping demand curve and a sloping marginal cost curve. From the earlier analysis, we know that the increase in consumer surplus per period is $b+c+d$; producer surplus changes from $b+e$ to $e+f+g$. Total benefit

per period is thus $c+d+f+g$, since the area b is essentially former producer surplus that is now enjoyed by consumers.¹⁵ (This is called a *transfer*, in economic parlance.)

Figure A-3. Consumer and Producer Surplus



Dealing with interrelated markets

If a policy alters a price in one market, it may affect the demand for complementary or substitute products in other markets. In a transportation context, it is fairly typical that an improvement of one link in a transportation network affects other links, and improvements in one mode affects other modes. Consumer or producer surpluses may be affected in these markets. Many benefit-cost studies ignore these secondary effects. These effects can only be ignored under certain conditions and are particularly hard to ignore in the context of transportation networks.

There are some general conditions under which effects on interrelated markets can be ignored. If the likely effect in other markets is very small, the effects on surpluses in the secondary markets can be ignored. This is probably the case only if the policy itself is a minor policy. Most transportation projects and policies, in contrast, are significant policies, affecting demand for interrelated products (e.g., other modes and routes) in non-trivial ways.

Even if demand in other, related markets is significantly affected, however, one need not calculate changes in surpluses in that second market *if the price in that market remains*

¹⁵Specifically, the change in consumer surplus is $b+c+d$ to which must be added the change in producer surplus; i.e., $(e+f+g)-(b+e)$. Hence, the total of all surpluses is $b+c+d+(e+f+g)-(b+e)$, or $c+d+f+g$.

unaffected.¹⁶ If prices change in the secondary markets, producer surpluses must also have changed. These effects are rarely already captured in the cost relationships represented in the primary market. It is very likely that major changes in demand on secondary markets also will result in changes in prices and costs. This is especially true on networks where the secondary "markets" are congested network links — i.e. links whose generalized cost will change significantly if trip making changes. The transportation demand analyst usually has to worry about effects on secondary or related markets — usually other modes or routes.

How is this accounting accomplished? A simple case is presented in Figures A-4a and b. Imagine that because of a policy change in the primary market (Panel 4a), the price falls from P_0 to P_1 . (For simplicity, we do not show the marginal cost curves.) We would then proceed to calculate consumer and producer surpluses, and the aggregate net benefits as in earlier examples. However, let us further imagine that because of the lower price in the primary market, demand shifts back for the related commodity (Panel 4b). This would be the case if it were a substitute route or mode, for example. In this case, there is a loss of producer surplus equal to b , that offsets any net consumer and producer gains measured in the primary market. Thus, if we ignore this effect, we tend to overstate the benefits of improvements made in one portion of the transportation system.¹⁷

An intuitive description may clarify this notion. Improvements on the facility in Figure A-4a generates benefits because more people are able to travel and they travel at less cost per trip. However, the facility in Figure A-4b used to generate travel benefits that it no longer does because trips have moved over to facility in Figure A-4a. This decrease in use and the corresponding decrease in benefits to those who produce and consume the trips must be counted as an offset to the benefits where the investment is made.

¹⁶This is a theoretical result that follows from the fact that the changes in consumer surpluses from rearranging consumption among substitute or complementary goods is already captured in the shape of the demand curve in the primary market.

¹⁷A further complication arises if the good in the primary market has an upward sloping marginal cost curve and prices change in the secondary markets. As the prices of the goods in the two markets adjust to one another, the path of the adjustment (i.e. which price and demand curves are assumed to adjust first) affects the calculated net benefit. This so-called path dependency is assumed away by virtually all benefit cost analysts because of its complexity. The required theoretical assumption that allows it to be assumed away is that the income elasticity of demand is equal to one. Clearly, this need not be the case in all instances. However, most economists also believe the effect of path dependency is small in practice.

Figure A-4a. Welfare Calculation, Primary Market

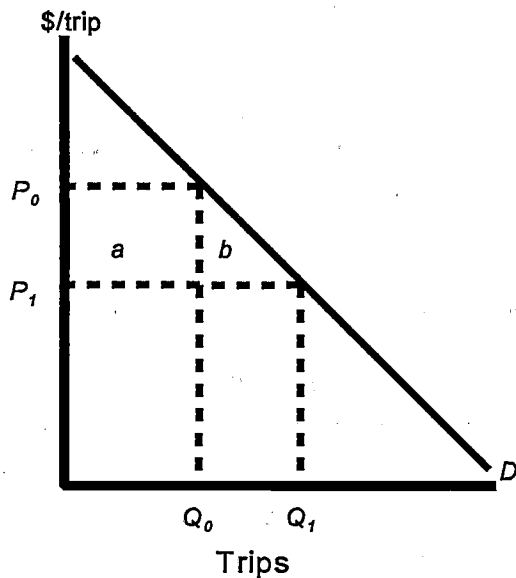
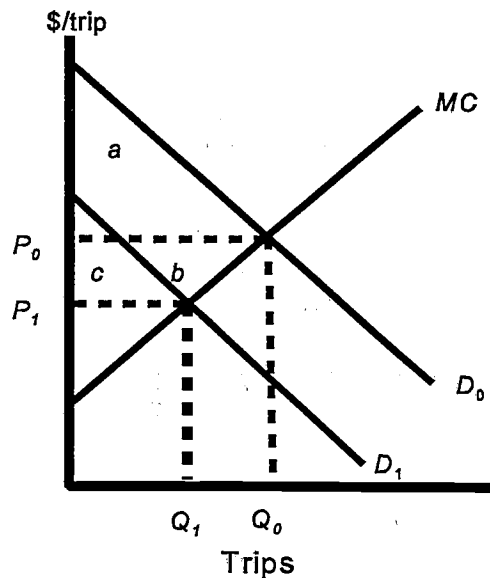


Figure A-4b. Welfare Calculation, Secondary Market



Special conditions in transportation markets

Note some special features of transportation demand and cost relationships. First, as transportation economists, we typically think of transportation prices and costs as including more than just the cost to us of buying things from third parties. The reason is that consumers of transportation services are both consumers and producers of transportation services; they “pay” for transportation services not only by paying for gasoline, tires, parking, transit fares, and so on, but also by committing their time to travel. The full or generalized price *that they perceive* is the total of cash costs plus their valuation of their time. Thus, the demand curve typically relates trips per period (or sometimes VMT, if persons per vehicle can be reasonably thought of as fixed) on a particular link or between a particular origin-destination pair to the willingness of the consumer to pay in cash *plus* time. Similarly, economists usually calculate transportation marginal cost curves on the same basis; that is, physical resource costs plus the value of the time involved.

A second consideration concerns the special shape of roadway and transit marginal cost functions, and their connection to the full prices that consumers pay. Roadways are congestable facilities: each additional vehicle imposes time penalties on the other users of the roadway. More technically, marginal full costs are an increasing function of trip or vehicle volumes in the short run. Unless there is a special pricing scheme to communicate this fact to consumers (i.e., congestion pricing), consumers will perceive only the average cost, not the marginal cost.

Transit cost functions behave differently, especially bus transit costs. As the quantity of users of a given bus line rises, and the bus company adds more buses, headways drop and (if special routing is added) walking time can be reduced as well. The cost function for transit users behaves, exactly the opposite that of the cost function for automobile users: marginal full costs in a given corridor decline with additional quantities of trip making. Economists must recognize, however, that, depending upon the pricing scheme used to pay for transit, users may or may not perceive the true marginal costs: they may perceive average costs, or something else.

This discussion of cost functions is central to proper measurement of benefits and costs in transportation networks. The shape of transportation cost functions determines the effects of policy on producer surplus calculations. The effects on producer surplus are key to properly estimating net benefits.

Practical computational implications

The benefit-cost analyst usually does not do the transportation network modeling; consequently, the analyst cannot be certain that the correct transportation cost relationships were actually used in the modeling. In this sense, benefit-cost analysis is only as good as the underlying economic assumptions embedded in the model of the transportation network. Frequently, the model works acceptably well for some types of policies, but less well for others.

Those cautions aside, however, the benefit-cost analyst faces the task of aggregating properly the changes in consumer and producer surpluses across the network—i.e., across modes, routes, and customer classes. Fortunately, this task is not as daunting as it might first appear. Here are the steps that need to be taken, for each period of the analysis:¹

Determine which transportation market(s) are the primary markets (i.e., the markets that are affected directly by the policy).

1. For the *Primary Markets*:

- a. Estimate the change in *Consumer Surplus*, by customer class if appropriate
 - (1) Estimate the change in total consumer benefits (i.e., the change in the area under the demand curves at the respective level of Q). This calculation requires only the before and after quantities and prices.
 - (2) Estimate the change in total payments made by consumers (in cash or in kind). This is a simple calculation from quantities and generalized prices.
 - (3) Subtract the change in total payments from the change in total benefits, to obtain consumer surplus.
- b. Estimate the change in *Producer Surplus*
 - (1) Estimate the change in revenue received by producers. This involves only information on quantities and prices.

- (2) Estimate the change in total cost incurred by producers. If this is not provided by the network modelers as a consequence of their modeling, it must be estimated from knowledge of the underlying cost relationships in each market. In general it is not simply a matter of multiplying quantities by unit costs, unless average costs are directly observed.
 - (3) Subtract the change in total cost from the change in total revenue.
2. For the *Secondary Markets*:
 - a. Identify those secondary markets in which the change in the equilibrium price is small or zero, and eliminate them from further analysis
 - b. Identify those secondary markets in which significant price changes occur because of the changes in the primary market. For those markets, estimate the change in producer surplus using the same technique as in the primary market case.
3. Aggregate the *Total Direct Transportation Effects* by adding consumer and producer surpluses calculated above.
4. Incorporate *External Effects*. Calculate any costs or benefits (such as the economic effects of changes in air quality) associated with changes in externalities
5. Estimate the *Present Value* of the net effects
 - a. Using the estimates from each period, calculate the present value of consumer and producer surpluses and external effects (net benefits before direct costs)
 - b. Using data on the pattern of construction or other developmental spending associated with the alternative, calculate the present value of spending on the improvement (direct costs)
 - c. Sum 6a+6b to estimate net benefits.

By following these steps, the analyst has the necessary information to calculate net benefits for a project, policy, or system alternative and to perform ranking and other selection exercises.

APPENDIX B - ASSUMPTIONS FOR BENEFIT-COST ANALYSIS

This appendix presents the details of the data used to estimate benefit and cost measures. Table B-1 presents the parameter values used for calculating user benefits. Table B-2 presents the cost estimates which were used.

Table B-1. Parameter Values for Benefit Calculations

Note: the cost parameters below for *Passenger* and *Commercial* travel are used to calculate potential reductions in cost (i.e., benefits) related to travel time savings or reduced vehicle miles traveled when comparing a given alternative with the "base case" (no build) alternative.

<i>Element</i>	<i>Parameter</i>	<i>Source</i>
Passenger Travel		
Regional hourly wage rate	\$15.74	Washington State Employment Security Department annual wage rate figures for the central Puget Sound region divided by the average number of hours in the U.S. work year.
In-vehicle value of time (VOT)	\$7.87	50% of wage rate. From Ken Small, <i>Urban Transportation Economics</i> (Luxembourg, Harwood Academic Publishers, 1992).
Out-of-vehicle VOT	\$15.74	Twice in-vehicle time per Small, <i>Urban Transportation Economics</i> .
Off-peak automobile operating cost / mile	\$0.365	Jack Faucett Associates, <i>The Costs of Owning and Operating Automobiles, Vans and Light Trucks, 1991</i> , FHWA, Washington, D.C. 1992.
Peak automobile operating cost / mile	\$0.386	Jack Faucett Associates, <i>The Costs of Owning and Operating Automobiles, Vans and Light Trucks, 1991</i>
Commercial Travel		
Commercial vehicle and driver cost / hour	\$60.00	Average of small and large truck lease rates from telephone conversations with truck leasing companies. Includes vehicle and driver costs.
Commercial vehicle inventory cost / hour	\$0.68	Economic output and equivalent truck loads data from the Regional Council study, <i>Analysis of Freight Movements in the Puget Sound Region</i> . Average value of \$75,000 per load, at 8% interest rate.
General		
Days / year	250	Models are for weekdays only. The estimates do not account for changes in weekend travel.
Discount rate (real)	6%	This rate includes a small risk premium to reflect project uncertainties. The effect of the discount rate will be tested in sensitivity analysis.
Start year for welfare differences	2000	
Base year for welfare calculations	1995	
End year for welfare differences	2020	

Table B-2 Public Capital and Operating Costs
(In millions of 1994 dollars)

	1996	2001	2006	2011	2016	Total
Highway Alternative						
MTP Highway Capital Costs	698.2	890.6	1,496.9	1,530.6	230.6	4,846.9
MTP Highway Operating Costs	5.7	7.2	12.1	12.4	1.9	39.3
MTP Arterial Capital Costs	671.9	504.4	492.4	316.9	316.9	2,302.5
MTP Arterial Operating Costs	11.1	8.3	8.1	5.2	5.2	38.
I-5/405 Capital Costs	0.	450.	450.	450.	450.	1,800.
I-5/405 Operating Costs	0.	2.8	2.8	2.8	2.8	11.1
Total MTP Capital Costs	1,370.1	1,845.	2,439.3	2,297.5	997.5	8,949.4
Total MTP Operating Costs	16.8	18.3	23.1	20.4	9.9	88.4
Total MTP Capital & Operating Costs	1,386.9	1,836.4	2,462.4	2,317.9	1,007.4	9,037.8
Net Present Value of Public Costs	1,308.4	1,313.6	1,297.1	912.4	296.3	5,127.9
Transit Alternative						
Transit Capital Costs	1,419.9	1,777.3	1,767.	1,668.8	1,688.9	8,321.8
Transit Operating Costs	146.6	390.9	663.	956.4	956.4	3,113.4
Total Transit Capital & Operating	1,566.5	2,168.2	2,430.	2,625.3	2,645.3	11,435.2
Net Present Value of Public Costs	1,477.8	1,528.5	1,280.1	1,033.4	778.1	6,097.9

APPENDIX C - NUMERICAL RESULTS FOR CASE STUDY

Table C-1 summarizes those user benefits and costs that were able to be estimated by mode for this case study, comparing the total benefits to total costs for each alternative. Table C-2 presents the results of the benefit calculations by mode and time of day. All costs and benefits are in net present value, using 1995 as the base year. *All results are for hypothetical alternatives only, and should not be interpreted as evaluation of actual plans under consideration for the central Puget Sound region.*

Table C-1 Net Monetized Benefits of System Alternatives* (in \$ millions)

	Transit Alternative	Highway Alternative	Pricing Alternative
User Benefits			
Transit	231	47	95
Carpool	1,279	2,353	3,210
Non-Carpool	3,197	5,812	7,816
<i>Subtotal - Passenger</i>	<i>4,707</i>	<i>8,211</i>	<i>11,121</i>
Commercial	5,378	9,896	14,044
Total	9,370	16,420	25,165
Public Sector Costs			
Capital	4,677	5,076	1,000
Operating	1,421	52	200
Total	6,098	5,128	1,200
Net Monetized Benefits - commercial excluded	(1,659)	2,451	9,921
Net Monetized Benefits - commercial included	3,272	11,292	23,965
Non-monetized Effects			
Air quality (% change in emissions from no-build case)			
CO	1.7%	4.8%	Not estimated
HC	(2.7)%	(1.4)%	
NO _x	(3.0)%	(6.1)%	
Land-use patterns	Not estimated	Not estimated	Not estimated
Other	Not estimated	Note estimated	Not estimated

* **Note on costs unable to be "monetized":** Other related but indirect and less traditionally measured transportation system costs should be considered in such an evaluation but were unable to be estimated for use in this case study. Examples are the following:

- Other public/municipal services costs (e.g. law enforcement, emergency services, street lighting, etc.)
- System preservation
- Air pollution
- Water quality impacts
- Additional solid waste disposal requirements
- Parking costs ("free" residential/commercial)
- Community equity/barrier impacts
- Land use/opportunity costs

Table C-2. Estimated User Benefits by Time Period (in \$ millions)

	Transit			Highway			Pricing		
	AM Peak	Off peak	PM Peak	AM Peak	Off peak	PM Peak	AM Peak	Off peak	PM Peak
Transit	99	132	N/A	49	(2)	N/A	60	36	N/A
Carpool	(16)	(1)	1,206	44	21	2,076	25	14	3,171
Non-Carpool	337	368	2,314	629	657	4,104	502	1,031	6,283
Commercial	53	234	4,644	104	574	8,164	133	1,370	12,540

As stated in the text, the monetary costs of pollution were not included in the formal calculation because time and resources did not permit us to adequately refine existing estimates. We did, however, carry out some informal calculations based on recent research presented by Small and Kazimi (1995). Using research on values of mortality and morbidity, and effects from air pollution, they estimated the air pollution costs for the Los Angeles basin to be about 3 cents per vehicle mile for passenger vehicles, 4.3 cents per mile for light-duty commercial vehicles, and 53 cents per mile for heavy-duty trucks. If these estimates are valid for the central Puget Sound region, the costs should be decreased by about \$1,000 million for the transit alternative and by about \$750 million for the pricing alternative. Costs should be increased by about \$100 million for the highway intensive alternative. Inclusion of these rough estimates in the formal benefit-cost calculations would require further refinement.

The analysis also did not include other automobile costs such as parking, accidents, social overhead, etc. Lee (1994) estimated those costs at about 14.5 cents per mile. Inclusion of these costs would not have affected the relative rankings of the alternatives. Table C-3 summarizes the rough estimates of the maximum costs of pollution and other mileage costs for the three alternatives.

Table C-3. Estimates of Costs Not Included (in millions of \$)

	Air pollution	Other costs	Total net effect on costs
Transit	(1,000)	(310)	(1,310)
Highway	100	(48)	52
Pricing	(750)	(240)	(990)

As stated in the text, a brief uncertainty analysis was conducted. Uncertainties were assumed to be normally distributed with a standard deviation such that the assumed error percentage represented a 90 percent confidence level. Table C-4 provides estimated percentage uncertainties.

Table C-4. Estimated Uncertainties in Benefit and Cost Measures

Measure	Estimated Uncertainty
Passenger benefits	20%
Commercial vehicle benefits	50%
Capital costs	30%
Operating costs	30%

Variations in the individual measures were simulated numerically and the relative rankings were tabulated. The probability that the rankings differed from the original estimates was less than 0.1 percent.

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