Puget Sound Regional Council

PSRC

Technical Memorandum
Regarding Procedural and Analytical Issues
Associated with Implementing
Integrated Transportation Planning

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1. INTRODUCTION

The Puget Sound Regional Council contracted with ECONorthwest to assist in the development of the theory and methods of least-cost planning as it applies to transportation. A draft report prepared by ECO for the Federal Highway Administration (FHWA) entitled *Least-Cost Planning: Principles, Applications and Issues* served as the starting point for ECO's work with the Regional Council. A draft of this report has received extensive review by a panel of national economics and transportation experts. Their comments were incorporated into the final draft of that report which will be completed in July 1995. The FHWA report developed a broad theoretical framework for applying least-cost planning to transportation. This memorandum uses that framework as a basis for a discussion of how least-cost planning could be implemented at the Regional Council and assumes that the concepts and approaches presented in that report are familiar to the readers of this memorandum.

This memorandum attempts to develop further the theory and methods of least-cost planning as they could apply in the Puget Sound region. The first section discusses some of the process issues associated with implementing least-cost planning. It begins with a discussion of the relationship between least-cost planning and strategic planning and explores how linking the two planning approaches could add clarity and facilitate the adoption of least-cost planning in transportation. It then discusses the relationship between system level planning and subarea planning and finally addresses how PSRC could adapt its existing planning processes to apply least-cost principles. The second section addresses some of the analytic issues associated with least-cost planning including the adequacy of existing data and approaches to addressing uncertainty in the evaluation of alternatives. An appendix provides greater technical detail on the analytic issues involved with modeling uncertainty.

One particular implementation issue surfaced early in the discussions among the participants in this project: the use of the term "least-cost planning". Members of PSRC's Technical Advisory Panel noted that in the utility sector the preferred term now is "integrated resource planning" to reflect the fact that cost is not the only criterion is selecting power resources. The participants in this study choose to adopt the term "integrated transportation planning" because it indicates the intention to apply least-cost planning principles to transportation while also acknowledging that transportation has some significant dissimilarities with electric utilities. For most of this memo we use the term integrated transportation planning (ITP) but we occasionally use least-cost planning as a synonym to avoid repetition.

2. PROCESS ISSUES IN THE APPLICATION OF INTEGRATED TRANSPORTATION PLANNING

2.1. INTEGRATED TRANSPORTATION PLANNING AND STRATEGIC PLANNING[1]

In this first section, we step back from transportation and put this proposed approach in a larger planning context. A review of strategic planning offers insights that may help make integrated transportation planning more effective and facilitate its introduction to transportation planning agencies and policymakers.

Definitions of planning are myriad, though they all share some common components: in planning one tries to anticipate a future state of affairs so that one can do things to prepare for or change that future state.

Most planning processes build on a standard model with the following steps:

1. Define the problem/goal/objective
2. Collect information germane to resolving the problem (achieving the goal)
3. Analyze the data (using any of the many techniques for manipulating quantitative and qualitative data)
4. Identify and evaluate alternative solutions (purchases, policies, programs, etc.)
5. Select and implement an alternative
6. Monitor and reevaluate the solution implemented
7. Return to Step 1 and begin again.

Where planning models differ is on:

1. *The relative importance of the steps of the model.* For example, we believe that most planning efforts spend relatively too much time on Steps 1 and 2 and relatively too little on Steps 3 and 4.

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[1]This discussion borrows heavily from work ECONorthwest did for the City of Portland's Office of Transportation on the uses of strategic planning.

2. *The order of the steps.* For example, though the model is often described as sequential, one step beginning only after its predecessor is finished, we believe that good planning has strong elements of recursion. For instance, new alternatives may suggest new goals or the need for additional data. The results of one step can often feedback and influence the content of a preceding step.

3. *The substantive scope of the planning effort.* A continuing debate among planners concerns the degree to which planning can be comprehensive (looking in detail at all variables that might impinge on a problem) or must be incremental (looking at just what is necessary to "muddle through"[2] to a decision). Systems analysts and visionaries tend to favor a comprehensive approach; political analysts and pragmatists tend to favor an incremental one.

4. *The time horizon of the planning effort.* To a large extent, this is part of the comprehensive/incremental argument: a comprehensive approach may look five to twenty years; an incremental approach no more than five years.

Few would argue with the position that, despite uncertainty, planning for future investments and operations will probably produce more desirable results than not planning, although many can and do differ on the most appropriate planning model. Our review of the planning literature has led us to conclude the following: (1) the type of planning model one uses depends on what one is trying to achieve, with what precision, in what environment, by when, at what cost; and (2) in general, both comprehensive and incremental (or long-run and short-run, or strategic and tactical) planning are needed: *the comprehensive view provides the context, the incremental view provides an action plan.* But given these conclusions, why should one adopt the planning methods embodied in what the literature calls *strategic* planning?

Strategic planning is a process of evaluation and decision-making that helps an organization establish and meet its objectives (ends) by facilitating the development of a strategy (ways) for achieving them and marshaling the

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[2]"Lindblom, C.E. 1980. *The Policy Making Process.* (2nd ed.) Englewood Cliffs, N.J.: Prentice Hall. "Muddling through" is not pejorative in this connotation ; it is the term Charles Lindblom used to describe an incremental planning approach that he recommends.

resources (means) for implementing the strategy. The term strategic planning has come to mean not only a long-run (strategic) view of organizations, objectives, and resources, but a system for making and evaluating that long-run view, and for using the view to make good decisions.

Strategic planning is in vogue with planners and decision makers in the public sector. Its advocates claim that it differs from traditional comprehensive planning because it:[3]

1. Focuses more on selected issues than on goals

2. Considers explicitly resource availability

3. Assesses explicitly strengths, weaknesses, opportunities, and threats

4. Considers major events and changes occurring outside the organization or jurisdiction; does not assume the continuation of trends

5. Looks not just at a government's existing role, but at its *potential* role; has more of a vision

6. Is action-oriented, with a strong emphasis on practical results

Until recently the literature on strategic planning dealt exclusively with the private sector. Only a few texts exist that are primarily directed toward strategic planning by public agencies. (See footnote 2 for the two best examples.) Although terminology differs, most strategic models include some close variation of the following steps:[4]

1. *Organize.* Identify and refine the objectives of the planning effort. Make sure those involved understand the plan's purpose.

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[3]Sorkin, Donna L. 1984. *Strategies for Cities and Counties: A Strategic Planning Guide.* Washington, D.C.: Public Technology, Inc., Page 1. Bryson, John M. 1988. *Strategic Planning for Public and Nonprofit Organizations,* San Francisco: Jossey-Bass, Pages 7-9.

[4]Sorkin, *op. cit.,* page 3.

2. *Scan the Environment.* Identify key factors and trends important for the future. Determine how external forces will influence events.

3. *Select Key Issues.* Choose a few issues whose successful resolution is critical.

4. *Set Mission Statements or Broad Goals.* Establish the direction for strategy development by setting general goals.

5. *Analyze Forces Affecting the Achievement of Goals.* Look in depth at external and internal forces affecting achievement of the goals. Identify strengths and weaknesses, along with the availability of resources.

6. *Develop an Implementation Plan.* Identify specific timetables, resources, and responsibilities for carrying out strategic actions.

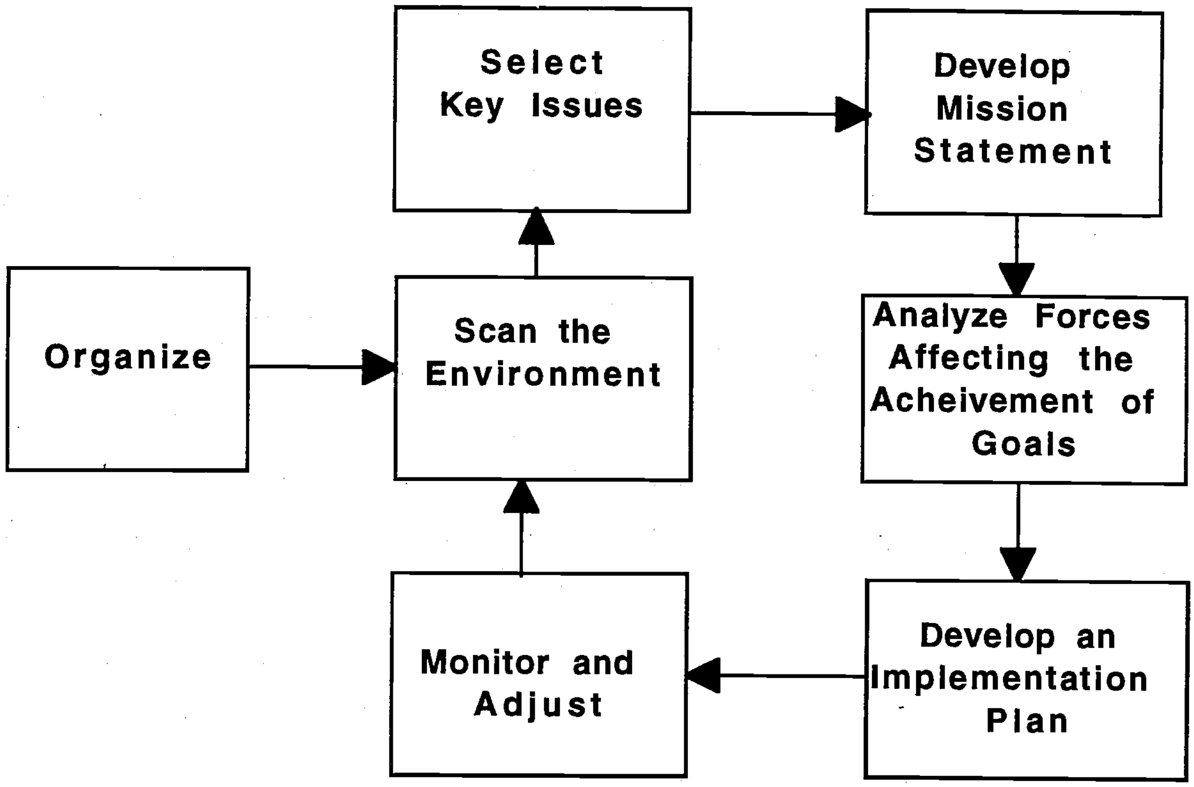
7. *Monitor, Update, and Scan.* Ensure that strategies are carried out. Adjust them as necessary in a changing environment. Update plan when major changes occur in the environment.

Figure 1 illustrates that although this strategic planning process appears to be a sequence of steps, each step may be performed a number of times, and various steps may take place simultaneously.

At the heart of all strategic planning models is an analysis of Strengths, Weaknesses, Opportunities, and Threats (commonly referred to as SWOT). The distinction among these elements is often blurry: for example, a weakness is threatening, but it presents an opportunity for change. Most of the literature defines opportunities and threats (or constraints) as coming from factors *external* to the organization and over which it has little influence (e.g., interest rates, population growth), and strengths and weaknesses as coming to those factors *internal* to the organization that help or hinder its abilities to resolve identified problems. SWOT analysis is conducted in a preliminary way during the Scan of the Environment (Step 2), and in more detail during the Analysis of Forces (Step 5).

Figure 1

GENERAL MODEL FOR STRATEGIC PLANNING



Although differences exist in terminology, the planning models we reviewed all incorporate the steps illustrated in Figure 1 The differences that exist are in the recommended techniques for achieving the objectives of each step.

Although most strategic planning models that we reviewed have a great deal in common, some differences exist. For example, since private business often has different goals than public agencies, strategic plans developed for private organizations have different characteristics than do those developed by public agencies: (1) public agencies are dominated by politics, business organizations are dominated by economic factors, (2) public agencies have more pluralistic decision-making, and (3) implementation of plans is often more difficult and less efficient in public agencies than in private businesses[5].

Strategic planning may differ depending on who wants it done. Three approaches are possible: (1) a top-down approach where the strategic plan is

[5]Steiner, George A. *Strategic Planning,* The Free Press, London, 1979, pages 321-324.

conceived and implemented by administrators, (2) a bottom-up approach where the plan is developed by employees and middle-managers, and (3) a combined approach that encourages administration and employees to work together in all phases of developing the plan. The literature generally recommends that strategic planning take the latter form so that all of those involved in carrying out the strategic plan perceive that they have a stake in the process. This bottom-up approach is the only approach that is likely to succeed when different jurisdictions must plan together and develop complementary plans and policies.

Although all of the models reviewed mentioned budgeting as an important part of the strategic planning process, models designed for the public sector were more sensitive to the importance of linking the budgeting process to the implementation of plans. The exact timing of the linkage varied. While some models recommended that budget linking take place in the organizational phase of the strategic plan, others delayed the linkage until the development of the implementation plan.

While most texts and articles recommend a comprehensive approach to strategic planning, a few made an argument for an incremental approach, stressing flexibility that allows an organization to change strategies at any point in the process.

2.1.1. Linking Strategic Planning and Integrated Transportation Planning

Integrated transportation planning clearly fits within the context of strategic planning. Strategic planning's emphasis on consideration of changing and uncertain external conditions, analysis of forces that affect the achievement of goals, and use of feedback loops to monitor and evaluate implementation are important elements of the ITP framework. These components of strategic planning also suggest a resolution to some of the debate about the relationship between benefit-cost analysis and least-cost planning. ECO's early version of the FHWA report argued that in making the transition to transportation, least-cost planning had to account directly for changes in user benefits and, therefore, benefit-cost analysis was the appropriate analytic framework. The draft of the report stated that least-cost planning was the same as benefit-cost analysis in transportation.

Experienced practitioners in the energy field objected to this characterization contending that least-cost planning was more that "just" benefit-cost analysis. They said least-cost planning takes a system-wide perspective, accounts for uncertainty, involves the public in meaningful ways, and considers both supply and demand side alternatives. They asserted that least-cost planning encompasses a broad planning process while benefit-cost analysis is primarily

an analytic technique. Proponents of benefit-cost analysis responded that it was designed for application to real policy choices and if done properly includes honest development of alternatives (which would include demand side measures), can accommodate system as well as project level evaluation, and is fully amenable to addressing uncertainty and public involvement.

To resolve this debate, we now think it appropriate to distinguish between the integrated transportation planning and benefit-cost analysis. Integrated transportation planning encompasses the entire seven steps depicted in Figure 1. Benefit cost analysis is the analytic tool that is used to help identify key issues in Step 2 and to evaluate alternatives in Step 5. Benefit-cost analysis is the analytic core of ITP but integrated transportation also encompasses the other elements of strategic planning.

The strategic planning model emphasizes at least one other area that deserves further attention in the development of least-cost planning for transportation. Step 1 in which the key stakeholders agree to the planning effort's goals and objectives is essential to the success of least-cost planning. The process for building agreement about objectives among the participants in a transportation least-cost planning process is a significant obstacle. The consultant review panel emphasized the many examples in their experience in which alternatives analysis was manipulated or ignored by policymakers who had pet projects they wanted approved.

For electric utilities in the Northwest, the costly expansion of unnecessary nuclear generation capacity and the bond default by the Washington Public Power Supply System (WPPSS) prompted a crisis that helped change the practices around power planning. It is not yet clear if policymakers in the Puget Sound want or will be forced into a new planning process for transportation. Such a process will require agreements among policymakers about the goal of cost-effectiveness that may be difficult to reach.

In spite of this difficulty, the Puget Sound Region has more experience than many other parts of the country with multi-jurisdictional planning efforts. The planning required under the state's Growth Management Act has encouraged a long-term view of planning and an awareness of the constraints of the region's transportation system. The recent failure of the Regional Transit Authority's rail proposal with the voters has stimulated new debate about how best to meet the region's transportation needs. It may be that the least-cost planning process can help sort out the competing interests and build agreements about a cost-effective transportation system.

While it has been useful to consider ITP in a broader planning context to help sort out the analytic elements from the process and political elements, some

members of PSRC's Technical Advisory Panel cautioned against too close an association with the specifics of strategic planning. They observed that while strategic planning is currently popular in the public sector some variants of the approach are now out of favor in the private sector. Panel members did not want to see the benefits of better long-term planning in transportation undercut by association with what some may perceive as a passing management fad. The planning principles of integrated transportation planning are well established and should stand on their own.

2.2. PLANNING LEVEL FOR INTEGRATED TRANSPORTATION PLANNING

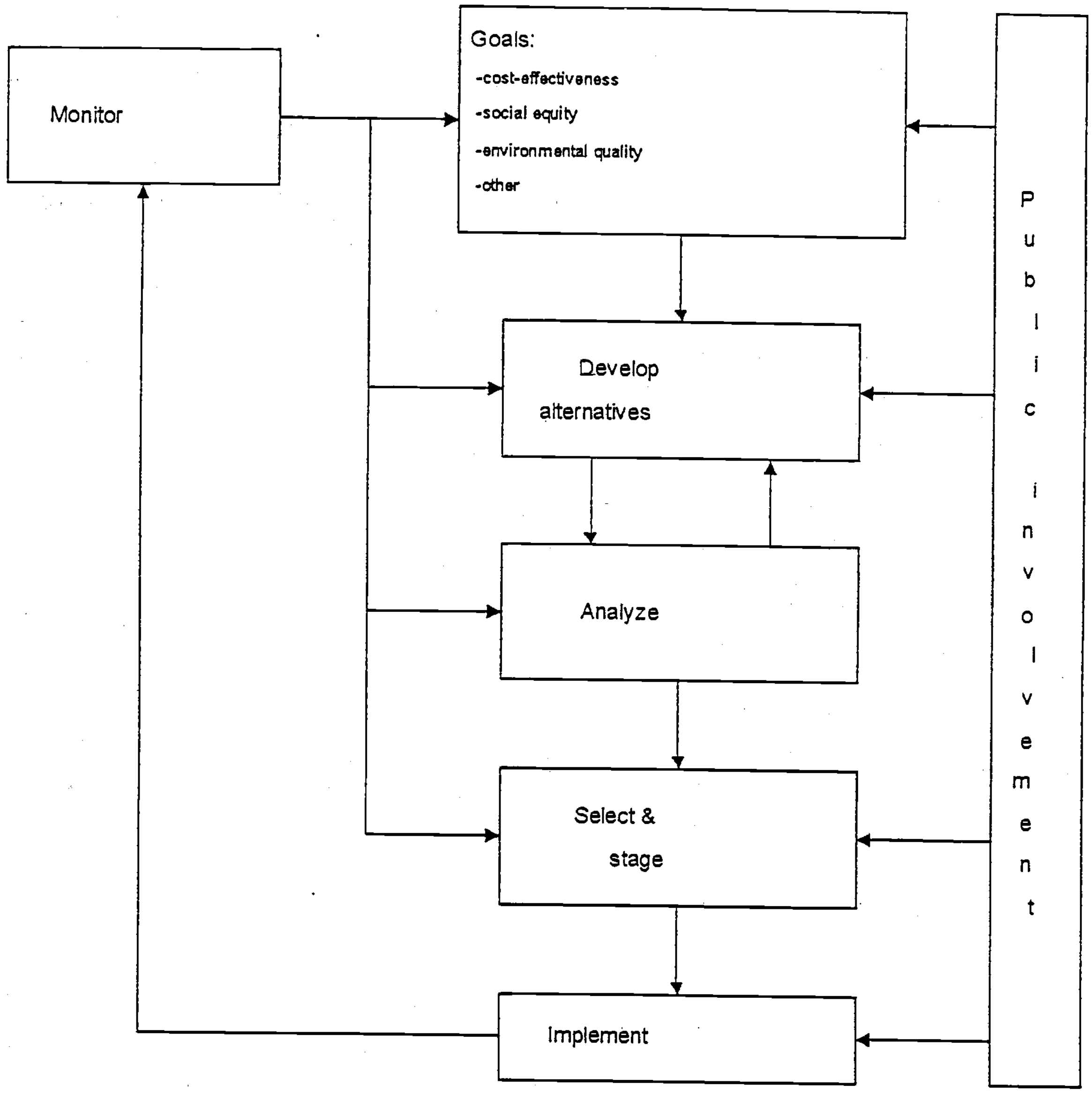
Integrated transportation planning is intended to be applied at all levels of planning, from system level to project level. Incorporating the key elements of integrated transportation planning at all levels ensures a consistent approach throughout the entire planning process. These key elements include the following:

- *Consideration of a full range of alternatives* appropriate to each level.
- *Analysis of all effects* of each alternative, including direct and indirect effects.
- *Consistent valuation of all effects.* To the maximum extent possible, the dollar value of the net social benefit of each alternative should be estimated. Effects that cannot be monetized should be quantified where possible. Effects that cannot be quantified should at least be stated qualitatively and compared.
- *Estimation of uncertainty of the results.*

2.2.1. Integrated Transportation Planning Process

Figure 2 gives an overview of the integrated transportation planning process. It represents an adaptation of the generic strategic planning model in Figure 1 to meet the special requirements of transportation planning. It also incorporates least-cost planning's emphasis on identifying cost-effective alternatives.

Figure 2 - Overview of Integrated Transportation Planning Process



Goals

Goals constitute the driving force for the planning process. Integrated transportation planning provides a consistent framework to simultaneously consider a number of seemingly diverse goals: e.g., a cost-effective transportation system, social equity, environmental quality. Integrated transportation planning puts cost-effectiveness at the top of the list of goals. It

places special emphasis on ensuring public resources are directed in a manner that achieves the maximum social benefit. ITP also recognizes that goals such as social equity and environmental quality are often not amenable to quantification in the benefit-cost framework but are nonetheless legitimate criteria for evaluating alternatives. It balances the cost-effectiveness criterion with other policy goals and given policymakers a framework for weighing tradeoffs.

Public Participation

Public participation is crucial to several key elements of the integrated transportation planning process. It is necessary for the articulation of goals, especially those that cannot be easily monetized or quantified. Public participation is required to develop a full range of alternatives that collectively address all goals. It is also a key factor in the selection of alternatives to be implemented, because this is the stage in the process where tradeoffs among goals must be made.

We recommend that the public be involved from the beginning of the integrated transportation planning process, especially the formulation of goals and the development of alternatives. Public involvement with the development of alternatives is important for several reasons:

- The public is likely to have its own views of which alternatives are desirable. Including these will help ensure that the fullest range of alternatives is considered.

- As discussed later, an important test of alternatives will be to see how well they perform under different future scenarios. Development of scenarios will require public agreement on things such as land development and population densities in the region. Public involvement will ensure that at least some of the scenarios are politically acceptable.[6]

- When alternatives are being analyzed, the first phase of the analysis will consist of screening all alternatives. The methods

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[6]But if the range of scenarios is to be broad enough to bracket all possible future conditions, there may be some scenarios that the public does not consider desirable. Nevertheless, these should be included in the analysis to allow testing the alternatives for robustness, and to provide policymakers and the public on which alternatives perform best should the "undesirable" scenarios actually occur.

of analysis used for screening will be more transparent than the detailed modeling process used in the second phase. Thus, it will be easier to explain the screening process to policymakers and the public; in particular, why planners recommend that some alternatives not be considered any further.

- Planners may recommend screening out of some alternatives that the public would like to see analyzed further. In that case, it may be necessary to include one or more of these in the detailed analysis if the planning process is to be perceived as legitimate by the public.

Monitoring

There are two aspects of monitoring in the integrated transportation planning process:

1. *Environmental scanning.* As discussed in the overview of planning approaches, environmental scanning is a key component of strategic planning. It consists of identifying key factors and trends that are important for the future, and determining how external forces will influence the environment within which alternatives will be implemented

2. *Project monitoring and evaluation.* Integrated transportation planning requires careful monitoring of the actual costs and performance of transportation projects and policies that are implemented. Feedback from how projects actually perform provides better information on cost-effectiveness and improves the models used to predict travel behavior. Integrated transportation planning should involve constant reevaluation of which measures work and corresponding adjustments to long-term strategies. Hence, implementation of a plan or project should include the establishment of an ongoing evaluation process to provide the necessary monitoring information.

2.2.2. Analytic Elements of the Integrated Transportation Planning Process

Figure 3 shows the relationships among the analytic elements of the integrated transportation planning process. These divide into two phases: 1) initial development and screening of alternatives, and 2) detailed analysis of candidate alternatives that remain after the first phase. Details of the process

will vary according to the scope of the analysis (e.g., system level, subarea level, corridor level, project level), but the general procedures will apply regardless of the scope.

Develop alternatives

This stage of the integrated transportation planning process is where the primary difference occurs between different levels of planning. At the system level, the alternatives consist of broad, region-wide policies; the policy that is selected will determine the context for carrying out more detailed planning analyses. System-level alternatives are likely to include not only modal alternatives (e.g., highway emphasis vs. transit emphasis), but other types of policies such as system management alternatives (e.g., demand-side management, road pricing) and land use alternatives (e.g., Vision 2020 land use patterns vs. no limits on land development); some alternatives may include a mix of two or more of these types. Most system-level alternatives will involve some changes to the supply of transportation, and therefore to the transportation network. But the level of network detail required for defining system-level alternatives will very likely be less than that required for corridor-specific or project-specific analysis.

At the project level of integrated transportation planning, the alternatives will consist of discrete projects that must be compared to each other (e.g., adding HOV lanes in a corridor, increased transit capacity and operating frequency, adding mixed-use lanes). The range of projects to be considered may be constrained to those that support the alternatives selected by integrated transportation planning at the system level. For example, if the region were to select system policy that consisted of a combination of improving transit service and pricing with no further significant additions to highway capacity; then the project-level alternatives could be constrained to projects such as specific transit service additions or implementation of road pricing on specific routes. In other contexts, however, project level analysis should include alternatives that are not in the current system plan as a means for developing data about supply or demand management options that could be added to future revisions to the system plan.

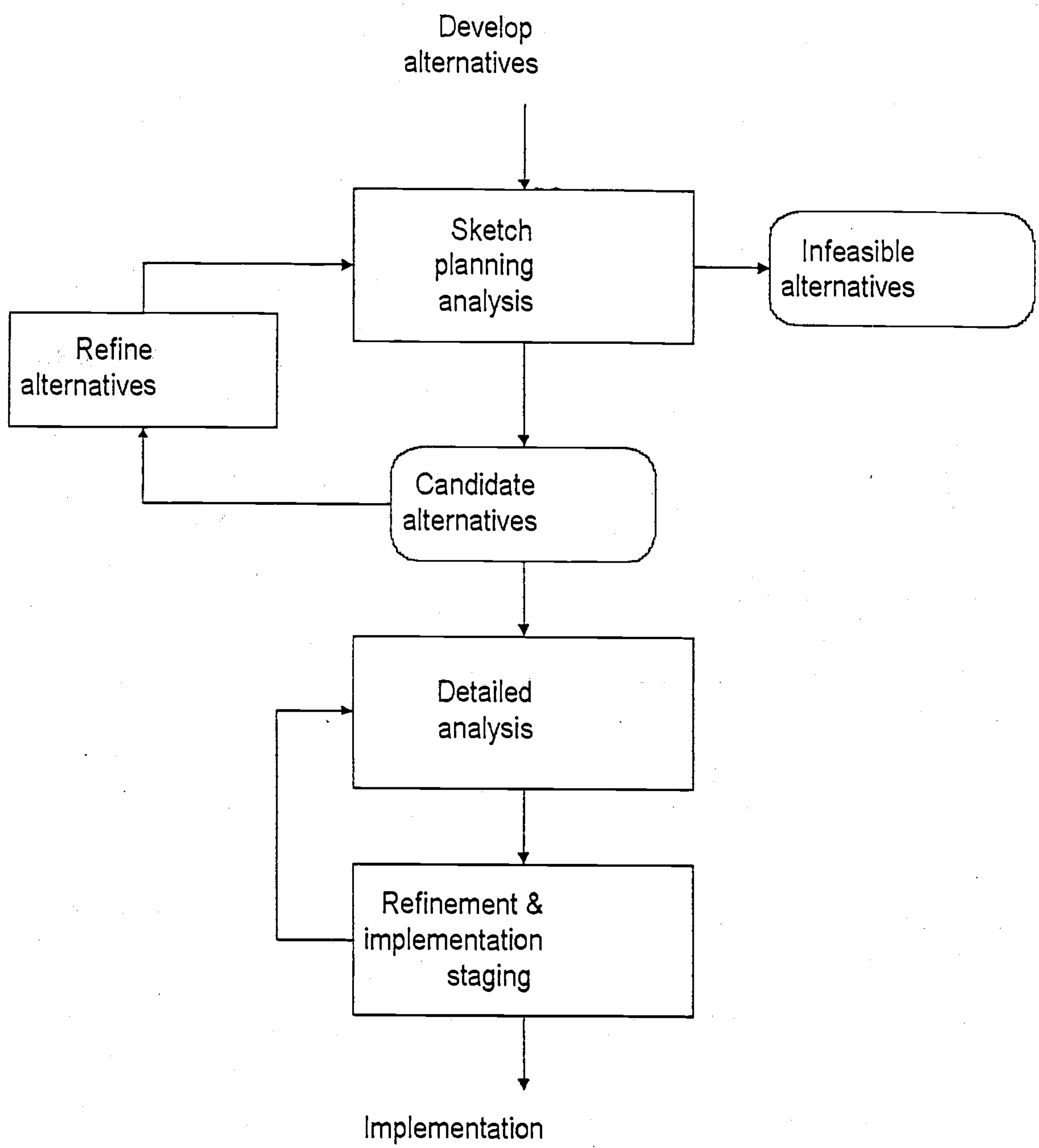

Figure 2 - Analytic Elements of Integrated Transportation Planning Process

Regardless of the planning level, the key aspect of developing alternatives for integrated transportation planning is that *a full range of alternatives must be considered*. Two elements are crucial to defining alternatives in order to carry out integrated transportation planning effectively at the project, corridor and system level:

- *Develop as many alternatives as possible to enable evaluation of all potential policy directions.* It frequently happens that planning resources are limited, forcing a tradeoff between the number of alternatives considered and the depth of analysis that can be applied. Impoverishing the alternatives places a limit at the outset on the information that integrated transportation planning can provide to decision makers.

- *Design each alternative to be as cost-effective as possible.* At the system level, it is necessary to generate information on broad policy directions. In order to fairly compare alternatives, it is essential that decision makers be provided with information on how well each alternative can possibly do. This means, for example, that a highway alternative should be designed to maximize user benefits through reduced travel time and consumer surplus; or that a transit alternative should be designed to provide the most cost-effective service. Integrated transportation planning cannot provide good information to decisionmakers if an alternative performs badly because of a flawed design.

2.2.3. Sketch Planning Analysis

The initial number of alternatives is likely to be quite large, especially when carrying out a system-level analysis. It is unlikely that the resource capabilities of planning agencies would be sufficient to model all the alternatives in detail. Sketch planning techniques should be used to screen out those alternatives that perform significantly less well than others being considered. Using sketch planning methods rather than full-scale application of traditional travel forecasting models makes it feasible to consider a sufficiently broad range of alternatives.

"Sketch planning methods" has been used as a term by transportation planners to describe analytic methods that range from simple rules of thumb, to "back of the envelope" analyses, to simplified models that can be implemented on a spreadsheet, to special-purpose computer packages. For purposes of this discussion, the term "sketch planning methods" is used to refer to any analysis method up to (but not including) the full PSRC

transportation planning models. Sketch planning analysis may make use of one or more of a number of methods. Existing network data can be useful for providing level-of-service estimates for models such as STEP, which provides results at a relatively greater level of detail than most sketch planning models.[7] Some studies of broad, regional-level policies have used sketch planning models that represent the transportation network at a more abstract level than that used in the four-step process.[8] Economic studies are available that provide information on the cost-effectiveness of various modal alternatives.[9] Documented experience with changes to the transportation system can also provide useful information on the likely effects.[10]

Whatever method is used, the sketch planning analysis should be done in sufficient detail to accomplish the following:

- Estimate the major effects of the alternatives (e.g., construction and operating costs, user costs, air quality effects).
- Provide sufficient detail to distinguish among most of the alternatives. (Some alternatives may perform so poorly that not much analysis will be required to screen them out.)

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[7]The STEP model is described in Greig Harvey, *Short-Range Transportation Evaluation Program: Description and User's Guide,* report prepared for Metropolitan Transportation Commission, Oakland, California, 1979. An abridged description of the model is contained in Michael Cameron, *Transportation Efficiency: Tackling Southern California's Air Pollution and Congestion*, Environmental Defense Fund, Oakland, California, 1991.

[8]An early example is the Boston transportation planning review, described in Ralph Gakenheimer, *Transportation Planning as Response to Controversy: The Boston Case,* (Cambridge, MA: M.I.T. Press, 1976).

[9]See, for example, Peter Fisher and Philip Viton, "Economic Efficiency in Bus Operations: Preliminary Intermodal Cost Comparisons and Policy Implications", volume 1 of T.E. Keeler *et. al., The Full Costs of Urban Transport,* Institute of Urban and Regional Development, University of California, Berkeley, 1974.

[10]A good example of documentation of past experience is Richard H. Pratt, *Traveler Response to Transportation System Changes,* 2d ed., Barton-Aschman Associates, Inc., R.H. Pratt & Co. Division. Washington, D.C. : Federal Highway Administration, Office of Highway Planning, Urban Planning Division, 1981.

- Test the sensitivity of the alternatives' relative performance to changes in underlying assumptions.

The initial analysis may reveal that some alternatives would perform significantly better if they were redesigned. For example, a transit-based policy alternative that is being considered may overemphasize line-haul service at the expense of collector service. If this occurs, the appropriate alternatives should be refined to make them more cost-effective in order that the sketch planning analysis can provide a fair assessment of which alternatives need to be considered further.

2.2.4. Detailed Analysis of Candidate Alternatives

The result of the initial phase of the process will be a set of candidate alternatives that are selected for more analysis. In general, these will consist of alternatives for which the sketch planning process estimated greatest net social benefit. There may, however, be one or more additional alternatives that are included as a result of public involvement.

Analysis of the candidate alternatives will be done at a greater level of detail than for the full set of alternatives considered in the first phase. Because those alternatives that survive this far are determined to be cost-effective, a greater depth of analysis will be needed to distinguish between them. Analysis of these alternatives will require full-scale application of the regional land use, travel forecasting, and air quality models to capture network effects that are absent from most sketch planning techniques.

A key aspect of this phase is to account as well as possible for the uncertainties in the results. As discussed in the next section, this will involve estimation of uncertainties in the components of the benefits and costs, and numerical simulation to estimate overall uncertainties in the net social benefit for each alternative.

2.2.5. Refinement and Implementation Staging

As in the first phase, the analysis in the second phase may uncover specific flaws in some alternatives that cause them to perform less well than they otherwise might. In those cases, the designs of these alternatives should be modified before completing the analysis.

The final stage of the analysis should include specifications of the projects that go into each alternative, including the staging of the projects and their lead times. As discussed earlier in this section integrated transportation planning process is dynamic, responding to changing future conditions.

Periodic environmental scans may reveal that exogenous conditions are changing differently than forecast, changing the relative cost-effectiveness of some alternatives. Hence, it is important that decision makers know the key decision points for each alternative in order to make policy and implementation decisions in a timely manner. *It is the lead times for these projects that are crucial to identifying when the key decision points will occur.* Identification of the key decision points will set the stage for system monitoring by informing the process on when information is needed from environmental scanning and project monitoring.

2.3. INTEGRATED TRANSPORTATION PLANNING AND PSRC'S EXISTING PLANNING PROCESSES.

Our discussion of the planning framework and relationship between system level and project level planning is entirely consistent with the federal requirements for the Regional Council to develop a Metropolitan Transportation Plan (MTP) and conduct Major Investment Studies (MIS) of projects in subareas and corridors. Applying an integrated transportation planning approach to existing planning processes will require a modification of existing processes; not a wholesale revision of the way the Regional Council does business. In this section, we review how, by complying with federal requirements, the Regional Council has begun the move toward integrated transportation planning. We then highlight the ways in which the MTP process could be modified to incorporate integrated transportation planning principles more fully.

2.3.1. Federal Requirements Point Toward Integrated Transportation Planning

The federal regulations require MPOs to consider fifteen elements in the development of their metropolitan transportation plans. These elements closely parallel the principles of integrated transportation planning. The following list highlights some of the federal requirements that, in essence, say "Do integrated transportation planning." The numbers correspond to their listing under §450.316 in the Federal Register (Vol. 58, No 207).

(1) "...meet transportation needs by using existing facilities more efficiently."

(3) "...use travel demand and reduction and operation management strategies."

(4) "...include projections of ...economic, demographic, environmental protection, growth management, and land use activities.."

(6) "(C)onsider the effectiveness, cost effectiveness, and financing of alternative investments in meeting transportation demand..."

(10) Preserve "rights of way for construction of future transportation projects,.."

(11) Enhance "the efficient movement of freight."

(12) Consider "(O)perating and maintenance costs ... in analyzing transportation alternatives.

(13) Consider the "overall social, economic, energy, and environmental effects of transportation decisions."

Section 450.322 of the federal regulations also identifies key components of the planning process which Metropolitan Planning Organizations must adopt. These process requirements include a twenty year planning horizon, projections of future travel demand for people and goods, consideration of a full range of new supply and travel demand management options and an active program of public involvement. In May 1995, the relevant federal agencies reviewed PSRC's planning activities and found that the Regional Council met the federal planning requirements in the recently completed Metropolitan Transportation Plan[11] . By complying with federal requirements, the Regional Council has already made substantial progress toward incorporating integrated transportation planning principles into their process.

2.3.2. Potential Changes to MTP Planning Process

While key elements of integrated transportation planning were included in the 1995 MTP process, the Regional Council should consider changes in several areas in the development of the next Metropolitan Transportation Plan.

Development of system alternatives

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[11]The Metropolitan Transportation Plan was adopted by the Puget Sound Regional Council General Assembly on May 25, 1995.

The Regional Council should examine the ways in which system alternatives are developed for the next MTP. Potential changes include:

- greater public involvement
- consideration of more system alternatives
- use of sketch planning tools to test alternatives at lower cost than traditional modeling approaches

Late in the review process for the 1995 MTP, environmental groups asked PSRC to consider a reduced automobile dependency (RAD) alternative. Staff at PSRC responded quickly to the request and performed a thorough analysis but the alternative was considered late in the process. Integrated transportation planning recommends soliciting alternatives from key stakeholder groups early in the process so a full range of options is considered. There are system alternatives other than the RAD alternative that the Region could have considered but didn't. These range from more aggressive expansion of highway capacity to a regional congestion pricing policy with no new highway or rail transit capacity.

The current four-step modeling process constrains the number of alternatives that can be considered because of the high cost of operating the model and because it fails to capture all of the relevant effects of some key policy measures such as pricing. Sketch planning tools such as the STEP model could be used early in the process to consider a greater number of alternatives prior to selecting those for more detailed modeling under the four-step process. The Regional Council's recent upgrade of the computer network used for running the four-step model will also permit more rapid analysis and facilitate the consideration of a larger number of system alternatives. Whatever sketch planning and modeling techniques are used, it is important that they allow a sufficient number of alternatives to be developed and tested early in the process.

Evaluation of benefits and costs of system level alternatives

The 1995 MTP provides data on the system's projected performance under a no action scenario and several alternatives. Performance measures include the total amount of vehicle miles traveled, the amount of the network experiencing congestion during peak periods, the total amount of delay in the network, and the level of air borne emissions. Integrated resource planning would supplement these performance measures with estimates of the relative costs and benefits of the different approaches. Policymakers would have data on the net social benefits of one alternative compared to another.

This information would help them compare alternatives that are difficult to evaluate when the analysis is limited to measures of system performance. Policymakers currently receive little guidance in choosing between a system alternative with medium performance and low capital investment and other with higher performance and high investment costs. Explicitly accounting for benefits and costs can begin to help policymakers distinguish between these types of policy choices

The benefit-cost analysis should be considered along with those measures of system performance that are not amenable to quantification as costs and benefits. The decision-making process should make clear which policy effects are captured in the benefit-cost calculation and which are not. Mobility effects such as the level of congestion and amount of delay as well as the total capital and operating costs can be expressed in dollars with a reasonable level of confidence. Other effects such as changes in air quality, urban form, and equity should be described and then considered in conjunction with the benefit-cost data.

Address uncertainty in forecasts and performance of travel policies

Section 3. 2 of this memorandum addresses how the analytic elements of an MTP process should address uncertainty in the evaluation of alternatives. We recommend that in addition to better data about social benefits and costs, the Regional Council provide information about the level of uncertainty associated with its forecasts of system performance. Policymakers should know if the likely variance in key parameters of the forecasting models prevents analysts from distinguishing between the performance of two alternatives. Integrated transportation planning avoids spurious precision in forecasts so policymakers understand the likely range of future effects.

Uncertainty analysis should also test how different transportation system alternatives will perform under a likely range of economic, demographic and land-use scenarios. Policymakers need to understand how changes in growth forecasts could influence the phasing and introduction of certain types of policies and investments

Emphasis on iterative nature of transportation planning

Informing policymakers about the uncertainty inherent in travel demand forecasts will reinforce another key element of integrated transportation planning: the periodic readjustment of plans. Although policymakers in the Puget Sound are aware that they must update the MTP every three years, many fail to fully understand the iterative nature of integrated transportation planning. Conditions change and plans need to adjust to those changes.

Policymakers understand this intuitively but often act as though plans are made and set in stone for the next twenty years. The planning process should illustrate how better information on the performance of certain supply and demand side transportation policies will inform adjustments to future plans. Ideally, policymakers will develop an interest in how different measures perform and use the information to guide system planning through the Regional Council and to influence the capital investments in their own jurisdictions.

This last point emphasizes one of the key challenges to implementing integrated transportation planning. The member agencies must be persuaded that ITP is a useful approach within their own jurisdiction if the method is to have a significant influence on the region's transportation system. While all local projects must be included in MTP and a conforming TIP, localities still have considerable discretion over how they spend their transportation resources. The MTP can help showcase the advantages of the ITP method and encourage local jurisdictions to adopt the approach.

2.3.3. Integrated Transportation Planning and Major Investment Studies

As with the MTP process, the Regional Council is moving toward integrated transportation planning in its Major Investment Study (MIS) approach by complying with the federal requirements. Guidelines under development by the Council staff on MIS procedures emphasize key elements of the integrated transportation planning including:[12]

- Collaboration among all the agencies with an interest in the project
- Consideration of a full-range of alternatives within the corridor or subarea.
- Application of benefit-cost principles to project evaluation
- Integration of MIS data and public involvement processes into system level planning under the Metropolitan Transportation Plan.

While federal mandates appear to require a formal evaluation of benefits and costs, most recent Major Investment Studies don't appear to move much beyond the requirements for environmental impact studies. The Regional

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[12]From a June 9, 1995 draft of *Regional Council MIS Procedures* under development by Peter Beaulieu.

Council will have to assert leadership to encourage sponsoring agencies to rigorously evaluate the social costs and benefits of the alternatives under consideration. Sponsoring agencies may also need encouragement to consider supply and demand side alternatives that are more than strawmen designed to favor a predetermined favorite. Major Investment Studies should be designed in a way that provides useful data to policymakers on the cost-effectiveness of the alternatives within the corridor and also helps inform and influence the development of subsequent system plans.

Integrated transportation planning will require changes in the existing processes for choosing alternative transportation investments and policies. Fortunately, many of those changes are already underway because of federal and state requirements that emphasize long-term planning and cooperation among jurisdictions. ITP will also require changes in the analytic methods used to evaluate alternatives.

3. ANALYTIC ISSUES IN THE APPLICATION OF INTEGRATED TRANSPORTATION PLANNING

3.1. DATA REQUIREMENTS

Integrated transportation planning requires the development of comprehensive information about the performance of each alternative. Table 1 lists the major effects of alternatives that are important to integrated transportation planning and measures of these effects. The current state of practice in transportation and air quality modeling will not in general provide all information at the required scope and level of detail. It will be necessary to adopt interim measures for estimating the required information until better information and procedures can be developed. Despite the current state of modeling practice, it is important that key effects be enumerated and that they be estimated consistently within the limits of current capabilities.

Table 2 lists the main issues arising from using current planning methods to develop estimates of benefits and costs for integrated transportation planning. Most of these issues have to do with the current state of practice in modeling travel demand. As discussed in the appendix, PSRC's current model system is modified version of the four-step approach. These models contain some inherent shortcomings with respect to the information needed for integrated transportation planning. The short-term improvements are ones that can be made without a full-scale overhaul of the model system, or by implementing improvements that are currently in progress as part of PSRC's model improvement program.

Table 1 - Effects and Measures Needed to Estimate Them

Effect	Measures
Lead times for implementation (plan, project)	• Time needed for public process (planning, evaluation, selection). • Implementation time for individual component projects (including construction time).
Construction and operating costs	• Construction cost. • Operating and maintenance costs.
User costs	• Vehicle operating costs. • Total passenger-hours of travel. • Travel times by mode. • Value of time. • Freight carrier person-hours of travel.
User benefits	• Consumer surplus. • Travel volumes by mode and time of day as function of time and cost. • Economic value of activities undertaken due to passenger transportation. • Economic value of freight travel.
Consumer surplus	• Travel volumes by mode and time of day as function of time and cost.
Safety	• Number and value of accidents.
Air pollution	• Air pollution emissions. • Mortality and morbidity from air pollution. • Value of life and health.
Other environmental effects	• Quantitative measures or qualitative statements of effects: e.g., noise, barriers, water quality. • Economic valuation of effects: e.g., economic value of reduced noise, improved water quality.
Equity	• Distribution of benefits and costs among different groups.

Note: All benefits and costs are in net present value, calculated over the lifetime of the project. Hence, all measures must be estimated by year, and will require a discount rate appropriate to that effect.

Table 2 - Analysis Issues in Integrated Transportation Planning, Recommended Improvements

Issue	Recommended Improvements	
	Short term	*Long term*
Trip generation insensitive to transportation supply variables (cost, level of service). Models cannot accurately represent effects of increased congestion or road pricing on tripmaking.	Implement new trip generation models that incorporate supply variables. Or, use available modeling techniques that incorporate supply variables (STEP).	Develop activity based microsimulation models with discrete trip generation models.
Peaking insensitive to level of service and pricing. Models cannot accurately represent effects of increased congestion or road pricing on trip timing.	For planning analyses where peaking factors expected to change, use available modeling techniques that contain time-of-day trip choice models (STEP).	Develop time-of-day models from household cross-section or panel survey. In longer term, develop trip or activity based microsimulation models with discrete time-of-day models.
Nonmotorized transportation not represented in modeling system. Difficult to estimate benefits of reduced automobile dependency policy.	Develop new trip generation model within existing four-step process that includes nonmotorized trips. Develop mode choice model that includes nonmotorized modes.	Develop activity based microsimulation models that can explicitly represent nonmotorized modes.
Existing models cannot represent effects of some TCMs (e.g., employer ridesharing programs, transit pass programs).	Use available data from household travel surveys to estimate market sizes for TCMs, estimate market penetration, adjust estimates at appropriate points in travel demand modeling process.	Develop activity-based models from cross-sectional data that are sensitive to demand-side TCMs.
Four-step models cannot provide estimates of benefits by socioeconomic group, which are needed for assessing equity effects.	Use available microsimulation models that can provide region-wide estimates of socio-economic equity effects (STEP).	Develop activity based microsimulation models that can provide greater detail for equity analysis.
Models are run only for base and forecast year. Difficult to get time stream of benefits and costs. Construction-period effects not modeled.	Interpolate between base and forecast year benefits and costs to get annual estimates. Develop simplified sketch-planning techniques to estimate construction-period benefits and costs.	Develop separate networks for construction period and each significant change to travel supply. Run models for each network.

Table 2 (cont.) - Analysis Issues in Integrated Transportation Planning, Recommended Improvements

Issue	Recommended Improvements	
	Short term	*Long term*
Uncertainties in model estimates unknown.	Conduct observations of key transportation system performance measures (travel times, travel volumes, mode splits, etc.) and compare to past model forecasts. Conduct backcasts using current models and compare to past transportation system performance measures.	Carry out numerical simulation to estimate uncertainties in current models. As newer models are developed (e.g., activity-based models), carry out numerical simulations and report uncertainties as part of model documentation.
Costs of environmental effects (air quality, noise, etc.) difficult to estimate.	Quantify environmental effects to maximum extent possible within existing state of art. Use available research on environmental costs to estimate ranges of costs; incorporate into uncertainty analysis.	Conduct additional research on costs of environmental effects (e.g., hedonic pricing studies of effects of environmental changes on land values, morbidity and mortality costs of air pollution).
Safety effects currently not estimated.	Use available methods to estimate changes in safety (e.g., accident rate data).	
Benefit-cost analysis for freight movement not possible with existing data	Estimate freight component of vehicle flows, freight vehicle-hours of travel, value of time savings.	Explicit freight movement model that provides estimates of freight vehicle trips that can be assigned to network.
No monitoring process in place.	Collect post-implementation data and evaluate projects recently implemented. Use PSRC panel data to try to detect effects of projects on travel behavior.	Enlarge PSRC panel and conduct waves at more frequent intervals to track changes in travel behavior. Establish project evaluation as part of implementation process; include project evaluation costs as part of project implementation budget.

Several of the recommended short-term solutions to shortfalls in the existing data involve the use of the STEP sketch planning model which offers the following advantages:

- STEP has already been implemented in the PSRC region for analysis of congestion pricing and is readily available.
- STEP explicitly models time-of-day tripmaking and the effects of travel supply on the number of trips made.
- STEP is a microsimulation model. It is a relatively simple matter to develop estimates of benefits and costs by socioeconomic group.

In the long term, a fundamentally new approach to travel demand modeling is needed. The current four-step process is over 40 years old, and is based on a process that was originally developed for purposes of planning new freeway links. The process was also developed in an era when computing power was limited and expensive to provide. Although there are a number of areas in which the current state of practice can be improved, new approaches are needed to provide accurate travel estimates.[13] The Federal Highway Program has begun a four-track travel model improvement program that includes the development of activity-based models for travel estimation. These models offer the potential for significant improvements over current practices. By modeling activities, they are closer to the behavioral processes that determine travel. Because they are microsimulation models, they can accurately represent linked trips, which are currently not recognized by the four-step modeling process. Microsimulation also allows the models to provide explicit data on socioeconomic distribution of benefits and costs.

It will be perhaps 5 to 10 years before activity-based models begin to be accepted as part of regular transportation planning practice. Nevertheless, we recommend that PSRC anticipate future developments in this area and prepare to implement them. One thing that can be done for now is to make sure that future household travel surveys (including future waves of the current panel) are *activity based* rather than trip based as they are today; this will enable PSRC to obtain better travel data in the short term, and to take advantages of activity models in the long term.

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[13] Harvey et. al., *Manual of Regional Transportation Modeling Practice.*

In addition, to the weaknesses of current travel demand models, integrated transportation planning must contend with a lack of good data on how to predict and value many important environmental effects. In particular, the effects of air pollution on human health, and the value of these effects, is still widely debated. Recent research has provided some basis for estimating these costs, but there is still a wide range of uncertainty about the magnitudes of effects and their value to society. [14]

Another weakness in existing data sources is that current travel forecasts are typically provided only for a base year and one future year (e.g., 2020). Integrated transportation planning requires estimates of benefits and costs on an annual basis so they can be discounted to their present value. One possible remedy is to run the forecasting models for three or four equally-spaced future years, and develop annual estimates by interpolating between these forecasts. A better procedure would be to run the forecasting models for those years when significant changes to population and employment patterns occur, or when significant changes to the network level of service occurs as a result of project implementation for an alternative.

Freight movement is perhaps the most under-analyzed aspect of the transportation system in regional transportation planning analyses[15]. The underlying behavioral motivations are less complex for freight than they are for passenger transportation. But the data collection problems are much greater, not least because of the proprietary nature of most of the data needed to truly understand freight transportation. Over the near term we recommend that benefit-cost analysis be conducted for freight movement by estimating freight vehicle movements as percentages of passenger vehicle movements (either for the region as a whole, or on a subarea or facility basis), and estimating the dollar value of travel time for these movements. The data collected for the 1995 MTP will facilitate making these estimates. The preferred long-term improvement would be to develop a set of freight movement models that provide outputs similar to those for passenger transportation models: vehicle movements and speeds by link and time of day.

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[14]An excellent summary of research to date is provided in Kenneth A. Small and Camilla Kazimi, "On the Costs of Air Pollution from Motor Vehicles," *Journal of Transport Economics and Policy*, v. 29, no. 1 (January 1995), pp. 7-32.

[15]The Regional Council's October 1994 report, *Analysis of Freight Movements in the Puget Sound Region* ,is an important exception to the general dearth of system level information on this topic.

Monitoring is yet another area in which current practice falls short of the information needs of integrated transportation planning. It is not common practice in transportation planning to conduct periodic region-wide monitoring. It is even less common to conduct periodic reviews of past travel forecasts and to compare them to current observed transportation system measures. The actual costs and benefits of existing plans and projects are rarely monitored or evaluated.[16]

PSRC's household travel panel represents a unique asset that can be used for monitoring changes in travel behavior in the region. Several longitudinal analyses have been conducted using data from the panel.[17] We recommend that this panel be expanded and that waves be conducted at more frequent intervals to provide better information to monitor the effects of changes to the transportation/land use system.

As a further long-range improvement to monitoring, we recommend that PSRC encourage its member agencies to incorporate the costs of evaluation into the implementation cost of projects. The budget for evaluation should include the cost of special before-and-after user surveys, and collection of other pre- and post-implementation data. The project implementation plan should include an evaluation plan that explicitly lays out the issues to be analyzed, the analysis methods to be used, and the data sources.

3.2. DEALING WITH UNCERTAINTY IN INTEGRATED TRANSPORTATION PLANNING

Any evaluation of transportation policy alternatives requires estimating future conditions and therefore the analysis will always contain some element of uncertainty. One of the important features of integrated transportation planning is that it explicitly incorporates consideration of uncertainty into its evaluation of projects and policies. In this section we

[16] Notable exceptions include the Service and Methods Demonstration program of the Urban Mass Transportation Administration in the 1980s, which was a program that provided grants to transit operators to demonstrate transit innovations (e.g., reduced fares, priority bus lanes, new types of paratransit service); the grants included a budget for evaluating the demonstrations. On a larger scale, the BART Impact Program of the late 1970s was the first U.S. effort to evaluate a new large-scale transit system.

[17] Elaine Murakami and W.T. Watterson, "The Puget Sound Transportation Panel After Two Waves," *Transportation* Vol. 19, no. 2 (May 1992). See also Fred Mannering, Elaine Murakami, and Soon-Gwan Kim, "Temporal Stability Of Travelers' Activity Choice and Home-Stay Duration: Some Empirical Evidence," *Transportation* Vol. 21, no. 4 (December 1994).

address the following questions about uncertainty in the evaluation of transportation alternatives:

- *What is it?* What do we mean when we talk about uncertainty? What are the sources of uncertainty in the analyses?
- *How do we estimate it?* What is the magnitude of uncertainty, and how does this influence interpretation of the results of the analysis?

3.2.1. Uncertainty in Planning Estimates

Planning analyses provide estimates of what might happen under various alternatives. For purposes of this discussion, uncertainty reflects the degree to which the "true" results can differ from the estimates. Hence, for each estimated result, there is an implied probability distribution of the true value around that result. The figures below illustrate two relative magnitudes of uncertainty for measuring user benefits.

Figure 3 gives an example for which estimated user benefits differ by a larger amount, and there is a lower degree of uncertainty in the estimates, as indicated by the lesser spread of the probability distribution for each alternative; Figure 4 shows an example for which there is less of a difference between the estimates for the alternatives, and there is a higher degree of uncertainty about the estimates. The extent to which the curves for the two alternatives overlap indicated the degree to which it is more difficult to state that the user benefits for the two alternatives differ by a significant amount.

Figure 3 - More Significant Difference

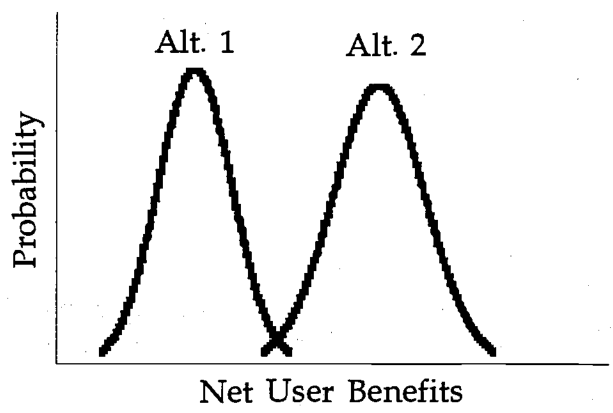
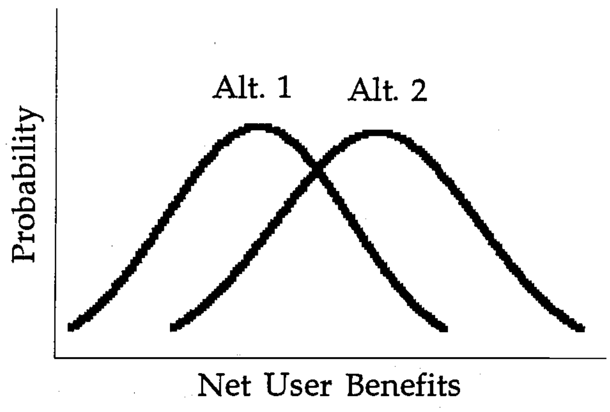


Figure 4 - Less Significant Difference



3.2.2. Sources of Uncertainty in Planning Estimates

Sources of uncertainty in planning estimates can be grouped into the following categories:

- Parameter covariance
- Errors in forecasts of independent variables
- Model error

Parameter covariance refers to uncertainty about coefficients in statistical models and to uncertainty in estimates of other exogenous parameters that may be used in the analysis.[18] The coefficients of a model are estimated from a sample of the population. Hence, the estimates of the model parameters will differ from the "true" values by some unknown amounts. Under certain assumptions, the joint probability distributions of these errors can be estimated. Covariances of other exogenous parameters may be more difficult to estimate.

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[18]The term "covariance" is used here to refer both to the variance of a single parameter and the covariance of two parameters. Both contribute to uncertainty; parameter variance will add to uncertainty; covariance of two different parameters may add to or subtract from uncertainty.

Errors in forecasts of exogenous variables add a further component of uncertainty to planning estimates. For example, forecasts of total travel in the future are based on forecasts of variables such as population and employment, which have their own uncertainties associated with them.

Model error is the residual error component in addition to that due to variance in the parameters. This error can arise from misspecification of the model or from a random error component that is beyond the scope of the model. The effects of model misspecification can go far beyond adding to uncertainties in the outputs; they can also include policy insensitivity due to misspecifying or omitting one or more key variables, making the model inappropriate for use in policy analysis.

Some sources of uncertainty can be considered to fall under more than one of the above categories, particularly in the case of travel demand estimation. The four-step modeling process as practiced by PSRC (see Figure 5) contains a sequence of models, where the outputs of one model (e.g., trip generation) are fed into the next model in the sequence (e.g., trip distribution). Hence, the errors in the forecasts from one model become errors in the independent variables for the next model in the chain.

Table 3 summarizes some examples of potential sources of uncertainty in transportation planning models that would be used for the detailed modeling phase of integrated transportation planning process. This list is not intended to be comprehensive, but it does illustrate some typical problems with the current state of the art in transportation policy analysis as practiced by PSRC.[19] A more detailed discussion of the uncertainties associated with four-step models is given in the appendix.

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[19]PSRC is currently in the midst of making significant improvements in its modeling capabilities which should improve the accuracy of its forecasts. For a thorough discussion and critique of current and emerging transportation modeling practices, see Greig Harvey et. al., *A Manual of Regional Transportation Modeling Practice for Air Quality Analysis, Version 1.0,* report prepared by Deakin Harvey Skabardonis et. al. for the National Association of Regional Councils, July 1993.

Figure 5 - PSRC Travel Forecasting Process

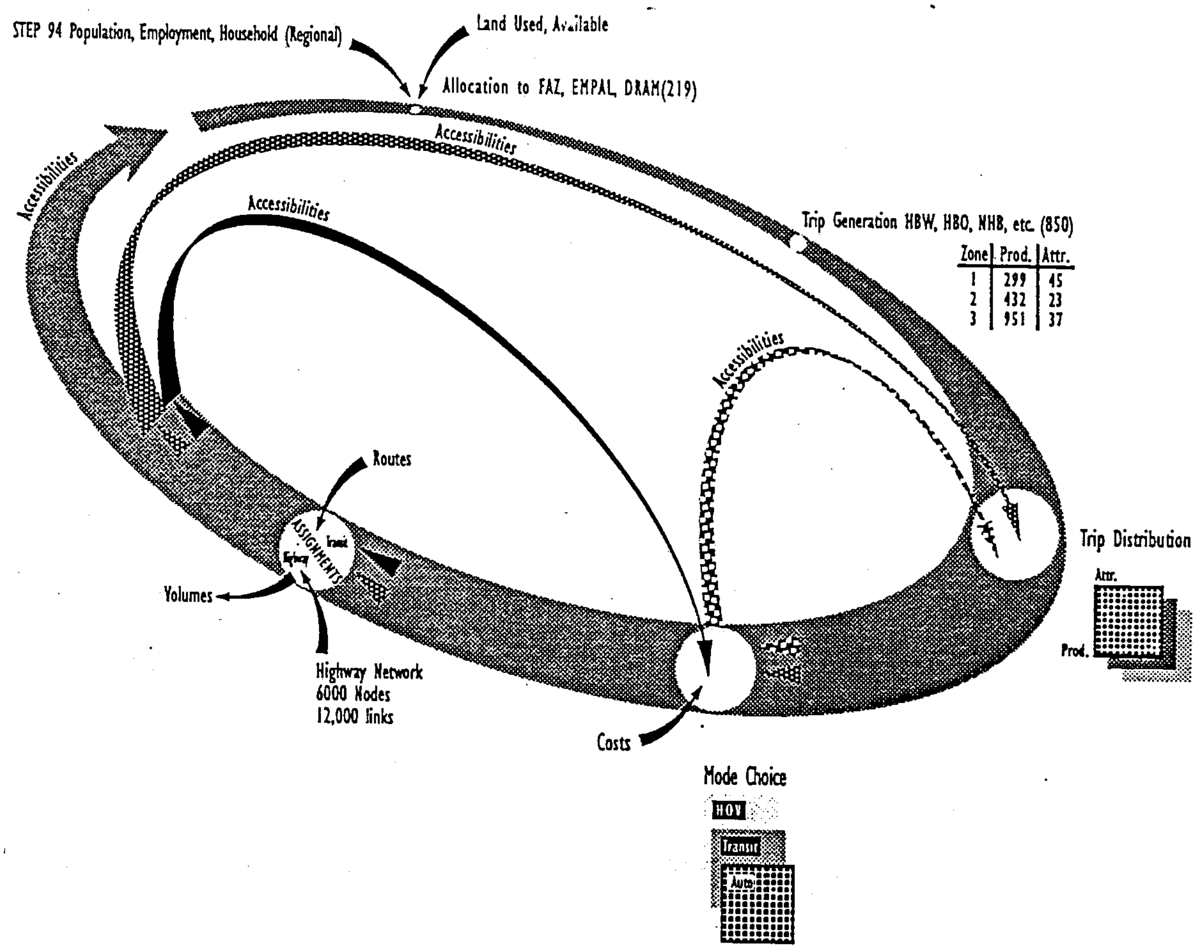


Table 3 - Sources of Uncertainty in Transportation Planning Models

Model	Potential sources of uncertainty
Trip generation	• Trip productions insensitive to changes in travel supply, costs. (M) • Incorrect cross-classification of households. (M) • Nonmotorized trips excluded. (M) • Variances in trip production rates. (P) • Uncertainties in population and employment forecasts. (I) • Aggregation errors in estimating trip attraction model parameters. (P)
Trip distribution	• Trip distribution depends only on automobile travel times between zones. (M) • Errors in network travel time estimates. (P, I) • Errors in trip production and attraction estimates. (I)
Time of day of travel	• Insensitive to changes in travel supply and cost. (M) • Travel times determined solely by trip purpose. (M)
Mode choice	• Exclusion of nonmotorized modes. (M) • Uncertainties in travel time and cost estimates, especially transit access time and wait times. (I) • Incorrect mode specification (e.g., failure to include transit access mode). (M) • Exclusion of key variables (e.g., need for car for midday work travel). (M)
Traffic assignment	• Incorrect speed/flow relationships. (M) • Assumption that travelers choose minimum-time path only. (M) • Queuing effects not taken into account. (M) • Misspecifications of link capacities. (P) • Errors in trip interchange estimates. (I) • Not all significant links included in network. (M)
Air pollution emissions	• Small sample sizes for estimating emissions by vehicle class. (P) • Test driving cycle does not match typical driver behavior. (P) • Failure to include effects of high-emitting vehicles. (P, M) • Difficulty in estimating time distribution of traffic, vehicle speeds, vehicle mix. (I)
Value of air pollution reduction	• Uncertainty in emission estimates. (I) • Uncertainty in mortality/morbidity rates from air pollution, value of life/health, and therefore unit value of emission reduction.
User benefits	• Uncertainty in value of time. (P) • Uncertainty in travel time reductions. (I)

Sources of uncertainty are denoted as follows: P = parameter variance, I = uncertainty in input variables, M = model or specification error.

As discussed in the appendix, the best way to account for the uncertainties in the parameters used to estimate the benefits and costs of transportation alternatives is through numeric simulation. Running hundreds of scenarios on a computer using plausible probability distributions for key parameters can simulate the likely range of results for the alternatives. The steps for a numeric simulation are as follows:

1. Determine the components of the benefit and cost estimates for which uncertainties exist.

2. For each component, estimate a probability distribution that approximates the uncertainty associated with that component.

3. Generate sets of random numbers that simulate the joint probability distribution of the input components.

4. Compute the benefit and cost measures associated with each set of random numbers.

5. Collect statistics on the distributions of the benefit and cost measures developed from the random numbers. Report means and standard deviations, and display graphically.

The actual process of carrying out the simulation involves a high degree of professional expertise and judgment. In particular, there will be a need to strike a balance between accuracy and detail, and computational feasibility.

When choosing which components of the benefit and cost estimates to numerically simulate, one would ideally go back to the beginning and choose all input variables to the planning analysis, and carry out the simulation based on these variables. This would entail, for example, estimating the uncertainties in population and land use forecasts and the variances in trip production rates, and so on through the rest of the travel forecasting process. Practically, it would be an analytical nightmare to consider carrying out a simulation through the entire travel forecasting process for a large number of sets of random input variables.

It will therefore be necessary to choose components at an appropriate state of the forecasting process. In the case of travel forecasts, the appropriate level would be the aggregate outputs of the travel forecasting process that are used to estimate the benefit and cost measures (e.g., total travel time, total vehicle-miles of travel). But the problem remains of how to estimate the uncertainties associated with the travel forecasts.

Comparing the outputs of the travel forecasting models to observed transportation system measures in the base year (e.g., observed traffic counts, vehicle speeds, transit ridership) is not statistically valid. The process of travel model estimation typically involves a validation process in which the models are adjusted, usually manually, in order to make their outputs match the observed measures as closely as possible. Comparing the final outputs of the adjusted models to observed measures can provide information only on how well the adjustment process was carried out. It says nothing of how well the models will perform when used for forecasting.

One way to estimate uncertainties in forecasts from the travel models is to use the models to simulate travel for a particular time that is previous to the base year, then comparing the model outputs to observations for that time. This so-called "backcast" can then provide an estimate of the performance of the models in a forecasting environment. Ideally, backcasts should be done for several time periods; although it is likely that available resources would allow only one or two backcasts to be carried out.

Uncertainties should be estimated for all key components of the benefit and cost estimates. This will entail estimating uncertainties not only in forecast quantities such as travel times, but also in key parameters that are usually exogenous to the process, such as value of time and components that determine the value of air pollution (mortality and morbidity rates, values of life and health).

The appropriate probability density for uncertainties is a matter of professional judgment. One could use a uniform density, as illustrated in Figure 6, in which the minimum and maximum values are specified and the "true" value is assumed to be equally likely to lie anywhere between these extremes. Alternately, one could specify a density with a modal value (in other words a "most likely" value) and minimum and maximum values. One example of such a probability density is the beta density illustrated in Figure 7, which can be scaled and shifted to match variable's particular minimum, maximum, and modal values. A normal density (or any other density function that can potentially take on extremely large or small values) may not be appropriate; use of these types of densities can sometimes lead to pathological results in the simulation.[20]

[20]The beta distribution is defined only on the range (0,1) whereas the normal distribution is defined on the range $(-\infty, +\infty)$.

Figure 6 - Uniform Density

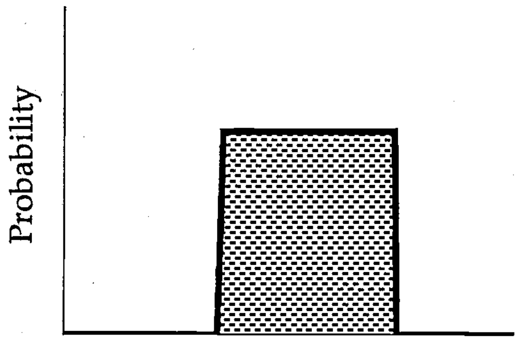
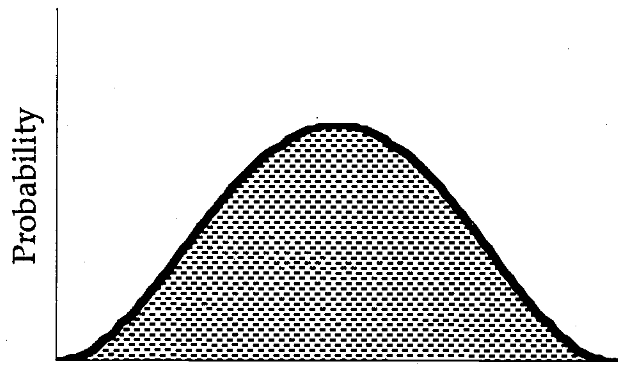


Figure 7 - Beta Density



Our recommended procedure for estimating uncertainties in the results can be summarized in the following steps:

1. Set up the analysis in a spreadsheet format to make explicit the relevant variables.

2. For each variable whose uncertainty is to be simulated, choose a probability density function and estimate the most likely, minimum, and maximum values. These estimates can be base on published information on ranges of the variables or on previous experience. If the information is available, spreads in the distribution should be estimated and the variables represented using a nonuniform density such as the beta.

3. Use a good source of random numbers to simulate uncertainties in the input variables. This can be done using a spreadsheet macro, a specially written program, or an off-the-shelf software package designed for the purpose. One should be aware that many random number sources may contain some serious flaws that can lead to biased results; hence, the choice of a random number source is not a trivial issue.[21]

4. Run the simulation and collect statistics on the distributions of the output variables (costs and benefits). The appropriate sample size (i.e., the number of simulation runs) will depend on the nature of the uncertainties in the individual variables and how well one wants to estimate the total uncertainty. Absent other information, the sample size should be at least in the range of 50 to 100.

3.2.3. Scenario generation

The potential range of exogenous conditions will add further uncertainty to the estimates from the analysis, especially when a widely divergent range of future population distributions, land use patterns, and economic activity increases could occur. Moreover, the joint probability distributions of these exogenous factors may be very difficult to estimate.

We recommend that scenarios be developed as part of the process of analyzing alternatives discussed in Section 2.2.1. These scenarios should bracket the range of likely trends in the exogenous factors. Scenario generation serves several purposes.

- It provides a range of possible future conditions against which to test alternatives. Those alternatives that perform best over the widest range of scenarios are the most robust, and therefore the most desirable.

- It avoids the difficulties associated with trying to estimate joint probabilities for simultaneous outcomes of numerous different exogenous factors. Each scenario presents a discrete description of a possible future against which to test alternatives.

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[21] For a discussion on random number generation, see Donald E. Knuth, *The Art of Computer Programming - Volume 2: Seminumerical Algorithms* (Reading, MA: Addison-Wesley, 1982).

- The uncertainties associated with exogenous factors, if incorporated directly into uncertainty analysis, could make the uncertainties associated with the net social benefits from different alternatives so large that it could be very difficult to distinguish among them.
- On the other hand, if sufficient information is available, and if alternatives are robust, one may assign probabilities to different scenarios and incorporate them into the uncertainty analysis.

4. SUMMARY

The Puget Sound Regional Council in response to state and federal mandates is already on its way toward implementing integrated transportation planning practices. This technical memo has discussed some of the process and analytic issues associated with furthering the application of least-cost planning principles. The major recommendations of this memorandum include:

4.1. RECOMMENDATIONS FOR PROCESS

- View integrated transportation planning as long-term strategic planning process that has benefit-cost analysis as its analytic core.
- Involve the public early in the process, particularly in the development of alternatives.
- For system planning, use sketch planning techniques to evaluate the cost-effectiveness of a broad range of alternatives.
- Apply more detailed network modeling to those alternatives which have been identified as cost-effective through sketch planning techniques.
- Monitor and evaluate past projects and policies and use the information to adjust future plans.
- Adjust the process for developing the Metropolitan Transportation Plan to include more elements of integrated transportation planning.

- Use Major Investment Studies as opportunities to apply benefit-cost analysis to transportation projects and to inform and adjust long-term plans for the transportation system.

4.2. RECOMMENDATIONS FOR ANALYSIS

- Refine sketch planning techniques for system level evaluations. Consider further applications of the STEP micro-simulation model.
- Adopt short and long-run strategies for addressing current deficiencies in the data required for ITP.
- Formally estimate the uncertainty associated with estimates of benefits and costs.

APPENDIX A - UNCERTAINTIES IN TRAVEL DEMAND FORECASTING MODELS

This appendix presents a more detailed discussion of some of the uncertainties in transportation and air quality forecasting models that was summarized in the preceding text. The first section discusses the sources of uncertainty for individual planning models. The second section presents some methods for developing analytic estimates of uncertainty.

UNCERTAINTIES IN INDIVIDUAL MODELS

Trip Generation

Trip generation models include trip production and attraction models. Trip production models are typically rate-based models that are applied to household cross-classifications. The numbers of forecast trips by purpose depend only on the numbers of households by type. This makes this type of trip production model particularly unsuitable for analyzing policies that would significantly change level of service or travel cost. Consider the case of conducting a policy analysis on congestion pricing. Two significant effects that are anticipated from a congestion pricing policy are a reduction in overall tripmaking and the rescheduling of trips from the peak period to the off-peak. (A third significant effect could be an increase in multipurpose trips to reduce overall travel.) None of these effects can be modeled by conventional travel models; they contain the implicit assumption that the total numbers of trips by purpose are constant, regardless of cost and travel time. They also have no explicit mechanism for reallocating trips to different times of the day.

Another source of uncertainty in trip production estimates can arise if nonmotorized trips are excluded from the trip production estimates. Including nonmotorized trips in trip generation will require more complex modeling procedures later in the process (trip distribution, mode choice). But, as Harvey et. al. note:

> ... recent work has shown that accessibility and land use conditions are powerful determinants of the decision to walk (and to link trips into complex chains), and thus strongly influence the number of person trips by vehicle.[22]

[22]Harvey et. al., *Manual of Regional Transportation Modeling Practice.*

This problem is even more significant when travel models are to be used for analysis of policies that emphasize nonmotorized travel, such as the Reduced Automobile Dependency Alternative for the PSRC Metropolitan Transportation Plan.[23] Explicit modeling of nonmotorized travel is needed to fully assess the extent to which these types of policies can result in shifts from motorized to nonmotorized travel.

Trip attraction forecasts can have significant errors because of the way in which trip attraction models are typically estimated. A common type of trip attraction model is a linear regression equation like the following:[24]

$$A_i = \alpha + \sum_j \beta_j x_{ij}$$

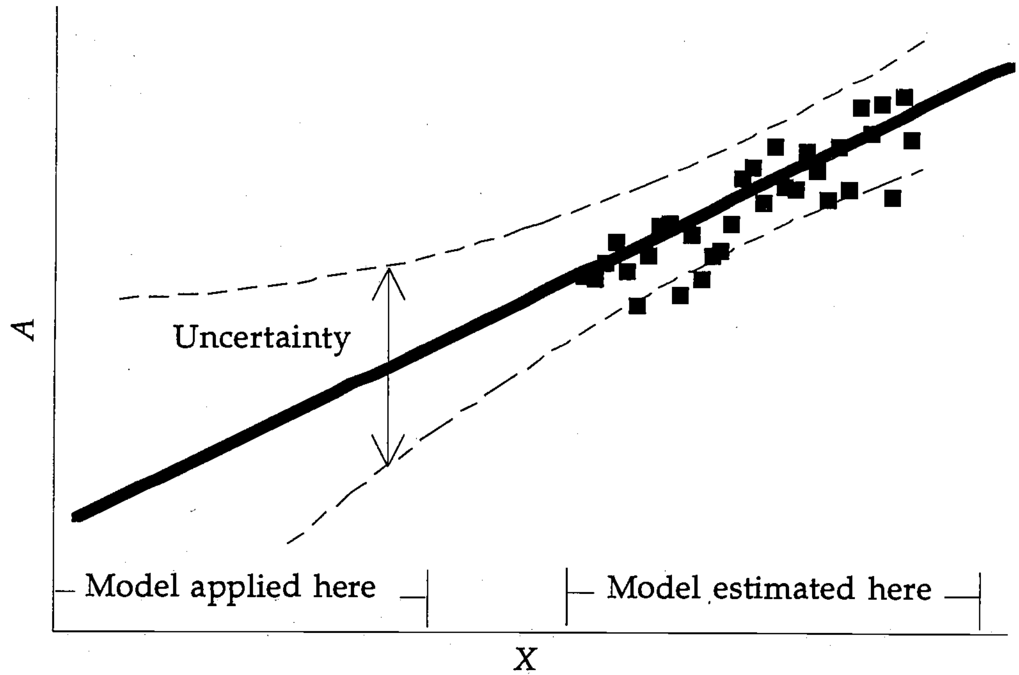
where A_i is the number of trips "attracted" to area i; x_{ij} are variables that describe various types of activity in area i, such as population, retail employment, and non-retail employment. These models are estimated from household travel survey data, which typically contain very few trips to any particular travel analysis zone. Hence, in order to have sufficient data to estimate the numbers of trips attracted to an area, zones are typically aggregated up to larger areas, and the regression model parameters are estimated on the aggregated data. But when the regression model is used to estimate the number of attractions to individual zone, the values of x_{ij} that are used for forecasting are typically much smaller than the values used for the estimation of the model parameters.

Figure 8 gives an example of a linear regression model "fitted" to the data points on the right-hand side of the graph. The "uncertainty band", which is a rough measure of the error in the forecast value of A, draws further away from the regression line as the value of X gets further away from the data points used to estimate the regression line.

[23]Puget Sound Regional Council, "Description and Evaluation of the Reduced Automobile Dependency Alternative," December 22, 1994.

[24]The common practice is to develop separate trip attraction models for different trip purposes (e.g., home-work, home-other, other-other).

Figure 8 - Model Uncertainty as Function of Independent Variable



As shown in Figure 8, if the values of the independent variable that are used from forecasting are greatly different from the values that were used for model estimation, the uncertainty in the forecasts increases significantly. Although seldom explicitly noted in technical reports on travel forecasting, this uncertainty can contribute significantly to uncertainties in estimates of trip interchanges from trip distribution models.

Trip Distribution

Trip distribution models in common use today are so-called "gravity models" with the following functional form:

$$T_{ij} = \frac{P_i A_j f(t_{ij})}{\sum_k A_k f(t_{ik})}$$

where P_i and A_j are the numbers of productions in zone i and attractions in zone j respectively, and $f(t_{ij})$ are a set of "friction factors" that represent the inverse of travel impedance between zone i and zone j as a function of the interzonal travel times t_{ij}. Estimating the gravity model consists of adjusting the friction factors for all travel times so that the distribution of trip times from the model matches

the distribution of trip times from a household travel survey. In practice, the t_{ij} are usually taken to be the highway travel times between zones.

The specification of the gravity model and its application in practice lead to model specification errors that may be significant. The friction factors are often proxies for a more complex set of factors that influence trip destination choice. Hence, trip distribution is insensitive to changes in transit level of service, and to characteristics of the particular traveler; these insensitivities can be called model specification errors. Uncertainty in the model estimates also depend on uncertainties in the network travel times used to estimate the friction factors. And uncertainties in trip production and attraction estimates contribute further to uncertainties in the trip distribution model outputs.

Time of Day of Travel

Estimating the time of day of travel is the undocumented "fifth step" in the four-step process. A number of transportation system performance measures that are essential to applying least-cost planning depend critically on estimates of the magnitude and duration of peak travel, especially travel times (and therefore user benefits) and emissions. Common practices for estimating peak-period travel include the following:

- Assign all trips of a given type to the peak or off-peak period. For example, work trips would be assigned to the peak period and all other trips would be assigned to the off-peak. Although easy to understand and apply, this method is too simplistic in that trips of all types occur in both the peak and off-peak.

- Develop time-of-day factors for each trip type. This is typically done from household travel survey data. Although this is better than the above method, there is no guarantee that the time-of-day factors will apply in the future.

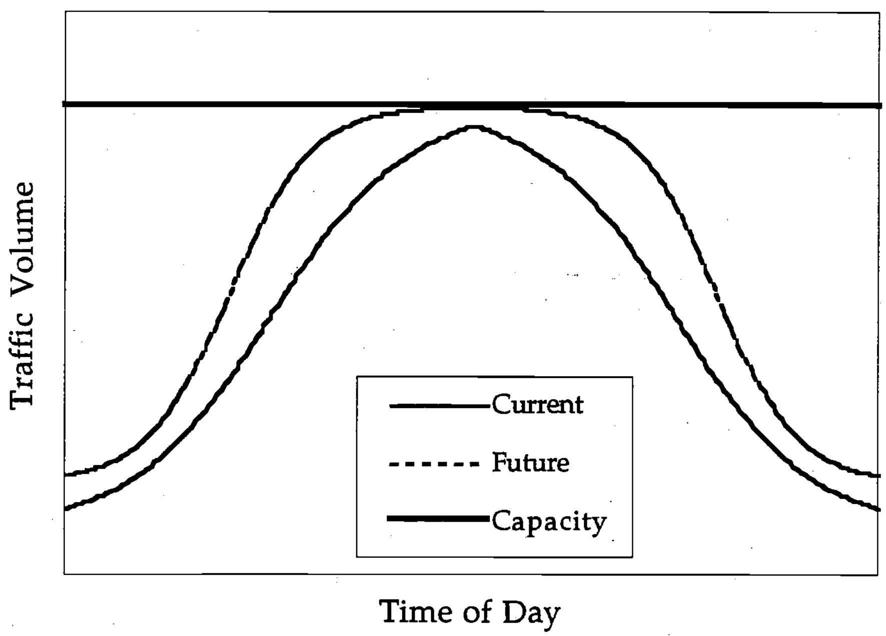
One problem with using fixed time-of-day factors is that the models are insensitive to policies that are intended to shift travel schedules, such as flextime and congestion pricing. Another problem is that as a transportation facility becomes more congested, the peak period on that facility tends to spread out, as illustrated in Figure 9. The current state of practice in travel modeling does not

explicitly account for this phenomenon. Hence, peak period speeds on congested roads can be underestimated.[25]

Mode Choice

Mode choice modeling has advanced more than any other component of travel demand modeling over the last 20 years. With the introduction of discrete-choice models, transportation modelers have been able to include a wide variety of explanatory factors in the mode choice models, including travel times and costs, waiting time, and characteristics of the traveler. However, mode choice modeling can introduce its own uncertainties, which arise from a variety of sources. Uncertainties in estimates from mode choice models result from misspecification of the model structure (including definition of travel mode alternatives), misspecification of inputs to the mode choice model (especially out-of-vehicle time components for transit alternatives), and insufficient market segmentation of travelers.

Figure 9 - Illustration of Peak Spreading



[25]There has been some work on developing and applying *ad hoc* post-processing methods to estimate peak spreading. See William R. Loudon, Earl R. Ruiter, and M. L. Schlappi, "Predicting Peak Spreading Under Congested Conditions," *Transportation Research Record 1046*, 1985, pp. 70-76.

Traffic Assignment

The traffic assignment step is critical to the four-step process. Not only does it provide the final estimates of link travel volumes and speeds, it also provides input back to the trip distribution and mode choice steps so that the travel times used in these steps matches the output of the traffic assignment. This feedback process, illustrated in Figure 5, is called "equilibration", and is an essential process to enforce consistency between the trip distribution, mode choice, and traffic assignment phases.

Because of the equilibration process, uncertainties in the traffic assignment step can further add to uncertainties in the trip distribution and mode choice steps. Hence, uncertainties in the trip distribution and mode choice steps can be fed back to those steps through the traffic assignment process.

Air Pollution Emissions

Air pollution emissions estimates depend critically on estimates of vehicle travel volumes and speeds; hence, uncertainties in vehicle volume and speed estimates contribute to uncertainties in air pollution estimates. There is also evidence that current methods for estimating air pollution emissions significantly underestimate actual emissions.[26] The main reasons appear to be that the emissions models underrepresent the frequency and severity of vehicles with extremely high emissions; and that the models are based on a test driving cycle that does not adequately account for high accelerations. Other sources of uncertainty include the effects of air pollution on mortality and morbidity, and the cost of air pollution related mortality and morbidity.

ANALYTICAL ESTIMATES OF UNCERTAINTY

Analytical estimates of uncertainty from forecasting models are difficult to obtain except for the simplest cases, such as linear models. For estimates derived from a system of models, such as the four-step process, there is no tractable formula for model error that can be derived. But there are simple analytical results and approximations that can give some qualitative insights into uncertainties from forecasting models.

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[26] Kenneth A. Small and Camilla Kazimi, "On the Costs of Air Pollution from Motor Vehicles."

Assume that a forecasting model can be represented as follows:

$$z = f(x_1,\dots,x_p;\ \theta_1,\dots,\theta_q)$$

where $x_1,\dots,x_p$ are the independent variables and $\theta_1,\dots,\theta_q$ are the model parameters. A forecast from the model entails estimating the values of the x_i and θ_j. A forecast from the model consists of taking estimates of the independent variables, denoted by $\hat{x}_1,\dots,\hat{x}_p$, and applying them to the model with parameter estimates $\hat{\theta}_1,\dots,\hat{\theta}_q$ to get an estimated value $\hat{z}$. The estimated values of the independent variables, parameters, and the forecast will vary around the "true" values. Assume that the estimates of the independent variables and the parameters are unbiased, and that the model parameters are independent of the forecast variables. Then a second-order Taylor series approximation of the expected value of $\hat{z}$ is given by the following formula:[27]

$$E(\hat{z}) = f + \frac{1}{2}\left(\sum_{i,j} Cov(\hat{x}_i,\hat{x}_j)\frac{\partial^2 f}{\partial x_i \partial x_j} + \sum_{k,l} Cov(\hat{\theta}_k,\hat{\theta}_l)\frac{\partial^2 f}{\partial \theta_k \partial \theta_l}\right)$$

where the function and all derivatives are evaluated at $\hat{x}_1,\dots,\hat{x}_p;\ \hat{\theta}_1,\dots,\hat{\theta}_q$.

Similarly, the variance of $\hat{z}$ is approximated by:

$$Var(\hat{z}) = \sum_{i,j} Cov(\hat{x}_i,\hat{x}_j)\frac{\partial f}{\partial x_i}\frac{\partial f}{\partial x_j} + \sum_{k,l} Cov(\hat{\theta}_k,\hat{\theta}_l)\frac{\partial f}{\partial \theta_k}\frac{\partial f}{\partial \theta_l}$$

Two results follow from the above:

Estimates from a nonlinear model will be biased. The magnitude and direction of bias will depend on the functional form and the covariances of the estimates of the independent variables. As a simple illustration, note that for a model of the form $z = xy$ using forecast values $\hat{x}$ and $\hat{y}$, the expected value of $\hat{z}$ is simply $E(\hat{z}) = \hat{x}\hat{y} + Cov(\hat{x},\hat{y})$; even though the forecasts of the independent variables may be unbiased, the estimate from the model is biased.

Covariances among forecasts of the independent variables will contribute an additional amount to the variance of the forecast from the model.

Although some of the models in the transportation forecasting process may be linear, the majority are nonlinear. Table 4 lists functional forms for some of the

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[27] See Appendix B for derivations of these formulas.

types of models typically used in travel forecasting. As shown, most of the models are nonlinear; and some (traffic assignment in particular) are highly nonlinear. The equilibration process, in which outputs from the traffic assignment step are fed back to the trip distribution and mode choice steps, add further nonlinearity to the travel forecasting model system. Hence, it would be expected that travel forecasts could contain significant biases and uncertainties.

Table 4 - Functional Forms of Travel Forecasting Models

Model	Functional Form
Trip production	Linear: household cross-classification
Trip attraction	Linear: regression
Trip distribution	Nonlinear: productions times attractions (potentially high covariance in forecasts); nonlinear friction factors.
Mode choice	Nonlinear: logit formulation (linear utilities)
Traffic assignment	Nonlinear: exponential volume-speed relationships; incremental assignment to shortest path.