

Least-Cost Planning: A Tool for Metropolitan Transportation Decision Making

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A new approach to transportation investment planning and a prototype sketch-planning model are described. The model was developed to assist metropolitan transportation planners and decision makers in meeting the new federal and state planning requirements. Based on two decades of experience in electrical energy planning, the model incorporates the principles of least-cost planning and full-cost accounting. It attempts to promote an efficient search for investment and policy strategies that enhance regional benefits, while reducing social costs. A demonstration of the model for the Puget Sound metropolitan region was carried out by comparing a limited number of options. These included a set of study options associated with a proposed light rail system, two commuter rail options, an option featuring the construction of a regional bicycle network, a highway expansion option, and a series of options emphasizing public and private incentives directed toward reduced single-occupancy vehicle use. Further refinements of the model will allow for the accounting of synergy among options, the comparison of decision packages, and the selection of an optimal and integrated set of investments and policies.

Under new federal and state planning requirements, regional planners and decision makers must assess the cost-effectiveness of a broad selection of transportation modes and policy options. Demand management strategies must be given equal consideration to highway and transit capacity enhancements. Pedestrian and bicycle modes must be allowed to compete on an equal basis with motorized modes. Costs, including indirect social and environmental costs, must be fully accounted for. And planning must recognize the reality of increasingly constrained revenues.

Traditional planning and decision-making tools were not designed to accomplish the comprehensive and integrated analysis now required. New tools must be devised that allow a broad comparison of modes and management strategies to identify the most cost-effective alternatives.

Metropolitan planning organizations and transportation decision makers face difficult challenges as they begin to address the requirements of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), the Clean Air Act Amendments of 1990, and, in an increasing number of states, legislation directed at management of growth. These challenges include provision for expanding mobility and access needs, management of congestion, integration of transportation investments and land use policies, and mitigation of air quality and other environmental impacts.

All of this must be accomplished in the context of fiscal constraints, especially regarding the available level of federal assistance that continues to decline as a share of all public transportation expenditures.

Planners and decision makers must also adjust to the ISTEA requirement that funding be more flexible. This will probably mean that transit and alternative travel modes, such as ride sharing, walking, bicycling, and telecommuting, will receive a larger share of available revenues. The concept of flexible funding must encompass the reality that traditional solutions involving major capacity investments, even transit investments, which use up scarce resources, may make less costly but more beneficial, solutions impossible to finance.

ISTEA, in fact, recognizes this imperative by requiring that the metropolitan planning process analyze the cost-effectiveness of alternative investments in meeting transportation demand and the ways transportation needs may be met by using existing transportation facilities more efficiently. The cost analysis requirements for major investments in highways and transit systems are even more specific. A major investment study (MIS) must evaluate the cost-effectiveness of alternative investments or strategies, and it must consider the indirect as well as the direct costs of reasonable alternatives. The MIS must take into account social, economic, and environmental effects; operating efficiencies; land use; economic development; and energy consumption, among other factors.

Clearly, cost must be an object of metropolitan transportation planning in a way that it has not been previously. New analytic tools must be devised that allow for cost and benefit comparisons across all feasible alternatives, whether new capacity investments or management strategies. External and indirect costs, as well as direct development and operation costs, must be considered.

Recent studies have compared the application of least-cost methods to energy planning with its potential application to transportation planning (1-3). These authors, while pointing to differences as well as similarities between energy and transportation, encourage the belief that the least-cost methodology, which has been highly refined and widely applied to energy, could be successfully translated to transportation.

Two authors who have contributed to the development of least-cost planning as it is practiced in the Pacific Northwest electric power industry, Ed Sheets and Dick Watson, observe a number of important analogies between the domains of energy and transportation that make both fitting candidates for least-cost planning (3). Both energy and transportation can benefit greatly from an analytical process by which demand-side resources are given consideration equal to the construction of facilities and infrastructure. In both cases, a full survey of options would highlight approaches to system design and management that could result in far lower costs than merely expanding capacity.

In addition, energy and transportation both require a full accounting of leveled life-cycle costs, including direct capital costs, envi-

ronmental costs, time costs, and preference costs. Least-cost planning mandates this degree of rigor in cost accounting.

Sheets and Watson also suggest that both energy and transportation must deal with an uncertain future. Demand for both transportation services and electricity are subject to unknown changes in technology, behavior, and economic constraints. Transportation planning could benefit from the flexibility to adapt to uncertainties that has been incorporated into electricity least-cost planning.

As noted earlier, a major challenge for transportation planning under the new planning rules is to assess the impact of a broad set of options on mode choice and then to assess all significant costs over all mode choices. The aggregate social cost associated with various options can then be computed.

An approach that can treat alternatives and costs in this way has been outlined by federal highway and transit researchers (4-6). Patrick DeCorla-Souza and Ronald Jensen-Fisher note that an integrated approach has been impeded historically for highways and transit by the use of different measures of effectiveness for each mode. Also, significant costs have been omitted. Transit cost accounting omits the cost of roadway use by buses, while highway cost accounting excludes vehicle ownership costs and the costs of parking. External social and environmental costs are ignored in all instances. The authors stress the importance of full-cost accounting to avoid favoring certain modes.

Least-cost planning is beginning to attract the attention of transportation decision makers. The Washington State legislature in 1994 enacted legislation that requires regional transportation planning organizations to use a least-cost planning methodology in formulating regional transportation plans (Substitute House Bill 1928, 1994). The methodology must identify the most cost-effective facilities, services, and programs.

If a least-full cost approach is to be useful, it must be more than just a planning tool; it must be capable of assisting decision makers who must often make tough choices in a highly political environment.

This paper describes a new least-full cost sketch-planning tool for application to metropolitan area transportation planning and investment decisions. With appropriate data, the tool would also be useful for subarea and corridor decision analyses.

SUMMARY OF LEAST-COST PLANNING

Least-cost planning (LCP) refers to an analytic procedure that incorporates the following elements and procedures:

- The process attempts to maximize the number and range of transportation alternatives on the table. No credible approach is ruled out a priori.
- The method is neutral among alternatives. Any element of subjectivity that would favor one alternative over another is minimized.
- A standard of performance is specified over a planning period. An example of such a standard would be a required level of regional accessibility and mobility. All transportation strategies to be compared within the framework of a least-cost analysis are constrained to achieve the required standard of performance.
- Under LCP, the standard of performance can be defined with some degree of flexibility and latitude. Where a given standard poses problems of measurement, other surrogate standards can be developed and the cost of alternative strategies can be compared as long as they achieve the surrogate standard. For instance, if general accessibility measures in transportation are deemed too difficult to

measure, more concrete standards—for example, congestion reduction, reduction in single-occupancy vehicle mode, etc.—can be substituted. If appropriate, a group of these standards can be designated, aggregated, and weighted as an accessibility index. This flexibility contrasts with other approaches (e.g., benefit-cost analysis) where the standard (net consumer utility) is predetermined.

- An efficient search among alternative strategies is conducted to determine that strategy or set of strategies that minimizes net social cost (alternatively, that maximizes net social benefit).
- A preferred strategy must account for alternative futures and the risk that current expectations may not be fulfilled. The process incorporates significant elements of uncertainty and risk:
 - The standard of performance (e.g., regional accessibility and mobility requirements) depends on the level and character of regional growth, which cannot be known with certainty.
 - The evolution of transportation and communications technology is a significant (and highly dynamic!) unknown over a 20-year or more planning horizon.
 - The future economic environment—prices, employment, currency fluctuations, industrial mix—is difficult to predict.
 - The future regulatory environment depends on political developments that are currently unknown.

LEAST-COST PLANNING AS A PRACTICAL DECISION TOOL

In considering the elements of a transportation model based on economic principles, it is essential to highlight those aspects that make it suitable in the context of planning as opposed to pure research. Planning is meant to inform political policy making and public decision making. Transportation investments are likely to continue whether or not they are informed by planning models. Models should be designed to maximize the probability that decisions will be in the public interest over the long haul. And, models should provide a quantitative framework for comparing alternatives at a level of precision sufficient to inform decision makers and account for the considerable uncertainty that pervades any attempt to forecast transportation options and behaviors.

Though a number of alternative investment analysis tools exist—including benefit-cost analysis and multiobjective analysis—least-cost planning, based on the energy experience and incorporated in a sketch-planning model, has the following unique advantages:

- It is easily comprehensible to policy makers, interest groups, and voters.
- It is fast and easy to implement at a useful level of approximation.
- It is neutral and unbiased with regard to outcomes.

FRAMEWORK OF THE LEAST-COST PLANNING MODEL

The least-cost planning model (LCPM) was designed (7,8) to identify a package of transportation options for a study area satisfying the following criteria:

- The package meets the access needs of the area for a variety of trip purposes and special populations.
- The package results in a maximum net reduction in social cost compared with a no-action base case.

- Costs are inclusive of private costs, government subsidies, environmental and pecuniary externalities, congestion, and other travel time costs.

- The range of options surveyed is complete, inclusive of transportation system management (TSM) and transportation demand management (TDM), and various ride sharing, transit, low-powered and nonmotorized modes.

- The optimal package accounts for synergies among options and for the time path over which the options are implemented.

In so far as the LCPM is designed to reduce the cost of meeting transportation needs, it can be regarded as a tool to enhance net social benefit, rather than simply least cost. The term "least-cost model" provides terminological continuity with energy prototypes, but suggests a too limited notion of what this model aims to achieve.

Model Description

A schematic description of the LCPM is shown in Figure 1. The exogenous driver is *access*, which is defined as a condition wherein individuals with the requisite economic means overcome the limitations of space that would otherwise impede the fulfillment of an economic objective. Access, in the context of this definition, is defined in units of potential trips. In a typical instance, access involves movement and takes the form of *mobility*. An expanding telecommunications infrastructure facilitates *telecommuting* or other activity allowing access to the work site while lessening the mobility requirements associated with traditional commuting.

The LCPM allows for the possibility of achieving access through nonmobility or reduced mobility options. For each trip purpose or special population (see Figure 2), access is discounted by variables that reflect the future incidence of means to achieve access without resort to mobility. The generalized form of these relations is as follows:

$$\text{mobility (trips)} = \text{access} \times \text{discount factor}$$

Mobility, as implied in the equation is measured as a vector of trips by trip purpose.

The objective is to compare costs over the universe of option packages. Costs are typically determined as the product of some measure of transportation activity and the cost per unit of this activity. A crucial question arises in this regard: What is the measure of activity appropriate to a least-cost transportation model? Several candidates suggest themselves:

- The number of person trips,
- Vehicle counts,
- Person kilometers of travel (PKT) defined as the product of trips and average trip length, and
- Vehicle kilometers of travel (VKT) defined as PKT divided by the average occupancy rate per vehicle.

In distinguishing among these measures, it is necessary to keep in mind the practical distinctions that occur among options. For example, VKT is inadequate as a sole basis for measuring transportation activity since it would fail to distinguish adequately among options that highlight vehicle occupancy rates, such as those that involve high-occupancy vehicle (HOV) lanes. By contrast, where congestion costs are at issue, traffic volumes and vehicle counts, or, in some instances, VKT, are more appropriate. Options

that highlight trip reduction in the face of constant access would focus on number of trips. Thus, no single measure of transportation activity is appropriate in the LCPM, but rather a vector of measures.

Trips multiplied by trip length yields PKT in aggregate (across modes). Trip length is a crucial variable in the efficient search for a least-cost package in that many long-term transportation options focus on land-use regulation. Growth management policies that limit the extent of development and that emphasize mixed use and higher density living implicitly target trip length reduction as a goal.

Mode choice is a major consideration in defining transportation options. The LCPM distinguishes among 20 modes as indicated in Figure 2. The model allocates PKT by trip purpose among modes using a multinomial logit specification for each distinct trip purpose (or special population). It computes the probability of an individual selecting a given mode for a particular trip purpose. This probability is a function of the following variables:

- Direct internal cost of travel per PKT by mode,
- Travel time per PKT by mode, and
- Real income.

Once mode choice probabilities are determined, total PKT is allocated among modes. Information on occupancy rates per vehicle allows the inference of VKT.

Estimation and Treatment of Costs— Sources and Methodological Observations

The LCPM is a full-cost model that attempts to account for all significant costs, internal and external, public and private, monetized and nonmonetized. (Travel time is an instance of a significant cost that is not monetized.) This objective raises the level of uncertainty associated with model outcomes. While some cost elements are easily computed, others are subject to controversy. The elements subject to the most uncertainty include the various components of environmental cost, land-use costs, congestion and travel time cost, and costs related to the achievement of such social objectives as equity. A complete list of cost categories and their categorization is shown in Figure 2.

Some observers have suggested that costs other than those associated with real-life monetary transactions be omitted from policy-oriented analyses due to their inherent uncertainty and poorly understood theoretical foundations. While conceding the embryonic nature of work in this area, it would seem reasonable to include as many of these costs as possible. The attempt to quantify environmental, social, and temporal costs reflects a need to assess their social importance compared with those costs that are quantified explicitly by market mechanisms. Without such quantification, transportation and land use decisions are necessarily biased in favor of those factors that enter an explicit market calculus. Where reasonable people might disagree over the specific magnitude of costs, process mechanisms can be devised to achieve compromise and consensus within specific planning jurisdictions.

Considerable recent effort has been directed at gaining an understanding of the full costs of transportation (9-13). A recent study sponsored by the Conservation Law Foundation (10) estimates costs across several modes for the components employed within the LCPM. Other recent studies by Litman (11) and Miller and Moffat (12) cover similar ground, though estimates differ.

The authors were confronted with the problem of choosing among three or more competing estimates. The cost data used in the LCPM

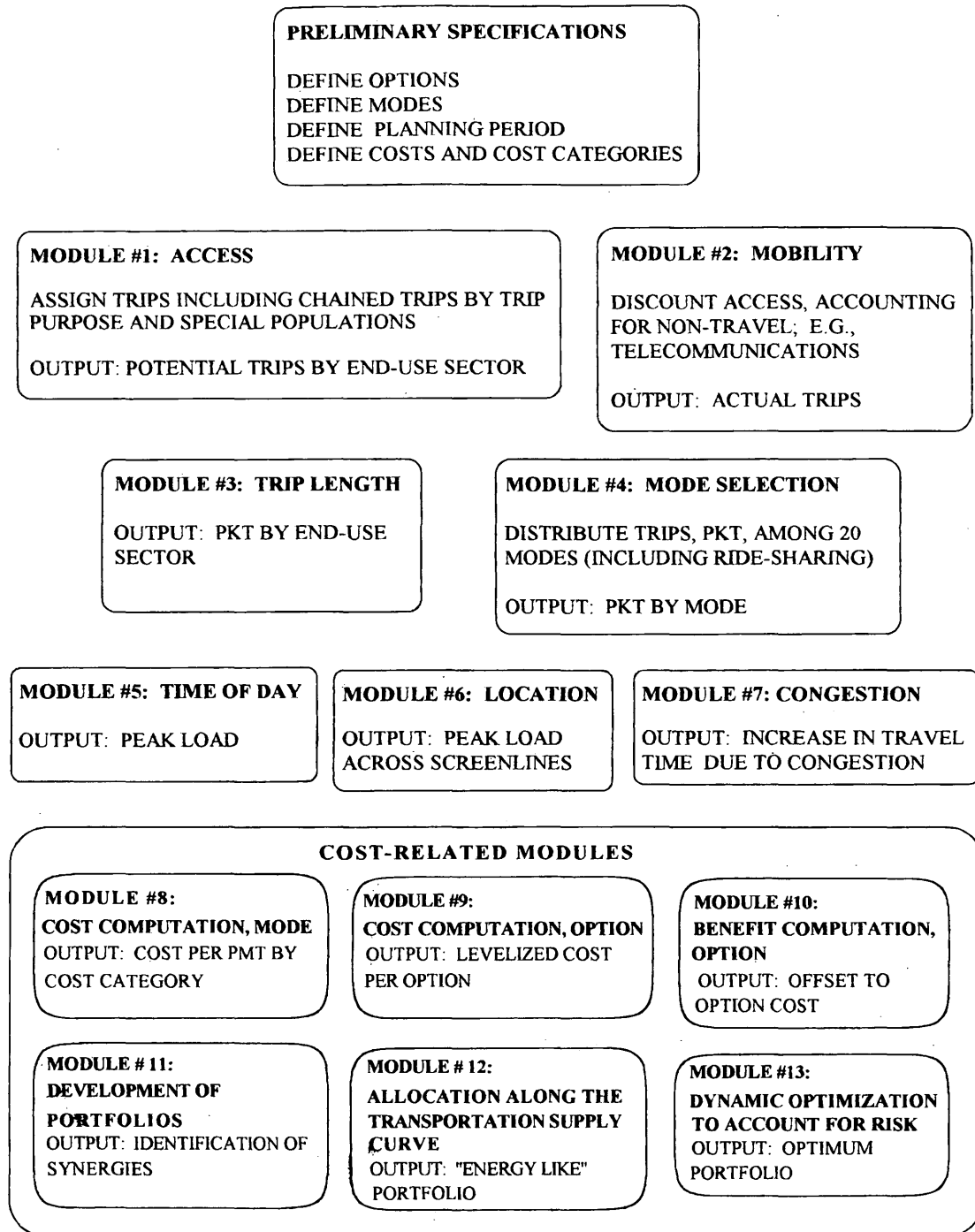


FIGURE 1 Least-cost planning model structure.

application base are based primarily on Litman since he has made the most complete review and comparison of the literature on costs.

The costs for various categories are summarized in Table 1. These values are continually being revised as new studies and theoretical arguments become known.

Travel Time Costs

A significant issue concerns the reckoning of travel time as a social cost. The Conservation Law Foundation study omits all noncon-

gestion travel time costs, arguing that "when deciding to make a trip, a driver implicitly considers his or her own time costs of the travel" (10, p. 12). In general, economists do not account as costs the time required to perform such personal tasks as mowing the lawn and washing the dinner dishes. In the case of travel, however, there are compelling reasons to break with this tradition and to impute a cost to the time required to travel. Given a choice between two alternative modes that require significantly different travel times, the traveler is likely to choose the more expeditious mode, all other things being equal. This is an economic calculation.

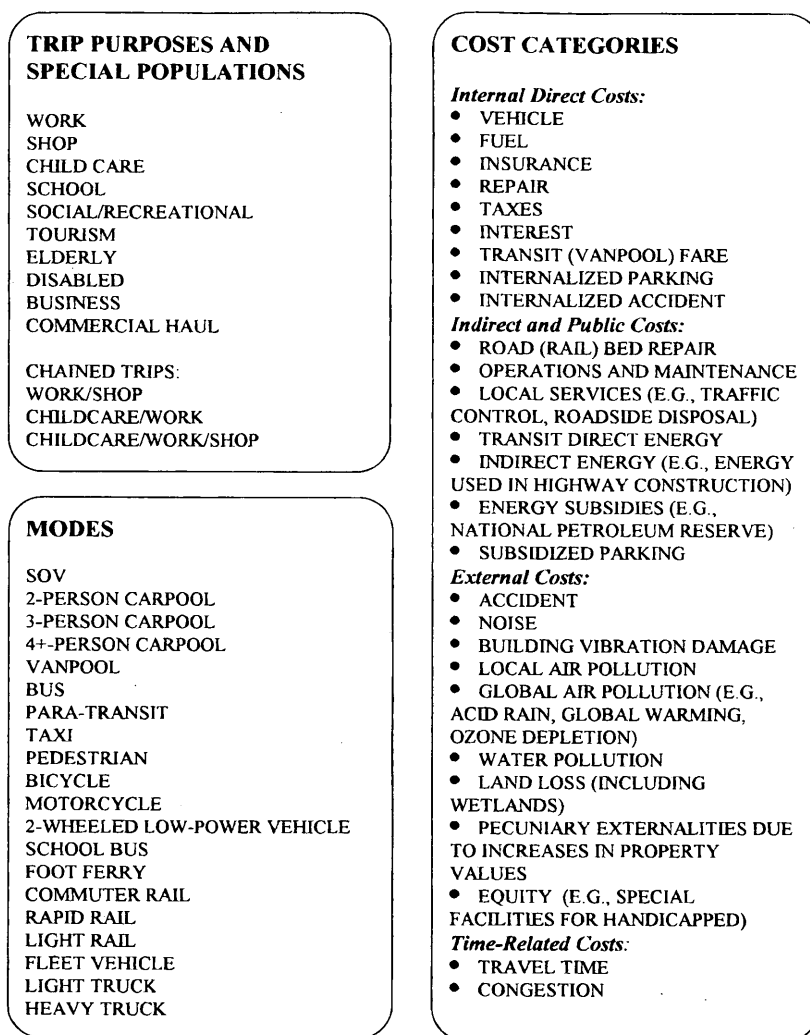


FIGURE 2 Trip purposes, modes, and cost categories used in least-cost planning model.

It has been claimed that the inability of public transit to increase its proportional share of ridership lies in the common perception (and often the reality!) that transit trips (including access times, wait times, and transfer times) absorb considerable time compared with automobile trips. Such nondelay-related travel time is appropriately factored into the overall calculation of transportation-related social cost. If such costs were omitted, the social cost of, say, land-use patterns that encourage home-based work trips of ever-increasing length and travel time is likely to be underestimated.

A condition where one-quarter to one-third of nonsleep, nonwork time is devoted to travel for many commuters cannot be regarded with indifference from an economic perspective. The LCPM, for these reasons, includes travel time as a cost and attempts to monetize these costs. In taking this position, the study team has followed the general practice of the British Columbia Ministry of Transportation (13), which accounts travel time costs for commercial and noncommercial drivers and for passengers of various age groupings.

Congestion Cost

Congestion cost is an important constituent of total social cost. Indeed, the public often perceives the level of congestion as a prin-

cipal index of how a regional transportation system functions. Moreover, the existence of congestion cost as a classic instance of market failure has been recognized and acknowledged by economists for many years.

Estimating congestion cost presents (at least) two difficulties in the context of the LCPM. A first problem involves translating time to dollars. The cost of delay clearly differs from person to person and from situation to situation. Bus riders are likely to represent lower-income travelers compared with single-occupancy vehicle (SOV) riders. Does this imply that the congestion cost of the former (approximated by their lost wages) is lower than that of the latter? In principle, it would be appropriate to stratify this cost by traveler characteristics; but for the present iteration of the LCPM, an estimate from Litman that averages over a range of characteristics was used.

A second problem involves the estimation of hours of delay for a metropolitan region. The LCPM attempts this without employing a detailed network or zonal model. System performance as measured by hours of delay is a major output of conventional travel demand modeling. Ideally, the apparatus of such models could be appropriated and integrated with a least-cost model. This integration has been suggested in the Puget Sound metropolitan area (14).

TABLE 1 Examples of Costs for Single-Occupancy Vehicles and Transit Employed in Least-Cost Planning Model

Cost Category	Cost (1994 Cents/PKT)
Private Internal Direct Costs:	
Vehicle capital	8.6
Vehicle fuel	3.8
Vehicle insurance	4.8
Vehicle repair	2.9
Vehicle taxes	1.1
Bus transit fare	4.3
Parking	2.6
Accidents	3.2
Indirect and Public costs:	
Road construction and repair	1.7
Local road services	0.7
Vehicle energy subsidies	0.9
Subsidized parking	7.5
Subsidized accidents	2.2
Subsidized bus capital	5.7
Subsidized bus O&M	27.7
External Costs:	
Noise	0.6
Local air pollution	2.8
Global air pollution	0.6
Water pollution	0.8
Land utilization	1.5
Property values	2.8
Time-Related Costs:	
Travel time	13.0
Congestion	5.7

In our simplified approach, regional congestion is estimated using a finite number of the highest-volume corridors. Congestion in these instances is a function of present and projected traffic volumes and system capacities produced by regional planners. These estimates are employed as an index for approximating congestion for the overall study area. The decision to abstract from the network detail is based on the view that congestion, in practice, is concentrated in well-defined corridors and that the margin of error associated with the omission of estimates for less congested corridors does not significantly affect the overall calculation of congestion cost for the study area.

Net Social Benefit Calculation

The net social benefit associated with a package of options is defined as savings less implementation cost. Savings are calculated relative to a base "no action" case. The model first calculates real discounted cost (using a 3 percent social discount rate) for the base case over a user-defined planning horizon. It then introduces a series

of options in succession. Options in some instances may combine several technological, policy, or institutional elements as a package. The net benefit of all options are then ranked. Options are then introduced in succession working down an "option stack" until marginal net benefit is no longer positive.

Disaggregation of Trip Purposes and Modes

The set of trip purposes, special population groups, and modes incorporated in the LCPM are listed in Figure 2. Their selection attempts to realistically and thoroughly account for the factors that underlay the response of transportation users to a set of options.

The most recent decade has witnessed fundamental changes in the structure and characteristics of families and households. Two-earner households are increasingly the norm and single-parent households are far more common than in the past. This holds significant implications for transportation choices. Multicar ownership is often a matter of necessity, while travel patterns are often dictated by child care needs. The LCPM recognizes these trends by specifying child care as a distinct trip purpose.

Child care, moreover, is likely to result in significant trip chaining. Neglect of the phenomenon of chaining is apt to bias transportation planning in favor of public transit options. The choice of transit for chained trips is likely to involve significant travel time costs since the traveler must embark and disembark at least twice. If the chain involves child care as an element, trip quality must be taken into account as well since parents may be reluctant to carry their child onto a bus or train.

Chaining occurs in many other contexts as well. Travel to work is often combined with shopping. Eating out (perhaps in fast-food drive-ins) on the way home from work and shopping results in multiple links on the chain. A recent study of National Personal Transportation Survey data suggests the importance of chained trips as part of all travel (15).

To factor chained trips in the LCPM model, three prevalent kinds of chained trips have been defined (see Figure 2).

In listing trip purposes, the importance of special population groups must be emphasized. The determinants of transportation choices for elderly or disabled persons are clearly different compared with young, able-bodied individuals. The LCPM distinguishes special populations in estimating access requirements, trips, trip length, and mode choice. This, in turn, allows consideration of options that target these populations (e.g., on-demand transit for elderly and disabled persons).

In its choice of modes, the LCPM aims to be as inclusive as possible. Aside from single-occupancy vehicles and the principal public transit modes—including bus and rail (commuter, rapid, and light)—the model considers a spectrum of ride-sharing modes, taxi, nonmotorized (bicycle and pedestrian), and foot ferry (a viable option for the central Puget Sound region). Commercial modes are also considered, distinguishing fleet vehicles and (heavy and light) trucks.

MODEL APPLICATION: OPTIONS, PACKAGES, AND PORTFOLIOS

The LCPM searches among a set of distinct transportation options to configure a least-cost *package*. These options range widely from major transportation investment projects to enhancements and

expansion of existing infrastructure to TSM and TDM measures that are individually modest in scope, but that offer a significant impact when bundled with other measures.

Application of the model to the Puget Sound metropolitan area was demonstrated by employing a limited set of options and portfolios (Table 2). The options and portfolios were selected because they represent a range of supply- and demand-side measures that are under active discussion in the central Puget Sound region or in other regions.

The system design, ridership forecasts, and costs for the bus emphasis, light and heavy rail emphasis, and commuter rail options were developed by the Central Puget Sound Regional Transit Authority. Each of the demand-side options required that a cursory design be accomplished and estimates of costs and performance be made. No attempt was made to perfect the design of these options to the extent that would be necessary to propose them for adoption by decision-making bodies. The options were sufficiently outlined such that they would be accepted as feasible by transportation practitioners.

Similarly, obvious linkages and synergies between options were ignored in this test run. A real-world application would require the design of comprehensive programs involving these options as elements.

Accounting for the Political Environment

In many cases, choices among options are not determined on efficiency grounds alone. Political and other factors may require that some options be "forced" into a mix regardless of cost. In certain cases, the public may favor the implementation of a given option regardless of cost. In other instances, a highway may be located to serve the needs of a favored constituency; a rail system might be routed to avoid disrupting a locality that would otherwise delay construction by litigating. The LCPM is designed to allow for these situations, optimizing under the political and other constraints to

TABLE 2 Transportation Options and Portfolios Included in Least-Cost Planning Model Demonstration

Options*	
19.	South corridor commuter rail
20.	North corridor commuter rail
32.	Passenger ferries
33.	Highway expansion (SR 18 & SR 522)
35.	Monorail expansion
48.	Commuter bicycle lane network
59.	HOV system completion
75.	Traveler information system
110.	Congestion pricing on SR 520
114.	Employer subsidized parking cash-out
117.	Transit passes for Commute Trip Reduction
120.	Telecommuting tax incentive
159.	Ride-share tax incentive
168.	Vanpool tax incentive
Portfolios*	
2.	RTP Rail/TSM recommended alternative
14.	RTA Study Option 1: Regional bus emphasis
15.	RTA Study Option 2: Surface rail emphasis
16.	RTA Study Option 3: Grade-separated rail

*Numbers correspond to list in Appendix A of reference 7.

design a second best package of options. Where this involves the inclusion of particular options without subjecting them to a benefit-cost calculus, the sets of options are termed *portfolios*.

Portfolios are also useful in assessing the costs and benefits of options that are on the table. In the central Puget Sound region, public discussion has recently centered on the relative merits of a rapid rail, light rail, monorail, bus, TSM, and TDM investment strategies, with other interests emphasizing highways, and still others non-motorized (i.e., pedestrian and bicycle) infrastructure. The LCPM can be applied to various portfolios that are constrained a priori to support these disparate emphases and interests.

RESULTS OF THE MODEL DEMONSTRATION

As previously indicated, the LCPM proceeds first by computing costs associated with a base case in which no new options or measures are adopted, but present trends are assumed to continue over a 30-year planning period. The social benefit of introducing options singly is then computed by comparing the full life-cycle cost of meeting regional access requirements under the option with the comparable estimate for the base case. This estimate of social benefit is computed net of the life-cycle cost associated with implementing the option.

Partial results of the Puget Sound demonstration are shown in Figures 3 and 4.

The LCPM has the capability of assessing the impact on travel demand of any single option or group of options. An example is illustrated in Figure 3, where single-occupancy vehicle PKT for the base case and for a grade-separated rail option are compared. The rail option was the most ambitious among those recently considered by the Central Puget Sound Regional Transit Authority. While some SOV displacement is indicated, the magnitude of this displacement is relatively small.

Figure 4 shows the breakdown between the implementation cost and the gross benefit of each of the options and portfolios that were analyzed in the LCPM demonstration. The difference between the implementation cost and gross benefit is the net social benefit.

The results indicate that the preferred combination among the 18 options and packages might involve significant expansion in bus service with limited light rail (Option 14), expansion of bicycle and pedestrian infrastructure (Option 48), HOV lane system completion (Option 59), implementation of a traveler information system (Option 75), a subsidized transit pass program (Option 117), and a ride-share tax incentive (Option 159). These results, although highly provisional, validate the proposition that there is no single dominating "fix" for an impending condition of excess transportation demand and excess social and environmental cost. Rather, the net social benefit would be greater—indeed even positive—if a number of undramatic but well coordinated synergistic measures were implemented in combination.

FUTURE WORK

To be useful as an operational tool in metropolitan planning, the LCPM requires further refinement. Model improvements will be directed to the following areas:

- Elaborating the specification of trip purposes, with a special emphasis on chained and linked trips.
- Refining the search algorithm to more efficiently compare a larger number of decision packages.

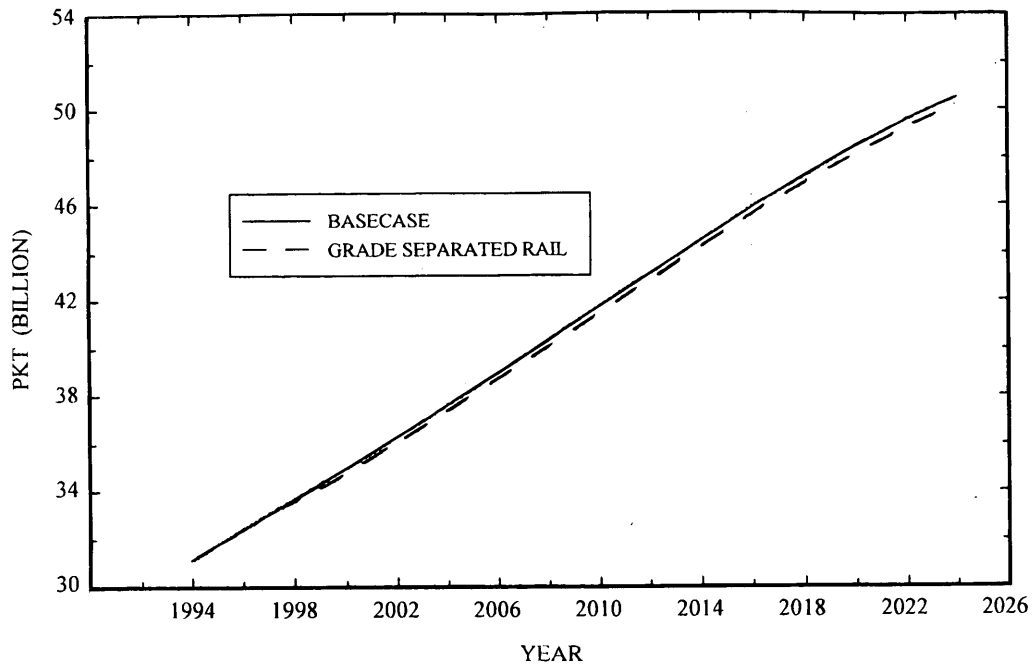


FIGURE 3 Person kilometers of travel by SOV—base case compared with grade-separated rail.

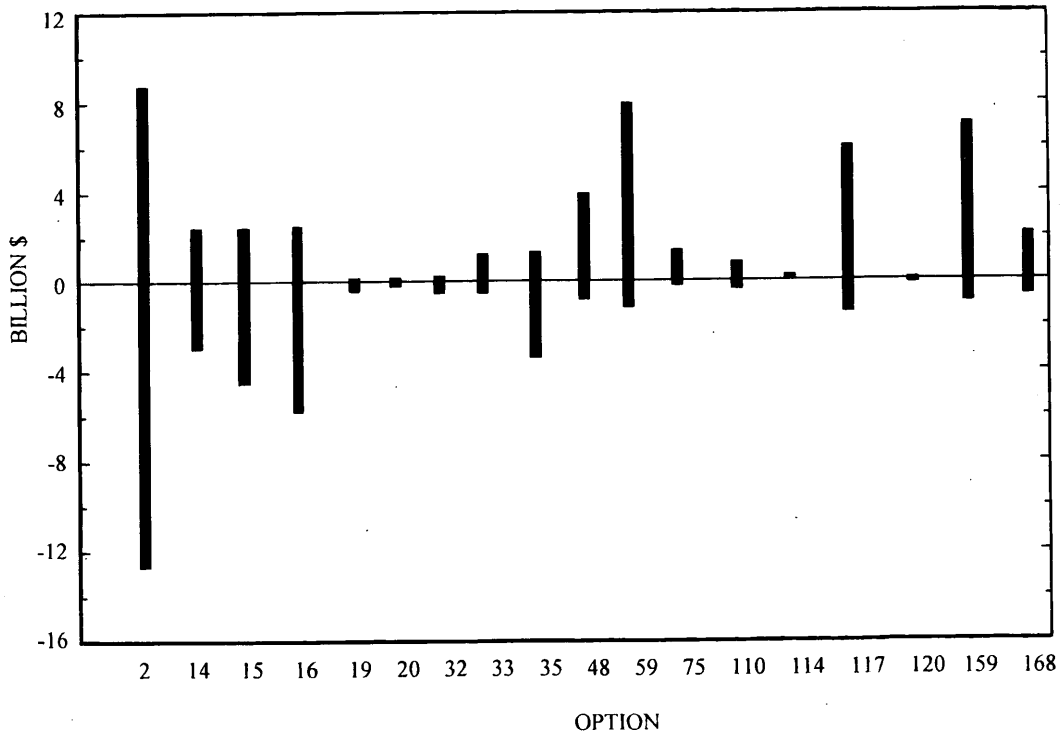


FIGURE 4 Transportation benefit (above) and cost (below) for options in least-cost planning model demonstration.

- Providing a more exact accounting of cost synergies associated with option combinations. The model formally allows for this at present, but there is little theoretical and/or empirical basis for actual estimates.
- Accounting more accurately for the timing of investments through a truly dynamic optimization procedure.
- Accounting more precisely for the direct, indirect, and induced benefits of options.
- Accounting for variability in travel demand—its relationship-changing population demographics, economic activity, technology, and land use.
- Providing a more accurate basis for estimating regional congestion.
- Providing a useful analog to the supply and demand curves employed in least-cost energy planning.
- Refining cost estimates—especially for nonmarket costs.

CONCLUSIONS AND RECOMMENDATIONS

The development of the prototype LCPM has confirmed that the objective of identifying transportation options that are of maximum social benefit to a metropolitan region is a feasible one. Moreover, the work has confirmed the essential role of this analytical tool in the search process. In the absence of such a model, the danger exists that no objective standard can be invoked to compare widely disparate options. In the transportation field—perhaps more so than in other venues—there exists an intensity of conviction among advocates that may dampen objectivity. The sheer magnitude of the expenditures involved in building a new freeway or constructing a rail system suggests that a rational economic standard should be invoked before scarce public and private funds are committed to these very costly projects. Indeed, such a cost-based methodology is required by statute under ISTEA. Once funds are committed and spent they cannot be unspent.

Professor Martin Wachs has recently commented that “. . . transport policy making is primarily a political exercise, and . . . analytic approaches by technical experts are invariably less influential than the pull and tug of influential interest groups” (*Transportation Research A*, Vol. 27, No. 4, p. 337). A least-cost planning approach attempts to provide a neutral basis that would mediate among such interest groups. Yet, for this to be achieved, a coherent analytic foundation is essential.

ACKNOWLEDGMENT

Support for this work was provided by the Energy Foundation, the Bullitt Foundation, the Medina Foundation, and the Cascade Bicycle Club. The authors wish also to express appreciation to Profes-

or Jerry Schneider and John Niles whose comments improved this paper.

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Publication of this paper sponsored by Committee on Transportation Programming, Planning and Systems Evaluation.