

Least-Cost Transportation Planning

Opportunities for the Vermont Agency of Transportation

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Executive Summary

Least-Cost Transportation Planning—meeting travel demand at the least cost to society as a whole—is an idea that in the past decade has gained traction in the transportation planning community. The transportation agencies of three states—Washington, Oregon, and Virginia—have already integrated elements of least-cost planning into their policy processes. Least-cost planning provides a framework for assessing long-term direct and indirect effects and overall cost effectiveness of proposed transportation projects, planning scenarios, and alternatives. The objective of least-cost planning is to identify the most cost-effective transportation policy options that will contribute meaningfully to broad agency and statewide goals and policies.

Implementation of least-cost planning has been under way in Oregon and Washington for the past few years. In Oregon, transportation agency staff are nearly finished with a cost-benefit analysis tests (using the Mosaic tool) that are scheduled for use in pilot projects across the next one to two years. In Washington, least-cost planning has meant a shift away from capital investment projects toward consideration of alternative transportation investments and a renewed commitment to public engagement. In Virginia, least-cost planning has been informative to the development of the state's Long Range Transportation Plan.

To the extent that least-cost planning overlaps with asset management planning, especially in the context of optimization across assets, it is important to note that VTrans is in the process of creating its own asset management plan. Both least-cost and asset management planning techniques entail identifying optimally cost-effective, long-term options. However, asset management typically relates only to physical assets. Because VTrans has begun to draw comparisons, and to consider planning strategies that involve cost effectiveness, it might be time to expand the scope of this planning beyond physical assets.

VEIC identified the following opportunities for implementation of least-cost planning at VTrans:

1. **Long range planning:** Following the lead of Virginia and the Puget Sound Regional Council, VTrans could include estimated direct and indirect costs associated with the proposed long-range plan (and alternate scenarios, if appropriate), as well as an evaluation of the plan and scenarios according to recent energy performance measures.
2. **Budget process:** VTrans could build budgets that not only reflect needed capital appropriations, but also consider out-year maintenance, and economic and health budget needs, even if they will not be in the VTrans budget request.

Introduction

Least-Cost transportation planning meets travel demand at the least cost to society as a whole. It is a policy idea that has begun to gain traction in the transportation planning community. At a minimum, a least-cost approach to transportation planning involves some form of comparative analysis to help with decision making, with how to account for real-world direct and indirect costs and benefits; and with public engagement in mind. Several states—notably, Washington, Oregon, and Virginia—have integrated elements of least-cost planning into their planning processes.

The Oregon Department of Transportation (ODOT) has addressed least-cost planning with a comprehensive cost-benefit analysis tool called *Mosaic*. This tool uses several data sources and models to help users make planning decisions via more than 30 indicators within 9 categories. These categories range from accessibility to safety, to environmental stewardship. Planners at the state level, metropolitan planning organization level, and town level are expected to derive the highest value from this tool. It is not intended for project level use. In 2015, it will enter a pilot phase.

In contrast, Washington Department of Transportation (WSDOT) uses a general approach to planning, not a tool, to drive its least-cost planning strategy. Least-cost planning was mandated by the Washington Legislature in 2000, and guides WSDOT's planning process. The Department uses least-cost planning to guide high-level planning decisions and corridor management, feeding into the Department's project-level management tool, *Practical Design*.

Virginia used a least-cost planning approach to create the Commonwealth's 2010 long-term transportation plan. The plan compared multimodal investment scenarios in corridors across the state, and linked back to the Virginia Department of Transportation goals and performance metrics.

Understandably, the form that least-cost planning takes varies among states that use it, but the basic tenants are the same: transparent and systematic comparison among options.

If least-cost planning is adopted at VTrans, the form it takes will depend on agency goals and processes, as well as on the amount of flexibility allowed in allocating federal funds. In a review that served as a guiding document to the ODOT's implementation of least-cost planning, consultants CH2M Hill and HDR (2010) set the following minimum criteria for a least-cost planning approach:

1. Planners measure costs and benefits in terms that facilitate the comparison of planning options (such as monetary equivalent units).

2. The planned approach makes use of quantitative and qualitative evidence.
3. Planners estimate impacts on users and non-users. Users might be commuters traveling via a new transit system along a previously congested corridor; non-users could be members of the general public who do not travel within the corridor, but who might benefit from improvements in air quality in the vicinity of that corridor..
4. The approach accounts for indirect effects such as changes in local employment and land use.
5. Planners consider interactions (“synergies”) among planning options.
6. The approach explicitly accounts for risks and uncertainty in forecasts, and in cost and benefit calculations.

Although planners often consider least costs in comparing the costs and benefits of supply side (expansion) options and demand side (TDM) options, least-cost planning is essentially about comparative analysis. The scope of least-cost planning is not limited to modal options, but involves system-level planning and optimization. Consideration of all demand side options might involve coordinating carpooling systems, telecommuting, and land use decisions, and promoting location-efficient development decisions.

In a rural context, where few modal options are likely, least-cost planning can provide a framework for comparison among transportation investment decisions. No one has yet used ODOT’s Mosaic tool in a rural planning process. That agency’s planners anticipate challenges in using Mosaic for rural areas, because the data are likely to be insufficiently robust. Nevertheless, ODOT plans to rely also on qualitative indicators explored in the stakeholder engagement process.

Like many state transportation agencies that are facing financial constraints, VTrans has few plans for roadway expansion. Least-cost planning can still be very informative for the planning prioritization process, scoping, and consideration of alternatives, and in the exploration of strategic disinvestment in VTrans assets. Because maintenance costs of assets have outpaced available funding, planners have become more interested in strategic disinvestment (FHWA 2008). Least-cost planning can provide a comprehensive, systems-level approach to determining relevant costs and benefits of disinvestment.

I. Least-Cost Planning Background

Least-cost planning (also known as *least-cost integrated planning* and *integrated resource planning*) first came to prominence in the electric energy sector in the 1970s. it has since transformed the energy planning process at many utilities and public utility commissions. Least-cost planning in the energy sector considers both supply side and demand side options in

determining how anticipated electricity demand will be met. Before least-cost planning in this sector, electric distribution utilities conducted their energy planning with considerations only for supply-side options: How much additional infrastructure (transformers, generating plants, wires, and poles) will be needed to meet demand? Many states now require utilities to consider demand side options that reduce overall energy use or shift peak demand so that they can avoid having to make new capital infrastructure investments. Least-cost planning requires a transparent and consistent process and cannot be achieved unless planners and other stakeholders explore all viable options in both the demand side and the supply side. In Vermont, least-cost energy planning is codified in statute and is the established state policy for all energy decisions:

It is the general policy of the state of Vermont:

(2) To identify and evaluate on an ongoing basis, resources that will meet Vermont's energy service needs in accordance with the principles of least cost integrated planning; including efficiency, conservation and load management alternatives, wise use of renewable resources and environmentally sound energy supply.¹ (*Emphasis added*)

The Vermont statutory definition of *energy* includes transportation energy,² enabling this sector to use a least-cost approach to planning decisions.

Least-cost planning addresses two structural challenges embedded in most of our energy resource development. First, in the regulated energy utility sector, there is a history of regulated “natural monopolies” that require the mobilization of significant capital in order to provide service. Regulation of the monopoly system provided customer protections and benefits. The surface transportation system is also a monopoly system that is generally government-owned and maintained. Although it is not regulated in the same manner as for energy (or other transportation) infrastructure, the active management by government attempts to provide comparable protections to consumers. Similar to how utility customers pay for consumption via “rates,” the transportation sector is funded primarily through gasoline and diesel use taxes.³

Both the energy and the transportation sectors have traditionally failed to account accurately for the full range of costs imposed by the energy system. The prices customers pay do not cover the full costs of energy use— namely, associated environmental externalities. Society as a whole experiences, and

¹ Title 30 Chapter 5, V.S.A. § 202a. State energy policy

² Vermont Statutes Annotated, Title 30 Chapter 5, V.S.A. § 201.: *“As used in this chapter, ‘energy’ means substances or processes used to produce heat, light, or motion, including but not limited to petroleum or other liquid fuels; natural or synthetic fuel gas; solid carbonaceous fuels; solar radiation; geothermal sources; nuclear sources; biomass; organic waste products; wind; or flowing water.”* (*Emphasis added*)

³ Utility monopolies include government run public power systems similar to government owned and operated transportation systems.

If planners do not comprehensively assess costs and benefits, they cannot determine society's least-cost option.

sometimes addresses, these costs, which tend not to be equitably distributed among populations. Perhaps even more important, planners do not consider the full range of benefits from alternative strategies for providing the energy or mobility benefits, when the planners are contemplating major new investment decisions (or growing infrastructure maintenance and replacement). It is important to acknowledge that this dynamic of least-cost planning changes the rules for infrastructure investment. In effect, the notion of least-cost planning introduces a new decision tool for resource planning: one that aims to include the full range of costs and benefits of alternatives. Such an approach introduces new challenges to the traditional financing and cost recovery structure of these energy sectors.

Similar to the electric energy sector, a least-cost approach to transportation planning involves consideration of options that both increase capacity and manage demand (Nelson and Sakaw 1996). Least-cost transportation planning can also consider fuel switching from petroleum and diesel as part of a long-term strategy to reduce societal and environmental impacts of the transportation system and to reduce energy costs. Least-cost planning is particularly relevant to transportation because so many of the costs (and benefits) associated with transportation projects are externalized and not included in traditional cost-benefit analysis. It is crucial that externalities be considered, quantified, and monetized to the extent possible because ultimately it is society who pays for these costs. If planners do not comprehensively assess costs and benefits, they cannot determine society's least-cost option.

Least-cost transportation planning first came into discussion in Vermont in the state's 1998 *Comprehensive Energy Plan*. This plan defined *least-cost transportation planning* as

...focusing transportation planning on meeting the needs of Vermonters for access to goods, services, and activities (after environmental, historic preservation, and safety considerations) at the lowest present value life cycle cost (including public and private costs) by combining investments and expenditures on new transportation capacity and comprehensive transportation demand management.

The plan further declared that least-cost transportation planning is "the most significant step that Vermont can take toward meeting its energy goals," contributing to environmental sustainability and economic vitality through reduced transportation energy use and costs.

An important aspect of least-cost planning is the consideration of long-term operational costs and annualized replacement costs, and consideration of the risk associated with capital investment. Electric utilities derive much of the value of demand side management programs not only from reduced or deferred capital outlay, but from reduced maintenance and operations costs at these infrastructure systems. In addition, there are risks inherent in any

large capital investment: risks of going over budget, delays in construction, failure to perform, and risk that infrastructure will be damaged by a natural disaster. In electric energy planning and cost-benefit analysis, demand management options are often discounted by 10 percent, because they present a relatively low risk to the participating utility and ratepayers.

The impetus for regulated energy least-cost planning has often been actual risk or the perception of risk. Massive overbuilding by utilities (driven in significant part by their desire for return on such investment) historically led to costs that dramatically exceeded initial projections. In some cases, projects were never actually completed. The willingness and ability to pay for these assets created political pressure that opened the door to alternative strategies. The percent of growth in energy demand was sometimes projected to be in the mid to high single digits. In Vermont, annual underlying electric load growth has been below zero since 2007, and has stayed there. Similar challenges confront the transportation sector as it faces a massive need for infrastructure repair, potentially reduced revenues, and declining willingness to pay among the public.

Under some circumstances, initial capital costs and other such priorities can drive transportation planning decisions, without full consideration of either long-term costs of maintenance and preservation, or long-term risk. Ideally, planners will estimate all long-term costs associated with a project or business-as-usual scenario, considering capital costs and risks, long-term maintenance costs over specified time period, any avoided costs, and designated externalities.

II. Elements of Least-Cost Transportation Planning

Although the transportation sector will need to implement least-cost planning in a different manner from that of the electric energy sector, prior work in the electric sector provides a valuable framework for that implementation. There are obvious parallels between the energy and transportation sectors: both are built to accommodate peak demand, although this demand comprises only a small portion of time each day and week (and season), leaving capacity idle much of the time. Both of these sectors also engage in management practices to reduce peak demand, either through shifting demand to non-peak times or reducing it altogether through increased efficiency. In the electricity sector, however, there is generally one unit or metric: kWh of electricity. In transportation, there are several modes and fuel sources, as well sometimes competing interests between system users (for example, drivers and non-drivers). In addition, valuation of factors such as travel time and reliability can be difficult.

LEAST-COST PLANNING TOOLS

COST-EFFECTIVENESS SCREENING

The electric energy sector uses a standardized method of cost-benefit analysis in least-cost planning. In fact, it is similar to the ODOT's Mosaic tool. The goal is to level the playing field in capturing all possible quantifiable associated costs and benefits of a given project or proposed scenario; this can be accomplished by fairly valuing and comparing supply side and demand management options. Many utilities use a screening process to determine cost effectiveness of potential efficiency measures and programs. It is through this process that planners can compare the costs and benefits of proposed projects and thus determine the least-cost option. The assumptions underlying the screening process are generally developed in collaboration with the state's public utility commission and must ultimately receive regulatory approval before being implemented. Efficiency measures that are deemed cost effective during the screening process are typically included in a state or utility's *Technical Reference Manual* (TRM). This manual characterizes estimated costs, performance attributes, load shapes, energy savings and other non-energy and environmental benefits of efficiency measures and programs. It also is a comprehensive reference document for designing efficiency programs and for verifying energy savings.

LONG-TERM PLANNING

Long-term integrated resource plans, or IRPs, are another important component to least-cost planning. IRPs minimize the total costs of energy generation, distribution, and use, rather than just reduce average electricity rates (ACEEE 2010). Currently 39 states require utilities to develop IRPs, or similar plans, detailing how anticipated demand will be met and describing the scenarios considered in the planning process (Wilson and Biewald 2013). The corollary in the transportation sector is the Long-Range Transportation Plan, or Long-Range Business Plan, required of each state's DOT. Federal law mandates that each DOT must develop a plan with a minimum 20-year forecast, describing how the state's multimodal transportation system will be developed.⁴ There is wide variation among long-range plans: some are based on policy, others are project based. Not all are fiscally realistic. Despite this variation, all long-range transportation plans are now required to contain elements of performance-based planning, including development of necessary performance measures and targets.⁵ Least-cost transportation planning can provide a framework for the development and implementation of performance measures, as it has done in the integrated resource planning process.

Integrating least-cost planning into the transportation planning process might first involve developing or modifying an existing tool or process for comprehensive cost-benefit analysis. Broadly, costs and benefits to consider in a least-cost planning process, relative to a business-as-usual scenario, are: initial capital costs, long-term maintenance and operation costs, user

⁴ 23 CFR 450.214: Development and content of the long-range statewide transportation plan.

⁵ 23 USC § 135(d)(2); 49 USC § 5304(d)(2): Statewide and nonmetropolitan transportation planning.

costs, and indirect costs or externalities. Because they might have little direct impact on the VTrans budget, externalities are not likely to be a driving force of the agency’s planning process. However, they might have large impacts on the overall state budget. It could be informative to estimate the broader societal impact of proposed projects and policies, such that they are one of many factors evaluated (**Table 1**).

Table 1. Potential factors and data sources to consider in a least-cost transportation planning approach

Factor	Easily Quantified?	Cost to whom?	Data available?
Upfront capital costs	Yes	VTrans	Yes
Long-term maintenance costs	Yes	VTrans	Yes
Public health (emissions, activity levels)	No	Society (incl. state agencies)	Yes. Estimates available in public health literature, possibly not specific to Vermont
User costs (fuel, vehicle maintenance, travel time)	Mixed	Users, incl. VTrans via the state fleet	Yes. Vermont Fuel Report (Public Service Department), AAA cost of ownership, travel time valuation in the literature
Crashes (property damage, value of statistical life, injury)	Mixed	Users, VTrans, other state agencies	Yes
GHG emissions	Can be quantified through travel demand modeling quantified, less easily monetized	Society	Yes. Values have been proposed for the cost of GHG emissions in 2014, ranging from \$5-\$100 per ton.
Land use	No	Society	Yes. A growing body of literature is addressing the public health, economic, and environmental impacts of land use; estimates of these impacts vary widely and few are specific to Vermont. A recent Strategic Highway Resource Plan (SHRP) report provides a comprehensive review: <i>Interactions Between Transportation Capacity, Economic Systems, and Land Use</i> .
Economic impacts	No	Society	Yes. A growing body of literature addresses questions of how transportation projects and policies can impact local and regional economies. The Transportation Project Impacts Case Study (T-PICS) tool can provide guidance on economic impacts at the project level: http://www.tpics.us/ . See also the SHRP report under Land use in this table.

INDIRECT COSTS AND BENEFITS (EXTERNALITIES)

Because so many of the costs associated with the transportation system are externalized, a standardized approach to identifying and valuing these factors is critical. Pertinent externalities are: health impacts (from vehicle emissions, active transportation, bicycle and pedestrian safety, vehicle noise); climate effects from emissions; effects on vulnerable populations such as the elderly, children, low income, non-drivers; effects on accessibility; effects on quality of life; and social capital, and economic impacts. Many costs and benefits of transportation planning decisions can be neither easily quantified nor monetized. Thus, such an analysis can never be the sole factor in evaluating a project or policy. It can, however, inform the project prioritization process and facilitate systematic comparison among alternatives.

External factors, both costs and benefits, are often not captured by market forces, and indeed have been systematically excluded from most government budget processes. Even so, their impacts are real. For instance, the average cost of health impacts caused by particulate matter gasoline emissions (PM_{2.5}) is estimated at \$0.34 / gallon (Hill et al. 2009). PM_{2.5} can instigate or aggravate respiratory ailments such as bronchitis and asthma. Counting both state and federal taxes in Vermont, each gallon of gasoline is taxed approximately \$0.40. Both the federal government and the state, which collect that revenue, dedicate nearly all of it to system maintenance, not to public health. The entire economy bears these health costs: private citizens through direct healthcare costs and increased premiums, government programs, and employers through reduced productivity and increased employee absenteeism. Society ultimately absorbs and pays these costs, even though they elude quantification and are rarely aggregated to the extent that their combined economic impacts are apparent. Further, society absorbs and pays these costs typically in an equitable manner.

VTrans might consider only direct costs when comparing upfront capital costs and long-term maintenance costs. This approach is likely to be the most politically expedient and most fiscally responsible. However, from a perspective of economic efficiency, equity, and affordability for VTrans customers, the agency might be compelled to consider and quantify a broader range of factors: public health, environmental stewardship, climate impacts, and quality of life. This effort would help achieve societal cost effectiveness. Societal cost effectiveness is a primary metric used in the electric energy sector. Regulatory processes often subject proposed demand management programs and business-as-usual scenarios to cost-effectiveness tests: cost-effectiveness for ratepayers, for the utility, and for society as a whole. The societal cost test uses clear boundaries and assumptions to consider all relevant costs, both direct and indirect, in an attempt to comprehensively value proposed programs.

Although least-cost planning is a useful analytical tool, and can identify options that will be at a relatively low cost over their lifetimes, it is essential to recognize that many “least-cost strategies” are very different from traditional

infrastructure investments. They are often strategies to stimulate other sectors of the market, usually in ways that offer many benefits. These strategies can also continue to erode revenue. Least-cost investments in the regulated utility sector address “market barriers” to adoption of new technologies and energy management (and generation). In the transportation sector, they might reflect directly competing investment choices (public transportation, bicycle paths, and walking lanes) that also require new sources of funding.

THE CHALLENGE OF CROSS-AGENCY OR GLOBAL BUDGETING

Transportation planning and asset management strategies that explicitly and quantitatively include externalities to the extent possible (for example, air quality, energy security, and health impacts) can result in altered or new planning and implementation priorities for VTrans. Such an approach considers what is most cost effective for Vermonters, rather than what is most cost effective for VTrans. What might be the “cheapest” strategy for VTrans might increase costs for other agencies—the Agency of Natural Resources or the Department of Health, for example—and ultimately, the total cost to Vermonters.

III. Transportation Cost-Benefit Analysis Tools

Cost-benefit analysis tools are available to transportation professionals. These tools differ according to analysis factors and the types of projects and alternatives they are able to consider. **Table 2** summarizes the analysis features of these models and tools.

Surface Transportation Efficiency Analysis Model

The Federal Highway Administration (FHWA) commissioned the Surface Transportation Efficiency Analysis Model (STEAM) for state and regional transportation planning agencies to evaluate investments in multi-modal infrastructure, demand management programs, and policy alternatives. STEAM can be employed at the regional and corridor levels. Factors in the model consider: travel time, crashes, emissions, energy consumption, access to jobs, and noise. It also considers capital and operating costs, and economic performance measures.

Highway Economic Requirements System

Known as *HERS* (or *HERS-ST*), this system guides state DOTs in maximizing cost effectiveness and economic benefits for highway investments. The model illustrates how differing levels of investment and mixes of investment type affect highway system performance. The model considers highway operation and maintenance costs, and non-GHG emissions.

Intelligent Transportation System Deployment Analysis System (IDAS)

IDAS is a cost-benefit analysis tool that specifically evaluates intelligent transportation systems. Model outputs are: travel time impacts, travel time

reliability, crashes, non-GHG emissions, fuel use, and capital and operating costs.

StratBENCOST

StratBENCOST is a tool that guides strategic highway investment, including pavement treatments and capacity expansion. This model differs from other cost-benefit tools because it explicitly considers uncertainty and risk. Benefit categories: travel time, user vehicle operating costs, crash rates, and non-GHG emissions. Cost categories: capital and maintenance, and rights of way. The tool outputs economic performance measures such as net present worth, internal rate of return, and payback period.

TREDIS Multimodal Cost Benefit Analysis Tools

TREDIS cost-benefit analysis tools apply across modes. Tools produce benefit-cost ratios, estimated economic impacts, and non-GHG emission values of proposed projects.

Health Economic Assessment Tool (HEAT) for cycling and walking

This World Health Organization quantitative model informs cost-benefit analysis of transportation projects. HEAT calculates the economic value of improvements to mortality rates from increased rates of biking and walking. Although developed for use in Europe, the tool has been applied to North America (Gotschi 2011).

Infrastructure Voluntary Evaluation Sustainability Tool (INVEST)

FHWA launched INVEST in 2012 as a resource of best practices to guide state DOTs and metropolitan planning organizations in integrating sustainability into their practices. The tool considers lifecycle costs and can be used for system planning, project development, and operations and maintenance. WSDOT’s community planning office has used it in their implementation of least-cost planning.

Table 2. Transportation cost-benefit models

Model	Long-term operating costs included?	Some indirect costs included?	Considers multi-modal alternatives?
STEAM	Yes	Yes	Yes
HERS	Yes	Yes	No
IDAS	Yes	Yes	No
StratBENCOST	Yes	Yes	No
TREDIS	Yes	Yes	Yes
HEAT	Partially*	Yes	Yes
INVEST	Yes	Yes	Yes

* Limited to bicycle and walking infrastructure

Despite the availability of modeling tools to assist in transportation cost-benefit analysis, a U.S. Government Accountability Office’s 2004 survey of state DOTs revealed that few actually employ a standardized or quantitative means of evaluating cost-effectiveness of competing projects or policies.

Similarly, although survey respondents reported that economic impacts of potential projects is an important consideration in decision-making, few regularly performed technical analysis to measure such impacts (CH2MHILL and HDR 2010).

IV. Least-Cost Planning in Other States

OREGON

In 2009, the Oregon Legislature defined *least-cost planning* as:

Least-cost planning means a process of comparing direct and indirect costs of demand and supply options to meet transportation goals, policies or both, where the intent of the process is to identify the most cost-effective mix of options.

The Legislature directed ODOT to develop a system to compare transportation investments fairly. Using the definition as guidance, Oregon DOT developed and launched the least-cost planning tool Mosaic (<http://www.oregonmosaic.org>). It offers nine categories of indicators for evaluating proposed bundles of actions at the local, regional and state levels. ODOT moved away from the term *least-cost planning*, replacing it with *Mosaic*. ODOT cited confusion about what *least-cost planning* meant: The cheapest outcome? The cheapest planning process? ODOT's approach to least-cost planning is broader than cost-benefit analysis, encompassing both qualitative and quantitative factors. The goal of the Mosaic tool is to provide decision makers with options, and estimated costs and direct and indirect impacts of a particular planning scenario. The tool is designed primarily for planning at the state, regional or city level, not at the project level. For that reason, little interaction between the National Environmental Policy Act and Mosaic or least-cost planning is anticipated (interview with ODOT staff).

ODOT is progressing toward full implementation of least-cost planning. As of October 2014, the Mosaic tool was near the end of its testing phase. Pilot projects are planned for the coming one to two years. The Mosaic tool's nine categories are listed below. Within each category are general indicators and specific indicators (available at <http://www.oregonmosaic.org/17/categories-&-indicators.html>). For instance, the Accessibility category contains the general indicator *modal availability*, and within that indicator, the specific indicators of amount of multi-use paths and bike boulevards, pedestrian network coverage and crossings, and population and employment within a quarter-mile of a transit stop served by at least 30 vehicles per day.

1. *Accessibility*: Ease of connections, modal availability, proximity
2. *Economic vitality*: Impact of transportation services, impacts of spending for construction, structural economic effects
3. *Environmental stewardship*: Air quality, GHG emissions, resources at risk

4. *Equity*: How are impacts on environment and accessibility distributed across geographies and demographics?
5. *Funding / finance*: Capital costs, operating revenue, lifecycle costs, funds from private sector and other agencies, net impact on state and local fiscal balance and debt
6. *Land use and growth management*: Population and employment density, efficient development
7. *Mobility*: Out-of-pocket costs, quality of service, travel time, travel characteristics
8. *Quality of life*: Journey ambience, noise, physical activity
9. *Safety and security*: Safety, resiliency to terrorism and natural disasters

WASHINGTON

Similar to ODOT, WSDOT has been undergoing implementation of least cost planning since the 2000s. As of July 1, 2000, Washington law (RCW 47.80.030) required that all regional transportation plans be based on least-cost planning methods:

The methodology shall consider direct and indirect costs and benefits for all reasonable options to meet planning goals and objectives. The methodology shall treat demand and supply resources on a consistent and integrated basis. The regional transportation planning organizations shall consult the guidelines set forth by the department for implementing a least cost planning methodology. Regional transportation plans should incrementally incorporate least cost planning methodologies as these concepts are developed. The regional transportation plan adopted after July 1, 2000, shall be based on a least cost planning methodology appropriate to the region.

Washington statute defines *least-cost planning* as

a process of comparing direct and indirect costs of demand and supply options to meet transportation goals and/or policies where the intent of the process is to identify the most cost-effective mix of options.

At a minimum, WSDOT least-cost planning involves:

- Costs and benefits of any policy changes that are part of the strategy or alternative
- Costs of potential environmental damage
- Costs of collisions and traffic generated or reduced
- Time and cost barriers and consequences for all modes and user groups
- Population groups that bear the costs and who accrue the benefits
- Energy efficiency and air emissions
- Distinctions among long, medium, and short-term impacts
- Community characteristics (context sensitive)

In contrast to Oregon, WSDOT did not develop a cost-benefit analysis tool. Instead the agency took a broader approach to least-cost planning, emphasizing a shift away from capital investment projects and toward alternatives and strong focus on system performance. This shift is viewed as a long-term cultural shift that will taking place within WSDOT and in collaboration with local towns and municipalities. Land use planning is an important component of the agency's least-cost planning approach, despite the fact that most planning occurs at the local level. One WSDOT official noted that just making communities aware of "what's possible," given current budget constraints, can help to adjust expectations and encourage communities to plan and develop in ways that are less dependent on large WSDOT-funded capital projects. Engagement with local governments and the public is a crucial piece of WSDOT's least-cost planning approach.

Further, the emphasis on system performance helps reduce politically driven decision making and facilitate comparison among options. At WSDOT, least-cost planning is viewed as feeding into the NEPA process—specifically, the NEPA purpose and needs statement, and the evaluation of alternatives (interview with WSDOT staff).⁶ In her remarks to the U.S. House Subcommittee on Highways and Transit in September 2014, WSDOT Secretary Lynn Peterson highlighted the public engagement processes of both least-cost planning and NEPA, as well as the need to link these two processes (Peterson 2014).

In 2013, the Washington State DOT implemented Practical Solutions, an approach similar to least-cost planning that minimizes cost and maximizes benefit to the transportation system as a whole. Under Practical Solutions, the scope of work on individual projects might be limited to reducing spending on lower-priority items. The approach is included in the WSDOT strategic plan. Practical Solutions and least-cost planning work in conjunction with Practical Design, an approach to making project-level decisions. Least-cost planning identifies strategies early in the planning process to meet goals cost effectively. Practical Design helps in project-level decisions, and attempts to ensure maximum benefit to the system rather than to the project. **Figure 1** illustrates the interaction between least-cost planning and Practical Design at WSDOT.

According to the WSDOT website, Practical Design has informed many projects, including a corridor study in the Spokane area, and intersection improvement studies. Again, vital to this process is an element of community engagement.

⁶ NEPA processes, which are required in transportation systems that receive federal funds, ask agencies (and their subrecipients) to disclose environmental impacts of federally funded projects. There is a public engagement process that allows state DOTs to fully understand problems before they decide on solutions.

Among the more prominent examples of least-cost planning implementation in Washington is the Puget Sound Regional Council long-range transportation plan *Transportation 2040*. This plan was finalized in 2010 and used least-cost principles to estimate a net value for each of the region's transportation investment scenarios. The plan uses customized cost-benefit software and the region's travel demand model to evaluate the costs and benefits of scenarios and transportation investments.

Factors in the cost benefit analysis are:

1. Travel time and reliability
2. Growth and development
3. Project costs
4. Safety
5. Environmental quality
6. Fairness



Practical Solutions How a Collaborative Transportation Solution is Implemented

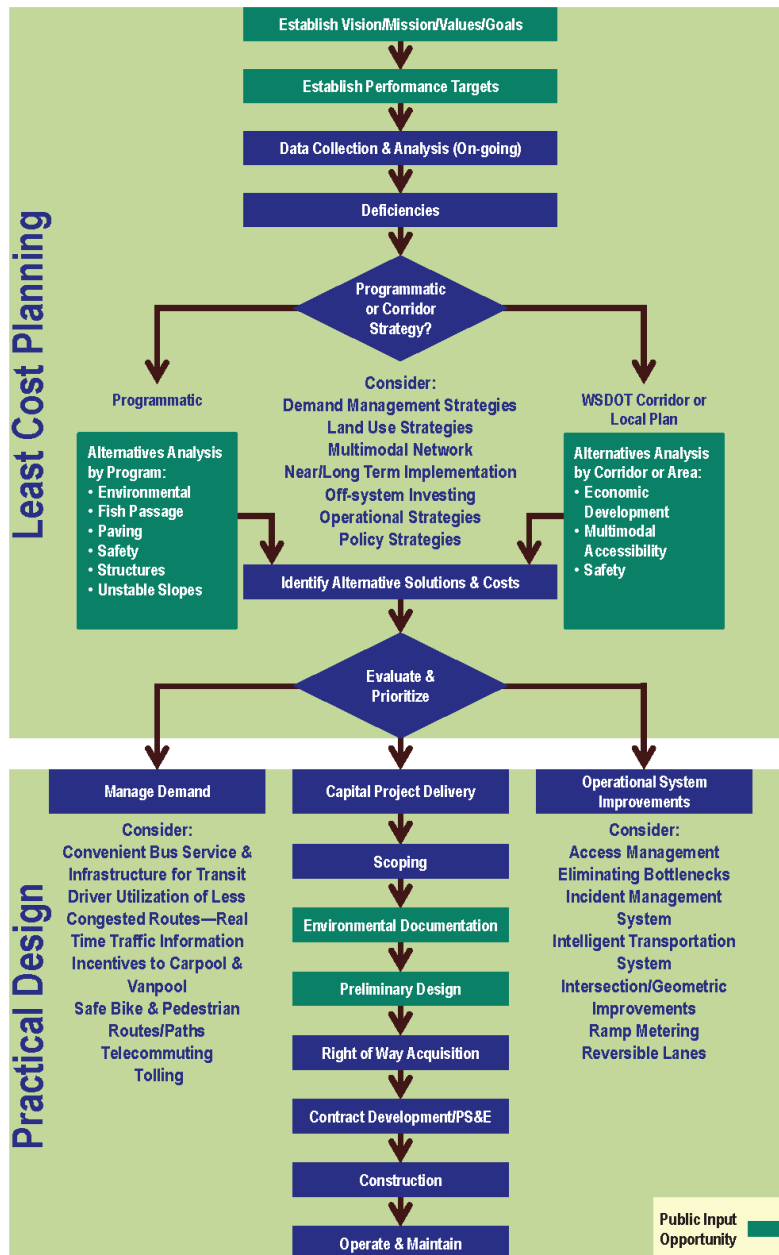


Figure 1. Washington State DOT approach to least-cost planning and Practical Design.



VIRGINIA

In 2010, the Virginia Agency of Transportation (VDOT) released *VTrans 2035*, the state's long-range multimodal transportation plan. Although this plan does not explicitly use the term *least-cost planning*, it is included in a review of applications of least-cost transportation planning for the Oregon DOT in 2010 (CH2MHILL and HDR 2010). It uses a systematic, multimodal approach and community engagement to support decision making. The plan describes 11 corridors of statewide significance, and describes the needs of all modes within each corridor. The plan presents six goals, each with accompanying investment priorities. The plan also defined performance measures to assess progress toward each goal, and to evaluate how each would be affected by the scenarios. The plan also estimates funding needs by investment categories, such as strategic infrastructure investment, enhancing economic competitiveness, safety, and maintenance. The development of performance measures tied back to the plan's goals; the plan's categorization of broad investment needs helps planners compare those needs across the available options.

V. Least-Cost Planning at VTrans

The examples above demonstrate how least-cost approaches to planning are being implemented across three key transportation agencies. Least-cost planning at VTrans would likely have greatest relevance for planning scenarios in the long-range transportation plan, corridor management, and project development and scoping. It can provide standardized planning methods that consider alternatives and define the public engagement process.

NEW PERFORMANCE METRICS

VTrans might want to consider new performance measures for shifting smoothly to least-cost planning. Specifically, measures related to accessibility and cost-effectiveness are expected to have greatest relevance in evaluating different options for transportation investment. Access is considerably harder to estimate than mobility. But, as the *1998 Comprehensive Energy Plan* notes, this is the goal of the transportation system: access to goods, services, employment, social interaction. A performance measure based on cost-effectiveness could help the agency integrate cost-effectiveness analysis into the project prioritization process; further, it would help in making multiple comparisons across projects.

ESTIMATING AND MONETIZING GREENHOUSE GAS EMISSIONS

Reasonably reliable estimates of greenhouse gas impacts can generally be made from projections of vehicle miles traveled (VMT) in travel demand modeling. The EPA model, *Motor Vehicle Emission Simulator (MOVES)*, provides estimates of tailpipe emissions. In the Mosaic tool, Oregon DOT hopes to capture fuel lifecycle emissions, rather than just tailpipe emissions, as well as any emissions associated with project design and construction.

GHG estimates for MOSAIC are derived from the model GreenSTEP, developed specifically for Oregon, and used by FHWA as the basis for the Energy and Emissions Reduction Policy Analysis Tool (EERPAT), a tool which can be used by any state DOT.

Monetized estimates of greenhouse gas emissions vary widely. Values of carbon in the California compliance market have been approximately \$14 / ton CO₂e (Smith 2013), considerably less than the \$100 / ton used by the Vermont Public Service Board in its cost-effectiveness screening. In the Mosaic Tool, Oregon DOT uses the Social Cost of Carbon estimated by the Interagency Working Group on Social Cost of Carbon (2010). These cost estimates range from approximately \$6 to \$70 per metric ton CO₂ for 2015.

FACTORS FOR VTRANS TO CONSIDER WITHIN A LEAST-COST PLANNING COST-BENEFIT ANALYSIS

A comprehensive approach to cost-benefit analysis that would inform a least-cost planning process would most likely involve some or all of the variables listed in **Table 3** (an expansion of many of the variables that appear in **Table 1**). This information should assist VTrans in determining the scope of direct and indirect effects to be considered, depending on the availability of data and agency goals and priorities. Identifying variables of interest can inform future data collection efforts. For most of the variables listed, VEIC provides a proposed value or range of values, derived from VEIC research and the literature. A more in-depth analysis or Vermont-specific modeling efforts will be required to determine the most appropriate value.

Table 3. Factors and proposed values for a VTrans least-cost transportation planning cost-benefit analysis

Variables	Notes
Upfront capital costs	
Impacts on VMT	Estimated through travel demand models.
Long-term or lifetime maintenance and operations costs	Including any associated energy / fuel costs.
Associated risks or avoided risk	Generally associated with capital investments (risk that projects will go over budget, risk of construction will be delayed, etc.).
GHG impacts	A value of \$100 / ton is used by the Vermont Public Service Board; Oregon DOT bases GHG estimates on VMT estimates derived from travel demand modeling and the GreenSTEPS model. GHG emissions can also be estimated via MOVES.
<i>Health impacts:</i>	
Air quality (non-climate)	CH2MHill et al. estimate that nationwide, the health costs of tailpipe emissions average \$0.34 / gallon of gasoline. Vermont-specific modeling efforts could refine that value.
Rates of active transportation	Research suggests that areas that provide bicycle and pedestrian infrastructure tend to have higher rates of active transportation (Buehler and Pucher 2012, Parker et al. 2010, Sollis et al. 2009) and that higher rates of active transportation have clear health benefits. Gotschi (2011) estimates that the per-capita benefit of 30 minutes of daily exercise is \$544 annually in avoided healthcare costs.

Variables	Notes
Noise impacts	Monetized estimates of transportation noise impacts vary widely: FHWA (1997) estimates noise impacts per VMT of an urban highway to be less than a penny, whereas Weisbrod et al. 2008 estimate the per-km noise cost of a car in a rural area to be \$0.06.
Safety and security	These categories can include the estimated energy security costs associated with dependence on gasoline and diesel (\$0.94 / gallon of gasoline; Leiby 2012), as well as impacts on emergency management systems and network resiliency. "Safety" includes injury and fatality costs associated with all system users.
Accessibility	The ODOT Mosaic tool considers indicators of modal availability, ease of connections among modes, and proximity in its assessment of accessibility.
Land use	Values available in the literature can be adapted for Vermont. Land use modeling efforts performed at the University of Vermont might be relevant (at the Transportation Resource Center and Spatial Analysis Lab).
Economic impacts	Values available in the literature on the economic value of transportation investments.
<i>Qualitative considerations:</i>	
Equity	How will the proposed project / planning scenario affect different groups (drivers, non-drivers, low income, young, elderly, people in specific geographies)?
Quality of life	How will least-cost planning impact social capital, sense of community, opportunities for social interaction?

VI. Least-Cost Planning and Transportation Asset Management

There is considerable overlap between transportation asset management and least-cost planning. Transportation asset management is defined in MAP-21 as

...a strategic and systematic process of operating, maintaining and improving physical assets, with a focus on engineering and economic analysis, based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the lifetime of the assets at a minimum practicable cost.

Similar to least-cost planning, asset management plans compare scenarios and estimate long-term costs.

Unlike least-cost planning, asset management considers only physical transportation assets (primarily pavement, bridges), whereas least-cost planning considers transportation investments more broadly. The goal of an asset management plan is to determine the most cost-effective way to manage maintenance / preservation, operation, and capital expansion needs

across assets. Although least-cost planning creates conceptual buckets of costs and benefits, asset management has buckets of investment: operation, maintenance, and expansion. An important aspect of asset management is the ability to manage across asset types, known in the industry as *cross asset optimization*. To have this ability, a common metric needs to be available to compare among assets and potential maintenance schedules. Similarly, a crucial piece of least cost is the ability to compare across projects and planning scenarios, using common metrics. Both approaches are driven by cost-effectiveness analysis but ultimately their outputs and applications are different. Asset management generally does not consider externalities, although planners could estimate economic impacts of proposed asset management schedules.

VTrans current has asset management under development and has established a bureau for asset management. In accordance with the federal mandate, VTrans will be completing a Transportation Asset Management Plan (TAMP) within the coming year. An objective of the TAMP is to drive the agency's budgeting process, the same way that cost-benefit analysis can drive planning decisions under least-cost planning. VTrans' asset management primarily addresses bridges and pavement. Multimodal assets (pedestrian and bicycle infrastructure, for example) and rail and air assets, as well as vehicle assets owned by the agency are not yet a priority. However, the agency intends to include them, once a system is in place to do so.

Another parallel between asset management and least-cost planning is the component of stakeholder engagement that involves legislators and customers. Implementation of a TAMP and subsequent clear communication with stakeholders can increase VTrans' credibility by providing not just a plan, but clear justification. Like least-cost planning, ideally, asset management has the characteristic of a transparent and consistent decision-making process that clarifies the agency's long-term plans and priorities.

Under MAP-21, all states must now create an Asset Management Plan. VTrans might want to consider how, a new asset management plan can be coupled with a least-cost planning approach. Least-cost planning offers a comprehensive approach to cost-effectiveness assessment, beyond physical assets. Implementing a standardized means of cost-benefit analysis to compare costs and impacts across projects and scenarios will help to maximize the agency's ability to effectively allocate resources. And even though it might be imperfect, standardized analysis will likely help the agency achieve its mission of safe and efficient movement of goods and people.

VIII. Conclusions

Vermont Statute directs VTrans to meet objectives that coordinate all modes of transportation, support projects that improve the state's economic infrastructure, and use resources "in efficient, coordinated, integrated, cost-

effective, and environmentally sound ways.”⁷ An official, least-cost planning approach will help VTrans meet an overarching objective: At a minimum, least-cost planning involves standardized cost-benefit analysis that allows comparison among options. This approach also aligns well with recent requirements for asset management, especially as it applies to cross-asset optimization and performance-based planning. A broad, agency-wide commitment to least-cost planning could facilitate integration of both the asset management plan and the *Long-Range Transportation Plan* into the agency’s decision-making processes, ensuring consistency of vision across divisions.

Research in least-cost planning in other states reveals that this planning approach is being used at the system level (as in the Virginia DOT long-range multimodal transportation plan) and at the project level (WSDOT implementation of Practical Design and Practical Solutions). In speaking with VTrans staff, VEIC learned of interest in a more standardized way for the agency to consider projects in the context of long-term costs of operations, rather than upfront capital only. A standardized and transparent approach like that used in asset management and more broadly applied in least-cost planning may help the agency build credibility with legislators and the public.

We identified the following opportunities for implementation of least-cost planning at VTrans:

1. **Long-range planning:** Following the lead of Virginia and the Puget Sound Regional Council, VTrans could incorporate estimated direct and indirect costs associated with the proposed long-range plan (and alternate scenarios, as appropriate). It could also incorporate an evaluation of the plan and scenarios according to newly developed performance measures.
2. **Budget process:** VTrans could create budgets that itemize not just capital appropriations but out-year maintenance and potential economic and health budget impacts, even if they are not in the VTrans budget request.

⁷ Chapter 1: State Highway Law, 19 V.S.A. § 10b. Statement of policy; general

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