White Paper #1

Potential Effects of Tolling and Pricing Strategies on Greenhouse Gas Emissions

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report

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prepared by

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Executive Summary

Advances in electronic technology have dramatically expanded how highways can be tolled and priced. It no longer is necessary to stop all vehicles at toll plazas. Vehicle usage of a particular highway, or even within an entire geographic area, can be recorded and a charged to the motorist electronically.

Tolling was traditionally a means of financing highway construction. Recent technological advances, however, create the possibility of tolling road use to accomplish other public objectives. In fact, pricing strategies are now being used in places to manage congestion and/or to generate revenue for other needed transportation improvements. This paper examines the potential effects of different forms of tolling and road pricing strategies on greenhouse gas emissions and discusses issues related to the analytical approaches used to quantify those effects. With the current emphasis on climate change, there is an emerging question about the degree to which road tolling and pricing can be used as a means of reducing greenhouse gas emissions from transportation sources. This paper is based on two presumptions. First, global warming is a complex issue. While much is known with a high level of confidence, there also are areas of continued uncertainty. Second, a strategy for how fast or how best to reduce greenhouse gas emissions has not yet been agreed upon. To gain public acceptance, emission reduction strategies will need to: a) reflect perceptions of the magnitude of the problem, and b) represent relatively cost-effective solutions.

Including greenhouse gas considerations in an analysis of road tolling and pricing strategies triggers important additional analytical requirements. These requirements go beyond those of the Oregon Department of Transportation (ODOT) and the state's metropolitan planning organizations. Tolling and pricing strategies may affect the number and type of vehicles owned by a household as well as where people live and work, the number of trips they take, the time of day trips are taken, whether they choose to drive or use transit or another mode of travel, and the roadway operating conditions in terms of vehicle operating speed and frequency of accelerations and decelerations. Some of these impacts may occur immediately, while others may take place over several years. An analysis of the impacts of road pricing on greenhouse gas emissions, therefore, needs to be based on how each of these factors will change over time and the resulting impacts on vehicle miles of travel (VMT) and vehicle operating conditions.

Carbon dioxide (CO_2), the most important transportation-related greenhouse gas, is emitted in direct proportion to vehicle fuel consumption, with variation by type of fuel. Factors influencing fuel economy and, in turn greenhouse emissions are vehicle type, model year, and vehicle operating conditions (speed and acceleration).

While significant data and analytical methods are available to evaluate travel and emission impacts of potential road pricing strategies, existing approaches are still less than fully satisfactory. Improved and more detailed analytical approaches are being developed at the national level, but are not yet widely used. New and emerging comprehensive analytical approaches to quantifying transportation and greenhouse gas impacts are both data and resource intensive, thereby limiting their use to larger agencies with access to more advanced analytical tools. As a result, simplified quantitative methods often are employed. An important challenge for ODOT and metropolitan planning organizations, therefore, is to improve current travel demand, traffic, and greenhouse gas modeling capabilities. This data can be used to analyze the full range of potential road tolling and pricing applications.

A broader set of guidelines is needed to frame a greenhouse gas measurement and assessment process. These include using a time horizon that extends at least 40 years into the future and accounts for likely changes in vehicle fuel efficiency and vehicle fleet characteristics.

The importance of road pricing as a greenhouse gas emissions reduction strategy is dependent on the extent of its geographic and temporal application. A pricing measure implemented on a statewide or even an urban area basis in a way that affects all travel is likely to result in larger reductions in emissions than those in effect only during the peak-period or on a given roadway. Even if effective locally, the latter may represent only a very small portion of total state emissions.

While the relative cost-effectiveness of alternative approaches to reducing greenhouse gas emissions is an important decision-making criterion, it is only one of a number of concerns that transportation agencies need to consider when making capital investment and system management decisions. Other considerations such as institutional responsibility, public acceptance, technology, legal authority, administrative expense, and economic impacts should also be weighed. For example, the administrative expense of initiating and managing an urban congestion pricing program compared to traditional fuel taxes may be an especially important consideration.

Potential forms of road tolling and pricing include expanded use of traditional road and bridge tolls; implementation of systems of high-occupancy toll (HOT) lanes, express toll lanes, and truck-only toll (TOT) lanes; the use of cordon or area pricing around or within a defined area such as a central business district (CBD); and various approaches to mileage-based pricing. A mileage-based fee could be as simple as a fixed price per mile regardless of when or where traveled, or the fee could vary either by time-of-day or historical level of congestion. Other possibilities include fees based on the carbon content of the vehicle's fuel, the type of fuel or power used, or the fuel efficiency of the vehicle.

Based on currently available quantitative estimates of greenhouse gas emission reduction effectiveness, the following conclusions emerge:

- Major decreases in motor vehicle greenhouse gas emissions are more likely to result from improvements in fuel economy standards and motor vehicle emission controls than from changing the pricing of road usage.

- The increase in fuel tax or magnitude of VMT fee necessary to achieve large reductions in travel and associated greenhouse gas emissions is significantly higher than the amount implied by currently proposed carbon taxes. Pricing implementation at these levels, therefore, should be based on more comprehensive objectives than just reducing greenhouse gas emissions.

- On a facility or project basis, road pricing designed for a more efficient operation of a roadway system should also lower greenhouse gas emissions. In other words, road pricing for other purposes can be designed to support greenhouse gas reduction efforts.

- The Minneapolis, Seattle, and U.S. Department of Energy findings represent a reasonable baseline estimate of potential areawide benefits of HOT or express toll lanes. Fuel savings in the range of 1.4 to 2.5 percent are likely attainable within those urban areas where regional systems of HOT and TOT lanes are feasible. If rolled out in national metropolitan areas that experience moderate to heavy congestion, these savings in fuel consumption are likely to range from 0.5 to 1.1 percent. New urban freeway lanes, however, can be expensive; so these costs, the full range of potential benefits, and potential economic and land use changes should be included when assessing the cost effectiveness of these systems as an emissions reduction strategy.

- Achieving larger emission reductions from pricing strategies, such as those projected in many state-level climate change action plans, will require an aggressive and comprehensive program of pricing strategies broader in scope than typically associated with tolling and congestion-based road pricing. Road tolling and pricing, by itself, is not sufficient to achieve the desired reduction in transportation sector greenhouse gas emissions often targeted in state climate change action plans.

Improved analytical capabilities are needed for estimating project, regional, and state-level changes in greenhouse gas emissions that could result from candidate road tolling and pricing strategies. A two-pronged approach is recommended. ODOT's Greenhouse Gas Statewide Transportation Emissions Planning (GreenSTEP) model should continue to be enhanced. This modeling approach can be used to conduct initial "sketch planning" analyses for a broader range of road tolling and pricing strategies than presently are possible. In parallel, existing state and urban area modeling systems should be improved to provide more detailed network-level analyses of potential changes in greenhouse gas emissions that could result from road tolling and pricing strategies.

■ 1.0 Introduction

This paper examines the potential effects tolling and road pricing can have on greenhouse gas emissions and discusses issues related to the analytical approaches used to quantify those effects.

The objective of using road tolling and pricing to reduce greenhouse gas emissions differs in important ways from the objectives that underlie both traditional tolling and current approaches to congestion pricing. Tolls traditionally have been used as a mechanism to finance the construction, operation, and maintenance of road and bridge facilities. The primary objective of congestion pricing, sometimes referred to as value pricing, is to improve the operating efficiency of either a particular roadway link or a larger transportation system. Implementing tolling and road pricing may or may not result in the reduction of greenhouse gas emissions. To date, reducing greenhouse gas emissions has not been a primary motivation for tolling and road pricing. The focus of this white paper, therefore, is on the potential impacts of road tolling and pricing on greenhouse gas emissions; specifically how such strategies should be analyzed and designed if their primary--or even sole--purpose is to reduce greenhouse gas emissions produced by motor vehicles.

The paper discusses the relationship between travel and the greenhouse gas emissions produced and addresses the following aspects of a road pricing-related greenhouse analysis:[1]

- Basic concepts;
- Quantification issues;
- The role of cost effectiveness in evaluation;
- Potential tolling and road pricing approaches if the primary objective is to reduce greenhouse gas emissions;
- Preferred analytical methods; and
- The results of recently completed analyses in other places.

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[1] The underlying science associated with climate change is not discussed as a part of this paper. The Intergovernmental Panel on Climate Change (IPCC) has published numerous reports describing various aspects of climate change (http://www.ipcc.ch/). The IPCC is a scientific intergovernmental body set up by the World Meteorological Organization (WMO) and by the United Nations Environment Programme (UNEP). The purpose of the IPCC is to provide an objective source of information about climate change. An economics-based approach to evaluating alternative greenhouse reduction strategies is contained in *A Question of Balance: Weighing the Options on Global Warming Policies* by William Nordhaus (2008). For public consideration of pricing strategies, see Jens Schade & Bernhard Schlag (ed), *Acceptability of Transport Pricing Strategies* (2003).

The paper concludes with a summary of findings and possible next steps that could be taken by the Oregon Department of Transportation (ODOT).

2.0 Basic Concepts

Factors Affecting Emissions from Motor Vehicles

Tolling and pricing strategies may affect the number and type of vehicles owned by a household as well as where people live and work, the number of trips they take, the time of day trips are taken, whether they choose to drive or use transit or another mode of travel, and the roadway operating conditions in terms of vehicle operating speed and the frequency of accelerations and decelerations. Some of these impacts may occur immediately, while others may take place over several years. An analysis of the impacts of road pricing on greenhouse gas emissions, therefore, needs to be based on how each of these factors will change over time and the resulting impacts on vehicle miles of travel (VMT) and vehicle operating conditions.

The estimation of changes in greenhouse gas (GHG) emissions resulting from motor vehicles differs in important ways from approaches used to estimate other emissions.[2] Carbon dioxide (CO_2) is emitted in direct proportion to fuel consumption, with a variation by type of fuel. The amount of CO_2 produced, therefore, is the result of the amount of fuel consumed, the carbon content of the fuel, and the fraction of carbon that is oxidized when the fuel is combusted. Factors influencing fuel economy are vehicle type, model year, vehicle operating conditions (speed and acceleration), vehicle maintenance, tire pressure, temperature, and air conditioner use. These relationships are not linear and vary by both model year and vehicle type and size. In general, the rate of fuel consumption in terms of miles per gallon increases with vehicle operating speed up to approximately 55 miles per hour (mph), and then starts to decline with further increases in vehicle operating speed. Recent vehicle models, though, show less of a drop-off than vehicles manufactured during the 1970s and 1980s. Because of these relationships, approaches to estimating fuel consumption that assume either an average fuel economy by vehicle type or a standard rate of fuel consumption by vehicle speed will not be fully satisfactory for evaluating the changes in CO_2 emissions.

It is important to know the distribution of vehicle fleet characteristics that may be affected by tolling and pricing strategies, how these characteristics will change over time, and the operating profile of these vehicles both before and after implementation of the pricing strategies. Because fuel consumption, and thus greenhouse gas emissions, are determined

[2] *Assessment of Greenhouse Gas Analysis Techniques for Transportation Projects,* prepared by ICF Consulting for the American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Environment, NCHRP Project 25-25, Task 17, May 2006.

by vehicle power rather than simply vehicle operating speed, it is important to know how different tolling and pricing strategies affect not only VMT but also vehicle driving cycles in terms of the number of speed change cycles and the rate at which accelerations occur. Emission characteristics will differ, therefore, among general purpose travel lanes, high-occupancy vehicle toll (HOT) lanes, and TOT lanes.

Transportation as a Contributor to Greenhouse Gas Emissions

Transportation is an important source of GHG emissions, and consequently represents a major target of efforts to reduce GHG emissions over the short-, medium-, and long-term future. More than 35 states, including Oregon, either have completed or are in the process of preparing climate change action plans that include significant attention to reducing GHG emissions from transportation sources.[3,4] Under a 2007 Oregon law, the growth in GHG emissions is to be eliminated by 2010. By 2020, GHG emissions must be reduced to 10 percent below 1990 levels, and by 2050, GHG emissions must be 75 percent below 1990 levels.

On a global basis, the United States emits roughly 20 percent of carbon emissions from fossil fuel combustion, even though the country's population is only 4.7 percent of the world population. Oregon's greenhouse gas emissions in 2004 were 67.5 million metric tons of carbon dioxide equivalent ($MMtCO_2e$), a growth of 22 percent from 1990 levels. This compares to a 16 percent growth for the United States as a whole over the same period. Greenhouse emissions from transportation in Oregon represent 34 percent of the state's total greenhouse gas emissions. Electricity consumption accounted for 32 percent, with nine other sectors accounting for the remainder. Within the transportation sector, highway vehicles comprise 81 percent of total energy consumed.

Strategies for Reducing Greenhouse Gas Emissions from Motor Vehicles

Emissions from motor vehicles can be controlled through implementing vehicle emission standards, changing the composition or type of fuel consumed by motor vehicles, managing demand for transportation, and improving the operating efficiency of transportation infrastructure.[5] These strategies, while typically thought of as separate and independent, can be implemented in combination.

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[3] *Final Report to the Governor, A Framework for Addressing Rapid Climate Change*, The Governor's Climate Change Integration Group, State of Oregon, January 2008.

[4] *Oregon Strategy for Greenhouse Gas Reductions,* Governor's Advisory Group on Global Warming, State of Oregon, December 2004.

[5] Pricing strategies also can be used to influence the types of vehicles purchased and the type of fuel used. The scope of this paper, as elaborated upon in Section 5.0, is limited to tolling and road pricing.

Vehicle emission standards have been implemented for the "criteria" air pollutants (VOC, NO_X, CO, and PM) and for heavy-duty as well as light-duty vehicles. Vehicle emission standards for CO_2 have been adopted by California but, pending approval from the U.S. Environmental Protection Agency (EPA), have not yet been implemented. Vehicle standards are the most important emission control strategy implemented to date because they result in lower emissions for all travel. During a period when VMT has grown at a significantly faster rate than population, VOC emissions from on-road vehicles, as one example, declined by more than 73 percent.

Greenhouse gas emissions from motor vehicles also are influenced by the Corporate Average Fuel Economy (CAFE) standards, first enacted by Congress in 1975. The Energy Independence and Security Act of 2007 requires fleetwide vehicle fuel economy for passenger vehicles, including light trucks, to be increased to 35 miles per gallon (mpg) by the year 2020. On January 26, 2009, President Obama requested that the U.S. Department of Transportation implement a final rule by March 30, 2009, that transitions to this higher standard, beginning with model Year 2011 vehicles. It is important, therefore, that analyses of changes in greenhouse gas emissions account for this projected change in vehicle fuel economy as newer vehicles are introduced into the vehicle fleet because they will lower over time baseline greenhouse gas emissions.

■ 3.0 Quantification Issues

Transportation Effects on Greenhouse Gas Emissions

To analyze changes in greenhouse gas emissions that would result from the implementation of one or more road tolling and pricing strategies:

- Changes in land use, vehicle ownership, and travel conditions over time need to be estimated using a combination of travel and traffic data in conjunction with travel demand and traffic models.
- These changes in travel patterns should be translated into changes in greenhouse gas emissions using fuel consumption and emissions estimation models.

A challenge in estimating the response, both travel and the associated emissions, is capturing both the full range of potential short- and long-term changes and the full range of factors that influence these changes. While significant data and analytical methods are available to evaluate the travel and emission impacts of potential road pricing strategies, these approaches still fall short of being fully satisfactory.[6] Improved and more detailed

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[6] White Paper No. 3, T*ravel Demand Model Sufficiency*, prepared by Parsons Brinckerhoff Inc. with David Evans Associates and Stantec describes the degree to which existing Oregon metropolitan

(Footnote continued on next page...)

analytical approaches are under development, but are not yet in wide use. New and still emerging comprehensive analytical approaches to quantifying transportation and greenhouse gas impacts, in addition, are both data and resource intensive, thereby limiting their use to larger agencies with more advanced analytical tools. As a result, simplified quantitative methods are often employed. While these are easier and cheaper to use, these methods are inherently less accurate and may miss one or more potentially important effects. Experience has demonstrated a tendency to overestimate benefits when using overly simplistic analytical methods. Key factors are likely to be overlooked.

Travel Responses to Pricing Strategies

Potential travel-related responses to different types of tolling and pricing strategies are summarized in Table 1. This set of responses, to the degree possible, should be quantified when assessing the relative importance of the associated emission reduction impacts.

One observation apparent from Table 1 is the wide range of potential responses. Consequently, a wide range of factors need to be quantified when assessing potential land use, vehicle ownership, travel, and emission changes. The choice of where a person or household lives may be affected by the price of travel. Similarly, businesses may base their location decisions on the transportation costs associated with alternative locations. In response to certain types of road pricing strategies, households may choose to own fewer or more fuel-efficient vehicles. At the other end of the spectrum, certain types of pricing explicitly are designed to improve the traffic flow operating characteristics of a facility or a corridor. Even if no change in VMT occurs, changes in vehicle operating speed and the number of acceleration/deceleration cycles will result in changes in greenhouse gas emissions. For purposes of estimating changes in greenhouse gas emissions, detailed information on vehicle operating data by vehicle type rather than vehicle speed averaged over a relatively long period of time (such as the entire morning or evening commute period) is desired.

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area and statewide travel demand models satisfy the travel-related requirements of a road pricing analysis, and recommends a program of model improvements and data collection that would improve the ability of these existing travel models to evaluate the travel impacts of various candidate road pricing strategies. White Paper No. 3, however, does not address either the estimation of associated changes in greenhouse gas emissions or road pricing strategies that are specifically designed to reduce greenhouse gas emissions as opposed to raising revenue or managing congestion.

Table 1. Potential Transportation Responses to Tolling and Pricing

Strategy	Potential Impact								
	Land Use (Housing, Business)	**Number and Type of Vehicles**	**Number of Trips**	**Destination of Trips**	**Mode of Travel**	**Time-of-Day of Travel**	**Route of Travel**	**Travel Speed**	**Congestion/ Traffic Flow**
Traditional Road and Bridge Tolls	●		●	●	●		●	●	
HOT Lanes						●	●	●	●
Express Toll Lanes	●		●		●	●	●	●	●
TOT Lanes							●	●	●
Cordon or Area	●	●	●	●	●			●	●
Tollways Areawide	●	●	●	●	●		●	●	
Mileage or Carbon Fee	●	●	●	●	●		●	●	●

For a road pricing strategy specifically designed to reduce VMT, it is especially important to consider the full range of behavioral changes, including residential and employment locations, the number and type of vehicles owned, and the number and destination of trips. As these types of changes likely will occur over a number of years, an analysis should consider mid- and long-term effects in addition to an immediate or short-range time horizon.[7]

As described in White Paper No. 3, both the Oregon statewide and the Portland Metro travel demand modeling systems represent the leading edge of the state of the practice. The analysis of road tolling and pricing, though, was not an important objective in the design and development of these modeling systems. As a result, improvements are merited for these models to improve their ability to assess the full range of impacts associated with road tolling and pricing strategies.

[7] The range of potential economic impacts of congestion pricing strategies are discussed in White Paper No. 5, *Assessing the Economic Effects of Congestion Pricing*.

Aggregation Issues

In evaluating the greenhouse gas emission impacts of road tolling and pricing strategies, an important set of "aggregation" issues need to be addressed. For example, a peak-period pricing strategy may be highly effective within its defined time period, but not in terms of total daily emissions. Similarly, a strategy may be effective within a well-defined geographic target area, but have only a limited potential for wider implementation. Thus, the effectiveness on a statewide or urban area basis expressed in terms of a percentage reduction will be proportionally lower than on a project basis.

In making policy decisions on a statewide or urban area basis, it is desirable that effects be evaluated on an equivalent geographic basis. Consequently, the degree to which a particular tolling or pricing strategy can be implemented over the geographic area of interest should be assessed. Questions such as "is the strategy applicable in rural as well as in urban areas" should be considered. For example, a mileage-based fee or a similar change in vehicle fuel pricing most likely would be implemented on a statewide basis and, therefore, would affect all travel. HOT and TOT lanes, in contrast, are most logically implemented along corridors with relatively heavy congestion. These lanes normally are limited to larger urban areas. Thus, a system of HOT lanes could be beneficial within a metropolitan area, but have limited potential in other parts of the state.

A key, therefore, in evaluating the emissions reduction effectiveness of a particular tolling or pricing strategy is determining the geographic and temporal extent of its application. Table 2 shows the likely geographic and temporal characteristics of the pricing measures identified in Table 1.

Table 2. Geographic and Temporal Applicability of Pricing Strategies

	Travel Condition		Application		Time Period		Geography			
Strategy	**Congested**	**All**	**Urban Areas**	**Statewide**	**Peak Conditions**	**All Day**	**Link**	**Corridor**	**Cordon**	**Areawide**
Traditional Road and Bridge Tolls	●	●	●	●		●	●	●		
HOT Lanes	●		●		●		●	●		●
Express Toll Lanes	●		●		●		●	●		●
TOT Lanes	●	●	●			●	●	●		●
Cordon or Area	●	●	●		●	●			●	●
Tollways Areawide		●	●			●				●
Mileage or Carbon Fee		●	●	●		●				●

With the exception of a mileage or fuel fee, each of the listed pricing measures under consideration is likely to be applied only in one or more of Oregon's urbanized areas. Further, they may be applied only during a peak-period under generally congested conditions and only on selected links or individual corridors. Thus, a 10-percent emissions reduction may occur within these geographic areas and within the given time periods where the emission reduction benefits may occur. This could be an important impact. However, if the application only represents 10 percent of total statewide travel, then this savings is equivalent to a 1-percent reduction when expressed on a statewide basis. Generally, pricing strategies implemented on a corridor basis over a network of roadways will result in larger emission reductions than those implemented on a limited number of individual links.

Quantifying Greenhouse Gas Emission Impacts

In addition to accurately estimating changes in travel patterns, travel behavior, and traffic flow operating characteristics, it also is essential to link travel models with emissions data and analytical procedures that are sensitive to the effects of road pricing.

The U.S. EPA's MOBILE6.2 model is, with the exception of the state of California, the approved emissions modeling approach for estimating onroad motor vehicle emission factors. The model is based on driving cycles for different types of roadways, vehicle speed, and vehicle types, and can be adapted to local conditions. The MOBILE model originally was developed to analyze mobile source CO, VOC, and NO_X emissions and subsequently was extended to include CO_2. The major limitation of using MOBILE6.2 to analyze the impacts of road tolling and pricing strategies is that the model does not account for the effects of either vehicle speed or operating conditions on emissions of CO_2. Therefore, it is not adequate for analyzing the greenhouse gas emission impacts associated with road tolling and pricing strategies because it can account only for changes in VMT and not changes in vehicle speed and operating conditions.

The U.S. EPA is developing a new generation motor vehicle model as a replacement for MOBILE6.2. Known as MOVES, for MOtor Vehicle Emission Simulator, the model is based on more disaggregate descriptions of vehicle operating activity than MOBILE6.2. MOVES covers all pollutants, including hydrocarbons, carbon monoxide, oxides of nitrogen, particulate matter, air toxics, and greenhouse gases for both on- and offroad vehicles. MOVES is intended for application at all geographic scales, spanning project-level analyses to the development of national-level emission inventories. The next release of MOVES is scheduled for 2009.

MOVES calculates vehicle-specific power and energy consumption using a physical emissions rate estimator (PERE), which accounts for the effects of vehicle type, vehicle speed, vehicle acceleration, grade, and load.[8] MOVES also combines well-to-pump estimates of greenhouse gas emissions produced for different fuel types using the Argonne National Laboratory's GREET model.[9] The estimates of fuel consumption then are converted into estimates of CO_2 emissions. For purposes of estimating the emission changes associated with road tolling and pricing strategies, MOVES represents an important improvement over the capabilities available within MOBILE6.2. MOVES, however, is data intensive, default data and assumptions are difficult to change, and the level of computing power required to efficiently run MOVES may exceed that available within some transportation agencies.

A Simplified Approach for Quantifying Greenhouse Gas Emission Impacts

Given the greenhouse gas limitations inherent in both the MOBILE6.2 model and the current demonstration version of MOVES, an important challenge involves the approaches that can be immediately applied to estimate project- and regional-level changes in greenhouse gas emissions that may result from road tolling and pricing strategies.

One possible simplified method was utilized by Cambridge Systematics, Inc., and Energy and Environmental Analysis, Inc., in analyzing for the U.S. Department of Energy (DOE) the potential reductions in fuel consumption associated with systems of HOT and/or express toll lanes.[10] In this case, the fuel consumption relationships incorporated in the ITS Deployment Analysis System (IDAS) were utilized (Figure 1). This analytical method plots fuel consumption against average vehicle speed for two roadway types: freeway and arterial. In this relationship, fuel consumption improves up to about 35 mph, levels off, and then starts to increase at speeds above about 55 mph. While these data capture the effect of changes in vehicle speed and, at least to some degree, changes in traffic operating characteristics associated with different roadway types, the fuel relationships incorporated in IDAS do not capture projected changes in fuel economy over time due to technology changes. Changes in fuel consumption can be converted to changes in CO_2 emissions using the DOE calculated conversion factor of 5.5 pounds of carbon per gallon of gasoline.[11]

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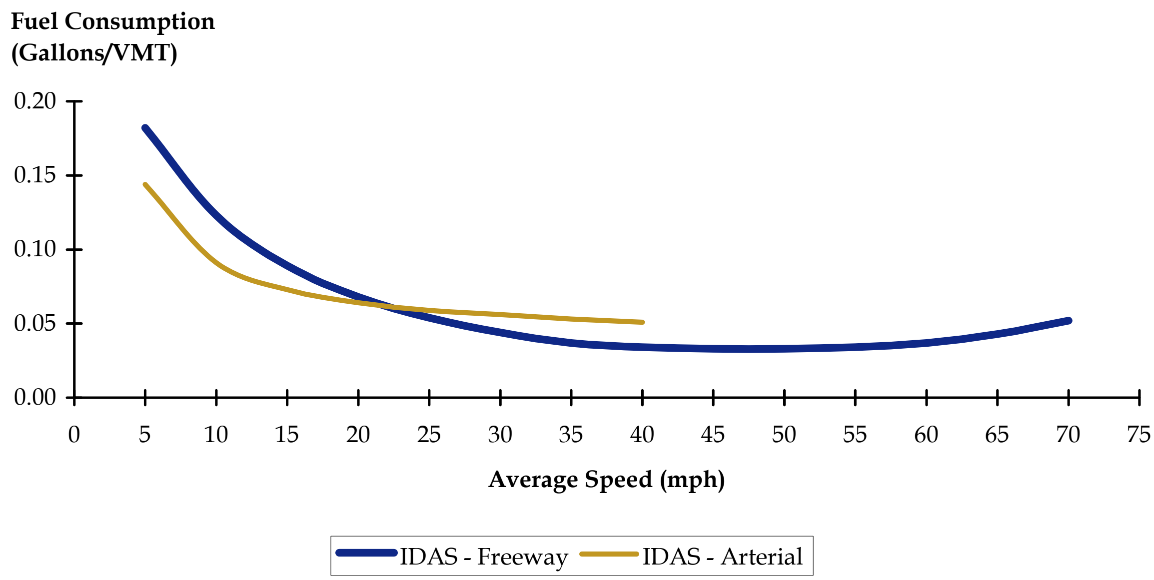
[8] *Assessment of Greenhouse Gas Analysis Techniques for Transportation Projects,* prepared by ICF Consulting for the American Association of State Highway and Transportation Officials Standing Committee on Environment under NCHRP Project 25-25, May 2006.

[9] *User Manual and Technical Issues of GREET for MOVES Integration*, Argonne National Laboratory, March 2005.

[10] *Market-Based Approaches to Fuel Economy: Summary of Policy Options,* prepared by Energy and Environmental Analysis, Inc. and Cambridge Systematics, Inc. for the U.S. Department of Energy, Washington, D.C., July 2008.

[11] U.S. Department of Energy, http://www.fueleconomy.gov/feg/co2.shtml.

Figure 1. IDAS, Gallons per Mile versus Average Speed



ODOT's GreenSTEP Model

ODOT has developed the GreenSTEP model, which estimates the projected changes in greenhouse gas emissions over time that would be associated with the implementation of selected, but not all, types of road pricing strategies. GreenSTEP was developed to analyze the potential of a broad array of transportation and land use strategies for reducing greenhouse gas emissions on a statewide basis. In contrast to the statewide SWIM activity-based integrated land use and transport model, GreenSTEP is considered to be a "sketch planning" model, meaning that simplified modeling approaches are used. An important advantage of this style of modeling is that it is much less data and resource intensive than SWIM, thereby resulting in the ability to easily develop estimates for a range of alternative strategies that are sufficiently accurate to serve as the basis for policy-level decisions.

Road pricing is treated in GreenSTEP as a change in household income. As a result, GreenSTEP is able to analyze mileage- or fuel-based pricing strategies, as well as cordon or large area (e.g., Urban Growth Boundary) pricing schemes. Because GreenSTEP does not include a highway network traffic assignment capability, it currently is not able to analyze pricing strategies based on the use of HOT, TOT, or toll lanes.

GreenSTEP considers changes in demographics, urban form and density, whether development is occurring in urban or rural areas, highway capacity, the availability of public transportation services, demand management programs, congestion effects, vehicle fuel efficiency, electric vehicles, fuel pricing, and the carbon content of fuels.

GreenSTEP simulates the behavior of all Oregon households over a 40-year time horizon. While it is statewide in scope, the model is run on a county basis with the results summed to a statewide total. Submodels include population density, vehicle ownership, vehicle fleet characteristics, highway and transit service levels, household VMT, household travel cost, truck VMT, fuel consumption, electric power consumption, and greenhouse gas emissions. For each of the five fuel groups, VMT is divided by an estimated MPG to determine the number of gasoline energy equivalent gallons of fuel consumed. This is then converted into CO2 equivalent emissions using grams of CO2 equivalents per megajoule based on California Air Resources Board (CARB) estimates by fuel type using the GREET model. The CARB CO2 equivalent estimates for ethanol and electric power generation were modified to reflect the types of ethanol distillers in Oregon and the electric power mix used by Oregonians. The estimates of CO2 equivalent emissions include well to pump emissions in addition to pump to wheel emissions.

The most recent ODOT work included additional calibration and validation of both individual submodels and the overall modeling system. A series of policy application analyses then were performed, including, but not limited to, the cost of travel.[12]

■ 4.0 Considerations of Cost Effectiveness

The combination of travel, fuel consumption, and emission models will result in an estimate of changes in greenhouse gas emissions of a candidate road tolling and pricing strategy. Alternative emission reduction strategies should then be prioritized based on their relative cost effectiveness. In its simplest form, this is the ratio of emissions reduced to the estimated cost of achieving this emissions reduction.

The Air Quality Perspective

The calculation of cost-effectiveness analysis is widely applied within the air quality profession, where cost per ton of emissions reduced is commonly reported.

In response to a congressional requirement, the Transportation Research Board undertook an assessment of the 10-year implementation effectiveness of the Congestion Mitigation and Air Quality (CMAQ) improvement program.[13] The assessment included a calculation of cost-effectiveness values for each of the different categories of CMAQ measures. The

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[12] *Modeling Greenhouse Gas Emissions Starting with Small GreenSTEPs,* Presentation by Brian Gregor of the Oregon Department of Transportation to the 2009 Annual Meeting of the Transportation Research Board, January 11, 2009.

[13] *The Congestion Mitigation and Air Quality Improvement Program: Assessing 10 Years of Experience*, Transportation Research Board, Special Report 264, Washington, D.C., 2002.

cost effectiveness for the six pricing examples ranged from a low of $800 to a high of $49,400 per ton, with a median of $10,300.

In response to Section 1808 of the 2005 Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), the U.S. Federal Highway Administration (FHWA) recently completed an evaluation and assessment of 67 CMAQ projects.[14] While none of the projects involved pricing, high-occupancy vehicle (HOV) lanes were among the least cost-effective of the 16 project types examined in terms of air quality cost effectiveness. The one HOV lane examined cost $18.9 million per ton of VOC reduced, $40.5 million per ton of NO_X reduced, and $1.3 million per ton of CO reduced.

The FHWA analysis also found a wide variation in cost effectiveness, dependent on local context and a variety of project-specific factors.

Alternative Approaches to Cost Effectiveness

While the relative cost effectiveness of alternative approaches to reducing greenhouse gas emissions is an important decision-making criterion, it is only one of a large number of concerns that should be considered by transportation agencies in making capital investment and system operation decisions. Other considerations such as institutional responsibility, public acceptance, technology, legal authority, and economic impacts also need to be weighed when deciding whether to undertake pricing and tolling projects.

Within the transportation profession, no single agreed-upon approach to characterizing the cost effectiveness of transportation air quality actions exists. Cost per ton of emissions reduced is commonly reported within the air quality profession because many, if not most, air quality control strategies do not have other associated benefits. The equivalent measure of cost effectiveness is not widely practiced within the transportation profession, given that a wide range of other benefits and costs typically occur and must be taken into consideration in agency decision making. An examination of the available literature indicated that several general approaches have been undertaken, as summarized below.

Qualitative and Tabular Rankings

NCHRP Project 20-24A, Task 63, being performed for the American Association of State Highway and Transportation Officials (AASHTO), assesses various aspects of congestion management strategies, including the effectiveness of different approaches.[15] Six of the 32 strategies involve some aspect of pricing. Effectiveness is classified on both a local and

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[14] U.S. Federal Highway Administration, *SAFETEA-LU 1808: CMAQ Evaluation and Assessment*, prepared by ICF International, Report FHWA-HEP-08-019, October 2008.

[15] *Effective Strategies for Congestion Management*, NCHRP Project 20-24A, Task 63, draft reporting by Cambridge Systematics, Inc. for the American Association of State Highway and Transportation Officials, Washington, D.C., July 2008.

areawide or network-wide scale as being high, medium, or low. "High" corresponds to an impact on congestion of at least 10 percent; "medium" is an impact between 2 and 10 percent, and "low" is an impact of under 2 percent. Strategies involving new toll roads, managed HOV and HOT lanes, road pricing, TOT lanes, and congestion pricing are classified on both a local and areawide basis as having either a high or a variable impact in terms of the potential to reduce delay, increase vehicle speed, or reduce vehicle miles of travel. Current implementation of the pricing measures is characterized as being only limited. Road pricing, though, is judged to have the potential for having an extensive future implementation potential.

Incorporation of Additional Benefits in a Cost-Effectiveness Analysis

Maryland is one of more than 35 states that either are developing or recently have developed climate change action plans.[16] In calculating the cost effectiveness of alternative approaches to reducing greenhouse gas emissions, Maryland took an approach that is broader than the typical air quality application. Their quantitative analyses included estimates of greenhouse gas reductions in 2012, 2020, and cumulative reductions from 2008 to 2020, present value of benefits and costs from 2008 to 2020, and cost effectiveness expressed as dollars per ton, where the dollars include not just the cost of implementation, but also associated benefits. The greenhouse gas emission reduction benefits for their comprehensive program of pricing measures were larger than for any of the other nine sets of transportation and land-use strategy programs. These include road user fees, time-of-day cordon pricing, incremental fees based on the carbon intensity of fuels, and the pricing of parking without providing specific values of the prices to be charged. The program of pricing measures was estimated to result in benefits that exceeded costs. Overall, 13 of the policy options (both transportation and non-transportation) were estimated to result in savings that exceeded costs, although net savings associated with transportation pricing were lower than for the other 12. These results must be viewed cautiously, as sufficient detail was not provided in the available documentation regarding either operational specifics or analysis methods.

Classification Approaches

Using a combination of quantitative data and judgment, Maryland's Commission on Climate Change used the following four "bins" to classify 42 measures under consideration for their potential to reduce greenhouse gas emissions within the state:

- **Bin 1 –** Higher emission reductions and easier to implement;
- **Bin 2 –** Lower emission reductions and easier to implement;

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[16] *Comprehensive Greenhouse Gas and Carbon Footprint Reduction Strategy,* Report of the Maryland Commission on Climate Change, August 2008.

- **Bin 3 –** Higher emission reductions and harder to implement; and
- **Bin 4 –** Lower emission reductions and harder to implement.

Of the transportation and land-use strategies considered, only transportation technologies were placed in Bin 1 (higher emission reductions and easier to implement). The program of incentives, pricing, and resource measures was placed in Bin 3 (higher emission reductions but harder to implement).

Benefit/Cost Analysis

Benefit/cost analysis (BCA) is a traditional and long-practiced economics approach for assessing the economic value of a project. In this approach, a time stream of potential costs and benefits are estimated and valued, discounting future year values to a current year. A project is favorable if the ratio of benefits to costs exceed one.[17,18] Costs commonly include construction, operating, and maintenance costs. Transportation benefits frequently are expressed in terms of travel-time savings. For air quality strategies, the economic value of public health benefits can be included. An important challenge is the difficulty of placing a monetary value on impacts such as the value of open space and environmental quality.[19]

5.0 Potential Tolling and Pricing Applications

The range of potential tolling and pricing applications being considered nationally is broadening. The ability to collect charges electronically is one reason for this change. Technology greatly expedites payment and facilitates time-of-day-based pricing. The broadening of tolling and pricing applications, however, also is influenced by an evolving set of objectives. Where early toll operations were a funding mechanism to cover the cost of construction and maintenance, today's pricing applications are motivated by the desire to improve the roadway operating efficiency; expedite the movement of freight and thereby promote economic viability and growth; engage private investment in

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[17] Benefits and costs of different alternatives are compared to both a reference or base case, and incrementally to each other.

[18] The use of least-cost planning methods has been proposed for use in Oregon transportation planning and decision-making. least cost planning is a variation of Benefit Cost Analysis that considers transportation demand management solutions equally with strategies to increase capacity. The total costs and benefits for all alternatives or combinations thereof are examined with emphasis given to treating them on an "equal footing." Least-cost planning originally was applied within the electric power industry, but is now being proposed for use in other sectors.

[19] The use of Benefit Cost Analysis for comparing tolled and non-tolled alternatives is discussed in White Paper No. 6, *Economic Comparison of Alternatives for Tolling Projects*.

transportation infrastructure and operations; reduce fuel utilization and the consumption of energy resources; and improve environmental conditions.

The 2006 Oregon Transportation Plan (OTP) identifies a number of pricing strategies, including peak-period pricing, tolled express lanes, and HOT lanes. A basic typology of tolling and pricing applications, based on these OTP strategies, is listed in Table 3. There are, in addition, variations in which many of the options listed in Table 3 could be implemented, with these variations having the potential to influence the nature and magnitude of the potential resulting impact on greenhouse gas emissions. For example, TOT lanes could be implemented on either an optional or a mandatory basis. Under a voluntary scenario, drivers of heavy- and medium-duty trucks could choose to use the TOT lane based on their willingness to pay. Or, all drivers of heavy-duty trucks traveling through an urban area or corridor containing TOT lanes could be required to use the toll lane, but drivers of medium-duty trucks could opt out of toll lanes because the majority of these trips presumably would be local rather than through trips. In addition, TOT lanes also could be either open or restricted for use by public transportation buses.[20]

With cordon or area pricing, drivers in a defined region pay a toll. This concept can be implemented in two ways: one in which drivers pay each time they cross the cordon, and another where they pay for the privilege of driving within the cordon (more properly termed "area pricing"). The policy intents are similar and both are referred to as "cordon area pricing" in this paper. An extension of cordon area pricing in Oregon may be to go beyond dense urban centers to cover a much larger metropolitan area, such as the area defined by the state's urban growth boundary.[21]

Mileage-based pricing, similar to the approaches pilot-tested in Oregon and Washington state and now being proposed in Oregon as a replacement for the state's fuel tax, would involve pricing all travel in the state (or alternatively within a given area on a subset of roads). The fee could be as simple as a fixed price per mile regardless of when or where traveled, or the fee could vary either by time of day or historical level of congestion. Other possibilities include a fee based on the carbon content of the vehicle's fuel, the type of fuel or power utilized, and fuel efficiency of the vehicle.

Combinations of different pricing strategies also have been proposed. For example, an emission-based road user fee could be implemented in combination with time-of-day cordon pricing, parking pricing, the introduction of pay-as-you-drive insurance, and vehicle purchase price incentives.

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[20] A more detailed discussion of TOT lanes is contained in White Paper No. 7, *Truck-Only Toll (TOT) Lanes*.

[21] Issues associated with the geographic coverage of tolling and pricing strategies are discussed in White Paper No. 2, *Geographic and Situational Limits*.

Table 3. Typology of Potential Tolling and Pricing Applications

1. **"Traditional" projects:**
   a. New terrain toll road; and
   b. New toll bridge or tunnel.
2. **Tolled managed lanes:**
   a. High-occupancy toll (HOT) lane:
      i. Convert existing HOV to HOT;
      ii. Build new lanes and make HOT; and
      iii. Convert existing general purpose lane to HOT.
   b. Express toll lane (like HOT, but without HOV priority):
      i. Build new lanes as express toll lanes; and
      ii. Convert existing general purpose lane to express toll.
   c. Truck-only toll (TOT) lane:
      i. Convert Existing HOV lane;
      ii. Build new lane(s); and
      iii. Convert existing GP lane.
3. **Toll existing corridors or systems:**
   a. Replacement bridge as toll bridge (potentially with expansion);
   b. Convert existing freeway to tollway;
   c. Cordon or area pricing around or within a defined area (e.g., a CBD); and
   d. Convert system of freeways to tollways within a defined area.
4. **Mileage or fuel/carbon fees**

6.0 Guidelines for Greenhouse Gas Pricing Analyses

In deciding whether to implement a road tolling and pricing strategy, the candidate approach should be systematically evaluated using state-of-the-art quantitative methodologies. The introduction of greenhouse gas considerations into an analysis of road tolling and pricing strategies triggers important additional requirements beyond those covered in Working Paper No. 3, *Travel Demand Model Sufficiency*. As discussed in Section 3.0, Quantification Issues, of this white paper, it is essential that the methodologies used result in accurate estimates of changes in vehicle operating conditions, fuel consumption, and greenhouse gas emissions. A set of broader analysis guidelines, however, should be reflected in the assessment process. To achieve the objectives of a greenhouse gas analysis, the following suggestions are applicable for the entire range of road tolling and pricing strategies under consideration.

1. Use a time horizon that extends at least 40 years into the future, and preferably longer. This corresponds to the minimum period to be used to examine the impacts associated with climate change.

2. Account for improvements in vehicle fuel efficiency over time and changes in vehicle fleet characteristics.

3. Account for changes over time in fuel type and fuel composition. The vehicle fleet should be characterized by type of fuel used as well as by vehicle technology and vehicle size.

4. For each particular pricing application to be evaluated, identify the range of both first and second order impacts that potentially could result over time from implementation of this measure. Make sure the geographic area considered is large enough to capture changes that may extend beyond an immediate facility, corridor, or subarea. Ensure that travel demand, traffic, and emission analysis methods used incorporate the ability to estimate these changes. For road pricing, changes in the location of population and businesses, vehicle ownership, travel patterns (e.g., time of day, destination, mode), and vehicle operating speed are especially important. If changes in the time of travel are anticipated, as one example, then changes in traffic flows on the roadway network need to be estimated with a corresponding differentiation of time.

5. Estimate how a pricing strategy will affect the number and type of vehicles owned by a household.

6. In conducting analyses for future years, express the value of the pricing measure in a constant-year figure.

7. Use a common base case for all analyses. In their *Economic Analysis Primer, the U.S. Federal Highway Administration* defines this as a "do minimal" option. The base case represents the continued operation of the current facility under good management practices but without major investments.

8. Specify a range of implementation possibilities for each basic type of pricing measure of interest. For example, a travel fee could be implemented as a VMT fee, a fuel tax, a carbon tax, an emissions fee, or vary by vehicle fuel efficiency. To evaluate a system of HOT lanes for the Seattle urban area, two separate implementation scenarios were evaluated: 1) conversion of all existing and planned HOV lanes to HOT lanes; and 2) adding one new lane along existing and planned HOV corridors to form two HOT lanes in these corridors.[22]

9. Where important areas of uncertainty exist, conduct a series of sensitivity analyses to determine the possible effects of these uncertainties.

10. Compare alternatives on an equivalent geographic scale, generally either an entire urban area or the state as a whole. Because climate change strategies normally are

[22] *Market-Based Approaches to Fuel Economy: Summary of Policy Options Final Report*, prepared by Energy and Environmental Analysis, Inc. and Cambridge Systematics, Inc. for the U.S. Department of Energy, Washington, D.C., July 2008.

being developed at a state level, calculating statewide totals and changes typically is the norm. To aggregate the results of a single corridor, subarea, or urban area to a corresponding state-level impact, systematically assess the potential for equivalent implementation over a larger geographic area. For example, the aggregation of congestion pricing results can be based on an analysis of congestion levels.

11. Express annual changes in greenhouse gas emissions on a percentage basis as well as in millions of metric tons.

12. To compare a road tolling and pricing application to other potential means of reducing greenhouse gas emissions, calculate a cost-effectiveness ratio based solely on the annualized estimated total cost divided by the change in annual greenhouse gas emissions.

13. Estimate the full range of potential environmental, social, and economic impacts beyond greenhouse gas emissions that would be associated with the candidate pricing approach--including the manner in which these impacts would be distributed, both geographically and by household income. Calculate a benefit/cost ratio (or equivalent economic measure) and examine changes in the incidence of benefits and adverse impacts, as well as overall totals.

14. Examine potential changes in the spatial "attractiveness" or competitiveness as a place to live and work either between Oregon and other states or among different areas within Oregon.

15. Public outreach has proven to be essential to the acceptance and implementation of new forms of road tolling and pricing. This becomes even more important if a primary objective of a road pricing proposal is the reduction of greenhouse gas emissions. Throughout the analysis process, engage the full range of potentially relevant stakeholders and interest groups so that they can contribute to and guide the analysis, and develop an understanding of the particular applications under consideration, their potential contribution to reducing greenhouse gas emissions and the effects of climate change, and possible associated environmental, economic, and quality of life impacts.

■ 7.0 Results of Previous Effectiveness Analyses

In addition to conducting a rigorous quantitative analysis of the benefits and costs of one or more candidate approaches to road tolling and pricing, it also is useful to examine the results of similar analyses and evaluations that are available from other urban areas. While important issues of transferability need to be recognized, these results serve as one means of validating the methodological approaches and assumptions used in the conduct of Oregon-specific analyses. The following subsections present the results of estimated *effectiveness* for the primary strategies identified in Table 3 based on previously conducted analyses that conform in large part to the methodological guidelines recommended in Sections 3.0 and 6.0.

While experience shows effectiveness results encompass different areas, and dramatic differences in magnitude are far less common. The following results, therefore, serve as one guide for assessing the likely effectiveness of similar policies implemented in Oregon.

Mileage or Fuel/Carbon Fees

Mileage or fuel/carbon fees have been proposed as an alternative to the current fuel tax. While one approach is to use a simple VMT fee similar to that demonstrated in Oregon's pilot program, other options include an emissions fee, a carbon tax, and an increase in the current fuel tax. As an alternative to statewide implementation, the fee also could be implemented within a specific urban area or region as a form of congestion pricing.

The results of a recently completed analysis conducted by the Congressional Budget Office (CBO) illustrate the likely effects of such a fee.[23] The CBO examined the changes in VMT that resulted from the recent increases in the price of gasoline in terms of an implied price elasticity. They then compared the resulting changes in greenhouse gas emissions to those projected to occur under the recently revised CAFE fuel economy standards. Finally, they converted currently suggested levels of a carbon tax into a corresponding fuel tax and associated increase in the price of gasoline. They found that the effect of the CAFE fuel economy standards dominates the effect of an increase in gasoline price. Further, "a CO_2 price high enough to induce sizable reductions from other sources of emissions would have only a small effect on vehicle emissions of CO_2."

The CBO found that the rise in gasoline prices between 2003 and 2007, from $1.50 to more than $3.00 per gallon, resulted in only a small decline in the amount of driving. In analysis through April 2008, they found that motorists drove 2.8 percent less in the first 6 months of 2008 than during the corresponding period of 2007. This translates to a price elasticity of -0.6, meaning that VMT and associated fuel consumption declines by 0.6 percent for every 10 percent increase in the price of gasoline. The long-run response is estimated to be about seven times greater because of likely changes in residential, employment, and other travel patterns as well as changes in the number and types of vehicles owned. The CBO estimated long-run gasoline price elasticity to be -4 percent, meaning that fuel consumption would reduce by about 4 percent for every 10 percent increase in the price of gasoline.

To compare the recent increases in gasoline prices to those that would occur with a carbon tax, the CBO translated currently suggested levels of a carbon tax into an equivalent increase in the price of gasoline. A carbon tax of $23 per metric ton in 2009 corresponds to about $0.20 per gallon, with a 2018 carbon tax of $44 per metric ton resulting in a gasoline

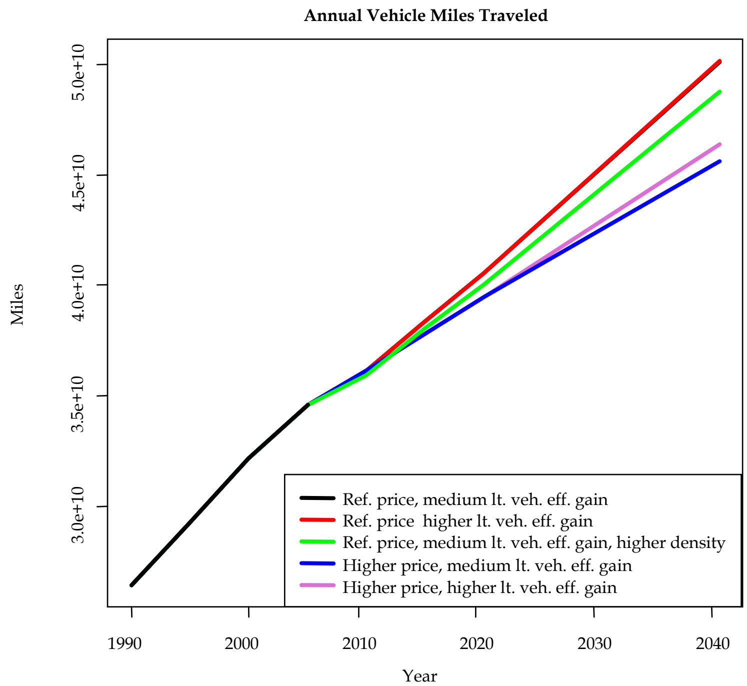
[23] *Climate Change Policy and CO_2 Emissions from Passenger Vehicles*, U.S. Congressional Budget Office, Economic and Budget Issue Brief, October 2008, Washington, D.C.

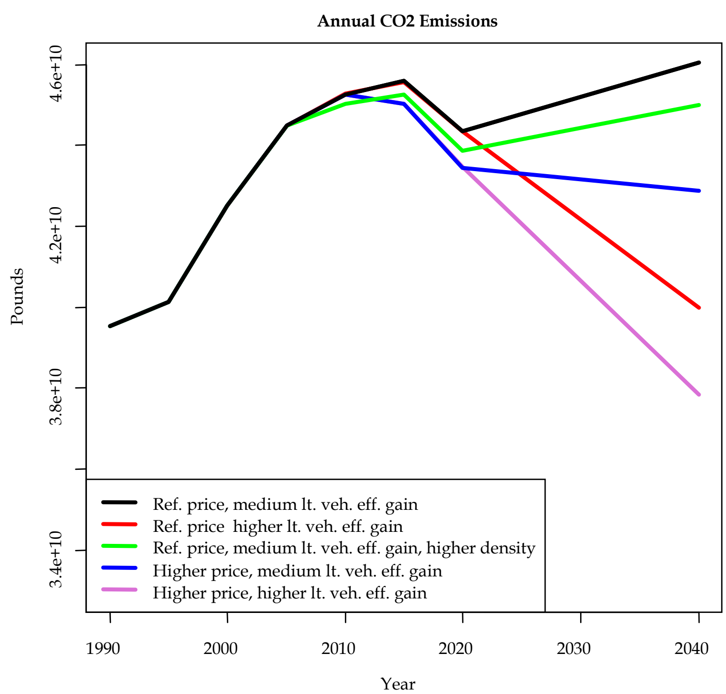
price increase of $0.40 per gallon. The recent Intergovernmental Panel on Climate Change (IPCC) suggestion of a 2030 carbon tax of $80 per metric ton would increase the price of gasoline by about $0.70 per gallon. These are all smaller price changes than have occurred as result of recent market forces. Based on observed price elasticities, the price of gasoline would have to rise to above $6.50 per gallon to approach the effectiveness of the recently revised CAFE fuel economy standards. This corresponds to a carbon tax that adds $2.00 to $2.50 per gallon to the price of gas, far higher than current proposals. Current CAFE standards, thus, already require greater improvements in fuel economy than a CO_2 price would achieve at the levels being proposed. Oregon certainly could increase the cost of driving by more than the currently suggested carbon tax levels, but this increase may have to be based on an objective other than climate change.

The CBO's estimate of the relative effectiveness of price and vehicle fuel efficiency is confirmed by sensitivity analysis testing conducted by ODOT using the GreenSTEP model.[24] Figure 2 compares four scenarios with a projected reference or base line case from the years 2000 to 2040. In the higher "cost" scenarios, fuel costs are increased over time to a maximum of $13 per gallon (in today's dollars) in 2040. For the higher "efficiency" scenarios, automobile fuel economy is assumed to improve to 60 mpg in 2040 and light truck fuel economy is assumed to increase to 45 mpg over this same period. While these may be optimistic assumptions, the important take-away is the comparison among the results. The increase in the cost of driving results in the largest decrease in the rate of VMT growth as one would expect, although VMT still is expected to grow over the modeled 40-year time horizon because of assumed population growth. Vehicle fuel efficiency, though, contributes to the largest decrease in annual CO_2 emissions. A combined cost-plus-efficiency option is expected to result in roughly a 5 percent larger decrease.

[24] The results illustrated in Figure 2 represent sensitivity testing of several hypothetical policies, conducted before the final recalibration of the household and travel models. They are included to illustrate both currently available Oregon DOT greenhouse gas modeling capabilities and the interactions between different pricing and vehicle efficiency factors.

Figure 2. Preliminary Results of Oregon GreenSTEP Cost and Efficiency Tests





Source: *Modeling Greenhouse Gas Emissions Starting with Small GreenSTEPs,* Presentation by Brian Gregor of the Oregon Department of Transportation to the 2009 Annual Meeting of the Transportation Research Board, January 11, 2009.

Regional Systems of HOT Lanes

In a study for the U.S. DOE, Cambridge Systematics examined the potential effects of regionally implemented tolling and pricing strategies in Minneapolis, Minnesota, and Seattle, Washington, and then aggregated these results to produce a national-level estimate of the potential reductions in fuel consumption that would result from a broader national implementation of similar strategies.[25]

The Minnesota study evaluated a system of express toll lanes (new capacity) and HOT toll lanes (conversion of existing HOV facilities) on existing freeways in the Minneapolis-St. Paul region. The study found that when compared to the no-build case, the system of new toll express lanes would result in overall VMT reductions of 0.1 percent in 2010 and 0.4 percent in 2030, and increases in average speed ranging from 2.6 percent in 2010 to 4.9 percent in 2030. Link-level traffic volumes and speeds led to reductions in energy use of 41,000 gallons per day (0.9 percent) in 2010 to 147,000 gallons per day (2.5 percent) in 2030.

In Washington state, a system of HOT lanes in and around Seattle was analyzed under two scenarios: 1) conversion of all existing and planned HOV lanes to HOT lanes; and 2) adding one lane along existing and planned HOV corridors to form two HOT lanes in these corridors. Four time periods were modeled representing an average weekday. In 2030 under Scenario 1, VMT was expected to increase by 1.4 percent relative to the no-build case, average speed to increase by 2.0 percent, and fuel use to decrease by 7,000 gallons per day (0.1 percent) compared to the base case. Under Scenario 2, VMT was expected to decrease by 0.2 percent, average speed to increase by 1.3 percent, and fuel use to decrease by 66,000 gallons per day (1.4 percent) compared to the base case.

To extrapolate the results of these two urban areas to the nationwide estimate desired by the U.S. DOE, the most congested urban areas in the country were identified by analyzing the travel-time index developed by the Texas Transportation Institute. The travel-time index measures the ratio of peak-period travel time to offpeak travel time. Two different thresholds were examined. With a threshold value of 1.2, 40 urban areas were judged to have a significant implementation potential. These 40 urban areas represent 95 percent of current HOV-lane miles and 36 percent of total U.S. vehicle miles of travel. Lowering the travel-time index threshold to 1.1 increases the number of potential urban areas for HOT-lane systems from 40 to 69. These 69 areas have all of the present HOV-lane miles and represent 43 percent of total U.S. vehicle miles of travel. Using the estimated 2030 Minneapolis and Seattle results as a measure of the range of likely fuel reduction within any one urban area yields an overall estimated reduction on national fuel consumption due to systems of HOT lanes of 0.5 to 1.1 percent.

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[25] *Market-Based Approaches to Fuel Economy: Summary of Policy Options Final Report*, prepared by Energy and Environmental Analysis, Inc. and Cambridge Systematics, Inc. for the U.S. Department of Energy, Washington, D.C., July 2008.

Examining Oregon data, the Portland metropolitan area falls within the 40 urban area threshold and has a travel-time index similar to Seattle and Minneapolis. Salem is on the limit of the lower 69 urban area threshold. Thus, these are the two urban areas within the state where regional HOT pricing of some sort are most likely to provide both congestion relief and greenhouse gas reduction benefits. If similar projects were tried in Portland, their effectiveness most likely would be in the same general range as obtained in the Minneapolis and Seattle analyses. Extrapolation to a statewide basis likely would show a dilution effect similar to the national U.S. DOE findings.

The cost of a HOT lane will depend on whether it is a conversion of an existing lane or the construction of a new lane. The HOT-lane conversion for the 11-mile I-394 facility in Minneapolis cost $12,982,000, or $1.2 million per mile. In contrast, construction of the new 4-lane, 10-mile SR 91 HOT facility in San Diego cost $134,000,000, or $13.4 million per mile. Experience with HOT lanes suggests that revenues generally can cover operating costs as well as contribute to some, but not all, of the cost of construction of corridor improvements. In some cases, a portion of revenues also have been used to support transit and rideshare services.[26]

Regional Systems of TOT Lanes

Georgia Tech examined the potential impacts associated with implementation of a system of TOT lanes on Interstate highways located within the Atlanta, Georgia, region. Two scenarios were analyzed. In the first, usage of the TOT lanes was voluntary. In the second, all heavy-duty trucks traveling through the region were required to use the TOT lanes. Changes in VMT by vehicle type and operating speed were examined separately for the general purpose freeway lanes, the HOV lanes, and the TOT lanes.

In the voluntary usage case, total VMT on the affected roadways was forecast to decrease by 2.7 percent. Under the mandatory scenario, VMT would be expected to increase by 1.3 percent because of the longer distance truck routing required. CO_2 emissions, however, still were estimated to decrease because of changes in vehicle operating speeds on the different types of lanes.[27] Comparing the two scenarios from an emissions perspective, voluntary rather than mandatory usage results in a slightly higher decrease in greenhouse gas emissions.

As discussed in White Paper No. 7, *Truck-Only Toll (TOT) Lanes,* the cost of new lanes that cater to trucks can be even higher than the cost of constructing general-purpose lanes because of the need to account for special design standards. In Atlanta, the cost per lane

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[26] *Value Pricing Pilot Program: Lessons Learned*, Final Report prepared by K.T. Analytics, Inc. and Cambridge Systematics, Inc. for the U.S. Department of Transportation and Federal Highway Administration, Washington, D.C., August 2008.

[27] Changes in CO_2 emissions were calculated using a simplified methodology based on the differences of the cubes of vehicle operating speeds.

mile of implementing new truck-only lanes was estimated at approximately $21 million. Other TOT studies show lane-mile costs in urban areas ranging between $10 million and $30 million, which assume mixed at-grade and elevated structures, right-of-way costs, and other construction elements (e.g., interchanges, mobilization).

Cordon and Area Pricing

Cordon pricing systems in London and Trondheim, Norway, have reduced traffic in both peak and off-peak periods, as well as corresponding greenhouse gas emissions levels. In London, cordon pricing has reduced traffic congestion by 30 percent within the cordon area, while the volume of traffic entering the priced zone has decreased by 18 percent and congestion outside of the priced zone has not increased.[28] The improvements in travel times, increased transit use, and reduced congestion are estimated to have reduced CO_2 emissions from road traffic in London's priced zone by 20 percent.[29] In Trondheim, cordon pricing around the central business district has reduced peak-period traffic by 10 percent and offpeak traffic by 8 percent.[30]

A congestion pricing demonstration in the inner city of Stockholm, Sweden, in 2006 reduced traffic volumes within the cordon area by 22 percent. This reduction led to CO_2 emission reductions of 14 percent in the inner city, and 2 to 3 percent overall in Stockholm County.[31]

For London's cordon pricing, the initial costs of setting up the scheme were £161.7 million. Revenues from the congestion charge were £250 million over the financial year, of which half was spent to cover the £130 million cost of running the program. Once other charges were deducted, the congestion charge resulted in an annual operating net income of £89 million, which, by law was allocated for other transportation uses in London.[32]

The U.S. Federal Highway Administration's *Lessons Learned* assessment also reports that initial capital costs for Stockholm's congestion pricing demonstration were 3.0 billion SEK ($410 million), with operating costs incurred at the annual rate of 220 SEK ($30 million). Annual revenues of $760 million SEK ($100 million) imply an annual operating profit rate of $540 million SEK ($70 million) and suggest a "payback" period of about 4 years.

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[28] *Congestion Charging: Third Annual Monitoring Report,* Transport London, 2005.

[29] *Impacts Monitoring Second Annual Report,* Transport London, 2004.

[30] Replogle, Michael, *Using Road Tolls to Cut Congestion, Protect the Environment, and Boost Access For All: Lessons for Minnesota*, Environmental Defense, 2006.

[31] *The Stockholm Trial: Impacts on Air Quality and Health*, City of Stockholm, 2006.

[32] *Lessons Learned from International Experience in Congestion Pricing*, Final Report prepared by K.T. Analytics, Inc. for the U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., August 2008.

Traditional New Terrain Toll Road and Bridge Projects

It is difficult to generalize about the effects of a new terrain toll project on greenhouse gas emissions. Such projects can either increase or decrease VMT, and also can change vehicle speed operating conditions--either within or outside the most energy-efficient range. For example, a new toll road into an undeveloped area could increase VMT as it allows for new development in that region. Alternatively, a new toll road that provides congestion relief within an existing corridor could change the speed profile in the region from one that is fuel inefficient to one that is more efficient, thereby decreasing GHG emissions. In general, it is assumed that traditional toll projects are more likely to either increase greenhouse gas emissions by a small amount or leave current levels relatively unchanged since such facilities tend to increase vehicle operating speeds to values that exceed efficient fuel consumption levels.

Proposed Comprehensive Climate Change Pricing Programs

Comprehensive pricing programs are being included as part of state climate change action plans. Maryland is one example.[33] Maryland's plan, like those of other states, places a heavy reliance on a combination of "incentives, pricing, and resource measures" for accomplishing the desired greenhouse gas emission reduction goals. These pricing strategies include road user fees, time-of-day cordon pricing, incremental fees based on the carbon intensity of fuels, and the pricing of parking. To achieve the desired level of effectiveness, the Maryland Commission on Climate Change recommends that these pricing policies be implemented as a program along with other strategies such as transit and bicycling improvements.

Maryland estimates that the package of incentives, pricing, and resource measures will reduce 2020 CO_2 emissions due to transportation by 3.7 $MMtCO_2e$ out of 40.93 $MMtCO_2e$, or 9.0 percent.[34] Expressed in terms of the state's total greenhouse gas inventory, this represents approximately a 3.3 percent reduction. Compared to other proposed transportation strategies, the pricing program is comparable in effectiveness to the 3.6 $MMtCO_2e$ reduction estimated for integrated planning for land use and growth management. It should be noted that these are larger reductions than reported for

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[33] *Comprehensive Greenhouse Gas and Carbon Footprint Reduction Strategy,* Chapter 4 of the Report of the Maryland Commission on Climate Change, August 2008.

[34] The Maryland work also did not break out the specific impacts of the pricing concepts alone.

analyses of only road pricing measures since they represent a far more ambitious and comprehensive set of strategies.[35]

Summary of Effectiveness

Looking at these quantitative estimates of emission reduction effectiveness in combination, the following conclusions emerge:

- Major decreases in motor vehicle greenhouse gas emissions are more likely to result from improvements in fuel economy standards and motor vehicle emission controls than they are from changing the manner in which road usage is priced.

- The increase in fuel tax or magnitude of VMT fee necessary to achieve large reductions in travel and associated greenhouse gas emissions is significantly higher than the amount implied by currently proposed carbon taxes. Pricing implementation at these levels, therefore, should be based on objectives more comprehensive than just the reduction of greenhouse gas emissions.

- On a facility or project basis, road pricing designed to result in more efficient operation of a roadway system also will lower greenhouse gas emissions. In other words, road pricing can be designed so that the greenhouse gas reduction impacts are heading in the right direction.

- The Minneapolis, Seattle, and U.S. Department of Energy findings represent a reasonable baseline estimate of potential areawide benefits of regional HOT or express toll-lane systems. Fuel savings in the range of 1.4 to 2.5 percent are likely attainable within those urban areas where regional systems of HOT and TOT lanes are feasible. If rolled out in national metropolitan areas that experience moderate to heavy congestion, these savings in fuel consumption are likely to range from 0.5 to 1.1 percent.[36]

- Achieving larger emission reductions from pricing strategies, such as those projected in many state-level climate change action plans, will require an aggressive and comprehensive program of pricing strategies far broader in scope than typically associated with tolling and congestion-based road pricing. Road tolling and pricing, by itself, is not sufficient to achieve the desired reduction in transportation sector greenhouse gas emissions often targeted in a state climate change action plan. · Broad

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[35] The report available for preparation of this White Paper does not provide details on the operational specifics or analysis methods used.

[36] The cost effectiveness of HOT and TOT systems as an emissions reduction strategy was not addressed as a part of this White Paper. Construction of new urban freeway lanes is expensive, and the construction costs for new TOT and HOT lanes may exceed that of general-purpose lanes.

application of congestion pricing may result in a broad array of economic, land use, and other impacts that should be considered.[37]

8.0 Conclusions

This paper addresses the relationship between applications of road tolling and pricing and the emissions of greenhouse gases. The methods that should be used to evaluate the magnitude of these impacts and the results of existing analyses were examined. This provided an initial assessment of the possible importance of greenhouse gas emission reductions in determining whether to proceed with one or more approaches to road pricing.

Findings

1. Greenhouse gas emissions from transportation in Oregon represent 34 percent of the state's total greenhouse gas emissions, slightly higher than the 32 percent share for electricity.

2. Greenhouse gas emissions from motor vehicles are directly related to fuel consumption. Important factors influencing these emissions are the type and amount of fuel used. The amount of fuel used, in turn, is influenced by the type of vehicle, the applicable fuel economy standards, and the amount of travel. In assessing changes in greenhouse gas emissions resulting from road pricing, it is important to consider changes over time in the number and type of vehicles owned by a household, the turnover of the vehicle fleet, vehicle operating speeds and conditions, and changes in spatial and temporal travel patterns. A 40-year time horizon is reasonable to be able to capture these effects.

3. The statewide and urban area travel models currently used in Oregon should be improved to assess changes in greenhouse gas emissions that likely would result from road tolling and pricing. ODOT's GreenSTEP model represents an important new analytical capability to analyze some, but not all, types of road pricing applications.

4. A primary impact of congestion pricing strategies is on vehicle speed and roadway operating conditions rather than on VMT. Thus, it is important that fuel consumption and greenhouse gas emission models be sensitive to vehicle operating speed and power utilization.

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[37] Potential economic effects are discussed as a part of White Paper No. 5, *Economic Effects of Congestion Pricing*.

5. The importance of a pricing measure as a greenhouse gas emissions reduction strategy is dependent on the extent of its geographic and temporal application. A pricing measure implemented on a statewide or even an urban area basis in a way that affects all travel is likely to result in a larger reduction in emissions than a pricing measure in effect only during the peak-period on a given roadway. The latter may be highly effective within its targeted geographic and temporal scope, but this may represent only a very small portion of total emissions.

6. Air quality control measures commonly are evaluated and prioritized based on their relative cost effectiveness where annualized implementation costs are divided by the annual reduction in emissions. When expressed in these limited terms, transportation measures tend to have a high cost per ton cost-effectiveness ratio when compared to alternative strategies.

7. Transportation measures, however, typically provide benefits other than just the reduction in greenhouse gas emissions. As a result, the evaluation of potential road tolling and pricing strategies considers the full range of benefits and costs, rather than only their air quality benefits and costs.

8. Major decreases in motor vehicle greenhouse gas emissions are more likely to result from improvements in fuel economy standards and motor vehicle emission controls than from changing the manner in which road usage is priced, at least within the ranges of prices currently being discussed.

9. The increase in fuel tax or magnitude of VMT fee necessary to achieve large reductions in travel and associated greenhouse gas emissions is significantly higher than the amount implied by currently proposed carbon taxes. Prices at these levels, therefore, should be based on a set of objectives broader than just the reduction of greenhouse gas emissions.

10. The magnitude of road user charges and the manner in which vehicle operating speeds and conditions are affected are critical in establishing whether roadway pricing will be effective in reducing greenhouse gas emissions in a meaningful way. The price needs to be sufficiently large to result in changes in travel behavior and traffic operating conditions, and vehicle operating speeds and conditions need to become more efficient from a fuel consumption perspective. HOT lanes, by definition, must operate with speeds that are between 40 and 55 mph, the most efficient portion of the fuel consumption curve.

11. Systems of HOT lanes, express toll lanes, and TOT lanes adopted on a regional basis are likely to have a potential for contributing to measurable but not large reductions in greenhouse gas emissions. Traditional tolled roadways are unlikely to yield important reductions in emissions, but the specific circumstances can result in either positive or negative outcomes. Areawide or cordon-based pricing also has the potential to result in emissions reductions that are important on a regional basis.

12. Achieving the higher levels of greenhouse gas emissions reduction typically desired in state climate change action plans requires programs of pricing strategies more

comprehensive and more aggressive than HOT and TOT lanes or a VMT fee that corresponds in magnitude to today's gasoline taxes. In addition to altering the manner in which parking and insurance are priced, these broader pricing programs often assume the implementation of expanded transit, bikeway, and commuter choice incentives.

Recommendations

While the reduction of greenhouse gases traditionally has not been an objective of road tolling and pricing application, this is changing. There is a desire to know whether road tolling and pricing applications will result in increases or decreases in greenhouse gas emissions, and if so, by how much. There also is interest in determining whether road tolling and pricing approaches will result in a sufficiently large reduction in greenhouse gas emissions to justify their implementation based primarily, if not exclusively, on this objective.

Implementation of the following recommendations will enable ODOT to evaluate changes in greenhouse gas emissions associated with a possible road tolling and pricing application:

1. Implement improved analytical capabilities to estimate project, regional, and state-level changes in greenhouse gas emissions that could result from the implementation of transportation policies and strategies that include road pricing as one element. A two-pronged approach should be followed. The GreenSTEP model effort should be used to conduct initial "sketch planning" analyses.[38] In parallel, existing state and urban area modeling systems should be improved so that they are able to provide more detailed network-level analyses of potential changes in greenhouse gas emissions that could result from road tolling and pricing strategies.

2. Incorporate improvements into both GreenSTEP and existing travel and traffic models. For GreenSTEP, this includes the ability to examine effects of congestion and systems of HOT and TOT lanes. For the statewide and urban area modeling systems, attention should be given to accurately estimating impacts on vehicle speed and operating conditions by time of day and, including the analytical capabilities required to estimate effects of a pricing policy on the number and type of vehicles owned and vehicle fleet turnover.[39] The quantitative capability to estimate changes in fuel consumption and greenhouse gas emissions should build on the analysis capabilities incorporated in EPA's MOVES mobile source emissions model.

3. In evaluating a proposed road tolling and pricing application, quantitatively analyze the impacts on urban area and state-level greenhouse gas emissions using the analysis

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[38] *GreenSTEP Model Documentation*, Draft, Oregon DOT, Transportation Planning Analysis Unit, August 2008.

[39] The described analytical recommendations are in addition to those described in White Paper No. 3, *Travel Demand Model Sufficiency*.

guidelines contained in Section 6.0 of this white paper and state-of-the-art analytical capabilities that incorporate the described modeling recommendations.

4. Compare the magnitude and cost effectiveness of estimated changes in greenhouse gas emissions to those for other greenhouse gas reduction strategies that are either under consideration or already adopted. In undertaking this comparison, fully take into consideration the timeline of projected improvements in vehicle fleet fuel economy and vehicle fleet turnover.

Appendix A

Glossary of Terms

Glossary of Terms

Amortization – A financial term referring to terms of a loan where the provision is made in advance for the gradual reduction of an amount owed over time.

Area pricing – A tolling approach where vehicles are charged a fee to travel within a high activity center, such as a downtown or business district. Prices may vary by time of day to encourage motorists to enter the zone during less busy times or to use transit. An example is Fareless Square in Portland, where transit is available for free to discourage short-term and short-distance auto travel within the business district.

Bus rapid transit (BRT) – High-frequency bus service on dedicated lanes that are separate from general travel. BRT combines the advantages of rail transit – exclusive right-of-way to improve punctuality and frequency – with the advantages of a bus system – low implementation costs and flexibility to serve lower density areas.

Congestion pricing –an overarching term used to describe measures that reduce congestion by charging drivers tolls that vary by time of day or traffic volumes.

Consumer surplus – In economics, the difference between the price a consumer pays for an item and the price she would be willing to pay rather than do without it.

Cordon pricing – A pricing scheme where vehicles entering a high activity area are charged a fee when they cross the boundary line into the activity center. Motorists are charged each time they cross the cordon line. Prices could vary by time of day, to encourage motorists to enter the cordon zone during non-peak periods or to make peak trips using transit. This is similar to area pricing, distinguished by the toll being charged for crossing the cordon rather than for driving within the cordon zone.

Cost-benefit analysis (CBA*)* – An analytic technique used in determining the economic value of a project or plan. Costs and benefits are typically denominated in dollars and include the money, time, resources, and consequences associated with a project or activity.

Distance-based tolls – Fixed toll rates based on distance traveled and vehicle type.

Diversion – the result of people making different travel choices, in this case as a result of a toll. Diversion can refer to taking different routes, or changing modes, travel time or destination.

Dynamic congestion pricing – Tolls that change based on real-time travel conditions. For example, when traffic volumes go up, so do the tolls. Rates are lowered as demand eases.

Elasticity – The price elasticity of demand measures the nature and degree of the relationship between changes in quantity demanded of a good and changes in its price. High elasticity implies high sensitivity to changes in price while low elasticity, often referred to as inelasticity, means low sensitivity to price changes.

Electronic toll collection (ETC) – Using technology to collect tolls from drivers without requiring them to stop and make cash payments.

Equity – the idea that all travelers are of equal standing, and should be considered in the development of toll policy. Social, geographic and income equity are examples of equity issues that arise in toll policy development and implementation.

Express toll lanes – Limited access, normally barrier-separated highway lanes requiring drivers of all vehicles to pay toll in order to use the facility. All tolls are collected electronically.

Fixed tolls – Toll rates that don't change. They are typically used to pay for the bridge or road on which they are charged. Trucks pay more than cars.

Fixed-schedule congestion pricing – Tolls charged at predetermined rates reflective of demand levels at different times of day; rates can be based on hour of the day, day of the week, direction of travel and vehicle type.

Gas tax – A state levied tax on the consumption of gasoline. The primary means currently of financing highways in Oregon.

Greenhouse gas emissions – The generation and emission of gases, such as carbon dioxide, methane, nitrous oxide and halocarbons which accumulate in the atmosphere and have a long residence time, leading to a surface warming of the land and oceans.

High occupancy vehicle (HOV) – A vehicle containing more than one person.

High occupancy vehicle (HOV) lane - A travel lane restricted to transit and carpool vehicles meeting occupancy requirements of two or three people per car. HOV lanes are meant to carry more people in less space than general purpose lanes.

High occupancy toll (HOT) lanes – Travel lanes restricted to either qualifying HOVs or solo drivers willing to pay a toll. The toll typically varies by time of day or traffic levels and is collected electronically.

Investment grade – The top four rating categories for bonds. Important to tolling as special, independent analysis of the revenue generating capacity of a particular toll project may be required for bond issuance.

Managed toll lanes – Any toll lane that uses variably priced tolls to maintain superior, less congested travel conditions.

Mileage-based fee or mileage tax – A tax on vehicle use based upon miles driven rather than fuel consumption.

Non recurrent delay – A type of travel delay that occurs because of incidents, and is therefore not as predictable as recurrent delay caused by traffic exceeding capacity, bottlenecks, other infrastructure problems.

Open road tolling - use of electronic toll collection methods to keep traffic moving, as opposed to making people stop at toll booths to pay the toll.

Opportunity cost – In economics, the value of the next-highest-valued alternative use of a given resource.

Parking policies –Adopted means of managing access to a particular locale by changes in the price of parking.

Peak period – the busiest travel times of the day, also known as commute time or rush hour. There are typical two peak periods each weekday – the morning and afternoon commute times.

Public-Private Partnerships (PPPs) – Contractual agreements formed between a public agency and private sector entity, which expand on the traditional private sector role in the delivery of transportation projects. PPPs are particularly prevalent for tolling projects.

Pricing – A tolling concept where the level of toll (price) is used to change travel behavior.

Public good – In economics, a good that is non-rival and non excludable. This means consumption of the good by one individual does not reduce the amount of the good available for consumption by others and no one can be effectively excluded. A non-congested public highway can be considered a public good.

Recurrent delay – A type of highway delay that occurs regularly due to too much traffic and/or geometric constraints.

Single occupancy vehicle (SOV) – A vehicle containing only one occupant.

State Infrastructure Bank (SIB) – An ODOT managed revolving loan fund available for transportation projects.

System-wide tolling – implementing tolls on highways and major arterials to reduce congestion, minimize route diversion and increase transportation revenues.

Theory of the Second Best – In economics, a theory of what happens when one or more optimality conditions are not satisfied in an economic model. It implies the need to study the details of a situation prior to assuming theory based conclusions because improvements in market performance in one area may not mean an overall improvement. This is significant in congestion pricing schemes where theoretically optimal conditions are likely to be unachievable.

Time-of-day pricing – A tolling approach that varies by the time-of-day in order reduce congestion at peak hours; rates are higher at peak hours then at off-peak.

Tolling – Charging a price to use a road, bridge or tunnel.

Toll revenue bonds – A type of municipal bond where the principal and interest are secured by tolls paid by the users of the facility that is built with the proceeds of the bond issue.

Travel-demand forecasting – The analytical estimation of future travel volumes and patterns, typically performed with computer models. There are four basic components: (1) trip generation – predicting the number of trips that will be made; (2) trip distribution – determining where the trips will go; (3) Mode usage – how the trips will be divided among available modes of travel; and (4) Trip assignment – predicting which routes the trips will take, resulting in highway system and transit ridership forecasts.

Travel demand management – The application of techniques that affect when, how, where, and how much we travel done in a purposeful manner by government or other organizations. The techniques include education, policies, regulations or other combinations of incentives and disincentives.

Truck only toll (TOT) lanes – Limited access, normally barrier-separated toll lanes available only to trucks for a variably priced toll. All tolls are collected electronically.

Value of time – One of the most important benefits of road pricing, as well as other transportation projects, is travel time savings. What these savings are worth to motorists can vary by income, gender, age, trip purpose, mode used, length of trip, uncertainty of travel time and other factors. This in turn implies analytical difficulties in applying values to given situations.

Value pricing – Toll rates that vary in direct proportion to travel demand or congestion on alternative free routes.

Variable toll – a toll that changes by time of day, traffic volumes or other factor.