Multi-Criteria Analysis: An Alternative Approach for the Evaluation of Road Pricing Strategies

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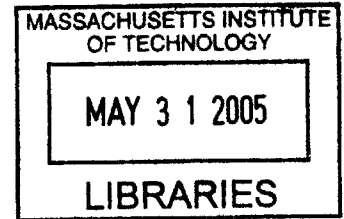Washington State University, 2003

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ABSTRACT

Interest in road pricing among political leaders, transportation analysts, academics, and government agencies has increased in recent years. There are myriad reasons for this newfound consideration, but the deployment of intelligent transportation systems, the desire for additional revenue sources, and the search for policies that can reduce congestion are among the most important. This thesis examines the impacts of six different types of road pricing strategies, namely: conventional tolling, facility congestion pricing, express lanes (e.g. HOT lanes), area-wide and cordon pricing, network pricing, and distance-based pricing. It also presents a new sketch-planning model, the Road Pricing Decision Analysis Tool (RPDAT), which highlights each strategy's unique set of strengths and weaknesses for achieving different policy objectives and recommends road pricing strategies for particular metropolitan areas.

Despite a growing interest in pricing, many decision makers feel unable to estimate the impacts of pricing strategies accurately with conventional models. This thesis discusses the factors believed to be responsible for drivers' choosing to use priced facilities, explains why conventional models are incapable of capturing many of these factors or the aggregate effects of a pricing policy, and identifies some improvements that could be made to existing transportation models.

RPDAT performs a multi-criteria analysis of nine road pricing strategies, one of which is a "no pricing" alternative, for a metropolitan area. The user inputs policy priorities and regional characteristics, and RPDAT's algorithms calculate how well each alternative meets the decision maker's criteria as well as index scores that reflect the overall preference for each alternative. This tool is applied to Kuala Lumpur (KL), Malaysia and is used to recommend road pricing strategies for the KL metropolitan area.

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1 INTRODUCTION

1.1 Road Pricing, Road Taxing, and Congestion Pricing

Road pricing refers to the practice of subjecting particular road trips at well-specified places and/or times to well-defined charges (NCHRP). It entails charging motorists for the road infrastructure and services they use and is used either to influence driver behavior or to allocate costs of expensive facilities (e.g., bridges and tunnels) to the subset of the population that uses them. Road pricing is also called 'pricing' or 'road user charging,' and is often confused with other terms, such as road taxing, congestion pricing, value pricing, dynamic pricing, and variable pricing.

'Road pricing' is a catch-all phrase that encompasses conventional tolling, congestion pricing, and distance-based pricing schemes.[1] The amount of the charge depends *directly* on the vehicle type and the road travel's location, time, and/or distance. Express lanes (e.g., high-occupancy/toll (HOT) lanes), conventional tolling, facility congestion pricing, network pricing, area-wide pricing, and cordon pricing are all examples of road pricing measures.[2]

Pricing can be differentiated from taxation in that taxes are compulsory contributions exacted by a government for public purposes (U.S. Census Bureau), whereas the sole function of pricing is not revenue generation. Road taxes are taxes that are levied on road users, but that are only crudely correlated to the extent of their road use and are intended primarily to raise money rather than alter behavior (NCHRP). Fuel taxes, vehicle excise taxes, annual licensing fees, and taxes on vehicle parts are examples of road taxes.[3]

Some argue that forms of road pricing, such as distance-based pricing, are actually road taxing because of the revenue generation motivation (CBS Broadcasting). Perhaps the most

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[1] Distance-based pricing is also referred to as distance-based charging or vehicle-miles-traveled (VMT) charging. The different forms of road pricing are defined in Chapter 3.

[2] HOT lanes are a form of managed lanes that allow high-occupancy vehicles (HOVs) to travel on the lanes at no cost or at a discount and charge low-occupancy vehicles (LOVs) a toll to use the lanes. HOV requirements are typically two or more persons in a vehicle. Some single-occupancy vehicles (SOVs) may be willing to pay tolls to use HOT lanes for a higher level-of-service than is available in the general-purpose lanes, which have no requirements for use.

[3] A fuel tax correlates to fuel consumption but it only corresponds to the amount of travel indirectly; it does not relate to where and when the travel takes place well.

appropriate classification for these measures would be 'hybrids' between road taxes and road pricing, but measures traditionally referred to as road pricing will be defined as such in this thesis.

Congestion pricing is an economic principle that is used in many road pricing schemes. With congestion pricing, users are charged a fee that varies by time-of-day or congestion-level. Higher tolls are assessed during peak hours to encourage drivers to change their time of, location of, frequency of, mode of, or propensity to travel, which smoothes out the demand peak. It is a method for using market forces to allocate limited facility capacity among users by their need to travel and their willingness to pay (TCRP). Congestion pricing is commonly used in the airline, telephone, hotel, and electricity industries in various guises and may be referred to as congestion charging, peak-period pricing, or value pricing.

Value pricing is a marketing term used to emphasize the benefits users receive from reduced congestion and additional toll revenue that can be used to improve transportation services.

Dynamic pricing and variable pricing are methods of applying congestion pricing that are often mistakenly used interchangeably. In dynamic pricing, the amount of the toll changes in real-time according to the level of congestion. In variable pricing, the toll changes by time-of-day and/or day-of-the-week according to a pre-determined schedule, which makes the toll charges predictable for drivers.

1.2   Interest in Pricing

Interest in transportation pricing among political leaders, policymakers, transportation analysts, metropolitan planning organizations (MPOs), state Departments of Transportation (DOTs), and academics has increased in recent years. There are myriad reasons for this newfound consideration, but three factors are responsible for advancing pricing as a realistic alternative. First, the deployment of intelligent transportation systems (ITS) and its best-known technology, electronic toll collection (ETC), has eliminated the need for manual toll collection, significantly reducing the cost of collection operations and creating larger net revenue possibilities. ETC also allows tolls to be changed in real-time, which adds flexibility and can guarantee travel time reliability for users. Second, cash-strapped state DOTs and regions are starting to view pricing as a means of revenue generation. Shrinking state budgets and

diminishing gas tax revenues are of major concern in some states—especially those with large population growth and dwindling transportation funding available to expand capacity. Finally, more urban areas are beginning to consider pricing and other traffic demand management (TDM) strategies as a means to combat the recurring urban gridlock that capacity expansion and other policies have failed to relieve. HOT lanes in particular are receiving increased attention in the United States for the following reasons:

- They allow a greater volume of traffic to use the road than underutilized high-occupancy vehicle (HOV) lanes;
- They do not divert traffic to alternative roads;
- They have the potential to create revenue; and
- They are a market-based solution providing users with the option to pay for a higher level-of-service.

Consideration of road pricing schemes has also become more common because of the technical and political success of congestion pricing schemes implemented around the world in recent years. Both users and non-users of the SR91 and I-15 HOT lanes in California strongly support the priced lanes and, as a result of this approval, the I-15 lanes are being extended (OCTA, 91 Express Lanes Fiscal Year 2003 Annual Report; Highway Communication Exchange). Other forms of road pricing, such as the area-wide London Congestion Charging (CC) scheme introduced in February 2003, have also been successful. While it was unpopular with the media before its opening, the CC scheme has reduced congestion, radically improved bus service, improved journey time reliability for auto users, and made the distribution of goods and services more efficient in central London (Transport for London, Central London Congestion Charging Scheme - Impacts Monitoring, Summary Review January 2005). Resolving traffic problems was the top pledge of Mayor Ken Livingston's 2000 election platform and when he was reelected in 2004 with a margin of 11 percent above his main rival who threatened to abolish the charge, the scheme was vindicated.[4] Leaders around the world have watched the London scheme closely and many of them have begun to consider forms of road pricing for their own regions.

Though transportation pricing can be used to address many different transportation-related concerns, there are three major areas where it is thought to have the most significant

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[4] Public opinion surveys before the scheme was implemented revealed that approximately 40 percent were in favor of the scheme and approximately 40 percent were opposed. Six months after the scheme began, 60 percent were in favor and 25 percent were opposed.

impacts: congestion, the environment, and finance. Pricing is also important in transitioning from a "one size fits all" highway system to one that offers different products to different users. A brief discussion of the role of pricing in each of these topics is discussed in this section.

1.2.1 Congestion

There is a growing consensus among researchers, decision makers, and the public that addressing congestion is one of the most difficult—if not the most difficult—challenges for urban transportation in the future. Congestion is a phenomenon that occurs when demand exceeds capacity, often attributed to the good—in this case travel—being under-priced. In this situation, drivers' perceived (and actual) cost of travel is less than fair market value, encouraging them to travel more than they would in free market conditions. This results in an increased number of per-person trips and, by extension, more cars on the road during peak periods.

Traffic congestion affects virtually every person in urban areas—either directly or indirectly—across the globe. Drivers experience increased travel time delays, decreased travel time reliability, and a greater risk of accidents. Non-drivers are also affected and may experience congestion's negative effects on bus services and air quality on a daily basis. Congestion inhibits the movement of goods, contributes to greenhouse gas emissions, wastes fuel, and decreases economic productivity.

The rising costs of congestion are frequently cited by transportation analysts and decision makers whom are trying to promote transportation projects or policies. Possibly the best-known reference to the economic costs of congestion in the United States is the *Urban Mobility Study*, which estimates those costs to be approximately $63 billion annually (Schrank and Lomax). The methodology used in the Urban Mobility Study overestimates congestion costs compared with what is economically efficient (Victoria Transportation Policy Institute), however, it demonstrates the potential scale of the issue.[5]

Many people wonder why transportation agencies have been unable to eliminate congestion. Anthony Downs addresses this question by suggesting that "[p]eak-hour traffic congestion is an inherent result of the way modern societies operate. It stems from the widespread desires of people to pursue certain goals that inevitably overload existing roads and

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[5] Economically efficient pricing is discussed in Chapter 2.

transit systems every day" (1). He also notes that congestion is not primarily a problem, but rather a byproduct of society's basic mobility problem of too many people wanting to travel at the same time of day. Adults need to go to work, children need to attend school, and the economy needs to move goods and provide services. Downs concludes that, "although traffic congestion is inevitable, there are ways to slow the rate at which it intensifies. Several tactics could do that effectively, especially if used in concert, but nothing can eliminate peak-hour traffic congestion from large metropolitan areas" (8). Congestion pricing is one tactic that has been proven to reduce congestion where it is implemented, and, if it is introduced in conjunction with other measures, it can slow congestion growth and improve the mobility and overall accessibility of a region. It is not desirable to eliminate all congestion, but Figure 1.1 shows that removing just a fraction of the trips from peak periods can result in substantial delay reductions.
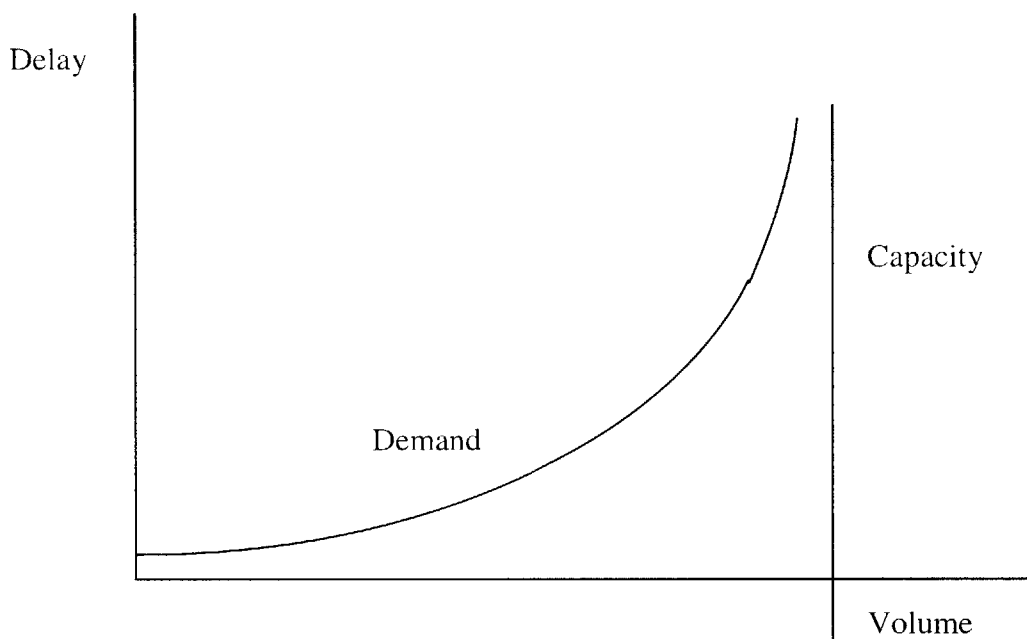
Figure 1.1: Volume-Delay Function

1.2.2 Environment

Automobile travel has both direct and indirect effects on the environment, including air and water pollution, ozone depletion, climate change, hazardous and solid waste production, noise pollution, loss of habitat, reduced visibility, and reduced biodiversity. Traffic congestion is closely related to the environmental impacts of the highway sector.

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Pricing can be used as an instrument to influence the demand for and the means of travel. It can provide economic incentives for users to:

- Shift trips to less congested periods of the day;
- Shift trips to transit and high-occupancy vehicles (HOVs);
- Combine trips through trip chaining or eliminate discretionary trips;
- Demand 'greener' vehicle technology from manufacturers; and
- Take externalities into account when making auto and travel decisions.

Although there has yet to be a road pricing scheme implemented with a primary objective of environmental improvement, some agencies have used the pollution class of vehicles as a factor in determining the level of the toll charge.

1.2.3   Finance

As it has in the past, road pricing can serve as a direct financing mechanism for transportation projects.[6] With growing travel demand, increasing construction costs, and opposition to increasing fuel taxes, many regions are again considering tolling to meet their transportation needs. However, non-traditional tolling can also generate revenue—perhaps even more than conventional tolling in many cases.

1.2.4   Product Differentiation

The highway system has traditionally been a "one size fits all" enterprise. Most highways in the United States were planned for and are operated by government agencies, in part because urban transportation is mistakenly considered a public good.[7] The mission of these

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[6] Many U.S. states—particularly those in the East—constructed toll roads in the late 1940s and early 1950s. However, the National System of Interstate and Defense Highways, commonly referred to as the Interstate system, brought the toll road movement to a halt with 90 percent federal aid for new infrastructure construction in the 1950s. J. Gómez-Ibáñez, "The Political Economy of Highway Tolls and Congestion Pricing," Transportation Quarterly 46.3 (1992).

[7] Transportation is not a pure public good. The formal definition for public goods is that they must be *non-excludable* and there must be *non-rival consumption*. Once non-excludable goods are provided, others cannot be prevented from enjoying them. If non-rival consumption exists, additional people can consume the good without reducing other consumers' enjoyment. J. Gómez-Ibáñez, "Externalities, Public Goods, and Commons," (Cambridge: Harvard University, Kennedy School of Government, 2005). Pure public goods are rare, and transportation does not meet these criteria. Only the public sector will provide public goods. A lighthouse and national defense are classic examples of public goods.

agencies historically has been infrastructure construction and expansion rather than efficient operation of the existing transportation system. This has led to a lack of a customer-oriented focus by transportation providers, an expectation that everyone will use the system in the same way, and the provision of only one level-of-service (Sussman, Perspectives on Intelligent Transportation Systems). This business model is problematic as it overlooks the heterogeneous characteristics of users and their different service requirements.

In recent years, this traditional idea that highway transportation only needs to offer one product has been challenged. The majority of the infrastructure system has been completed and organizations are transitioning to a focus on operations. To support this new objective, agencies must develop a customer orientation with a focus on quality service including the option of premium service to those customers who demand it (Sussman, Perspectives on Intelligent Transportation Systems). Others, such as the American Automobile Association, offer an opposing argument and believe allowing one market group to pay for better service while others remain in the congested general purpose lanes is a poor public policy decision (Wylie). Decision makers will ultimately make the choice of whether premium service should be provided, but road pricing measures will play a key role if it is to occur.

1.3 Motivation for this Research

Despite the growing interest in pricing, many decision makers still feel apprehensive about their abilities to estimate the impacts of road pricing accurately, and there remains some uncertainty as to which road pricing strategies are most appropriate for each metropolitan area. Some of the most important issues of concern to a decision maker are the revenue forecasts, potential diversions to alternative facilities, social implications, land-use changes, and environmental effects. Although there are multiple models that have been either developed or adapted to estimate one or more of these criteria for road pricing policies, each has only a limited capacity to do so accurately. One potential cause for poor estimates in the modeling process is that road pricing involves influencing driver behavior, which requires predicting human nature. Another explanation is that the most common model used to evaluate road pricing strategies, the four-step model (4SM), was developed for evaluating large-scale infrastructure projects and was not meant to evaluate policies that involve little or no change in the infrastructure supply such as road pricing. The model was not intended to analyze complex policies involving management

and control of existing infrastructure or policies that directly influence travel behavior (McNally). Adding to these difficulties, there is little empirical evidence available for researchers to develop a better understanding of the effects of pricing measures and its influence on driver behavior.[8]

Modeling transportation demand is a difficult process, and as Small and Winston note, "[f]orecasts for new travel options, whether conventional or exotic, have often been far from the mark" (Small and Winston 47). The introduction of toll charges makes estimating demand even more problematic. Toll road demand forecasting has a history filled with poor and wildly varying estimates, which has led to considerable uncertainty in the forecasting process (Estache, Trujillo and Quinet; Fitch Ratings; Standard & Poor's).[9] At least one credit rating agency has stated that it believes the regional planning models, which use the four-step process, are "not necessarily appropriate for use to support the issuance of toll road debt," (Fitch Ratings 2). The direct relationship between revenue estimates and travel demand also demonstrates the difficulties associated with determining the amount of traffic diversion that will occur if pricing is added to an existing facility.

Other issues, such as perceived equity and fairness, are also concerning to many decision makers. Some groups are worried that road pricing may change the distribution of benefits and costs relative to the existing distribution, which would be an "equity" impact. There are two types of equity concerns: horizontal equity and vertical equity. Horizontal equity refers to the distribution of benefits between users and non-users or geographic areas, while vertical equity refers to the impacts on disability, race, or income groups. Road pricing is likely to be more equitable from the horizontal perspective than most other approaches to congestion reduction or capacity expansion because the users who benefit the most pay for the improvements through tolls (TCRP); similar arguments are often used to justify new toll roads. In the case of converting an underutilized HOV lane to a HOT lane, non-users are recognizing they can also receive benefits, albeit smaller ones than those received by HOT lane users, because this action may reduce the number of vehicles traveling on the untolled general purpose lanes. Demographics, as an example of vertical equity, are one factor influencing whether a driver will

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[8] The exception is conventional tolling, which has abundant data, although a noticeable amount of this is proprietary.
[9] Standard & Poor's (S&P) found the standard deviation of toll road demand estimates to be 0.26, which is quite large. Additionally, their empirical evidence suggest that toll road forecasts have, on average, overestimated traffic forecasts by 20-30 percent.

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choose to use priced lanes, however, there are several others. Experience in California has shown that reliability is a very important factor (Brownstone and Small) and that drivers from all income groups use the lanes (TCRP). It is difficult to estimate equity impacts with accuracy, however, because there is a lack of sufficient data on road pricing and current models are incapable of modeling some of these factors. A recent Transit Cooperative Research Program (TCRP) Report agrees that "[e]xisting forecasting and accounting methodologies are often incomplete in addressing [equity] issues" (14-36).

In part because of the current inability to model road pricing well and the small number of road pricing projects with actual data to study, it is argued that decision makers are not comfortable with all of the estimates provided by existing models. If they were, the decision-making process would be much easier and it would be more clear which road pricing strategies would be the most beneficial.

Decision makers have to consider and weigh many factors and make trade-offs among them when coming to a decision about a policy or strategy. Tools to assist the decision maker with narrowing the range of alternatives would improve decision-making.

The hypothesis of this thesis is that decision makers have multiple conflicting objectives and a tool that helps them to understand how well different road pricing measures meet their criteria would be useful in determining the most appropriate forms of road pricing for their regions. Existing transportation models are not capable of providing accurate estimates of all the impacts many decision makers wish to consider, so an alternative evaluation approach is proposed. While this thesis presents a detailed discussion of the impacts of different road pricing measures, the tool presented in Chapter 5 gives decision makers a rank ordering of alternatives and qualitative assessments rather than specific numerical estimates of the impacts.[10] The tool can be used to determine which road pricing measures are most appropriate for a particular metropolitan area. The objectives of this research are discussed in Section 1.4.

1.4 Thesis Objectives and Organization

The primary objectives of this thesis are four-fold. First, it provides a comprehensive overview of the different forms of road pricing and discusses the impacts these measures are

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[10] In other words, the tool might determine a pricing measure decreases the number of accidents "very well," but it does not provide a numerical estimate of how many accidents a pricing measure will eliminate.

believed to have on areas of concern to decision makers. Chapter 3 categorizes road pricing strategies into six types, which will allow generalized statements to be made regarding the strengths and weaknesses of each form of road pricing. Chapter 2 provides background information on the economic principles of road pricing.

The second objective is to identify the difficulties associated with modeling road pricing and to explain why decision makers are not comfortable with using existing models to estimate the impacts of pricing strategies. Additionally, Chapter 4:

- Outlines the factors believed to be responsible for drivers' choosing to use a priced facility;
- Notes the models that are being used in practice to perform both sketch-planning and detailed analysis of road pricing alternatives in the United States;
- Explains why these models are incapable of modeling road pricing well;
- Presents the modeling issues that need to be resolved in order to model road pricing better; and
- Acts as background information in support of the development of an alternative method for evaluating road pricing strategies

The third objective is to develop a framework and tool that decision makers can use to assess road pricing strategies. Chapter 5 presents a tool, the Road Pricing Decision Analysis Tool (RPDAT), which was created to assist decision makers in determining which pricing strategies are most appropriate for a metropolitan area. The tool is not intended to evaluate specific projects or provide detailed estimates of the impacts associated with different measures, but it can be used as a sketch-planning tool to narrow the range of pricing alternatives to one or two that should be considered further. RPDAT can be applied quickly and allows the user to test how well different forms of road pricing work with different policy scenarios, thus improving the user's understanding of road pricing measures. One of the goals of this tool is that it can be used in the larger context of Regional Strategic Transportation Planning (RSTP).[11] RPDAT has been created with the idea that it would be easily adaptable to meet future planning and decision-making needs. A detailed description of the new framework and tool are located in Chapter 5.

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[11] For more information on RSTP, see: (i) J. Sussman, S. Sgouridis and J. Ward, A New Approach to Transportation Planning for the 21st Century: Regional Strategic Transportation Planning as a CLIOS (Cambridge: Massachusetts Institute of Technology, 2004) and (ii) S. Sgouridis, "Integrating Regional Strategic Transportation Planning and Supply Chain Management: Along the Path to Sustainability," Massachusetts Institute of Technology, 2005.

The fourth and final objective of this thesis is to apply RPDAT to a specific region in order to demonstrate the tool's usefulness. In Chapter 7, RPDAT is applied to the Kuala Lumpur Metropolitan Area (KLMA). To establish the decision-making context for the KLMA application, Chapter 6 presents background information on Kuala Lumpur and Malaysia.

The thesis concludes with Chapter 8, which presents a summary of the findings and recommendations for further research. Appendices A1-A4 provide additional explanations of some topics and Appendix B defines several acronyms and terms referred to throughout the thesis.

1.5 Contributions to Existing Literature

There are at least three contributions to the existing literature in this thesis. Chapter 4 documents the state-of-the-practice of modeling road pricing and identifies the modeling improvements and data requirements that would enhance the capacity of transportation analysts to estimate the impacts of road pricing strategies. There are many researchers attempting to incorporate road pricing into their models, however, there is no documentation found in the literature that explains why existing models have fundamental problems with estimating the impacts of road pricing policies.

A specific framework does not yet exist to help decision makers decide which road pricing strategies might be most appropriate for a metropolitan area. This research presents a decision-making tool (RPDAT) that takes various inputs from the user, such as prioritized criteria and regional characteristics, and produces recommendations identifying which forms of road pricing meet the user's set of criteria best and should be analyzed further. One of the major contributions of this tool is that it provides a quick and simple way for regional decision makers to develop a better understanding of the differences among road pricing strategies.

This thesis also applies RPDAT to Kuala Lumpur (KL) in Chapter 7. KL has certain characteristics that make it different from other major metropolitan areas, but it also has many traits that are similar. Although congestion pricing policies for KL have been studied in the past (Wilbur Smith and Jurutera Konsultant; Armstrong-Wright), these studies are quite dated. This analysis updates the existing studies and recommends road pricing measures for Kuala Lumpur, demonstrating the use of RPDAT for a metropolitan area.

2 ECONOMIC PRINCIPLES AND CONCEPTS

2.1 Chapter Purpose and Organization

This chapter discusses the economic rationale for road pricing strategies. Marginal-cost pricing, Ramsey pricing, and congestion pricing are reviewed to provide fundamental information for these concepts and terms, which will be referred to throughout the thesis. If the reader is already familiar with the economics of road pricing, he or she may wish to move directly to Chapter 3.

This chapter is presented in a hierarchical organization rather than according to level of significance. Marginal cost pricing is presented first, followed by Ramsey pricing, and then congestion pricing.

2.2 Function of Pricing in Urban Transportation

Road pricing has two primary functions in urban transportation; it (i) finances infrastructure and (ii) rations and allocates the use of infrastructure. Fuel taxes and conventional tolling are the most commonly used methods of infrastructure finance. Although the public and its elected representatives are primarily interested in tolling as a means to finance the expansion of facilities rather than as a means to manage existing facilities, economists and planners are usually more interested in the second function—rationing the use of transportation services (Gómez-Ibáñez, "The Political Economy of Highway Tolls and Congestion Pricing"). Congestion pricing and marginal-cost pricing are primarily methods of rationing and allocating road space, but Ramsey pricing can also encourage more efficient use of infrastructure. All three economic principles can be used to generate revenue.

2.3 Economic Principles and Definitions

2.3.1 Long Run vs. Short Run

The long run is the period that is long enough for a firm to adjust all of its inputs to their optimal levels. Conversely, a firm is defined to be operating in the short run when at least one factor is assumed to be fixed. Though the short run has fixed costs and variable costs, all costs and decisions are assumed to be variable in the long run.

From the users' perspective, a household often plays the role of the firm in transportation and the unit of output, or production, is a trip. When a household considers making a trip, the household will take a range of (input) factors into account, all of which have costs associated with them. These factors include the household's income, number of autos owned and their associated costs, and the trip's purpose, timing, cost, mode, and length, among others. Inputs that are assumed to be fixed in the short run, making them long-run factors, are household location, income, number of vehicles, and the fixed costs of auto ownership. Firms seek to minimize their variable costs in the short run.

From a transportation provider's perspective, the short-run is defined to be the period in which capacity is fixed and cannot be adjusted. Thus, as will be explained in Section 2.3.2, economists consider the passive toleration of increased congestion to be the short-run method of accommodating an additional vehicle. The long-run method would be investment in the facility to expand capacity.

2.3.2 Externalities

Externalities arise when the social or economic activities of one group of persons have an impact on another group and that impact is not fully accounted for or compensated for by the first group (European Commission). Externalities usually occur because of a lack of clear property rights. With negative externalities, those that cause negative impacts on third parties, the private market produces too much because producers and consumers do not recognize the full costs (Gómez-Ibáñez, "Externalities, Public Goods, and Commons").

Transportation has many negative externalities that drivers do not consider when choosing to make a trip because these externalities do not present a readily observable cost to

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them. Externalities include environmental impacts, the cost of accidents, and the congestion delay imposed on other road users. Consumers will only purchase a product—in this case, make a trip—if they value it at least as much as their personal cost; thus, internalizing negative externalities creates net benefits for society.

Some argue that congestion is not an externality because many of the negative effects are borne by a single user group.[12] With this argument, each driver causes an increase in congestion that delays other drivers who choose to use the system, making the effects internalized by a common group. This argument is incorrect, however, because multiple firms use the highway facilities and they do not consider the negative effects of their actions on other firms when they decide whether, when, where, and how to make a trip. The internal congestion costs to each additional driver are small compared to the additional congestion costs incurred by the system associated with that vehicle. Each vehicle also imposes additional delay costs on bus and non-motorized transportation users, which are outside the "drivers" system. Finally, emissions are additional costs for which drivers are not responsible, also contributing to the argument that congestion has negative externalities.

Gómez-Ibáñez ("Externalities, Public Goods, and Commons") identifies four methods for correcting externalities: property rights can be established, standards can be set, corrective taxes or subsidies can be imposed, or a cap can be established with tradable permits. Considered in the context of road pricing, the third method, taxing, is the most reasonable option for correcting highway externalities.

2.3.3 Marginal-Cost Pricing

The marginal cost is the additional cost incurred from producing one more unit of output; in this context, a vehicular trip. It is equal to the average user cost plus the change in average cost from serving one more user.[13]

Infrastructure is used most efficiently in an economic sense when users perceive they are paying the marginal cost of each trip. In a first-best world, which assumes perfect competition,

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[12] By definition, an externality does not exist if there are no effects outside the system.
[13] In this thesis, marginal-cost pricing and congestion pricing are presented as economic principles or techniques used by pricing strategies.

prices are equated with marginal costs.[14] However, first-best conditions generally do not exist in the real world and road prices are often set below the marginal cost in nearly all congested urban areas. Misleading signals about resource scarcity are conveyed to users and the incentive to use resources and capital assets efficiently is diminished accordingly. As seen in Figure 2.1, the marginal cost is equal to the average user cost (assuming the only externality considered is congestion) when there is no congestion. The marginal cost of another vehicle on the facility increases faster than the average user cost during congested periods because of the delay curve in Figure 1.1, but the user costs incurred by the marginal vehicle usually remain unchanged or vary only slightly, thus encouraging excessive use of the facility.[15]
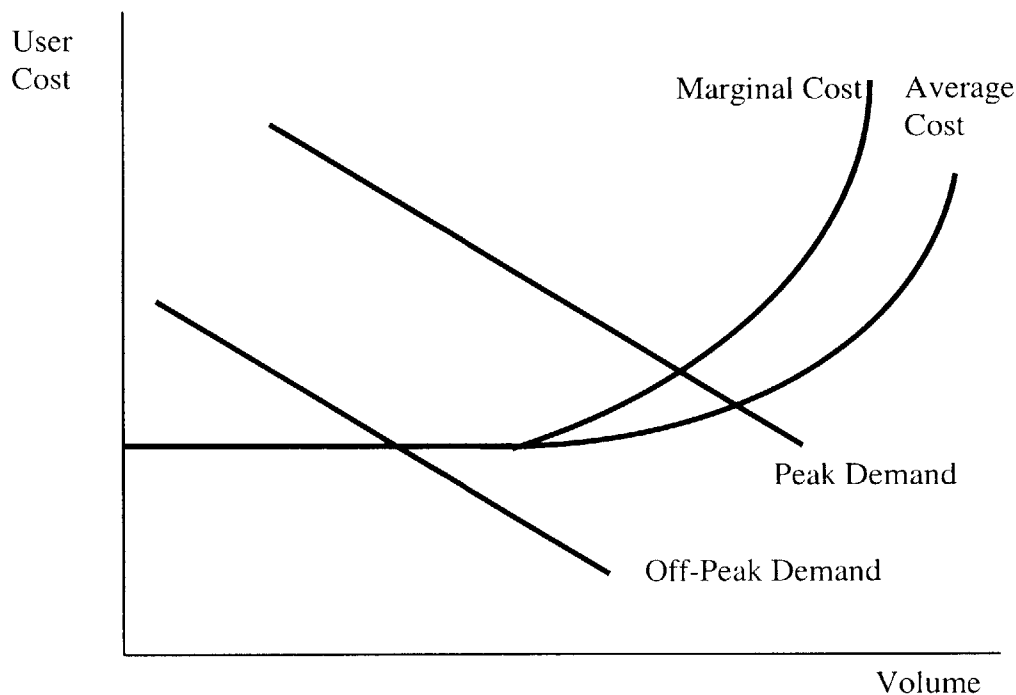
Figure 2.1: User Average and Marginal Costs

If externalities are considered, the average user cost is less than the social marginal cost of a trip during peak periods. The social marginal cost of a trip is the opportunity cost, or total sacrifice to society, of producing that trip. One of the primary causes of congestion (and the

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[14] First-best conditions assume perfect competition; complete information; no externalities; no subsidies; and no indivisibilities of supply or demand.

[15] Users only consider the average cost of a trip because they are from different firms. Users would consider the marginal costs of delay if they were from the same firm, because these costs are then internalized. A railroad facility used by only one firm is an example of where users consider the marginal cost of delay.

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level of externality impacts) in an urban transportation system is that the user does not pay 100 percent of the costs. Users are subsidized, thus encouraging them to consume more (i.e., make more trips) than is optimal for society.

Motor fuel taxes and other road use taxes and fees are not high enough to offset congestion and pollution externalities, so peak-hour driving is priced below the marginal social cost (Gómez-Ibáñez, "Pricing"). This problem could be alleviated through *marginal-cost pricing*, which charges users for the marginal cost of their trip, improving economic efficiency and supporting an efficient allocation of resources. As will be explained in Section 2.3.3.1, the short-run marginal cost (SRMC) and the long-run marginal cost (LRMC) are composed of different items. Charging the LRMC requires frequent toll schedule adjustments (different from variable pricing), which is undesirable from a customer service standpoint.[16] As a result, economists recommend charging the SRMC because it creates better utilization of the facility than the LRMC. Where there is strong demand and an absolute constraint on capacity expansion, tolls set at the SRMC would likely generate revenues far in excess of optimal investment that could be used to finance the cost of constructing roadways and subsequent maintenance costs (Gómez-Ibáñez, "The Political Economy of Highway Tolls and Congestion Pricing").

2.3.3.1 Short-Run and Long-Run Marginal Cost

The SRMC is the cost of accommodating one more vehicle by tolerating additional congestion. Traffic delays imposed on other road users caused by the additional vehicle and the pavement damage caused by the additional vehicle's passage are included in the SRMC. The SRMC does not include the costs of right of way acquisition, grading and constructing the road surface, or structures because such costs are fixed or sunk in the short run (Gómez-Ibáñez, "The Political Economy of Highway Tolls and Congestion Pricing"). Accident and environmental externality costs can also be considered as components of the social SRMC.

The LRMC is the amortized cost of accommodating one more vehicle with infrastructure expansion such that congestion does not increase. It includes the costs of right of way, grading, structures, etc. The LRMC is higher for peak-period and peak-direction traffic because the peak

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[16] Variable pricing changes tolls by time-of-day and/or day-of-the-week, while LRMC pricing might require the toll schedule be adjusted on a monthly basis.

volume determines the amount of capacity that is required to accommodate demand. When the level of transportation investment is not optimal, which is often the case, the SRMC does not equal the LRMC. If there is excess capacity on the highway facility (i.e., the level of investment is larger than optimal for current traffic volumes), the short-run marginal cost will be less than the long-run marginal cost. When the SRMC is greater than the LRMC, it is less costly to expand the facility than tolerate additional congestion. However, setting the price at the short-run marginal costs, which economists usually recommend, would cause toll revenues to fall short of the highway authority's costs (Gómez-Ibáñez, "Pricing"). Pricing that reflect the short-run marginal cost will produce more efficient utilization of the facilities, while prices that reflect the long-run marginal cost will send better signals for the optimal level of investment.

When an untolled substitute facility is present, however, there are complications to the rule that facilities should be priced at the SRMC. It is more difficult to calculate the optimal toll, which is mostly an esoteric interest of economists, and the appropriate toll is not necessarily the SRMC. Perhaps the most serious problem is that untolled competition may seriously reduce the effectiveness of tolls in managing demand (Gómez-Ibáñez, "The Political Economy of Highway Tolls and Congestion Pricing"). Untolled competing facilities are thus a very important factor in determining the amount at which a facility should be priced. Untolled competition, which is almost always present in urban transportation, makes determining the "correct" toll difficult in practice.

2.3.3.2   Benefits of Marginal-Cost Pricing

Economists recommend that prices be set at marginal cost instead of average cost because it ensures that users "will make an extra trip or shipment only when the value to them of doing so is at least as great as the cost of providing it" (Gómez-Ibáñez, "Pricing" 99).[17] According to welfare economics, social welfare is maximized when prices equal marginal costs

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[17] Transportation economics assumes the goal of pricing is to maximize net social benefits, which is the difference between the consumer willingness to pay and the cost of producing the service. This assumes the distribution of income is either just or not an appropriate concern for the pricing of this service, the consumer is the best judge of his or her own welfare, there are no externalities of production and consumption unless specified, and that all other goods that are close substitutes or complements are appropriately priced. These can be strong assumptions (Gómez-Ibáñez, "Pricing," adapted from Turvey). See also: C. Hendrickson and M. Wohl, "Efficient Prices for Roadways and Transit Services," Transportation Quarterly 36.3 (1982).

in a first-best world.[18] Empirical research supports this argument (Gómez-Ibáñez, "Pricing" 101) and the World Bank also advocates this approach (Cities on the Move: A World Bank Urban Transport Strategy Review). Therefore, it is appropriate to suggest that transportation providers align user prices more closely with the true marginal costs. Pure marginal-cost pricing is not feasible because some costs cannot be reasonably allocated; nonetheless, various pricing measures can approximate marginal-cost pricing relatively well.

Fair and efficient infrastructure pricing should support the development of a sustainable transportation system.[19] Failing to charge the marginal social cost for road transportation has several negative effects, including:

- Mode choice is distorted in favor of road transport, particularly private automobiles;
- Excessive use of infrastructure is encouraged, which can create "excess" congestion;
- Conventional commercial investment criteria cannot be used to determine the amount of capacity to provide because there is no direct revenue; and
- Funding to properly maintain existing infrastructure may be insufficient because the revenues are not distributed to the responsible local authority (World Bank, Cities on the Move: A World Bank Urban Transport Strategy Review 142).

Despite the increased social benefits, many decision makers are hesitant to charge users the marginal cost. As Gómez-Ibáñez explains, "policymakers often find raising prices more controversial than spending more money on infrastructure capacity, so Americans frequently enjoy more capacity and lower prices than would be optimal" ("Pricing" 106).

2.3.4 Ramsey Pricing

Inverse elasticity pricing, also referred to as *Ramsey pricing,* is recommended by economists where "first-best" conditions exist and marginal cost pricing would not generate enough revenue to meet budgetary constraints.[20] Ramsey pricing uses price discrimination and charges users with the least price elastic demand the highest amount over the marginal cost. By

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[18] It is desirable to maximize welfare because doing so creates net benefits for society.

[19] The distribution of the benefits and costs, however, are fundamental considerations of whether a policy is indeed "sustainable."

[20] For further information on Ramsey pricing, see: E. Ramsey, "A Contribution to the Theory of Taxation," Economic Journal 37.March (1927).

segmenting price elasticities of users, the reduction in consumption due to higher prices is minimized. If the cross-price elasticities of demand between different customers are zero, the Ramsey pricing formula to minimize distortions is:

$$P_i - MC_i / P_i = k / E_i \text{ where,}$$

P_i = price charged to user i;
MC_i = marginal cost of serving user i;
k = constant reflecting the amount of revenue needed to meet the budget; and
E_i = absolute value of the price elasticity of demand of user i.

The left-hand side of the equation is the percentage markup over marginal cost for user i. If there were a group of users with perfectly inelastic demand, this group could, in theory, be charged whatever amount was required to balance the budget. The formula reflects that as the price elasticity of demand becomes lower (i.e., more inelastic), the user should be charged a greater markup over the marginal cost.

Although Ramsey pricing is quite attractive from an economic theory standpoint, there are limitations in its practical application. It is frequently difficult to estimate the elasticities of demand for different user groups and Ramsey pricing creates strong incentives for customers paying high markup prices to find alternative services or sources (Gómez-Ibáñez, "Pricing"). This phenomenon essentially changes the demand elasticities for these users, modifying their Ramsey prices, and reduces the number of customers with inelastic demand, which can make Ramsey pricing responsible for its own failure. Another limitation is the assumption of "first-best" conditions, which implies that all complements, substitutes, and inputs to the service are also priced at the marginal cost. This is often a poor assumption in the highway sector because most roads are not priced at the marginal cost—especially in the United States. "Second-best" conditions are more prevalent in the real-world.[21]

A common example of Ramsey pricing is the segmentation of business and pleasure travelers used by legacy carriers in the commercial airline business.[22] Business and pleasure passengers traveling coach class receive the same product, but the airline imposes fare restrictions to make the majority of business travelers pay a higher fare. The airline industry

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[21] Second-best conditions and pricing are discussed in Appendix A1.

[22] Legacy carriers traditionally provide high quality passenger airline service to both business and pleasure travelers and use hub-and-spoke operations. United, Delta, Northwest, and American Airlines are examples of legacy carriers, while Southwest Airlines, JetBlue Airways, and Ryan Air are examples of non-legacy carriers.

takes advantage of the price elasticity of demand for business travelers being less elastic than for pleasure travelers by using a form of Ramsey pricing to increase profits.

HOT lanes may be another example of Ramsey pricing. Many HOT lanes allow HOVs to travel for a reduced rate or at no charge. The difference in price elasticities associated with the two user groups (HOVs and LOVs) is illustrated in this situation; some travelers (LOVs) are willing to pay for the HOT lane service and others (HOVs) are more sensitive to price and would rather carpool to save the expense of the HOT lane toll.[23]

2.3.5 Congestion Pricing

Congestion pricing is a technique that uses market forces to allocate limited facility capacity among users by their need to travel and their willingness to pay (TCRP). It involves varying the price for road use according to the level of traffic congestion to encourage people to travel during less congested hours, by less congested routes, by alternative routes, or not at all (NCHRP). The first ideas of congestion pricing were suggested by Pigou and Knight, and were built upon by Vickrey ("A Proposal for Revising New York's Subway Fare Structure"; "Congestion Theory and Transport Investment"; "Pricing in Urban and Suburban Transport"), who was later awarded a Nobel Prize for his work. Congestion pricing, also known as congestion charging, peak-period pricing, or value pricing, is commonly used in the airline, telephone, hotel, and electricity industries. It is particularly useful in infrastructure intensive systems such as urban transportation. The fundamental concept is charging higher tolls for the right to use a service or facility during peak periods, which smoothes out the demand peak.

The problem of congestion is essentially one of resource scarcity; demand exceeds supply for a given timeframe—the peak-period. Excess demand is accommodated by queuing and is the result of a market failure. Without prices that reflect the scarcity of the infrastructure resource (i.e., marginal costs), users only consider their private cost of travel and ignore the additional cost of their trip on society. Pricing is therefore necessary to correct the market failure and allocate the transportation service to those who value it the most.

Congestion can be an indicator of a strong economy, and Section 2.3.2 explained that some level of congestion is desirable from an economic perspective. However, there are

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[23] This example assumes HOVs would otherwise be low-occupancy vehicles if the HOV discount did not exist.

numerous negative effects with this phenomenon and many regions may benefit economically by reducing congestion because it:

- Is economically inefficient due to lost time incurred by persons and goods;[24]
- Decreases travel time reliability and predictability;
- Reduces the attractiveness of road-based public transportation;
- Creates adverse environmental impacts with more pollution per vehicle-miles-traveled (VMT) than free-flowing traffic;
- Decreases the quality of urban life;
- Increases the chance of road accidents; and
- Encourages sprawl.

Marginal delays from additional automobiles are very small when there is no congestion. Figure 2.2 shows that average vehicle speed can increase considerably by eliminating just a few trips when volume is near or at capacity. As Sussman states, "the linkages between capacity, cost, and level-of-service—the lumpiness of investment juxtaposed with the [speed-volume] function as volume approaches capacity—are the central challenges of transportation system design" (Introduction to Transportation Systems 81). In urban areas where additional capacity is particularly expensive, the LRMC (and SRMC) of accommodating additional peak-period vehicles can be very expensive.

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[24] Delay is economically inefficient because people value their time.

Average
Speed

Capacity

Demand
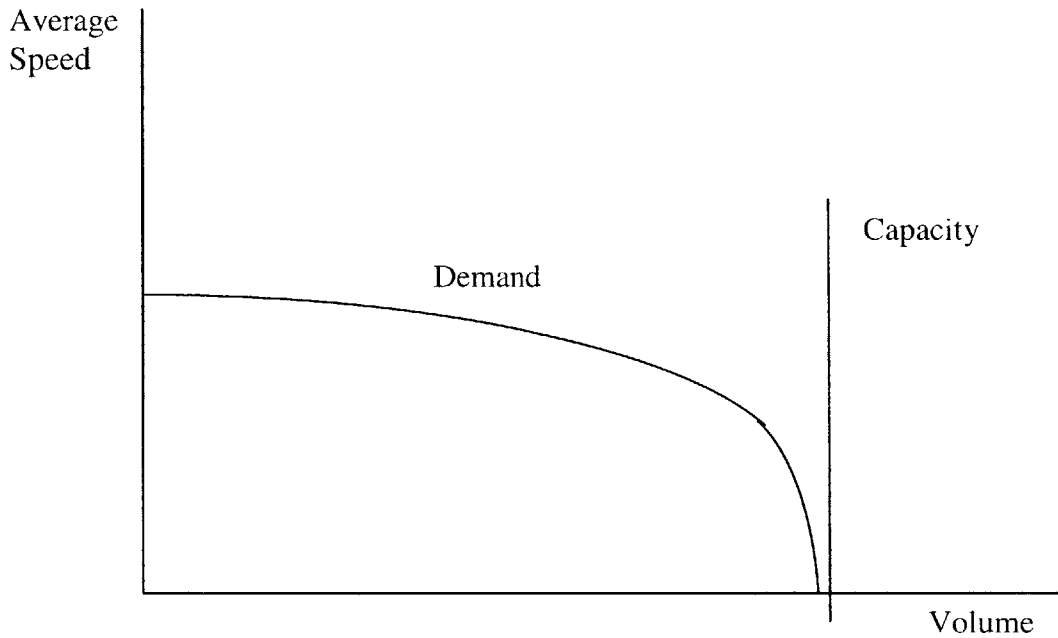
Volume

Figure 2.2: Speed-Volume Function

Some level of congestion in urban transportation is always economically desirable because the optimal level of investment occurs when SRMC equals LRMC. If the operating entity were to either impose extremely high tolls or widen the facility such that congestion was eliminated, the SRMC would be relatively low. The LRMC of this facility, however, is likely to be quite high because it is expensive to build urban roads; the level of investment would be especially poor if the facility were continuously expanded to accommodate increased traffic demand.

A congestion toll, shown in Figure 2.3, should be charged to levy the marginal cost of the facility to the users. If the LRMC equals \$3 and the congestion toll equals \$2, the facility operator should charge the congestion toll because LRMC is greater than SRMC. If the LRMC equals \$3 and the congestion toll equals \$4, however, the highway should be expanded.
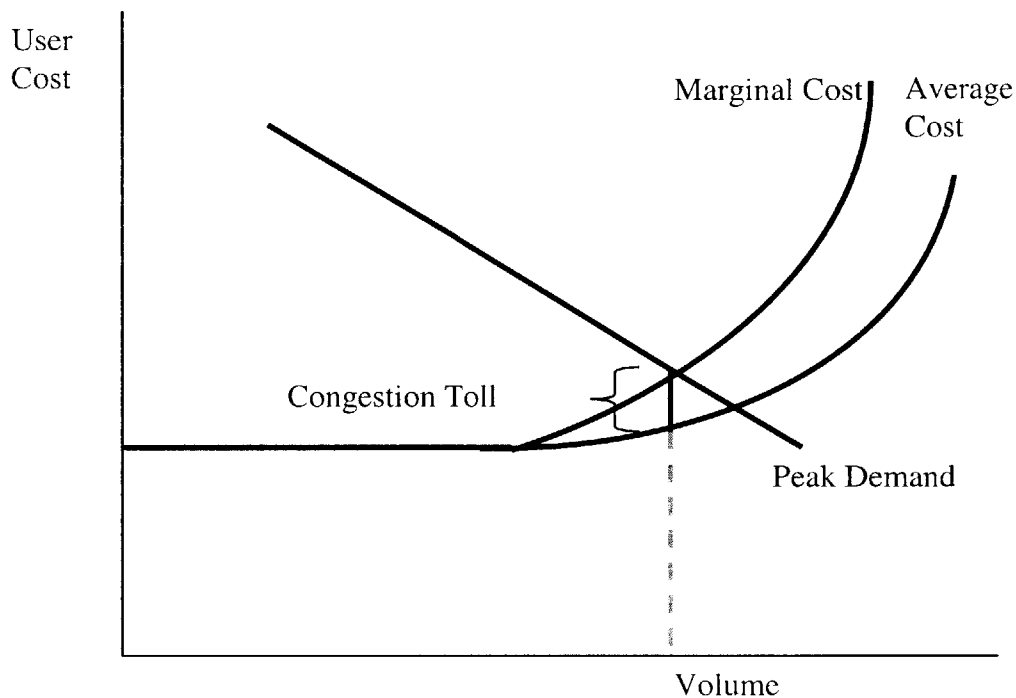
Figure 2.3: Congestion Toll

Tactics aimed at reducing congestion by influencing driver behavior can be generalized into two categories: "carrot" or "stick." The first approach can be considered the carrot, which attempts to entice drivers with incentives to act in a preferred manner. Many congested cities would prefer more drivers to take transit, which could reduce congestion, so transit farebox revenues are subsidized in the United States.[25] This carrot approach has had limited success, however, with encouraging a mode shift to transit; transit ridership accounts for less than ten percent of peak period trips in almost every North American city and has so far failed to have a large impact on mitigating congestion in most regions.[26] Transit subsidies have not been effective at influencing driver behavior in North America because "the convenience of auto travel is so great that, at its current heavily subsidized price, luring a substantial share of peak-period travelers from their autos would require negative fares of appreciable magnitude" (Moses and Williamson, cited in Mohring 192). Peak-period auto subsidies exist in North America because of the absence of marginal-cost pricing techniques and low fuel taxes. Imperfect pricing

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[25] Other factors, such as social obligation to provide mobility for the poor, are also motivation for providing transit subsidies.
[26] Eliminating transit where it is highly utilized, however, could have largely negative congestion impacts in some metropolitan areas.

measures, such as the vehicle fuel tax, exacerbate congestion when drivers are charged less than the marginal cost of travel.

The contrasting approach is analogous to the stick and reduces or eliminates peak-period auto subsidies. Congestion pricing is a most often analyzed as a stick approach for lowering peak-period congestion; however, it can also be considered as a carrot. Japan has used peak-period discounts to attract traffic to toll roads in order to alleviate congestion on the free parallel facilities (Matsuda, Tsukada and Kikuchi 9). This form of peak-period pricing might be thought of as *reverse congestion pricing*.[27]

An attractive feature of congestion pricing is, as a NCHRP report explains, that it "encourages motorists to find many ways to reduce congestion rather than promoting only a few" (NCHRP 5). Carpool and transit programs narrowly aim to persuade drivers to switch modes, but congestion pricing provides economic incentives to switch time-of-day, route, location, mode, or frequency of travel. Travelers are given the choice of which tactic to adopt rather than prescribing a particular change in behavior.

Box 1: Japan's Reverse Congestion Pricing Experiment

> Japan's expressway network has a very low utilization rate; the total traffic volume is less than 13 percent of all traffic, compared to 20 percent in the United Kingdom, 21 percent in France, 30 percent in Germany, and 31 percent in the United States. Low utilization of the tolled expressways is blamed on missing links in the expressway network, long distances between interchanges, and the high tolls themselves as the primary reasons why drivers choose toll-free alternative routes. The Japanese government is performing demonstration projects to determine the effects of morning and evening peak-period toll discounts in an effort to encourage drivers to use the toll roads instead of the congested toll-free roads. The goals of the demonstration projects are to improve the roadside environment, mitigate congestion, and promote traffic safety measures (Matsuda, Tsukada and Kikuchi).

Congestion pricing is a way of managing existing capacity to limit the amount of new capacity necessary to maintain traffic speeds and level-of-service. A relatively large share of economic and employment activity often occurs in the central business district (CBD) for developing countries, resulting in a large number of commute trips to and from the city center during the morning and evening periods, respectively. Directional peaking requires additional

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[27] *Reverse congestion pricing* would be analogous to a carrot approach.

capacity to accommodate the peak traffic demand, which makes the incremental cost of accommodating peak-period users much more expensive because infrastructure used for peak and off-peak travel is a joint cost (Box 2).[28]

Box 2: Joint Costs

> Joint costs occur when there is little or no cost to provide a second service once a primary service is provided. An example of a joint cost in transportation is the provision of infrastructure for peak- and off-peak demand. Once a highway is constructed for use during the peak period, it is automatically available for off-peak users at very little or no cost. If a joint cost exists, the costs of the facility should be allocated to the primary service, which is the peak period in this case (Gómez-Ibáñez, "Pricing").
>
> The presence of joint costs in transportation strongly supports the use of congestion pricing. Prices should reflect the costs of provision, and since the majority of the costs are associated with the peak periods, higher prices should be charged during peak periods, i.e., congestion pricing.
>
> Another example of a joint cost is the replacement of an underutilized HOV lane with a HOT lane. From an economic perspective, the underutilized HOV lane is the primary service and all costs associated with the lane should be allocated to the HOV portion of the project. By its nature of existence and underutilization, excess capacity can be provided to LOVs at very little cost.[29]

Despite being a better approximation of the marginal cost of travel than fuel taxes, congestion charging schemes are not true marginal-cost pricing. They are second-best tools traditionally used to manage demand—the degree of MCP approximation depends heavily on the characteristics of the particular scheme.

While pure marginal-cost pricing is not the primary goal of many municipalities, it is important to understand that there are differences between the marginal-cost approximations of policies. Congestion pricing has a higher correlation with the full social costs of vehicle travel than fuel taxes and vehicle excise duties. As seen in Figure 2.4, fuel consumption has little correlation to the social (marginal) cost associated with the amount, type, location, and time of travel. The social cost of congestion and pollution is small in rural areas but can be high in urban areas; this difference cannot be captured with fuel taxes. Congestion pricing is fairer than conventional tolling because it charges drivers who use the roadway at the most congested time

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[28] Higher directional peaking implies that a greater portion of all corridor traffic is traveling in the same direction during a given peak period.

[29] Examples of costs that should be allocated to the toll portion of the HOT lane would be the electronic toll collection infrastructure, toll collection costs, and any other costs above what would be required for HOV lanes.

the highest price, thereby approximating the social cost more closely. Congestion pricing can also charge users different tolls based on vehicle type, allowing externalities and variable costs to be assessed more accurately than with a tax.

User
Cost

MC
AC + Fuel
Tax
AC

Peak Demand

Volume
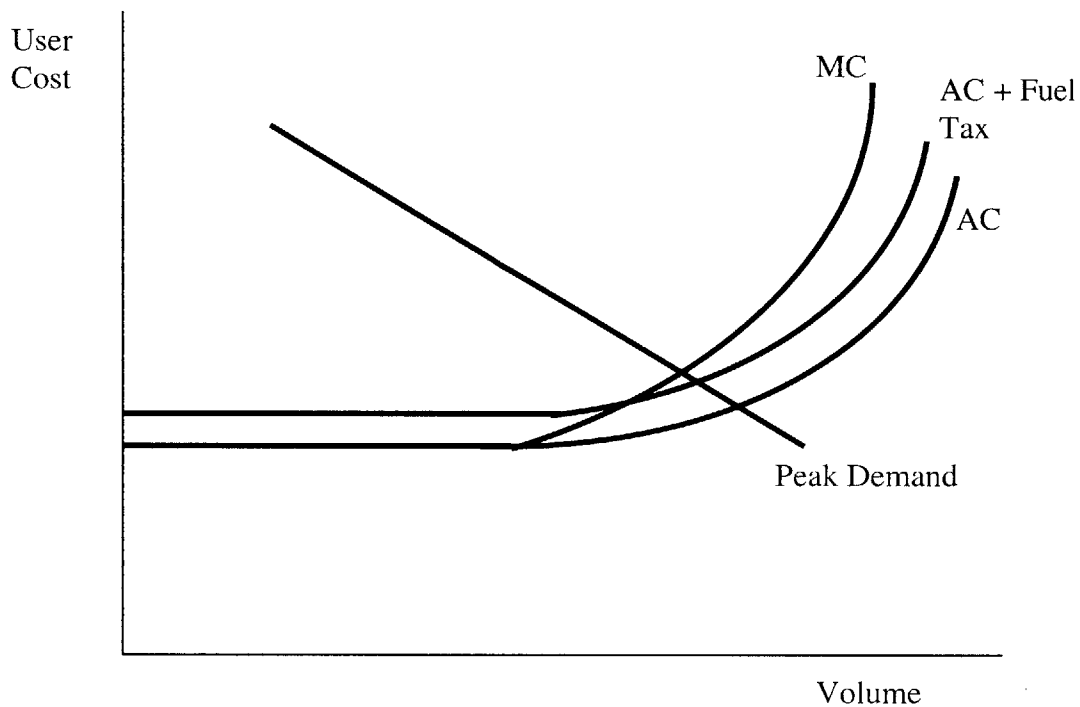
Figure 2.4: Effect of a Fuel Tax

The World Bank (Cities on the Move: A World Bank Urban Transport Strategy Review) cites several reasons why economists have long advocated congestion pricing measures. First, peak-period pricing increases economic efficiency by creating correct incentives over the entire range of dimensions involved in travel decisions, including travel time, choice of destinations, mode of transport, route, etc. Second, congestion pricing applied in the context of a flexible land and property market would create cities with more compact forms, more mixed land use, less resources devoted to spread of the road network into surrounding areas, and more funds available for improving infrastructure in currently urbanized areas. Most importantly, congestion pricing generates revenue instead of creating additional costs like many of the administrative measure alternatives. This potentially substantial revenue source can be used to build additional infrastructure, finance ITS projects, improve socially desirable aspects of the transportation system such as public transportation, or even be used for non-transportation purposes such as

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health care and education. Although most transportation professionals with congestion pricing experience recommend using the revenue to improve auto travel alternatives, the use of the revenue is dependent upon the case-specific legal framework and objectives of the implementing government; excess revenues could theoretically be used for other government programs or returned through lower taxes to the general public.

Congestion pricing can take several forms and therefore unique characteristics of each scheme and location need to be recognized. Chapter 3 and Chapter 4 will identify the attributes of different road pricing measures. There are, however, several common characteristics of "good" congestion pricing systems, which are identified in the following section.

2.3.5.1   Characteristics of 'Good' Congestion Pricing Systems

There are several characteristics associated with a "good" congestion charging scheme. These often include:[30]

- Clearly defined goals;
- Part of an overall transportation strategy;
- Net benefits;
- Hypothecated revenues for transportation improvements instead of general government funds;
- A viable transportation alternative mode or route;
- Reliable and proven technology;
- Easy for visitors and infrequent users;
- Able to accommodate future objectives;
- Ensuring personal privacy;
- Enforceable;
- Consideration of differences between vehicle types;
- Starting simple and being understandable for drivers;
- Effective marketing and educational campaigns;
- Predictable prices so drivers can make appropriate decisions ahead of time;
- Multiple payment options;
- Low administrative costs and burdens;
- Perceived as effective by the public;
- Perceived as fair by the public; and
- Exercising other controls, specifically land-use, in tandem.

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[30] Adapted from: J. Cracknell, Experience in Urban Traffic Management and Demand Management in Developing Countries (World Bank, Department for International Development, UK, 2000).

While many of these criteria relate to choice of technology and implementation, others are quite relevant for this thesis. One of the most important qualities of the tool discussed in Chapter 5 is its focus on helping the decision maker clearly define the overall objectives for road pricing policies. Many times projects are pursued without a clear set of goals, which can lead to implementing projects that have no apparent contribution to an agency's mission.

2.3.5.2   Criticisms and Opposition to Congestion Pricing

Despite the many benefits of congestion pricing and though more cities are considering pricing policies, few schemes have been implemented. The World Bank Urban Transport Strategy Review (Cracknell) cites the following reasons for the lack of congestion charging implementation:

- Political, and some public opposition;
- Failure of transportation planners to present convincing arguments as to the benefits of congestion pricing;
- Legal and institutional constraints associated with direct charging for road use;
- Lack of legal framework for dealing with offenders (e.g., "owner" versus "driver" liability);
- Institutional shortcoming in planning, designing, implementing, and managing a scheme on a continuous basis; and
- Tendency to regard congestion pricing as a "stand-alone" scheme and thus a failure to recognize and develop integrated policies for improved, quality public transportation as an alternative to car use.

In addition to the factors named by the World Bank, congestion pricing has also been opposed because the net financial benefits are not returned to the drivers who pay. Additional questions to consider include: (i) how to distribute the burdens of congestion pricing, (ii) how to use the revenue, (iii) how to cope with the synergetic effects (management of mobility), (iv) how is the natural environment affected, (v) how to overcome technical problems, and (vi) how to manage the political risks. These important issues need to be addressed before a scheme is introduced.

Some critics neglect to consider the benefits gained by other areas of the transportation sector with congestion pricing and that it is usually implemented as part of a package of measures. Others believe there will be an emigration from areas that are priced to areas that are not. Most of these concerns are overstated and can be dispelled with land-use controls.

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Congestion pricing may actually make the city center (if implemented in the form of area-wide pricing) a more attractive place to live for residents that work within the cordon.

2.4 Chapter Summary

This chapter examined the economic foundations and principles of road pricing. There are two primary functions of pricing in transportation: (i) financing infrastructure and (ii) rationing and allocating the use of infrastructure. Much of the focus was on marginal-cost pricing and congestion pricing, which are techniques for achieving the latter function, but these methods can also be used to generate revenue. Many regions stand to benefit by aligning transportation prices more closely to the marginal cost of travel, which would discourage excessive consumption of transportation resources in an economy. Ramsey pricing is another economic strategy used to increase revenue, which is an integral part of some road pricing strategies.

The following chapter categorizes road pricing strategies into six different types and examines the impacts. Real-world examples of the different scheme types are also presented.

3 ROAD PRICING STRATEGIES

3.1 Chapter Purpose and Organization

This chapter defines the different types of road pricing and examines the impacts each may have on areas of concern to decision makers. Individual strategies have different capacities to achieve various policy objectives (e.g., mobility improvement, revenue generation, and environmental improvement), which are also presented in this chapter.

Six types of road pricing strategies are presented first, followed by assessments of how well each strategy can achieve the different policy objectives.

3.2 Introduction

As established in Chapter 1, road pricing refers to when particular road trips, at well-specified places and/or times, are subjected to well-defined charges. The amount of the charge depends directly on the location, time, and/or amount of road travel.

There are several types of road pricing, which include conventional tolling, facility pricing, express lanes (e.g., HOT lanes), area-wide pricing, cordon pricing, network pricing, and distance-based charging; each of these forms will be discussed in the following sections. Road pricing strategies (excluding conventional tolling and distance-based charging) have traditionally been considered for congestion management purposes; however, these innovative forms of road pricing are being evaluated increasingly often for their ability to generate revenue. These strategies also have impacts on other areas of concern to decision makers, which will be detailed in the latter half of this chapter.

3.3 Types of Road Pricing

3.3.1 Conventional (Flat-Rate) Tolling

In what is defined to be *conventional tolling* in this thesis, all vehicles are charged a flat fee to traverse a transportation facility, which is most commonly a road segment, bridge, or

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tunnel. All or a portion of the infrastructure costs are assessed to the facility users rather than to the general tax base—a simple example of the user pays principle. With a flat fee structure, the scarcity of the resource during periods of greater demand is not reflected in the level of the fee, i.e., there is a fixed supply but prices cannot reflect changes in the level of congestion.

Conventional tolling is widespread and exists all over the world. In practice, it is the dominant application of road pricing today. Infrastructure providers have historically used this type of road pricing to finance additional high-speed limited access roads, tunnels, or bridges, which are particularly expensive to provide. Flat-rate tolling can be used for other purposes, however, such as discouraging auto travel. It is a less precise technique for reducing congestion than facility congestion pricing (discussed in Section 3.3.2) because the level of the toll does not change with demand, but the measure can be attractive for its simplicity. If the operating agency does not desire to shift demand to other times of the day, conventional tolling might meet the operator's goals. A major disadvantage of flat-rate tolling (versus other road pricing measures) is that it is a relatively inflexible policy lever.

3.3.2   Facility Congestion Pricing

This thesis defines facility (congestion) pricing to be the strategy where a toll charge is congestion- or time-dependent (i.e., dynamic or variable) and applicable to all lanes of a particular transportation facility.[31] The fee is usually highest during congested periods, reflecting the scarcity of the resource when demand is high. Similar to conventional tolling, there is no free alternative within the facility; drivers must use alternative routes or modes (if available) to avoid the toll. Because this tolling technique uses congestion pricing principles (outlined in Section 2.4), drivers have the option to adjust their time of travel to take advantage of lower tolls than those assessed during the peak period. Facility pricing strives to reduce the fluctuation in facility demand (i.e., spread out the peak period), eliminate unnecessary trips, and/or encourage drivers to change modes.

Facility pricing is most applicable to expressways, tunnels, bridges, or other limited-access transportation facilities. Similar to other forms of road pricing, exemptions and discounts

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[31] While conventional tolling on an expressway is a form of pricing on a facility, *facility pricing* is defined here to refer to tolling where the amount of the charge varies according to one or more time-of-day or congestion-related criteria.

can be targeted toward vehicle groups like HOVs using ITS. One of the benefits of facility pricing is that it provides the facility operator with more flexibility to meet objectives than conventional tolling. While it can be more controversial and it is slightly more complex from a user perspective, facility pricing can outperform conventional tolling in economic and transportation efficiency criteria. It is more attractive from the operator's standpoint because it can generate more revenue and create better utilization of the facility, i.e., it supports an optimal level of investment, by reducing demand fluctuations throughout the day.

3.3.2.1 International Examples

A private toll road company (SANEF) in France introduced facility pricing on an intercity expressway (the A-1) from Lille to Paris in 1992. There are three lanes in each direction and the A-1 is one of the most heavily traveled in France. The variable toll rates increase during peak hours, which occur during Sunday afternoons and evenings when Parisians return home from weekend and holiday vacations. Toll charges are reduced in the off-peak to compensate, making the scheme revenue-neutral relative to the base case.[32] Tolls are approximately 25 percent higher than the normal toll rate for longer trips and as much as 56 percent higher for shorter trips from 4:30 to 8:30 p.m. on Sundays. Before (2:30 to 4:30 p.m.) and after (8:30 to 11:30 p.m.) the peak period, the toll is 25 to 56 percent lower than the normal tariff. The scheme is viewed favorably by the majority of the public and government officials (NCHRP 44).[33]

Other examples of facility-pricing projects can be found in Lee County, Florida; Toronto, Canada; New York/New Jersey; and Seoul, Korea. Lee County gives electronic toll collection users discounts for traveling just before and after the peak period on two bridges, Toronto uses variable pricing on the 407ETR expressway, The Port Authority of New York and New Jersey uses variable pricing on multiple bridges and tunnels, and Seoul uses peak pricing on two tunnels. The author is not aware of any facility pricing examples where the tolls vary dynamically.

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[32] The primary objective of the entity was to improve traffic management and not to increase revenue; revenue-neutrality was viewed as a key in achieving public and government acceptance.
[33] For more information on the A-1 scheme, see: NCHRP, Road Pricing for Congestion Management: A Survey of International Practice (Washington: National Cooperative Highway Research Program (NCHRP), 1994).

3.3.3 Express Lanes (e.g., HOT lanes)

Express lanes charge certain vehicles for the use of dedicated (managed) lanes on an expressway that have a premium level-of-service (LOS). The toll charges are often higher during peak periods for demand management purposes, although the pricing structure can be flat, variable, or dynamic. Charges and regulations often differ between vehicle types. The defining characteristic of express lanes is the availability of a free alternative on the general purpose lanes immediately adjacent to the managed lanes, which all drivers have the option to choose. Express lanes are often separated from the general purpose lanes by a barrier, although some HOT lanes in planning phases (e.g., the SR 167 HOT lane project near Seattle, Washington) do not plan to incorporate barrier separation.

The most widely known form of express lanes is referred to as *high-occupancy/toll lanes*. HOT lanes allow high-occupancy vehicles to travel on the managed lanes of an expressway at a discount or no charge; vehicles that do not meet the HOV criteria, which are low-occupancy vehicles (LOVs), can travel on the managed lanes for a toll.[34] LOVs allowed on HOT lanes typically—but not always—include Single-Occupancy Vehicles (SOVs).[35] In some cases, "preferred" LOVs, such as hybrid fuel vehicles, may be allowed to travel on the lanes at no charge or a discounted fare. Trucks are not given access to the managed lanes, presumably because they cause more congestion and road damage than other vehicles.[36]

HOT lanes are most often considered where existing HOV lanes are underutilized or planned HOV lanes are not expected to utilize all of the lane capacity. From a transportation efficiency perspective, HOT lanes can preserve the benefits of HOV lanes while allowing more vehicles to pass through the same amount of road space.

In an express lane that is not a HOT lane, all vehicles pay tolls (buses may be exempt) and there may or may not be vehicle class restrictions on the lanes. Express lanes with no HOV preferential treatment segment the entire traveling population by willingness to pay, while HOT

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[34] Managed lanes are those on which the vehicles allowed to use the lanes are controlled according to some rules. HOV, HOT, and express lanes are considered managed lanes. Lanes that are not managed are referred to as general-purpose lanes.

[35] The Katy and Northwest freeways in the Houston (Texas) metropolitan area allow two-person carpools to use the HOT lane for USD 2.00 per trip during peak periods while HOVs with 3+ passengers and buses can travel at no charge. SOVs are restricted from using the facility.

[36] Truck toll lanes, a form of managed lanes advocated by the Reason Foundation, are a form of express lanes but are excluded from this discussion.

lanes offer the premium service to preferred vehicles at no charge and segment the LOV population according to willingness to pay.

Because HOV lanes and HOT lanes are both types of managed lanes, the two are often compared. HOT lanes can outperform HOV lanes by many criteria. A comparison between the two types of managed lanes is presented in Table 3.1.[37]

Table 3.1: Comparison between HOV and HOT Lanes

	HOV	HOT
Speed	Maintain free-flow conditions or flow is limited by the number of HOVs using the lanes	Maintain free-flow conditions or flow is limited by the number of HOVs using the lanes. LOVs will not be permitted to use the lanes if near free-flow conditions are not maintained
Capacity	Capacity not used by HOVs is not used	Allow some LOVs to use capacity not used by HOVs
Level-of-Service (LOS) on managed lanes	Determined by the number of HOVs using the lanes	Required to maintain a minimum LOS
Level-of-Service (LOS) on general purpose lanes	Base case	Generally an improvement to the base case due to HOT lanes removing a few vehicles from the general purpose lanes. The incentive to carpool can be reduced, however, which could increase the number of vehicles on the road and potentially increase traffic on the general purpose lanes. Net effect can be mixed or positive
Premium service available to LOVs?	No	Yes
Reliable travel time is available for:	HOVs only	HOVs and LOVs
Revenue	No revenue	Revenue generated by LOVs, which can be used to improve other parts of the transportation system

As noted in Table 3.1, HOT lanes generally retain the transit and HOV benefits associated with HOV lanes, but allow LOVs to use the capacity not utilized by the HOVs, creating numerous benefits. Restrictions on LOV travel and the use of congestion pricing can be placed on the HOT lanes to ensure HOVs do not receive any disbenefits from allowing LOVs to use the managed lanes. In other words, HOVs are not affected negatively by converting HOV lanes to HOT lanes as long as LOV demand on the HOT lanes is controlled such that free-

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[37] Any spillover effects of the managed lanes are ignored.

flowing conditions persist—controlling demand is the role of pricing. Tolls are either adjusted dynamically, variably, or set at a high-enough level such that delays do not occur on the managed lanes.

When considering a single facility in isolation, the benefit of HOT lanes over HOV lanes is reduced as congestion grows. HOV lanes may actually reduce traffic volumes more than HOT lanes when congestion is heavy because HOT lanes create fewer incentives to carpool. Similarly, the inferiority of an express lane (with no preferential treatment for HOVs) relative to HOT lanes increases with the level of congestion. The key question is how many drivers will not carpool if an express lane is available, but would carpool if there were merely HOV lanes.[38] Assuming some drivers are willing to carpool in order to receive preferential service, Figure 3.1 illustrates the economic superiority of the different types of managed lanes.
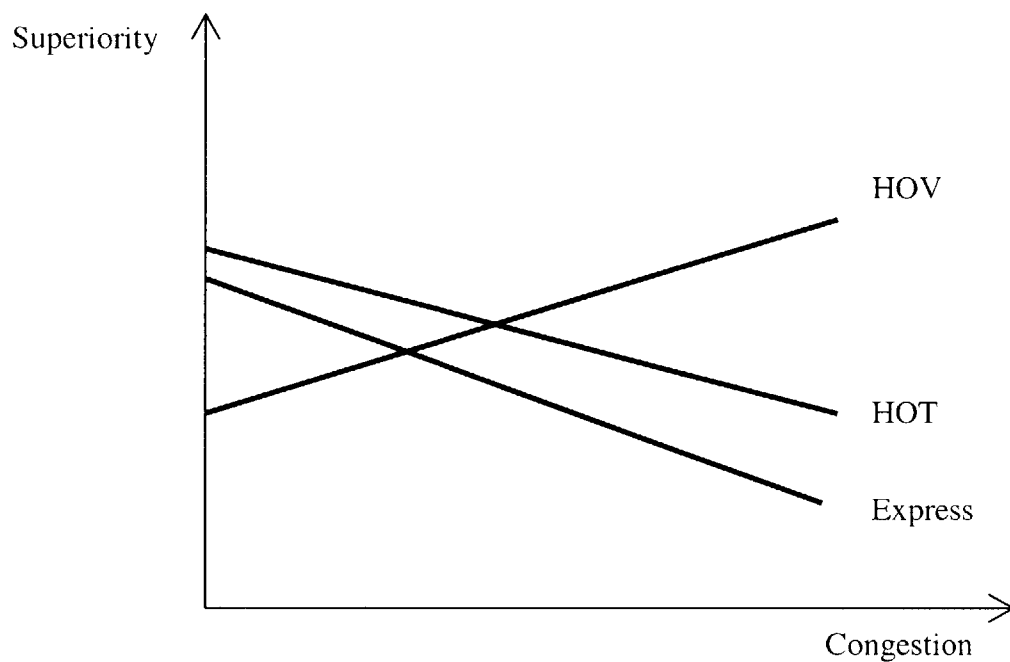
Figure 3.1: Superiority of Different Managed Lanes

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[38] The extent of any impact is unknown.

Currently, the network effects of HOT and other express lanes are unknown and there are not any HOT lane networks in place, although this concept is advocated strongly by the Reason Foundation.[39]

Although several HOT lane schemes have been implemented, which will be discussed in Section 3.3.3.1, and many more are being planned, HOT lanes have not been adopted on a larger scale in the U.S. primarily due to political opposition resulting from the perception of HOT lanes as "Lexus lanes" used only by the wealthy. The common argument against HOT lanes is that the majority of the benefits go to the people with the highest values of time (usually perceived as wealthy individuals), while people with lowest values of time are forced to sit in congestion on the general purpose lanes. Despite these arguments, HOT lanes are growing in popularity because:

- HOT lanes are believed to improve traffic flow for all users because they transfer vehicles off the general-purpose lanes and into the unused capacity of the HOV lanes; and
- Strained budgets have recognized HOT lanes as an additional source of revenue that can be used to finance additional capacity and transportation services.

The second point likely has been a greater impetus for increasing the number of planned HOT lanes, while the distribution of the benefits noted in the first point is still being debated as to whether the lanes are indeed equitable. Studies based on the SR91 facility in California have shown that drivers from all income groups use the lanes, but higher-income drivers use the priced lanes more often. Nearly half of the SR91 toll lane users, however, drove the lanes once per week or less (Sullivan, cited in TCRP 23). The large number of drivers who use the priced lanes infrequently implies that many drivers only use the lanes for certain high-value trips; these drivers value having an *option* for high quality and reliable service.

The segmentation of the market into two distinct groups—those willing to pay for a premium level-of-service during a particular trip and those who are not willing to pay—is both an asset and a liability for public support of HOT lanes. Some travelers view it as a way to ensure reliable travel times, while others are opposed to HOT lanes on ideological grounds. The latter group believes public agencies should strive to increase capacity and improve travel times for all travelers.

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[39] For more information, the reader is referred to: http://www.rppi.org

There are a number of challenges for HOT lanes—especially in developing countries. Enforcement can be an issue in any country and may be more difficult if a physical barrier does not exist between the managed lanes and the general-purpose lanes. Additionally, developing countries have a high level of paratransit services, which may create excessive demand for HOV lanes.

3.3.3.1 International Examples

Thus far, HOT lanes are strictly a U.S. phenomenon. This may be because the United States seems to suffer from a different type of congestion than that which ails the majority of the world. The U.S. has a large urban freeway system that is frequently congested in many large- and medium-sized metropolitan areas, while congestion in other parts of the world is often characterized as "urban gridlock," where city streets are the most congested.

Express lanes exist on San Diego's I-15 freeway, Houston's Katy Freeway, and Orange County's (California) SR91 Freeway. The I-15 project, denoted as FasTrak, converted two 8-mile underutilized reversible HOV lanes to HOT lanes in December 1996. The lanes originally sold monthly passes to SOVs on a first-come, first-serve basis, but converted the scheme to dynamic pricing in March 1998. The toll rate can be adjusted in real-time as often as every six minutes and depends on the level of congestion in the general-purpose lanes. Tolls range between $0.50 and $4.00 under normal traffic conditions, but can be as high as $8.00 during severe traffic congestion (TCRP 14-54). Toll rates are communicated to drivers through variable message signs before the entrance to the separated HOT lanes.

The goals of the I-15 project were to maximize use of the existing HOV lanes, fund new I-15 corridor transit and HOV improvements, test whether allowing priced SOVs to use the HOV lanes can help reduce freeway main line congestion, and set tolls on the basis of a market-based approach (TCRP).[40] The project appears to have met its goal of maximizing use of the existing HOV lanes:

- The number of vehicles using the managed lanes increased by 46 percent from October 1996 to April 1999 (from 9,200 to 13,500 average daily vehicles);

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[40] According to the Phase II Year Three Overall Report.

- In the a.m. peak hour, the HOT lanes carried 2,300 - 2,400 vehicles per hour at free-flow speeds in late April 1999, compared to 1,600 vehicles per hour in October 1996; and
- As of April 2000, FasTrak use of the Express Lanes comprises about 21 percent of total vehicles on the lanes. (FHWA)

I-15 has had the greatest success of all HOT lane projects in promoting transit patronage (FHWA). A new express bus service, the *Inland Breeze*, was funded with revenues from the project. The Inland Breeze connects the San Diego light rail transit to a transit center and has 30-minute and 60-minute service headways during peak- and off-peak periods, respectively. In April 1999, ridership averaged 525 passengers per day, short of the goal of 750 daily riders (FHWA). The new bus service attracted more reverse commute riders than riders traveling to San Diego, to the surprise of the HOT lane planners.[41] The Inland Breeze has improved bus service for existing transit users, but it has not attracted peak-direction travelers from the general-purpose lanes (FHWA). I-15 corridor bus ridership grew nine percent between fall 1996 and fall 1999, compared to a 23 percent growth for the entire San Diego Region (TCRP 14-56). While FasTrak improved bus service in the corridor, the results indicate few transit ridership impacts materialized with the express bus service.

No major changes in travel speed or travel time were recorded on either the HOT lanes or the general-purpose lanes (TCRP), which suggests any potential benefits for the general-purpose lanes were indistinguishable.

The majority of the increase in HOT lane traffic was from carpools, which grew by 30 percent from October 1996 to April 1999 (from 7,685 to 9,970 average daily HOVs). Carpools increased primarily during the monthly pass phase of the program and peaked during the first month of FasTrak operation at about 10,500 average daily vehicles. Several reasons have been suggested for the increased carpool usage on the facility. First, pricing provides a more tangible sense of the cost savings from carpooling, since carpools travel free and solo drivers must pay to use the HOT lanes. Second, increased enforcement by the California Highway Patrol encourages solo driver violators to become carpoolers (avoiding the risk of a high fine for a modest payment). Third, it has been speculated that HOT lanes allow more flexible carpooling

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[41] The a.m. peak-period bus ridership in March 1998 was 59 and 99 bus boardings southbound (toward San Diego) and northbound (reverse commute direction), respectively. TCRP, Road Value Pricing (Washington: Transportation Research Board, Transit Cooperation Research Program (TCRP), 2003).

arrangements, with commuters increasing their willingness to commit to becoming carpool members because they know the same time-savings will still be available, for a fee, on days when carpool members are not available (FHWA).

Most FasTrak customers do not travel on the HOT lanes on a daily basis. From April through September 1998, 53 percent of people with FasTrak transponders used the lanes one to five times a month, 18 percent used them six to ten times, 11 percent used them 11-15 times, and 19 percent used them 16 to 40 times (TCRP 14-55).

Support for the I-15 HOT lanes is high. A public opinion survey conducted in late 2001 revealed overwhelming support for the HOT lanes including operating policies, toll rates, use of revenues, and proposals for facility extension. These results were relevant across user and non-user, and socio-economic groups (TCRP 14-57). The lanes are being extended to create a 20-mile facility, and "when completed, there will be a four-lane facility in the median with a moveable barrier, multiple access points from the regular highway lanes, and direct access ramps connected to five bus rapid transit (BRT) centers. An overhauled high frequency BRT system will be operated in the managed lanes, taking advantage of the travel time savings offered by the [l]anes" (Highway Communication Exchange).

The SR91 project essentially added a pair of HOT lanes in each direction along a 10-mile stretch of the freeway, but the variably-priced lanes are technically an express roadway built in the median of an existing eight-lane freeway that offers discounts to select vehicles.[42] For the purposes of this thesis, the SR91 lanes will be referred to as HOT lanes. The HOT lanes were opened in December 1995; the facility has a pre-determined toll schedule, which varies by time-of-day and day-of-the-week. In 1996, tolls ranged from $0.25 (off-peak) to $2.50 (peak) and gave toll incentives to HOV-3s (TCRP). In 2005, tolls range between $1.05 and $7.00; HOV-3s, zero emission vehicles, motorcycles, disabled plates, and disabled veterans are permitted to drive free of charge on the 91 Express Lanes during most hours, but must pay 50 percent of the toll during the most congested hours of the week (OCTA, 91 Express Lanes Homepage).[43]

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[42] The 91 Express Lanes were originally owned and operated by a private company, but were expropriated by the Orange County Transportation Authority because of public complaints regarding a no-competition clause in the agreement. The project was expected to cover all capital and operating costs by the sixth year.

[43] According to OCTA (91 Express Lanes Homepage), "The exception that these users pay 50 percent remains in effect until such time as the Debt Service Coverage Ratio—inclusive of senior and subordinated debt—is projected to be 1.2 or greater for a six month period."

SR91 was one of the most congested freeway sections in California before the express lanes were constructed with typical peak period delays of 20 to 40 minutes (OCTA, 91 Express Lanes Homepage). The lanes have reduced delays for all users in the corridor, although continued traffic growth is reducing some of the delay savings on the general-purpose lanes that was created with the construction of the SR91 express lanes. The HOT lanes carry 40 percent of the freeway's traffic at three to four times the speed of non-toll lanes during peak periods (Wylie).

Nearly half the SR91 customers use the express lanes once a week or less. Only 25 percent of those in the lowest income group (less than $25,000 annual household income) indicate that they frequently use the express lanes (FHWA). Female commuters are significantly more likely than male commuters to be frequent users of the express lanes, which may be due in part to having more child-care responsibilities.

The Houston HOT lane project, entitled *QuickRide*, allows HOV-2s to travel on the Katy Freeway and Northwest Freeway HOV lanes, which have an HOV-3 requirement, during peak periods for a $2 toll.[44] Both the Katy Freeway and the Northwest Freeway have a single HOV lane in the median of the roadway. Before QuickRide began in 1998, the HOV criterion was increased from HOV-2 to HOV-3 due to excessive demand, but there was much unused capacity during the peak period with the new HOV-3 occupancy requirements. The HOT lanes sell this excess capacity to HOV-2s, maintaining the high level-of-service associated with HOV lanes and allowing more vehicles to use the managed lane capacity.

As with other HOT lane projects, the vast majority of QuickRide users are occasional users, with about one in four transponders being used in a given week, and about one in 20 transponders being used five or more times per week (FHWA). HOV utilization increases modestly during the peak, and the most common source of QuickRide participants are persons who formerly traveled in SOVs on the general-purpose lanes (FHWA).

The goals of the Katy Freeway portion of QuickRide are "[t]o use the HOV lane to help manage congestion during multi-year construction and prepare the public for the transition to toll-managed lanes in the future" (TTI 1). Daily use of the HOT lanes is small—between 150 and 200 vehicles use QuickRide for both peak periods combined (FHWA)—so if the intent of the HOT lane is to manage congestion, that is not occurring. The explicit statement of the

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[44] The Katy HOV lane is 13 miles in length.

objective to "prepare the public for the transition to toll-managed lanes in the future" may actually be the highest priority of its advocates. While some HOT lane promoters are hesitant to make this statement, the author believes this is one of the principle reasons, if not the principle reason, why many agencies and transportation analysts are pursuing HOT lane plans. Despite their inferiority from traffic management and revenue generation perspectives, HOT lanes are a more incremental approach to tolling existing capacity than other forms of road pricing, making them less controversial. This wider implication of HOT lanes, i.e., as a step toward increased tolling, may be responsible for some opposition to HOT lanes by special-interest groups.

3.3.4   Area-Wide and Cordon Pricing

Area-wide pricing charges vehicles a fee for crossing a cordon surrounding a defined area, driving within the area, parking on public roads inside the area, or a combination of these measures. It can essentially be a form of network pricing (discussed in Section 3.3.5) operated on a sub-geographic road network of the metropolitan area, although the fee assessment can be structured in different ways. Vehicles can be charged a single fee for traveling in a geographic area within a given time period (e.g., $5 per day), the toll can vary by time-of-day (e.g., $4 between 8:00-9:00 a.m. and $3 between 9:00-10:00 a.m.), or the toll can vary in real-time with the level of congestion. Area-wide pricing allows transportation managers to target congestion in a specific geographic area. It is typically best suited for the central business district (CBD) of a city or other major activity centers that have difficulty accommodating large numbers of trips during peak periods, which is why this form was chosen for use in Singapore and London.

Cordon pricing is a form of area-wide pricing—it is probably the most practical and understandable congestion pricing scheme. Depending on the objectives of the agency, charges can be levied each time a vehicle crosses a cordon, each time a vehicle enters a cordoned area, or once for unlimited crossings within a set time interval. Using this definition, all cordon pricing schemes are also area-wide pricing, but some area-wide pricing schemes involve more than just pricing a cordon. Cordon gantries can also be placed on heavily congested transportation facilities; however, for the purpose of this thesis, transportation cordons located on expressways are defined to be facility pricing. An exception is made when the cordons are arranged in a polyhedron around a geographic area, in which case the term cordon pricing would still be applicable.

3.3.4.1 International Examples

The Singapore Electronic Road Pricing (ERP) scheme is a form of cordon pricing that was introduced in September 1998. It replaced the paper-based Area Licensing Scheme (ALS), which was initiated in 1975 and the Road Pricing System that began in the 1990s. The ERP is a cordon scheme (covering about 720 ha) inside the ring road of the city. It uses a 2.54 GHz dedicated short-range radio communication system consisting of an In-vehicle transponder Unit (IU), ERP gantries, and a control center. Vehicles are equipped with an IU that accepts smartcards and each IU number correlates to an individual vehicle registration number. As of 2000, 97 percent of the total vehicle population was equipped with the $120 IUs, which were given to existing vehicle owners free of charge by the Singapore government (Menon).

Each time the vehicle passes under one of 29 overhead gantries at entry points to the Restricted Zone (RZ) between 7:30 a.m. to 7:00 p.m. on weekdays, the vehicle is charged a fee (ranging from S$0.50 to S$2.50 for cars with other fare structures for different vehicles) based on the time of day. There are also twelve additional gantries along congested expressways and other main roads, which are a form of facility pricing; these gantries are in operation only during the morning peak period (7:30 a.m. to 9:30 a.m.) on weekdays. The ERP fee is pre-determined for each half-hour interval during the day and charges increase during the peak periods. Digital images of the rear license plate are recorded for vehicles not possessing an IU, smartcard, or sufficient funds. This information is then sent to the control center where the information is stored for violation reference.

The London CC scheme introduced in February 2003 is an area-wide pricing scheme. The Central CC zone encompasses the 22 square kilometers inside the London Inner Ring Road commonly referred to as central London. Drivers are required to self-report (through various payment options) one £5 fee for unlimited entries, exits, travel within, and on-street parking for the charging period, which is 7:00 a.m. to 6:30 p.m., Monday through Friday, excluding holidays. As shown in Table 3.2, Transport for London estimates the scheme produces £50 million in net annual benefits.

Table 3.2: Estimates of Benefits and Costs of London CC Scheme[45]

ANNUAL COSTS	(£ millions)
TfL administrative and other costs	5
Scheme operation	90
Additional bus costs	20
Charge-payer compliance costs (telephone calls, etc.)	15
TOTAL	130
ANNUAL BENEFITS	
Time savings to car and taxi occupants, business use	75
Time savings to car and taxi occupants, private use	40
Time savings to commercial vehicle occupants	20
Time savings to bus passenger	20
Reliability benefits to car, taxi, and commercial vehicle occupants	10
Reliability benefits to bus passengers	10
Vehicle fuel and operating savings	10
Accident savings	15
Disbenefit to car occupants transferring to public transport, etc.	-20
TOTAL	180
NET ANNUAL BENEFIT	**50**

The London scheme will be modified beginning July 4, 2005. Several changes are planned to take effect, which are outlined in Box 3.

Both London and Singapore had a relatively low share of trips using personal automobiles for traveling to the CBD before the schemes were implemented. As a result, public support was higher because the group of individuals driving in the congestion priced zone, which is typically in opposition before a scheme is implemented, was small and composed of wealthier individuals. In fact, 90 percent of those driving into central London before the scheme was implemented were from the wealthiest half of society (EFTE).

As with other congestion charging schemes, area-wide pricing cannot solve long-term traffic problems by itself—it must be part of an integrated strategy to alleviate congestion and improve travel alternatives. London is spending all of the net revenues on local transportation improvements; additional buses have been added to the CC zone, improvements are being made to the Underground subway, and traffic flow improvements have been made on roads surrounding the CC zone in order to accommodate the additional traffic (Transport for London,

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[45] Source: Transport for London, Central London Congestion Charging Scheme - Impacts Monitoring, Second Annual Report (London: Transport for London (TfL), 2004). Payment of the charge is not included in the benefit/cost analysis because transactions are economic transfers.

Central London Congestion Charging Scheme - Impacts Monitoring, First Annual Report).

Marketing the idea of using CC revenues to improve other transportation facilities and services

has been credited with contributing to the public relations success of the scheme. The scheme

has been viewed so positively that a western extension to cover most of Kensington & Chelsea

and Westminster has been proposed.

Box 3: Changes to the London Congestion Charging Scheme

> Ken Livingston, the Mayor of London, announced several changes to the London CC scheme in an April 1, 2005 press release (Transport for London, "Press Release - Congestion Charge to Increase to £8; Fleet and Regular Users to Receive Discounts") to take effect July 4, 2005. With these changes, the congestion charge will increase from £5 to £8, the charge for vehicles on the fleet scheme will increase from £5.50 to £7, three charge-free days will be given for a monthly payment (i.e., 20 days for the price of 17 days), and 40 charge-free days will be credited for an annual payment (i.e., 252 days for the price of 212 days) of the congestion charge. According to the Mayor:
>
> *"The charge increase will maintain the benefits currently witnessed in the zone and build upon its success, cutting congestion even further, and raising more revenue to be invested in London's transport system...This will build on what has already been achieved in terms of extended bus provision, and in due course by providing additional underground capacity. At the same time, a number of measures will reduce the hassle of paying the charge....large discounts on monthly and annual payments will make the charge easier to pay for regular users and should lead to fewer penalty charge notices being incurred by drivers who forget to pay the charge."*

3.3.5 Network Pricing

Network pricing is the purest form of congestion or marginal-cost pricing, i.e., it is *first-best* pricing. With network pricing, individual vehicle movements are tracked through the entire

road network in the region and charged based on the congestion of the traveled links or the time

of travel. The charges could be predetermined based on a formula for the road and/or time-of-

day but they could also be assessed based on real-time conditions. Other externalities could also

be incorporated into the toll charge, if desired.

Technology could be adapted to implement network-pricing measures, which would most

likely occur with a form of Global Positioning Systems (GPS). Political obstacles, some

remaining technological challenges, and the complexity of network pricing are likely to be

overwhelming, however, without more real-world road pricing experiences for people to become

comfortable with the concept of paying for road use based on time-of-day and location. If one considers the criteria of a good congestion pricing scheme listed in Section 2.3.5.1, it is not surprising that network pricing has yet to be implemented. When technology improves and if public perception becomes more favorable toward pricing, network pricing may be considered a realistic alternative.

If network pricing were analyzed by a region, political economy considerations would suggest that it be implemented in conjunction with other measures. There would not be a free alternative route for autos in network pricing; if travelers believed they could not afford the charge, they would be forced to take public transportation, use non-motorized alternatives, or not make the trip.

3.3.6   Distance-Based Pricing

As one might anticipate from the term, distance-based pricing requires vehicles to pay charges that are based on the number of miles traveled. Distance-based pricing, or vehicle-miles-traveled (VMT) charging, is primarily a revenue-generation mechanism because the fees do not vary spatially or temporally; therefore, distance-based pricing does not address urban congestion directly. It is similar to network pricing in that all roads are priced, but it differs in that the amount levied does not depend on when or where travel occurs. If distance-based pricing were used in conjunction with congestion pricing, the scheme would be network pricing.

VMT charging is most often considered as a means for agencies to charge motorists using their infrastructure, but whose fuel (and licensing) tax revenues do not contribute sufficiently to the region. Some government entities in the United States, such as the state of Oregon, are considering a distance-based charging policy to replace the state fuel tax.

While distance-based charging may be used to generate large sums of revenue, it would be expensive to administer on a large-scale for passenger vehicles. Means for charging every vehicle traveling in the region would have to be in place, which could be difficult to enforce and would require an exhaustive billing system.

3.3.6.1   International Examples

The only known examples of distance-based charging to date are located in Europe and are applicable to only intercity heavy goods vehicles. Switzerland introduced a scheme in 2001 as did Austria in 2004, but the largest and most sophisticated system is in Germany. Germany introduced a distanced-based truck charging system, Toll Collect, in January 2005. Germany is located in the geographic center of Europe and has experienced a rapid growth in the volume of freight traffic on its motorways. There are approximately 22.7 billion vehicle-kilometers per year subject to tolls on the federal road system, 35 percent of which are made by foreign vehicles (Ruidisch). Due to the maintenance and capacity costs associated with increased traffic— particularly road damage due to heavy vehicles—the federal government decided to implement a distance-based charging scheme applicable to all heavy commercial vehicles and vehicle combinations with a permissible total weight of 12 tons or more (Toll Collect).   The public-private partnership contract was awarded to the Toll Collect consortium, which is made up of carmaker DaimlerChrysler, Deutsche Telekom AG (Germany's largest network operator), and the French motorway operator Cofiroute. The scheme is expected to generate more than $4 billion annually. The government plans to reinvest a large portion in the nation's road, rail, and waterway transportation infrastructure (Blau).

The Toll Collect system uses a combination of GPS and mobile communications technologies. A computerized on-board unit (OBU) installed on a truck locates the vehicle, tracks its route, calculates the toll fee, and transmits the data to a billing center. One of the major points touted by Toll Collect is that it does not disrupt traffic flow.

The toll charge per unit distance is based on the route traveled, the number of axles on the vehicle, and the pollution class of the vehicle or vehicle combination. This is important to note as it shows that the German government has adopted multiple criteria for this project; notably (i) cost-recovery for financial impacts associated with road use and (ii) protection of the environment. Toll rates range between €0.09 and €0.14 per kilometer.[46]

Enforcement is handled by the Federal Office for Goods Transport (BAG). BAG has the ability to determine if a vehicle has an obligation to pay the toll and if that vehicle has met this obligation fully, partially, or not at all. "The control system distinguishes between automatic

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[46] Toll rates can be found at http://www.toll-collect.de/pdf/en/mauthoeheverordnung.pdf;jsessionid=F27DB1064AB1E3893FEECC3EAE49990F.

enforcement through control bridges, enforcement by stationary and mobile teams, and company-level enforcement. This combination guarantees comprehensive, continuous enforcement of the requirement to pay toll[s] and allows the control system to be constantly adjusted to meet prevailing circumstances" (Toll Collect). There are approximately 300 control vehicles nationwide for mobile enforcement, which use infrared technology to determine whether passing trucks are logged onto the automatic system and if their vehicle information has been entered properly.

Until the deployment of Toll Collect, GPS was not considered mature enough to be a realistic toll collection option. Toll Collect had many difficulties deploying the system; in fact, DaimlerChrysler and Deutsche Telekom each lost a large sum of money due to delays in delivering the technology. At the time, Deutsche Well referred to Toll Collect as "Germanys biggest embarrassment" (Samuel). Once it was in place however, general trials of the system achieved a 99.3 percent accuracy rate (Samuel). The resulting technology advances are likely to benefit many regions around the world in the future.

3.3.7 Section Summary

This section defined several forms of road pricing and cited international examples of each form (if applicable). It also explained some of the principle impacts and common goals associated with each road pricing scheme. The following sections will further discuss the capacity of road pricing strategies to achieve policy goals, such as mobility improvement, revenue generation, air quality improvement, etc.

3.4 Capacity to Achieve Policy Objectives

Each road pricing measure has a different capacity to achieve policy objectives; for example, distance-based charging may be able to generate large sums of revenue, however, it might not be the most effective tool for improving mobility. This section describes the relative strengths of each road pricing measure.

3.4.1   Finance

As Gómez-Ibáñez states, the general public's primary interest in road pricing is for its potential to finance additional highway capacity. In the late 1980s and early 1990s, virtually all new tolling cases in the U.S. were sold to the public as a means to finance the construction of a new highway, bridge, or tunnel (Gómez-Ibáñez, "The Political Economy of Highway Tolls and Congestion Pricing"). Suburbs and population growth areas, such as the Sun Belt region of the United States, are especially more likely to view road pricing as a financing mechanism rather than a tool for achieving other means. Because many users want to feel like they are receiving something for the tolls they pay, the hypothecation of revenues for transportation (discussed in Appendix A2) is often viewed as necessary for public support. The potential for a pricing scheme to generate net revenues, therefore, is an important criterion for many entities that are considering road pricing.

3.4.1.1   Revenue Generation Potential

The level of the charge, quality of alternative routes and modes, socio-economic characteristics of potential users, and method of levying tolls are major factors in the gross revenue equation of road pricing schemes. As will be discussed in Section 4.3.3, the amount of revenue generated is highly site-specific and dependent on the specific design characteristics of the scheme.

Generally speaking, network pricing would generate the most gross revenues for a congested metropolitan area. Depending on the amount and type of traffic traveling within and across a cordon zone, area-wide and cordon pricing could also generate substantial revenues. If a large percentage of all traffic traveling within a cordon zone does not cross the cordon line, an area-wide scheme may generate more revenue than a cordon scheme. Whether the area-wide toll is a single daily charge or if it is assessed each instance a vehicle enters and/or leaves the charging zone may also greatly influence the results.

Conventional tolling can be used to generate revenue, but facility pricing can generate more revenue if travel demand is relatively inelastic, which it is in most instances.

With staunch public opposition to raising the fuel tax at the federal and state levels, some state DOTs are considering express lanes as a means to generate additional revenue, which can be used to either finance additional capacity or subsidize transit.

Anecdotal evidence suggests some transportation professionals believe express lanes, most often in the context of HOT lanes, can be fully or mostly self-financing; however, revenue calculations might suggest otherwise for many metropolitan areas. The Reason Public Policy Institute (RPPI), one of the original advocates of HOT lanes, performed an order-of-magnitude estimate of the financial feasibility of HOT lanes for the Los Angeles County area. In one scenario of this study, it was assumed that congestion lasts six hours per day, five days per week, and 52 weeks per year. The study also assumed that LOVs (in this case, all vehicles with less than three persons) pay 20 cents per mile (1993 dollars) to use a HOT lane, the lane carries 1,750 vehicles per hour per mile, and 70 percent of the vehicles are LOVs subject to the charge. In this case, annual revenue per lane-mile were estimated to be $382,200 (Fielding and Klein). Assuming the capital costs of HOT lanes were $5 million per lane-mile (in 1993 dollars), gross revenues would return only 7.6 percent of the construction costs per year to investors. "This is not a sufficient return to attract debt or equity investment, nor does it account for operating (e.g., electronic toll-collection) and maintenance expenses" (Fielding and Klein). This study's authors believed conditions in some corridors of Los Angeles County would be more favorable than the congestion level assumed in this scenario, but it could be argued that traffic is less severe for many potential HOT lanes in the U.S., which would imply that only a few could be financially self-supporting, if any.

Express lanes with bus rapid transit (BRT) should generate more revenue than HOT lanes. The HOT lanes revenue paradox is that as congestion increases demand for the lanes increases, creating a toll charge raising effect (i.e., with fixed supply, increases in demand raise prices). A counteracting effect, however, is that drivers have more incentive to form HOVs, which fill-up the lane and decrease the number of toll-paying customers. Without guarantees on the percent of traffic that will be subjected to tolls, financial institutions are not likely to provide capital for HOT lanes. Express lanes with BRT are more likely to be financially viable than HOT lanes.

As discussed in Section 3.3.6.1, perhaps the primary objective of Germany's distanced-based truck charging system, Toll Collect, is revenue generation. Thirty-five percent of the

vehicle-kilometers subject to tolls on the federal road system are foreign trucks. Much of the revenue that would be received from traditional funding sources, such as vehicle licensing fees and fuel taxes, is lost because these are not German-licensed vehicles. The scheme, which collects tolls from domestic and foreign vehicles alike, is expected to generate more than $4 billion annually, of which the government plans to reinvest a large portion in the nation's road, rail, and waterway transportation infrastructure (Blau).

3.4.2 Mobility

Congestion pricing strategies are often used to reduce congestion, which increases mobility of the priced facilities or geographic area. These measures can reduce travel time delays and potentially increase the reliability of travel times.

3.4.2.1 Travel Time

Road pricing measures that target congestion specifically, such as network pricing, area-wide pricing, facility pricing, and HOT lanes, decrease travel times for the users that pay the toll.[47] Measures that affect a larger percent of metropolitan-area trips, such as network pricing, will decrease travel times more than measures that are limited to a specific corridor or area because they encourage fewer and shorter trips.

If a high percentage of trips on an expressway are traveling to the CBD, area-wide or cordon pricing in the CBD may also be able to reduce congestion on the expressway. Although the results of these measures will likely be less dramatic than what would occur with implementing facility pricing or conventional tolling, these measures should be considered as policy levers for achieving the same effect. Similarly, facility pricing and conventional tolling on existing capacity can also reduce travel times in the CBD, but not to the extent that should occur with area-wide or cordon pricing.

Assuming a similar toll structure, area-wide pricing will reduce CBD congestion more than a cordon scheme if a non-negligible percent of vehicle trips using the CBD are internal trips. In other words, if drivers are only charged for crossing a cordon and there are many

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[47] Road pricing strategies that do not target congestion directly but may discourage some trips, such as distance-based charging, may also reduce travel delays because of fewer vehicles on the road.

vehicle trips that can drive within the cordon that would not be subjected to a toll, cordon pricing may be a less effective congestion management tool than area-wide pricing because it does not charge travelers to operate a vehicle within the zone.

Pricing can also cause negative effects on substitute facilities. If an expressway is priced and there are less expensive alternative travel routes, diversion may increase travel times on the alternative roads. Similarly, area-wide or cordon schemes may increase travel times on ring roads if traffic that otherwise would travel through the area is diverted around it. If implemented on a large scale, a network of HOT lanes could also increase travel times within the downtown if they increase the mobility of the CBD and encourage more trips.

3.4.2.2   Reliability

As will be discussed further in Chapter 4, reliability of travel times is an increasingly important transportation variable. With some indications suggesting that travelers are willing to tolerate increasing congestion, perhaps transportation providers should focus more attention on increasing the reliability of the road system.

It is clear that travelers value travel time reliability. One study found that individuals value travel time reliability more than twice as much as travel time savings (Small et al. 3). On the SR91 HOT lanes, a recent econometrics study estimated travel time accounts for two-thirds and reliability one-third of the service quality differential between the free and priced SR91 lanes (Brownstone and Small).

While pricing can increase reliability on a priced facility, it can also decrease reliability on alternative facilities if it causes diversion. Similar to the effects mentioned in Section 3.4.2.1, implementing road pricing on some facilities could decrease the reliability of travel times on less-expensive substitute facilities. Diverted vehicles increase congestion non-linearly, which may cause travel times to fluctuate more day-to-day.

3.4.2.3   Reliable (and Lower) Travel Time Option

HOT lanes create a reliable travel time option (with lower average travel times as well) for expressway travelers. When an individual is behind schedule and has strict penalties for arriving late—such as in a trip to the airport—he/she may have a high value of time and/or high

value of reliability.[48] Orski and Small refer to this as "travel insurance," and claim that other users would also gain because the general-purpose lanes would become less congested as some of the traffic switches to the express lanes.

As noted in Section 3.3.3, many HOT lane travelers are infrequent users that only use the lanes for special circumstances. Similarly, most businesses in the service industry, such as a plumber that can charge $30/hour, also have high values of time. These transportation customers are likely to choose HOT lanes because they value the higher quality service that express lanes offer. A two-tiered transportation system—offering standard-quality yet free services and premium for-payment services—recognizes that travelers are customers and different customers have different travel needs.

If one defined the system to be the corridor rather than the expressway, facility pricing would also be a more reliable and faster travel time option. Arterials would be the standard level-of-service and the priced expressway would be the premium option.

3.4.3 Natural Environment

The main impact of congestion pricing on vehicle emissions is expected to be effects on vehicle operating speeds, speed variations, and VMT (TCRP). Vehicle speeds should increase for a facility if congestion pricing measures are implemented. The extent of the increase in average speed will be site-specific and dependent in part on the level of the tolls, price elasticity of demand, design speed of the facility, and average speed before tolls were added or changed.[49]

3.4.3.1 Air Quality

There are six criteria pollutants for air quality, of which motor vehicles contribute to four. Motor vehicles emit nitrogen oxides (NOx) and volatile organic compounds (VOCs), which combine in sunlight to form ozone; carbon monoxide (CO); nitrogen dioxide (NO$_2$); and particulate matter (PM-10). The health effects of these pollutants include headache, eye

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[48] These concepts are discussed in greater detail in Chapter 4.

[49] The price elasticity of demand represents the sensitivity of consumers to price changes. In the case of road pricing, it represents the sensitivity of drivers to change in perceived out-of-pocket cost. A price elasticity <-1 represents elastic behavior, meaning that for a 1 percent increase in price there will be a >1 percent decrease in traffic. For inelastic behavior, which occurs if the price elasticity is >-1 and <0, there will be a <1 percent decrease in traffic for a 1 percent increase in price. Demand for automobile travel is often considered inelastic.

irritation, reduced lung function, lung damage, respiratory disease, and cancer. According to the American Lung Association (cited in ICF Incorporated 4), the health effects of air pollution in the United States alone are estimated to cost $50 billion per year.

The pricing structure of a scheme could theoretically be linked to the air quality of a metropolitan area, but air quality emissions more closely correlate to the number of cold starts and vehicle hours than the level of congestion. While congestion pricing can create incentives to decrease the number of cold starts and the number of vehicle hours, it generally does not discourage off-peak travel, which is when a large fraction of auto trips occur (Gómez-Ibáñez, "The Political Economy of Highway Tolls and Congestion Pricing" 346). In general, environmentalists are in favor of tolling and road user charges and are less concerned with the specific form of road pricing. If the only objective is to improve air quality, there might be fewer additional benefits associated with congestion pricing relative to conventional tolling or distance-based charging. With the latter option, charges could be linked to the pollution class of the vehicle relatively easily. Alternatively, toll charges could be linked to the air quality index of a metropolitan area, with higher tolls assessed on bad air quality days.

Individual vehicle emissions in the United States have improved dramatically since 1970—today's cars are 70-90 percent cleaner. However, vehicle-miles-traveled have more than doubled since that time (ICF Incorporated 3). Vehicle emissions are decreasing between five to fifteen percent per year while driving is increasing at less than two percent per year. Trends and current regulations suggest vehicle emissions will be about 80 percent below current levels in 20 years, despite large increases in driving (Poole). Therefore, the effect of pricing on air quality should be minimal in most U.S. cities since improvements are already occurring due to other measures.

Similar to other policy questions, there is very little empirical evidence with which to validate theories on the long-term environmental effects of congestion pricing. Overall, the environmental effects of congestion pricing range from neutral to positive (TCRP).

3.4.3.2   Greenhouse Gas Emissions

Carbon dioxide (CO_2), which is a greenhouse gas, is released into the atmosphere when fossil fuels are burned. The combustion of fossil fuels by mobile sources represents

approximately one-third of energy-related greenhouse gas emissions, which account for more than three-quarters of greenhouse gas emissions in the U.S. (U.S. EPA).

CO_2 emissions correlate well with fuel consumption, so consuming more fuel implies the discharge of more greenhouse gasses. Fuel consumption is discussed in Section 3.4.4.

3.4.4 Fuel Consumption/Dependence

During his term, U.S. President Jimmy Carter said, "With the exception of preventing war, [energy demand and supply] is the greatest challenge our country will face during our lifetimes". Transportation accounts for two-thirds of the total petroleum needs of the U.S., indicating the country's dependence on oil and its effect upon the nation's economy and security. The oil price shocks and price manipulation by OPEC from 1979 to 2000 cost the U.S. economy about $7 trillion, almost as much as the nation spent on national defense over the same time period and more than the interest payments on the national debt (U.S. EPA and U.S. DOE).

The ideal fuel consumption speed varies by vehicle and travel conditions, but fuel consumption is generally most efficient in the 40-50 mph range.[50] Figure 3.2 shows fuel economy versus vehicle speed data for the U.S. vehicle fleet (Oak Ridge National Laboratory).[51]

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[50] This is an average value across the vehicle fleet. Some vehicles have better fuel economy at higher speeds and others at lower speeds. The 40-50 mph range can be considered the most efficient speed for the fleet.

[51] The data is from the most recent study (1997) cited in Table 4.24 of the report.
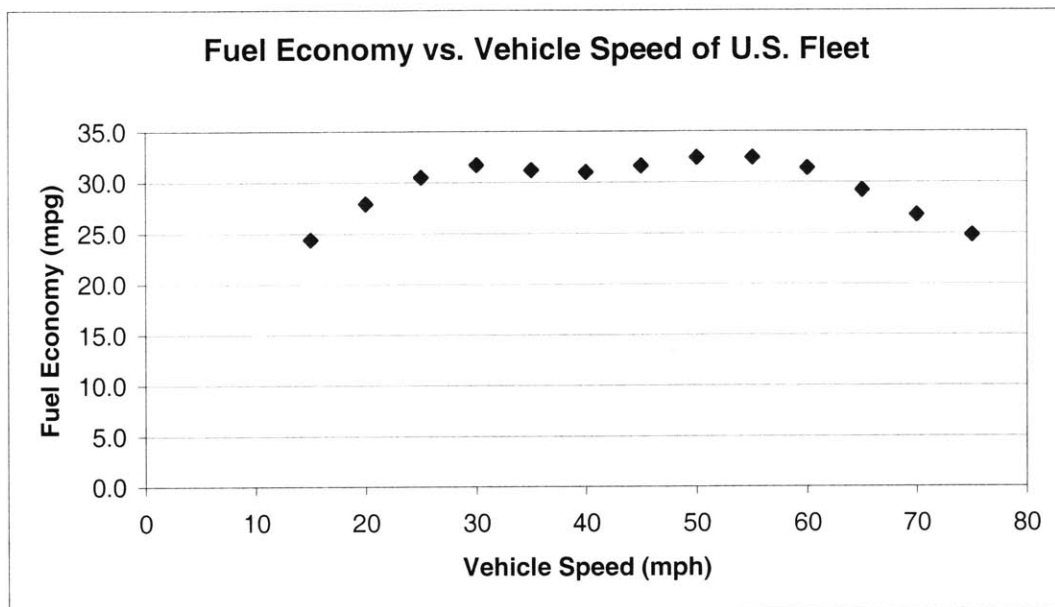
Figure 3.2: Fuel Economy vs. Speed

Road pricing policies' effect on fuel consumption can be mixed; the net impact will depend on the specific characteristics of the road network as well as the origin-destination patterns of trips in the region. Several qualitative effects can be assessed, however, which are outlined in the following paragraphs.

Idle and slow moving vehicles burn fuel less efficiently and operate for a longer period than vehicles moving at free-flow arterial speeds. Alleviating urban gridlock and stop-and-go traffic should have positive air quality impacts because increased vehicular speeds (in this portion of the fuel economy versus speed curve) and reduced speed variation will reduce fuel consumption.[52] Pricing on urban streets is therefore expected to reduce fuel consumption, unless significant diversion occurs. Diversion around a priced area could increase VMT, which would increase fuel consumption. The net effect could be mixed in this case.

All forms of road pricing imposed on existing capacity—except express lanes—should have reduction effects on the number of vehicle trips, which reduces fuel consumption. By

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[52] Congestion would decrease, but not necessarily eliminated, with pure marginal cost pricing in some urban areas where the cost of road capacity is extremely high. Some travelers would be willing to pay more than their own direct costs for the benefits they receive from making that trip, without the benefits of eliminating congestion being great enough to justify the high cost of additional capacity. World Bank, Cities on the Move: A World Bank Urban Transport Strategy Review (Washington: The World Bank Group, 2002).

increasing the cost of travel, travelers are less likely to make a trip.[53] Road pricing on new capacity, however, is likely to generate additional trips assuming the "induced demand" phenomenon exists.[54]

If vehicle speeds increase too much, road pricing measures could actually increase fuel consumption. This could only occur on roads that have design speeds greater than 50 miles per hour, e.g., expressways. If pre-pricing vehicle speeds are below fifty miles per hour, however, the net effect could be mixed or positive for fuel consumption reduction. The most likely factor for increasing fuel consumption with pricing on existing capacity would be traffic diversion, which could occur if vehicles are redirected to less expensive—but more congested—routes.[55]

Network pricing should have the greatest impact in reducing fuel consumption, whereas adding express lanes will most likely increase fuel consumption. The effects of other measures lie between these two extremes.

3.4.5 Transit

As explained in Section 2.3.2, roads are often subsidized—especially when they are congested—if they are not congestion-priced; this makes it difficult for transit operators to attract sufficient riders to cover their costs. Second-best pricing rules would suggest that transit should be priced below the marginal cost of provision because transit and personal auto are substitutes and the latter is priced below the marginal cost.[56] Cross elasticity estimates of auto use with respect to transit price, however, are practically zero in many medium-size metropolitan areas in the United States and Europe. This implies transit fares should not be reduced to compensate for auto mispricing (Gómez-Ibáñez, "Pricing"). From an economic perspective, a better strategy for increasing transit use would be to improve transit services. Road pricing could not only generate revenues for transit subsidy, but could also have several other positive effects, which are detailed in this section.

Reducing or eliminating the peak-period auto subsidy with road pricing may provide more incentives for travelers to choose transit. Fewer delays (resulting from fewer autos on the

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[53] Assuming road pricing increases the cost of travel.
[54] The induced demand hypothesis suggests that latent demand for travel exists in the presence of congestion, and when additional capacity is built to improve travel speeds, new and longer trips will be generated.
[55] Assuming there are alternative routes.
[56] For more on second-best pricing see Appendix A1. All transit in the United States is subsidized.

road) could improve bus transit frequencies and reliability, increasing the attractiveness of these services. Decreased route travel times allow the operator to either increase bus frequencies or decrease the number of buses that are required to serve the route with the same frequencies, which would provide capital and operating savings. If service improvements increased ridership, transit operators might add service, which could foster transit ridership even more. This effect could allow transit providers to capitalize on some of the economies of scale associated with transit provision, which would improve their financial health.

One might argue that transit subsidies are ineffective and that the benefits of subsidies are overstated because the revenues would not be used efficiently. Raising taxes to subsidize transit creates distortions and efficiency losses in the economy, and most of the subsidies are absorbed in higher wages for transit workers and reduced productivity rather than passed on to riders in the form of lower fares or improved service (Gómez-Ibáñez, "Pricing" 118). If road pricing revenues dedicated to transit could be used effectively, however, the transit gains might be substantial.

3.4.5.1   BRT and Pricing

Synergies exist between bus rapid transit and value pricing concepts. The two ideas have many similar objectives and could complement each other to deploy more systems than if they act independently. BRT offers a premium service for travel time on congested roadways, but requires a special right of way for that service. Inexpensive land is sparse in many urban areas where BRT could be desirable, however, making the land opportunity cost expensive for these BRT lanes. In addition, there is not sufficient demand for BRT in the U.S. to utilize all of the BRT right of way, resulting in extra capacity that could be sold to automobiles that have a high value of time for a particular trip. This involves the combination of BRT and value pricing concepts, which can work toward the greater goals of improving transit, raising revenue to improve transportation services, and creating a better and more reliable transportation option for automobile drivers. Robert Poole Jr. ("Hot Networks: A New Plan for Congestion Relief and Better Transit") of the Reason Foundation has been one of the biggest advocates of merging BRT and HOT lane concepts.

3.4.5.2   Effects of HOT Lane Projects

Thus far, the effects of HOT lane pilot projects on transit ridership in the United States have been limited (FHWA). As noted in Section 3.3.3.1, the I-15 project has had the greatest success in promoting bus usage, with ridership on the new express bus line averaging 525 daily passengers in April 1999. It has not attracted peak-direction travelers from the I-15 general-purpose lanes. Other HOT lane projects have had "no perceptible effect on either bus or commuter rail traffic in the corridor," (FHWA), but if HOT lanes were implemented on a wider scale, one might expect to see more transit benefits created by HOT lanes projects.

3.4.6   Auto Ownership

As noted in Chapter 1, the demand for auto travel in industrial economies has grown over time. As many developing economies transition to a developed status, they often experience rapid rates of motorization and auto travel. With limited ability to expand infrastructure capacity in urban areas, some entities could consider road pricing strategies as a means to decrease auto ownership.

Road pricing that increases the cost of travel should have retarding effects on vehicle ownership; the exception, however, may be HOT lanes. Because they increase capacity, the creation of HOT lanes (relative to a "do nothing" case) may encourage auto ownership. The preceding statement would be false if HOT lanes made improvements to transit such that it persuaded some travelers to use mass transportation that might otherwise drive, but empirical evidence suggests that HOT lanes have yet to increase transit ridership (see Section 3.3.3.1).

3.4.7   Road Safety

There is a trade-off between the number of vehicle accidents and the severity of fatal vehicle accidents. Higher levels of congestion usually increase the number of accidents, but often these are at lower speeds; reducing congestion tends to increase vehicle speeds, and incidents that occur at higher speeds are more likely to be severe or fatal.

Road pricing schemes that decrease congestion should reduce the number of accidents. Transport for London estimated their Congestion Charging scheme produced £15 million per year in accident savings (Transport for London, Central London Congestion Charging Scheme -

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Impacts Monitoring, Second Annual Report). If pricing results in increased expressway speeds, there could be an increase in the number of fatalities, although the author is not aware of any documented study that has reported an increase in the number of traffic fatalities attributable to road pricing.

3.4.8 Pedestrian-Friendliness and Public Health

There are several reasons why a city might encourage its citizens to walk more frequently. The medical costs of physical inactivity in the U.S. are estimated at $76 billion per year (STPP). From a transportation perspective, less road and parking capacity would need to be provided if there were fewer vehicles using the roadways.

Myriad factors influence whether a person will choose to walk for a trip: climate, weather, air quality, convenience, the quality of pedestrian facilities, and the cost of alternative modes of travel are just some of the variables potential walkers may consider. If traffic congestion is very severe, the number of automobiles on the roads may also be a deterrent to walking; in this case, it is believed that fewer automobiles on the streets would make the facility more attractive for walking. When higher auto charges are combined with a community commitment to increase pedestrian activities, people are also encouraged to walk more often.

All things being equal, higher costs for driving could encourage more people to walk for some trips. Improved air quality from pricing could also increase the attractiveness of walking, assuming other factors are conducive to walking as well (i.e., if the climate is such that it is always hot and humid, people may avoid walking regardless of the number of vehicles on the streets).

Conventional tolling and facility pricing could also contribute to improving walking conditions of a severely congested downtown if either decreased the number of vehicles traveling to the CBD. This type of pricing, however, could divert traffic off expressways and onto parallel surface streets, which may discourage walking on these facilities.

Road pricing schemes that increase reliability or decrease travel time will improve access to health care and emergency facilities. While the author has found no empirical evidence, there is theoretically potential for road pricing to have a positive effect on this aspect of public health.

3.4.9 Social Equity

"Transportation is not as central to ensuring equality of opportunity as are other services, notably education and health. But transportation provides access to those services, as well as to jobs and information" (Gómez-Ibáñez, "Pricing" 101). Transportation is approximately 19 percent of consumer expenditure in the United States (Bureau of Labor Statistics), so it also has importance because it is a major expenditure for most households.

Economists often argue it is more beneficial to give low-income or disadvantaged people a cash equivalent rather than reducing the cost of a good. They "are painfully aware of the limitations of pricing as a mechanism for redistribution" (Gómez-Ibáñez, "Pricing" 117). In the context of road pricing, this suggests it is more efficient to compensate individuals that are worse-off from a road pricing scheme with cash or credits rather than subsidizing travel for all users. While this approach may be appealing in theory, it is seldom (or never) done in transportation for at least two reasons. First, it may be difficult to implement such a scheme and it would likely be cumbersome or expensive to manage. A second reason is that there is often insufficient political will for such policies because the cash benefits are too targeted to a small population that is not well-connected politically. Low income individuals vote in far smaller proportions than higher-income individuals; consequently, their voice and policy priorities are often unheard (Lijphart).

"[I]n the largest and densest U.S. metropolitan areas, the average household income of urban public transit users is similar to the average household income of all metropolitan residents because transit patronage is dominated by commuters to the central business district, many of whom are highly paid. In the smaller and lower-density metropolitan areas, by contrast, most public transit riders are poor" (Gómez-Ibáñez, "Pricing" 117). Because of the relationship between metropolitan area size/density and the income of public transportation users, city center pricing is an inefficient tool for achieving income redistributions in these metropolitan areas. Conversely, where improvements to the public transit system in the smaller and lower density metropolitan areas would provide a larger share of the benefits to the poor, there is less likely to be sufficient congestion to warrant a congestion pricing scheme.

Despite the economists' arguments that equity should not be a major road pricing issue, equity concerns may be the most difficult obstacle for implementing road pricing schemes in most industrialized nations. These concerns, however, are less applicable to most developing

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economies. Automobiles are typically a luxury and the poorest segments of the population in developing cities typically use transit, paratransit, motorcycles, or non-motorized modes such as walking and bicycling. The costs of the congestion charge are typically borne by individuals who are not low-income.[57]

Road pricing is likely to have positive impacts on poverty reduction for many cities in the developing world. Lowering the transportation costs for the low-income population enhances their employment and social opportunities, which could ultimately promote the elimination of poverty. Transit improvements, which planners argue should occur in conjunction with road pricing measures, would directly improve service for the poor and expand employment opportunities with shorter travel times, higher reliability, and potentially less expensive fares.

Peak-period road pricing could have mixed effects on education, which is a social concern. Children need to travel to school during the morning peak period, which will have the highest congestion charge. If they are driven to school, it would increase costs and some people (notably the poor) may feel they cannot afford the financial cost if there are not good transit alternatives and parents may not be willing to drive their children to the better school that is farther away. On the other hand, for families that value travel time and reliability highly on average, which are more likely to be high-income households, the increased mobility may outweigh the financial costs. At this time, any potential effect on education is indistinguishable, but may be worth exploring with future research.

3.4.9.1 Opportunities to Internalize External Costs

As noted in Chapter 2, auto travelers seldom pay for the marginal cost of travel, which implies they are not internalizing some of the external costs associated with their travel choices. Policymakers may wish to internalize external costs to minimize distortions in the economy and discourage perverse travel decisions. Interest groups seeking to justify low prices, cross-subsidies, and other policies have incentives to exaggerate the difficulties in allocating costs or the degree to which marginal costs fall short of average costs; however, "[m]arginal cost pricing—or a reasonably accurate approximation of it—is often practical to implement and consistent with cost recovery" (Gómez-Ibáñez, "Pricing" 101).

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[57] If freight charges are passed on to consumers, however, additional tolls could raise the cost of basic goods such as food.

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Figure 3.3 presents a rough qualitative analysis of the marginal-cost pricing approximation of different road pricing measures, taxes, and vehicle costs. Some road taxes and vehicle costs are also included in this diagram to indicate how road pricing measures compare against other costs drivers may incur. Implementation choices and site characteristics will have a large effect on the degree of marginal-cost approximation, but this diagram provides a rough assessment.

No Road Marginal-Cost Pricing Effects

Initial Vehicle Purchase Costs ——— Vehicle Quotas

Monthly Insurance ——— Yearly Depreciation

Vehicle Ownership Taxes ———

Fixed-Rate Parking ———
——— Open Toll System
——— Cheap Fuel Taxes

Transit – Single Rate Fares ———
——— Closed Toll System

Pay-by-the-Mile Insurance ——— VMT Charging

Mileage Depreciation ———
——— Variable-Rate Parking

Area-Wide Pricing - London ———
— Transit – Distance-Based Fares

Partial-Facility Pricing ——— Car Sharing
(e.g., HOT Lanes)

Facility Congestion Pricing ———

——— Cordon Pricing - Singapore

Network Pricing ———

True Road Marginal-Cost Pricing
(Diagram not to scale)

Figure 3.3: Marginal-Cost Pricing Diagram

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3.4.10 Land Use

As incomes rise, households typically prefer to move away from the central business district and into low-density housing in the suburbs—especially in the United States. Housing is typically less expensive farther away from the central business district. Residential location theory predicts that commuters will evaluate the rent gradient, trading off transportation costs to gain location rent savings; it does not predict that commuters minimize travel time (Ingram 1026).

Many businesses are also lured to the urban fringe where rents are less expensive and more mobility is available. As cities evolve, residential units and businesses usually relocate, often to locations further from the central area. "Both theory and empirics indicate that household residential locations are systematically determined relative to the household's workplaces. The direction of causation is not clear" (Ingram 1029).

Since commuters consider transportation costs, and since road pricing on existing capacity increases costs, forms of road pricing on existing capacity should discourage development further away from the central business district. Road pricing on new capacity, however, could encourage some households or businesses with high values of time to move further away from existing development because they can traverse longer distances in the same amount of time.

The overall effect of road pricing on land use will depend on the specific characteristics of the region as well as the details of the individual pricing scheme.

3.5 Chapter Summary

This chapter examined the different types of road pricing and the impacts that they have on other policy variables. Each road pricing measure has a unique combination of strengths and weaknesses, making it better suited to achieve some policy objectives than others are. Therefore, the definition of the "best" road pricing strategy depends on what policy objectives a decision maker is trying to achieve. Chapter 5 will present a new tool, the Road Pricing Decision Analysis Tool (RPDAT), which demonstrates the strengths and weaknesses of each strategy for particular metropolitan areas.

The following chapter identifies the most-often used techniques for estimating the impacts of road pricing and the difficulties associated with modeling road pricing with conventional models.

4 MODELING ROAD PRICING

4.1 Chapter Purpose and Organization

The objectives of this chapter are three-fold: first, it identifies many travel factors, such as travel time, cost, travel time-of-day, and reliability that are believed to influence driver behavior. Road pricing targets many of these factors and it is important to understand which factors these different scheme types influence in order to model road pricing well and create accurate estimates of the impacts.

The second objective is to provide an overview of the current practice of road pricing modeling in the United States. The models most commonly used to forecast the effects of road pricing strategies are discussed and several methodological issues that make it difficult to capture the effects of road pricing with these models are identified. Transportation analysts, demand modelers, and econometricians need to address these issues in order to improve forecasts. It is argued that existing models do not provide decision makers with accurate estimates of information about pricing policies; these models are critiqued in order to highlight their inadequacies. Chapter 5 will present an alternative evaluation methodology.[58]

A third objective of this chapter is to identify some major issues that need to be addressed in order to improve road pricing modeling. Addressing these issues could lead to either improvements being made to existing models or as a basis for the development of new models. This section of the chapter further demonstrates the need for alternative methods to assist in the decision-making process for road pricing strategies. One modeling technique that is more capable of capturing the characteristics of road pricing is also presented in brief.

Most of this chapter relates to HOT lanes or congestion pricing on a single facility. Many of the concepts also apply to network pricing, although this strategy is discussed to a lesser extent. Statements made about the effects of pricing in this chapter assume that measures will add or increase the user fee for driving on a priced facility. Different road pricing strategies— despite using a common economic theory—have different effects on individuals' travel behavior

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[58] The proposed analysis tool, denoted as the Road Pricing Decision Analysis Tool (RPDAT), is primarily intended for sketch-planning purposes but may also be used for detailed analysis. A thorough discussion of this tool and its methodology is presented in Chapter 5.

and choices; thus, they have different requirements for how they need to be analytically modeled. Similarly, different objectives (i.e., traffic demand management vs. revenue generation) will produce different suggested toll rates.[59] It should also be noted that different clients (i.e., public agencies vs. investment banks) make different assumptions and take different approaches to evaluate pricing strategies, thus making the results of one study not immediately transferable to another.[60]

4.2 Limitations of Current Methodologies to Model Pricing

While modeling transportation demand can be difficult, modeling urban transportation pricing policies presents an even greater challenge. This section discusses the characteristics particular to road pricing that make it so difficult to estimate its impacts.

4.2.1 Effects of Road Pricing Strategies

Many forms of road pricing have the potential to decrease congestion, encourage trips to shift to HOV and transit, and increase economic efficiency. These aggregate effects can occur because pricing influences driver behavior. However, each strategy influences a unique set of factors that drivers and businesses consider when making a trip, which means that each has a unique set of characteristics that must be captured by a model for it to produce adequate traffic and revenue estimates.[61] Effects resulting from the following strategies must be considered in the model for it to be a useful tool for decision makers:

4.2.1.1 Express lanes (e.g., HOT Lanes)

- Certain high-value trips (not just high-income drivers) will choose HOT lanes when they need to be somewhere quickly (e.g., trips to the airport);

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[59] A study with revenue curves from sensitivity analysis can make it easy to identify the optimal tolls for both maximizing revenue and maximizing the volume of traffic using the facility during a given timeframe.

[60] Techniques to analyze distance-based pricing are not discussed in this chapter. Many of the modeling problems identified in this chapter are less acute with distance-based charging because diversion and equity impacts are expected to be less than with other types of pricing policies. Area-wide and cordon pricing schemes are only discussed in brief.

[61] For more on the different types if pricing strategies, see Chapter 3.

- People value the consistency of day-to-day travel times associated with uncongested travel on HOT lanes, which is reflected in the value of reliability (VOR);
- Business and service industry jobs (e.g., plumbers)—whose hourly rate is higher than the equivalent hourly toll rate—may choose HOT lanes; and
- HOT lanes may encourage more trips in the long-term because they improve the level-of-service and add capacity;[62]

4.2.1.2 Facility Pricing

- Business and service industry jobs—whose hourly rate is higher than the equivalent hourly toll rate—may choose the tolled alternative;
- Some vehicle trips will shift from the peak period to less-congested periods of the day;
- Diversion to alternative (less expensive) roadways will occur, but the extent of which depends on the specific characteristics of the corridor;
- Some discretionary trips will be eliminated if there are not attractive alternative roadways or destinations; and
- Some motorists may change their trip destination.

4.2.1.3 Area-Wide and Cordon Pricing

- Some vehicle trips will shift from the peak period to less-congested periods of the day;
- Diversion around the priced zone may occur, but the extent of which depends on the specific characteristics of the area and how many trips were previously traveling through the zone;
- Some discretionary trips will be eliminated if there are not attractive alternative roadways; and
- Some motorists may change their trip destination.

4.2.1.4 Network Pricing

- Some vehicle trips will shift from the peak period to less-congested periods of the day;
- Diversion may occur on some facilities;
- Some discretionary trips will be eliminated; and
- Some motorists may change their trip destinations.

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[62] The long-term effects of HOT lanes are not known at this time due to a lack of empirical data.

These aggregate traffic effects occur because pricing policies change the variables individuals consider when they decide when, where, how, and how many trips they will make. The reasoning behind individuals' choices is discussed in the following section.

4.2.2 Pricing Factors that Influence Driver Behavior

There are several factors influencing the choices travelers make when deciding whether, when, how, and why to use a priced facility. Small and Winston claim that "researchers are still a long way from being able to derive the demand for transport from its first principles" (48). However, it is necessary to identify and include known factors if a model is to produce accurate estimates. This section attempts to identify the salient choice factors particular to road pricing based on current theories and experience-to-date in the United States.

Researchers and analysts who specialize in modeling road pricing use the value of time, vehicle operating cost, and toll charges as the three main elements in their models to determine how a trip is made. Vehicle operating costs can be estimated satisfactorily with existing techniques, and toll charges are specified in the model, so the main input to critique in determining how trips are made is the quality of the value of time estimates and assumptions. More specifically, one needs to determine if the estimates are based on the most important variables travelers consider when making a trip.

Small and Brownstone show the value of reliability to be quite an important factor for why people choose HOT lanes. The VOR measures travelers' willingness to pay for reductions in day-to-day variability of travel times on a particular roadway (Brownstone and Small). For example, a positive (utility) change in the VOR would be obtained by decreasing the daily commute variation of 15-45 minutes to a commute that only varied between 25 and 35 minutes. The average travel time in this example could remain the same, but the driver would benefit from not having to plan around the potential of being much later than expected. Small and Brownstone found travel time to account for two-thirds and reliability one-third of the service quality differential between the free and priced SR91 lanes (Brownstone and Small).

The VOR is difficult to measure, but Small and Brownstone have made progress toward quantifying it for the variably-priced SR91 lanes. They have not been able to identify the VOR coefficient for the dynamically-priced I-15 lanes because dynamic pricing also acts as a signal to the driver regarding the level of congestion on the unpriced lanes.

Despite being an important factor individuals use when deciding to use a HOT lane, the VOR is not accounted for in any well-known forecasting models. This implies models are (unintentionally) biased in favor of under-predicting HOT lane demand because the benefit of added travel time reliability is ignored.

It is likely the VOR is not included in forecasting models because the data necessary for estimating the VOR is difficult to collect and therefore has not been analyzed. The VOR is particular to each facility and it takes many observations of the speed on the facility across days and by time-of-day to create the distribution of travel times (Brownstone and Small). Small and Brownstone appropriately suggest using the upper tail of the travel time distribution (i.e., difference between the 50th and 90th percentiles) to measure unreliability. Using the upper tail captures excessive delays, which is more likely to be related to the decision-making mechanism used by drivers when deciding to use priced lanes than the standard deviation. People tend to value travel time higher when they are late as opposed to being early, so they would not be willing to pay as much for travel time savings if they believe they can arrive on time.[63] Another potential reason for excluding reliability in forecasting models is that it was much less of an issue in the 1950s and 1960s when the four-step model was developed. If congestion continues to increase as many professionals predict, the VOR may become an even more important factor for travelers and businesses.

The value of time (VOT) is the decision-making factor that receives the most attention in the modeling analysis and is perhaps the input most scrutinized by traffic analysts. Traffic and revenue estimates are quite sensitive to the VOT value(s) used in the analysis, so it is very important to have estimates that closely mirror reality in a model.

The decision to use priced lanes for a particular trip is in part based on the individual's value of time for that particular trip. This implies that an individual's VOT is different for each day, time of day, and trip purpose. The change in individuals' VOT is logically intuitive, but data explaining the variation of individuals' travel time is not yet available. Nevertheless, it may be possible to create rough VOT "rules of thumb" for particular trip purposes after more real-world experiences are available. For example, a few studies suggest congested travel time is

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[63] Additionally, the VOR for women is roughly twice that of men on SR91. Therefore, gender is an important factor in choosing to use priced lanes. K. Small, C. Winston and J. Yan, Uncovering the Distribution of Motorists' Preferences for Travel Time and Reliability: Implications for Road Pricing (University of California Transportation Center, 2002).

valued about twice as highly per minute as uncongested travel time (Brownstone and Small). This implies models should be using at least a different VOT for peak and off-peak periods, but different VOTs according to the trip time-of-day or purpose are often not used in practice.

The VOT is not only determined by the trip purpose but also influenced by the socio-economic characteristics of the traveling population in a region. The traditional technique is to use either (i) a single VOT for all drivers, or (ii) a single VOT for each income market segment (with usually 2-3 market segments). This VOT is typically assumed to be 40-70 percent of the hourly wage rate and is derived from household income.

One method that has been used by road pricing consultants derives a VOT from median household income for each traffic analysis zone (TAZ) in the four-step model (4SM). A TAZ is a small geographic unit within the region assumed to have homogeneous characteristics. The VOT cost/minute for each zone is calculated using the median household income and average household worker hours. Multiplying factors are then applied to the zonal VOT to account for different trip purposes and for peak and off-peak periods. The VOT specific to each TAZ is then used in the assignment process of the 4SM to create a more disaggregate and consequently more realistic representation than traditional methods.[64] This is one of the best 4SM methodologies used in practice for modeling the heterogeneity of socio-economic characteristics. An alternative approach, bi-criterion equilibrium traffic assignment, has a better theoretical foundation; however, this approach is not being used in practice at this time. This modeling technique is discussed further in Section 4.3.1.2.4.

Work-hour flexibility of individuals may also be an important characteristic in determining whether pricing will affect their travel choices, but it is unclear how to model the trade-off of pricing versus time-of-day travel. In other words, it is not known what percentage of the traveling population has the option of traveling earlier to avoid paying a toll or whether congestion exists because everyone believes they have no choice but to travel during the peak periods.

Experience-to-date with pricing projects suggests the aforementioned factors are important variables influencing which and how many trips will use a priced facility. However, the dearth of empirical pricing data and analysis makes it difficult to identify the factors

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[64] The VOT is used to convert the toll amount into a travel time penalty in the assignment step of the 4SM.

individuals are actually using; more real-world experience and research are necessary to develop a better understanding.

4.3 Description of the Current Methodologies and their Shortfalls

4.3.1 Tools

Multiple tools are available to evaluate road pricing strategies and policies. This section describes some of the assumptions and methodologies associated with the tools that are available and those that are being used to evaluate road pricing in the United States.[65]

4.3.1.1 Sketch Planning

Sketch-planning refers to analysis that is more sophisticated than "back-of-the-envelope" planning yet can still be performed quickly, although it is less detailed than an in-depth analysis. Sketch planning is often used to produce an indication of whether particular policies or projects are worthy of further consideration.

The 4SM is the principal tool used to evaluate road pricing for sketch planning purposes. Other tools such as SMITE-ML and SPRUCE (discussed in Section 4.3.1.1.2) have been developed with the intent to provide agencies with tools that can produce quick estimates of the major effects of HOT lane projects, but these tools are not being utilized by planning agencies.

4.3.1.1.1 Four-Step Model (4SM)

The four-step model is the regional model used by MPOs.[66] Most MPOs use the 4SM as a detailed analysis tool and a sketch-planning tool to estimate the traffic and revenue impacts of pricing. When the 4SM is used for sketch-planning purposes, a common practice is to make more simplifying assumptions than would be performed in a detailed study. This sketch planning usually only affects the mode choice and consequently the route choice steps of the 4SM and assumes more homogeneous characteristics of the driver population than would be

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[65] Studies in the U.K. have used the APRIL and AREAL models (developed in the U.K.) to estimate the effects of the London Congestion Charging scheme. A review of these models is not included but is suggested if a region wishes to create detailed estimates of the impacts associated with an area-wide or cordon pricing scheme.
[66] A brief overview of the four-step model is presented in Appendix A3.

performed in a detailed analysis. Therefore, sketch-planning with the 4SM assumes that the number of trips, trip time-of-day, and trip destination are not affected by road pricing measures.[67] This can be a poor assumption, especially since congestion is only captured during the route choice step unless feedback loops are incorporated into the model.[68] However, feedback loops are often not included due to financial and organizational capacity constraints.

4.3.1.1.2 SMITE-ML and SPRUCE

Two relatively new models, *SMITE-ML* and *SPRUCE,* are analytical tools that can be used to screen managed lane alternatives.[69] These quick-response tools are relatively simple spreadsheet models capable of producing estimates of traffic impacts, environmental costs, and revenue; performance measures are also included in the model output. SMITE-ML is intended to assist policymakers in evaluating proposals for specific additions to highway capacity involving either general-purpose or managed lanes. It can be used to refine the alternative groups of transit, carpool, and toll policies under consideration for managed lane projects; these refined alternatives can then be analyzed with the 4SM for more detailed analysis.

One of the main advantages of these models is that they have relatively limited data requirements. Many inputs for the models assume "typical" values, but the model allows the user to replace these values with better estimates from region-specific data. The aggregate nature of these models allows the user to produce estimates and make changes to the policy assumptions relatively quickly.

4.3.1.1.2.1 Model Methodology and Assumptions

SMITE-ML uses traffic estimates from the MPO's 4SM as the base case. Therefore, it is necessary to have a good original 4SM and realistic estimates of socio-economic characteristics and growth factors within the MPO model to have meaningful results produced from SMITE-

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[67] Network pricing and area-wide pricing studies may assume the number of trips will be reduced, but this phenomenon is commonly accounted for outside the model.

[68] The validity of assuming these values are constant is lessened considerably when a large part of the network is priced, such as the case with network pricing or VMT charging.

[69] These models were developed by Patrick DeCorla-Souza, who is the Team Leader for the Value Pricing Pilot Program at the FHWA in the U.S. DOT. Mr. DeCorla-Souza developed these models in his personal time (i.e., they are not U.S. DOT models) and FHWA has not commented on the models. For more information on the models, see: P. DeCorla-Souza, Using Smite-ML 2.2 to Evaluate Road Pricing Alternatives (Washington: Federal Highway Administration, 2005).

ML. This is important to note because unrealistic MPO traffic estimates are possible due to the 4SM's tendency to assign more traffic to a link than the road can actually carry.[70] For example, the 4SM might assign 4000 vehicles per hour per lane to a road during the analysis period, but the maximum flow rate is less under optimal conditions and is even less when the road is congested.

SMITE-ML makes several simplifying assumptions that include:

- A single VOT is used for all travelers;
- The toll rate is calculated based a simple relationship with the assumed VOT;
- The different characteristics of CVs from passenger automobiles are not accounted for in the model;
- A "demand elasticity with respect to travel time" is used to estimate induced travel;
- Aggregate point elasticities are used;[71]
- The model requires the user to either input or assume a demand elasticity estimate, for which good estimates are not always available;
- Induced demand is estimated for the general-purpose lanes only;
- There is no road network in the model, so realistic diversion estimates for specific alternative routes cannot be produced; and
- Geometric characteristics of the facility (i.e., whether it is a radial or beltway road) in question are not considered in the model; the user must try to account for these characteristics with means outside of the model framework.

SPRUCE is another sketch-planning spreadsheet model intended to provide policy analysts with benefits and revenue estimates from HOT lanes (DeCorla-Souza, An Evaluation of "High Occupancy Toll" and "Fast and Intertwined Regular" Networks). SPRUCE also uses a pivot point mode choice model, but has a different methodology and produces fewer types of output than SMITE-ML. Details of the SPRUCE model are not discussed in this thesis, but could be considered as being in the same classification as SMITE-ML.

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[70] This is because the 4SM does not take into account congestion or delay unless feedback loops are used and the model is not well-suited to evaluate changes in policy, such as pricing.

[71] Aggregate point elasticities are valid for small changes. Ideally, disaggregate forecasting (sample enumeration) should be performed, but aggregate point elasticities should produce acceptable estimates for sketch-planning purposes. For more on aggregate elasticities, see: M. Ben-Akiva and S. Lerman, Discrete Choice Analysis (Cambridge: MIT Press, 1985).

4.3.1.1.2.2 Where the Models Stand at this Time

Based on an informal survey, most planning agencies that have considered pricing are not familiar with SMITE-ML or SPRUCE.[72] Neither model has been applied in practice by a state DOT or MPO in the United States and there is no evidence of their use outside the U.S. SMITE-ML produces quick estimates for many of the factors decision makers wish to know when they are considering a policy, but the model makes a lot of simplifying assumptions. SMITE-ML could be quite attractive to planning agencies if its model validation were presented.

SMITE-ML should be applied to existing HOT lane facilities to determine if the model produces valid results. Its model outputs should also be compared against best practice methods used by pricing consultants to determine if it can consistently produce results similar to those that are generally accepted. Further sensitivity analysis should be performed to develop a better idea of what changes in the model's assumptions creates the greatest change in the outputs.

4.3.1.2 Detailed Analysis Tools

Three detailed analysis tools are discussed in this section: the four-step model, microsimulation, and the STEP model. Bi-criterion traffic assignment is also presented as a potential improvement for existing models.

4.3.1.2.1 Four-Step Model

The 4SM is used for both sketch-planning and detailed analysis. In fact, the 4SM or its sub-models are used to evaluate virtually all pricing projects in the U.S. Formal documentation for the state of the practice of transportation modeling that compares the abilities of MPOs and consultants in the United States does not exist, but strong anecdotal evidence suggests that there is a wide range of modeling capabilities between individual MPOs and with consulting firms who specialize in pricing. Some models and assumptions are noticeably better than others are. The models used by pricing consultants that were reviewed for this research can be thought of as the state of the art for four-step models because they typically make fewer simplifying

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[72] This informal survey was performed by the author while working at the U.S. DOT Office of the Secretary of Transportation (OST) in July 2004. The survey results were not published, but were used as a reference for an unpublished OST Policy report.

assumptions and take more factors into account than most analyses performed by public agencies in the United States.

Most efforts to incorporate pricing focus on the mode choice step and also affect the trip assignment (route choice) step of the 4SM. In contrast, consultants who specialize in modeling pricing use proprietary mode choice and diversion models that are claimed to produce more realistic estimates than one could expect from the traditional mode choice models. Trip generation and trip distribution steps have been modified by these consultants to look at pricing in some instances when they are analyzing area-wide, distance-based, or network pricing. The level of sophistication consultants employ in their studies varies and generally depends upon the amount of funding available as well as the quality of the base models they are provided with from the MPOs. These consultants often take existing MPO models or trip tables and disaggregate them with data obtained from roadside surveys they perform for the pricing study. The better surveys and traffic data account for a large part of the improved estimates consultants can provide.

It is very important to note that consultant studies for finance purposes focus on revenue generation and not demand management. Modifications to the investment banking studies should be made if the objective is to manage demand because the maximum revenue toll is most likely not equal to the optimal demand management toll.

4.3.1.2.1.1   General Problems with the 4SM

The 4SM has been used for the last 40 years as the principal urban transportation planning tool. Although some changes have been made, it can be argued that there have been few substantial modifications. The needs of the transportation system have changed during that time and the 4SM is no longer capable of supporting decision makers facing contemporary transportation issues. This is because the model was originally designed to help size and locate large infrastructure projects and to estimate the locations and amounts of traffic congestion likely to occur (Replogle and Reinke). Simply stated, the 4SM is not well-suited to look at policies or operational changes.

Some of the general problems with the 4SM are as follows:

- The 4SM is an aggregate model. This means it cannot model the effects of heterogeneity of the traveling population.

- The 4SM has a very difficult time modeling congestion. It is a static model, meaning that it can only perform steady-state evaluation (i.e., the model assumes all demand occurs during one time interval). A good time-of-day sub-model is needed to evaluate congestion or delay. The evaluation periods need to be short time intervals to produce more realistic estimates.
- The 4SM is incapable of evaluating trip scheduling. In other words, it cannot estimate when a person will choose to make a trip or the relationship between trip scheduling and other variables (such as trip cost).
- The 4SM cannot model trip chaining and assumes every trip is independent of all other trips.
- There is no good sub-model to look at the relationship between trip generation and congestion. The 4SM can take congestion into account between the trip distribution, mode choice, and route choice (trip assignment) steps if there are feedback loops, but these are not in widespread use because of organizational capacity and financial resource constraints. Only some regions use feedback loops, and even then congestion is not accounted for fully.

These general problems make the 4SM a less-than-ideal tool to model traffic or routine policies. The issues discussed in the following section are either unique to evaluating pricing policies with the 4SM or are made worse because of the specific characteristics of pricing.

4.3.1.2.1.2   Problems with the 4SM Unique to or Made Worse by Pricing

The aggregate nature of the 4SM makes it very difficult to capture the effects of pricing because pricing schemes specifically target the heterogeneity of the driver population and trip purposes. The 4SM cannot assign different VOTs to different drivers (only aggregated populations).

It is also believed that pricing has an effect on trip scheduling. Pricing changes the attractiveness of travel during certain times of the day or days, which would make some people decide to make fewer trips during congested periods. A major problem with the 4SM is that it cannot model or account for any travelers deciding to shift their time of travel because of a pricing policy.

The trip generation step of the 4SM is completely independent of the remaining three steps, so the number of trips that will occur in the model is not influenced by pricing. In reality, adding a toll will affect the perceived cost to some travelers, which will change the number of trips generated. Neglecting the reduction in the number of trips generated is more likely to be a

poor assumption if a toll is added to a road and alternative routes are not very attractive to travelers. The change to the number of trips generated is often ignored in practice for corridor pricing projects, but the validity of this assumption is site- and policy-specific. Pricing consultants have modified trip generation tables in the event they are evaluating area-wide or VMT pricing strategies because these policies specifically target reducing the number of trips.[73]

Other problems with the 4SM unique to or made worse by pricing include:

- Pricing may encourage people to link more trips, but the 4SM cannot model trip chaining;
- Pricing should be incorporated into the impedance values of the trip distribution step of the 4SM; however, this does not always occur in practice;
- It is not possible to account for any effects of unreliability or the VOR because of the static analysis period in the 4SM;
- It is not possible to evaluate dynamic pricing using the 4SM because it is a static model and only evaluates aggregate demand; and
- Different capacity values should be used for priced and non-priced lanes in the assignment step of the 4SM.

The 4SM is an inadequate in-depth analysis tool by itself for most pricing strategies because of the aforementioned problems. For this reason, microsimulation is necessary to create a better approximation of the delays and tolls on a facility if better traffic and revenue estimates are desired.

4.3.1.2.2 Microsimulation

Microsimulation explicitly accounts for the time-of-day in the modeling process. It is a disaggregate approach, making it much more capable of capturing the heterogeneity of drivers and trip purposes than the 4SM. Disaggregate models have generally been the most successful in capturing the essential features of travel behavior and are well grounded in a microeconomic theory of individual or firm behavior (Small and Winston).

Microsimulation is preferable to the 4SM in theory and it is the direction modeling tends to be heading, although in practice, microsimulation does not produce substantially better estimates than the 4SM because it relies heavily on the input assumptions. Microsimulation

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[73] VMT charging is also being considered as a replacement for the gas tax. In this case the goal is revenue generation, but the change in the number of trips generated is a very important policy variable.

attempts to derive demand from its first principles, but it remains to be seen whether current efforts to build such models will have more success than traditional models (Small and Winston). There is currently no documentation on the ability of public agencies in the U.S. to perform microsimulation, although informal interviews suggest many public agencies have not adopted microsimulation and they prefer to continue using the 4SM. The hesitancy to adopt a substantially different technique might be attributed to the microsimulation results not being a large enough improvement to encourage the modelers to change; the case for retaining the 4SM is strengthened when considering the large demands and limited resources of public agencies. Many of the demand modelers interviewed in the informal study indicated they believe the United States modeling community is conservative relative to modeling communities in other parts of the world.

Consultants sometimes use microsimulation to evaluate pricing studies for planning agencies, but the technique substantially increases the cost of the study so it is not always performed.[74] Microsimulation is necessary to evaluate dynamic pricing strategies and it is often used to estimate the effects of managed lanes because this technique can capture delay, which is the reason travelers opt to use the priced facility.

Several microsimulation techniques for estimating road pricing impacts have been proposed by different academic researchers around the world in recent years, although there is not yet a widely accepted approach. Research and academic institutions are one of the most likely groups to make intellectual advances in modeling road pricing in the future.

4.3.1.2.3 STEP (STEP2)

The STEP model was originally being developed for the Metropolitan Transportation Commission (MTC) in the San Francisco Bay Area by Greg Harvey. However, when Harvey suddenly passed away in 1996, much of the work was lost. A private corporation (Caliper Corp.) has resumed model development for STEP, now called STEP2.

STEP2 performs some advanced procedures and provides a framework for household travel activity microsimulation to create more sophistication than what is available with the 4SM. Overall, STEP2 appears to be more scientific and more capable of representing road pricing

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[74] One consultant informally stated microsimulation doubles the cost of a study.

policies than the 4SM, but it has not been used in very many cases. There are still some further model development needs for STEP2; it should model more than just auto trips, i.e., commercial vehicle modeling will be necessary, if it is going to be useful for many instances of pricing. STEP2 should undergo a validation procedure to determine how well it models pricing policies.

Many planning agencies, modelers, and decision makers are not familiar with STEP or STEP2. As the STEP2 model is further developed, refined, and validated, its value as a tool for estimating the impacts of pricing strategies and policies may increase.

4.3.1.2.4 Bi-Criterion Traffic Assignment

In most road pricing strategies being considered in the United States, many of the challenges associated with modeling road pricing relate to assigning traffic to travel paths in the network.[75] As discussed in Section 4.2.2, the four-step model converts tolls from financial costs to a travel time penalty using an assumed *average* value of time. This means that once the conversion to travel time is completed, drivers are assigned to a travel path based on only one criterion—travel time.

In reality, each driver has a different average value of time; further, this VOT changes with trip purpose and time-of-day for each driver. This implies that there is a *distribution* of values of time across the vehicle population. If a model assumes an average value of time, it will invariably produce large estimation errors and inaccurate forecasts (Dial).

Robert Dial presents an alternative traffic assignment model that generalizes classic traffic assignment. This approach uses a bi-criterion user-optimal equilibrium traffic assignment model, which relaxes the VOT parameter in the generalized-cost function from a constant to a random variable with an arbitrary probability density function (PDF). The essential idea of this bi-criteria traffic assignment approach is that it assumes a trip minimizes its generalized cost $g_p(\alpha)$ and chooses a path p, where:

$g_p(\alpha) = c_p + \alpha t_p$;
c_p = the out-of-pocket ("dollar") cost of path p;
$\alpha \in [0,\infty)$ = value of time, which is a random variable; and
t_p = time of path p.

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[75] A travel path is represented as a link in the network. When trying to estimate whether a vehicles will choose to pay a toll or choose a free alternative, the 4SM uses toll-free links and the toll link in the network and assigns each vehicle to the network using a shortest-path algorithm. The shortest-path is based on travel time.

The probability of a trip choosing a particular path will depend on the particular path's time and cost relative to the other paths and the trip's particular VOT α. Classic trip assignment models assume the perceived generalized cost of a path for all trips is identical. As one can note, a bi-criterion approach assumes different trips perceive the same path as having different generalized costs—a more plausible assumption. The generalized cost function can be expanded to include other variables to the cost of a link. For example, a βd_p term could be added to $c_p + \alpha t_p$ to account for additional factors a driver considers when choosing a link, such as the reliability of the travel times on the particular path.

Although this technique is an improvement over traditional approaches, it is still a static model, meaning it is very difficult to incorporate congestion. As Dial notes, bi-criterion traffic assignment is open to further development that could make the model dynamic and "the algorithms can be applied with minor modification to a discrete time-staged expanded network" to develop even more accurate dynamic models (98). While there are some difficulties with applying this approach in practice—primarily with the algorithms—its foundation and basic idea are much more apt to capture the effects of road pricing. Research efforts should be made to adapt such an approach into models that assign traffic onto a road network—especially if networks have a toll alternative.

4.3.2 Addressing the Equity Issue

Although equity is a very important political issue to decision makers, there are no modeling techniques at this time that can effectively estimate the impact of a pricing policy on socio-economic groups. A few models analyze equity by providing estimates by income group, but these models rely heavily on inputs and the value of time assumptions. In practice, the value of time is modeled solely as a function of household income; however, real-world HOT lane experiences have shown this not to be the case. The value of time for a particular trip is more appropriate and cannot be modeled with available data at this time. A recent Transit Cooperative Research Program report agrees that "[e]xisting forecasting and accounting methodologies are often incomplete in addressing [equity] issues" (14-36).

Travel behavior in the context of pricing is not understood well enough to estimate the effects of pricing on equity. More experience with pricing and research of that data will be

needed to obtain a better understanding of why people choose to use variably-priced and dynamically-priced roads.

Another large equity question is how to address mobility for low-income drivers who might not receive proportional benefits. One of the proposed solutions is to improve public transportation. If transit services are to be part of the HOT lane equation, then adequate modeling of transit should be performed to obtain realistic ridership estimates.

4.3.3   Addressing the Revenue Generation Issue

Revenue estimates are closely tied to the traffic estimates and VOT assumptions in the model. The gross revenue from the pricing scheme is simple to calculate once the toll charge and number of vehicles for each analysis period are determined, but the number of vehicles is difficult to calculate.

Consultants who specialize in pricing create revenue estimates by running their models multiple times with different toll rates to produce revenue curves, which show the revenue-maximizing toll and make it easy to see the predicted effects on revenue if the amount of traffic or the toll changes.[76] The revenue analysis should be performed for a.m. peak, p.m. peak, off-peak, and in some cases the weekend time periods. The results of these analysis periods are summed to produce a gross revenue estimate. These revenue curves are important to determine the sensitivity of users to changes in the toll rate and provide decision makers with an idea of the effects on revenue in the event travel demand is less than expected.

Investment banking studies require traffic consultants have independent (i.e., non-MPO) socio-economic forecasts because the finance community believes MPO forecasts are sometimes biased upward in terms of future growth or may use inconsistent methodologies. Investment banking forecasts are likely to make conservative assumptions about when alternative (competing) roads will be built and about the future growth of the corridor.

Economic growth and socio-economic estimates are perhaps the most important inputs to the model for investment banking studies. Housing and non-residential land-use estimates— specifically the type, timing, and location of development—have a large effect on the financial feasibility estimates.

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[76] Analyzing approximately five different toll rate scenarios is common.

Sensitivity analysis for the toll rates is one of the main items investment banks consider when reviewing traffic and revenue studies for potential toll projects. Toll road studies have a reputation for being poor predictors of actual revenue; thus, investors often require a higher rate of return to compensate for the risk. Investment-grade revenue estimates require the consultant perform microsimulation in addition to running the 4SM.

4.3.4 Addressing the Commercial Vehicle Modeling Issue

Most regions do not have good commercial vehicle (CV) models or data. The difficulties associated with modeling CVs well are not specific to pricing, but accurate estimates of CV travel patterns and choices will increase the accuracy of demand forecasts if CVs are expected to be a non-negligible percentage of the priced facility user population. CVs are likely to choose priced facilities in many cases because priced facilities reduce travel time and improve reliability—service business CVs are especially likely to be willing to pay for these benefits. This vehicle group could easily constitute a large portion of the mid-day traffic on a priced facility, so accurate estimates of the CVs could be especially important for revenue estimates.

One modeling issue is that some public agency models do not permit CVs to travel on the HOT lanes, even though 4-tire CVs are allowed to use the HOT lanes in reality. These vehicles need to be accounted for in the models and should have a higher value of time than most autos in the model. However, the VOT for CVs and businesses is not known, which is part of the reason why they are not modeled; this is data public agencies do not have.

It is difficult to estimate the extent to which service businesses will value using a priced roadway. Increased reliability and travel time savings are likely to benefit this industry, allowing service businesses to reduce their required amount of capital expenditure (i.e., fewer trucks because of increased productivity) because they are avoiding congestion. Estimating what amount this group would be willing to pay to use priced lanes is difficult because it is not known how to quantify this capital savings in a way that it can be an input for the model.

Another modeling problem for CVs is that their travel patterns are poorly understood. The travel patterns of households are understood better because of household surveys, but private companies are less willing to divulge their travel patterns and routes for proprietary reasons.

4.4 Data Problems and Needs

Various data are needed to evaluate pricing policies. Some of the data is already available to planning agencies, some may need to be compiled, and some will not be realistically attainable in the near future.

Household survey data is required for microsimulation, which can be done with sample enumeration / synthetic population techniques. Much of this data is already available to planning agencies, but some agencies may need to perform updated surveys. Stated-preference (SP) household survey data is better than no data, but revealed preference (RP) data is much more valuable. However, RP data by definition does not exist in regions that do not already have at least one toll road or HOT lane, so this is not attainable for some agencies. One hindrance is that the United States has little experience with SP or RP data in the context of road pricing.

SP data tends to be particularly less representative of RP data (and therefore actual choices) for pricing projects in the U.S., possibly because HOT lanes and congestion pricing are relatively new and substantially different concepts than what drivers in the U.S. have dealt with in the past. Experience in Southern California has shown the scale of RP VOT coefficients to be about twice those of SP coefficients, implying SP data will undervalue travel time savings benefits by about 50 percent. As a consequence, it is very difficult to forecast how drivers will react to pricing in areas that have not had any toll roads. The theory of travel behavior in the context of pricing—particularly dynamic pricing—is not well understood and will probably need more real-world experiences and research before it is understood better.

Travel diary data from HOT lane projects should provide modelers with an estimate of what types of drivers are more sensitive to reliability. Obtaining this data should increase the analytical capability of models to estimate demand for HOT lanes accurately if certain socio-economic characteristics are revealed to increase a driver's reliability sensitivity.

One major data requirement to evaluate a priced corridor with good free alternatives is a distribution of the values of travel time. By definition, assigning one (average) value of VOT, which is frequently done in practice with the 4SM, does not produce a VOT distribution. Vehicles with a perceived VOT for a particular trip greater than the toll rate being charged will choose to use the priced lanes; vehicles with a perceived VOT less than the toll will choose the

free lanes.[77] The data issue with creating a VOT distribution for any given point in time is simply that the necessary data does not exist. However, collecting and analyzing extensive RP travel diary data from various pricing projects around the country would help researchers better understand what influences VOT distributions and could lead to the creation of some rules of thumb that other regions considering HOT lanes could use to help improve their estimating abilities.

For commercial vehicles, there is simply insufficient data available. A good estimate of the number of 4-tire CVs that use the priced corridor is an important variable in determining who will choose to travel on the priced facility. The problem is that this data is usually not available because private companies do not wish to divulge their proprietary routes. Agencies could potentially create VOTs for CVs with recent business survey data of their hourly rates, but this data is unavailable to most agencies. Another CV data issue is the difficulty of quantifying the value received from capital expenditure savings for these businesses, for which there is little (if any) discussion in field.

One data need public agencies should address is sample enumeration for businesses. Currently, surveys in many regions are only performed for households because regional models focus on estimating household travel behavior. To understand the behavior of CVs better, regional business surveys must be conducted.

4.5 Chapter Conclusions

There is evidence to support the hypothesis that the analytical tools and data are currently not available to create accurate estimates of pricing impacts. More reliable estimates of revenue and traffic diversion might make more roads financially feasible by lowering the required rate of return from reduced risk. Increasing the accuracy—and consequently the trust—in models used to look at pricing could mitigate some of the major concerns associated with road pricing projects.

There are no good tools available to public agencies in the United States for estimating the traffic impacts and revenue potential of pricing strategies, especially in the case of dynamic pricing. The most-often used approach is the four-step model, which has fundamental

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[77] Some vehicles will not choose the tolled alternative for other reasons (e.g., they may not have an electronic toll tag, they may be infrequent visitors to the system, they may be making a very short trip, etc.).

difficulties in capturing the most relevant characteristics of pricing. The model is being used for a purpose different from its original intent, which did not include the evaluation of policies involving little or no change to the infrastructure supply. Some approaches, such as bi-criterion traffic assignment, are theoretically more appealing than the traditional traffic assignment models used in the 4SM but there are still refinements necessary to make these techniques operational. Despite its faults, the four-step model is not likely to be replaced as the principal modeling tool for urban areas in the near future—especially in the United States. The 4SM has become a complex process demanding sizeable effort and data requirements. As a result, many public agencies do not have the resources to develop new or more sophisticated models, resulting in the state of the practice trailing the state of the art.

Consultants who specialize in modeling road pricing have developed more advanced techniques for creating heterogeneity in the traveler population than those traditionally used, but they are still using the four-step model. These consultants also use microsimulation for either investment banking studies or public agency studies with a large budget. Microsimulation is preferable to the 4SM in theory, but its estimates are only as good as the input assumptions. Nevertheless, many academic researchers are developing more advanced microsimulation techniques, which may prove to be the most appropriate for modeling road pricing.

Consultants' revenue bond estimates for investment banking studies are more likely to under-predict traffic demand than MPO estimates because they make more conservative growth estimates and assumptions. Independent economic growth and socio-economic estimates and sensitivity analysis are the main items reviewed by investment bankers, who do not have confidence in MPO estimates and assumptions. Investment banking studies should not be viewed as the most likely outcome for planning purposes and are not immediately transferable to a demand management strategy unless demand management is specifically examined in the study.

There are several models that may prove valuable tools to evaluate pricing policies if they are further developed and validated. STEP2 is an incremental approach that might be accepted by the modeling community in the United States, although this is not known. SMITE-ML and SPRUCE would be helpful sketch-planning tools if the models were validated against existing HOT lane projects and the validation results were presented to planning agencies and state DOTs. A new analysis tool, RPDAT, is presented in Chapter 5 as an alternative methodology

for evaluating potential road pricing policies. While RPDAT does not provide specific estimates of the impact of road pricing strategies, the decision-making tool can (i) help narrow the set of alternatives to be analyzed in-depth and (ii) incorporate criteria into the decision-making process that are omitted from traditional transportation models.

The influence of pricing on driver behavior is not well understood and thus poses challenges for modeling. Significantly more accurate modeling estimates cannot be made until additional empirical data and research from new pricing projects are available. Current research from the HOT lanes in California indicates two of the main variables considered by drivers when deciding to use a HOT lane are the value of reliability and the value of time for that particular trip (i.e., the value of time changes by day, time-of-day, trip purpose, etc.). It should be possible to estimate the value of reliability for variably-priced HOT lanes; however, the data does not exist to quantify the value of time for each individual's trips. Further, it could prove to be difficult to build an analytical tool capable of modeling the variation of individuals' value of time. The collection and analysis of empirical data from more pricing projects will be necessary to understand what factors are used as decision variables better. This should advance the theory of driver behavior, which could lead to improved models and help address equity issues of concern to decision makers.

Finally, there are several data insufficiencies that need to be resolved to develop more accurate pricing models. The travel characteristics and behavior of commercial vehicles are not understood well and better data is needed to estimate how this group will react to pricing policies. Commercial vehicles are likely to benefit greatly from priced facilities if they can increase productivity, but it is very difficult to estimate how many commercial vehicles will use a priced facility or what they would be willing to pay for the improved service. Other major data problems include the lack of empirical data from pricing projects, the poor quality of stated preference data, and little available data to see who is sensitive to reliability.

This chapter raised several issues that need to be addressed if transportation models' abilities to estimate the effects of road pricing are to be improved. It did not attempt to provide specific solutions, but rather simply established groundwork for further research in this area and demonstrated the need for alternative modeling techniques. There are clearly many opportunities to advance the state of the art and develop models whose results will be trusted more by decision makers.

The next chapter presents an analytical tool that allows decision makers to consider multiple criteria for determining which type(s) of road pricing strategies might be most appropriate for their region. It is argued that such an approach is quite suitable for evaluating road pricing issues facing decision makers at this time.

5 RPDAT: THE MULTI-CRITERIA ROAD PRICING DECISION ANALYSIS TOOL

5.1 Chapter Purpose and Organization

This chapter introduces a new tool, the Road Pricing Decision Analysis Tool (RPDAT), designed to help decision makers assess which forms of road pricing might be most regionally-appropriate and consistent with policy priorities. This tool was developed in response to the discovery, during the course of a literature review, that no similar model or multi-criteria framework for evaluating road pricing strategies exists. As will be discussed and demonstrated in this and subsequent chapters, the RPDAT framework is a useful tool for deciding which road pricing measures merit further consideration.

RPDAT uses multi-criteria analysis (MCA), an economic evaluation technique, to derive index scores for each road pricing alternative.[78] The index score for each alternative indicates its overall rank among several options as an appropriate pricing strategy for the region. This technique is useful when a decision maker (DM) is confronted with a multitude of objectives.

Prior to the presentation of RPDAT, Section 5.2 provides background information on the theory of multi-criteria analysis and uses it to analyze a simple auto purchase problem. Section 5.3 outlines the decision-making context for the RPDAT evaluation and Section 5.4 presents the model framework and logic. Section 5.5 provides the reader with visual images of the RPDAT user interface and applies the tool to a hypothetical metropolitan area.

5.2 Multi-Criteria Analysis (MCA)

While benefit-cost analysis (BCA) is a common technique used to evaluate public sector projects, it has its flaws. This method reduces all the impacts of a proposed alternative to a common monetary unit, which allows the impacts to be aggregated using a discount rate. The net benefit and/or the benefit/cost ratio are calculated for each alternative and then the results are compared to determine which, if any, alternative should be selected. While BCA is very helpful

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[78] Multi-criteria analysis is sometimes referred to as multi-attribute analysis.

in some situations, it is often criticized for lack of capacity to assess intangibles.[79] It is very difficult, if not unreasonable or even unethical, to monetize social, environmental, aesthetic, health, and security benefits or costs. Because of the difficulties inherent in quantifying these factors in monetary units, they are often either incorporated into analysis in faulty ways or omitted entirely. Not accounting for these factors is problematic, however, because the public sector is responsible for promoting the "overall good," which should include consideration of these parameters.

An alternative analysis approach, multi-criteria analysis, allows the impacts of alternatives to be compared without converting all variables into monetary terms, although a MCA could use the results of a BCA to score some criteria in an analysis. When there are multiple objectives, which is often the case, MCA is an especially useful process for choosing among alternatives. Multi-criteria analysis "is based on the fundamental idea that deliberate decision making generally requires that the decision maker takes into consideration various points of view. Thus, when evaluating the set of possible actions, the decision maker should try to do justice to a multiplicity of objectives or options" (Rietveld 1).

One of the advantages of MCA is that it defines objectives clearly. If a DM does not define all objectives explicitly, he/she may not realize that some of the goals probably conflict. One alternative is not usually the best means for achieving every objective, so gains and losses in criteria performance usually need to be traded-off among alternatives. For example, if a consumer were to consider purchasing an automobile, he/she would likely consider the comfort, size, safety, horsepower, and price of each vehicle option. However, it is not likely that one could find a vehicle that had the best comfort, size, safety, horsepower, *and* price. Thus, the buyer will have to make trade-offs among the different attributes. Clearly, the choice the consumer will make must depend on the relative values he/she places on the different criteria. The MCA process, defined subsequently, provides a framework to capture these types of necessary trade-offs among objectives and determine how well each alternative meets the DM's criteria.

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[79] For a more-detailed critique of monetary analysis methods, see: P. Nijkamp and A. Delft, Multi-Criteria Analysis and Regional Decision-Making, Studies in Applied Regional Science, P. Nijkamp, vol. 8 (Leiden: Martinus Nijhoff Social Sciences Division, 1977).

5.2.1 Basic MCA Process

There are many different MCA techniques, but the basic principles and processes are simple. First, a DM assigns numerical *weights* to several *criteria* to identify and quantify policy priorities. To illustrate, assume the decision maker in the auto example above is a customer who now has only three criteria: size, horsepower, and cost. The DM can assign weights to each criterion by allocating 100 points among the three criteria. For example, the customer may assign 50 points to cost, 20 points to size, and 30 points to power. This set of weights implies the customer places the highest value on cost, the customer values power at 60 percent (30/50) of cost, and the customer values size at 40 percent (20/50) of cost.

In the next step, each *alternative* receives a *score* with respect to the criteria and the scores are documented in a *performance matrix*.[80] These scores are independent of the weights assigned to each criterion in the previous step. In the auto example, assume the DM is considering the purchase of three cars: a Honda Accord, a Porsche 911 turbo, and a Ford Windstar minivan. The Honda is inexpensive, however, it is small and lacks power. The Porsche has considerably more power, but it is still small and it is very expensive. The Ford costs more than the Honda but significantly less than the Porsche, it is much larger than both of the other vehicles, and it has more power than the Honda but significantly less than the Porsche. If the alternatives were scored from one to four for each criterion, with four being the best, the performance matrix might be similar to the one shown in Table 5.1.

Table 5.1: Auto Example Performance Matrix

	Porsche	Honda	Ford Windstar
Cost	1	4	3
Size	2	2	4
Power	4	1	2

According to the MCA technique used in this thesis, the scores and weights are then aggregated with a simple linear additive model to produce the index scores, creating an overall preference ordering of the alternatives. In mathematical notation, the index score for each alternative is simply:

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[80] Note that this process is independent of the assigning weights. The results of the two steps are combined in step 4.

$$S_i = \sum_{j=1}^{n} w_j s_{ij} \quad \text{where,}$$

S_i = the overall index score for alternative i;
w_j = the weight assigned to criterion j; and
s_{ij} = the score of alternative i for criterion j.

For the automotive purchase example, the index score for each alternative would be:

$S_{Porsche}$ = 50*1 + 20*2 + 30*4 = 210
S_{Honda} = 50*4 + 20*2 + 30*1 = 270
S_{Ford} = 50*3 + 20*4 + 30*2 = 290

These index scores imply the Ford Windstar minivan is the best vehicle for the customer, the Honda is the second best, and the Porsche is the worst choice. Assuming that a linear rating scale is appropriate to capture the differences between the alternatives, one can infer the preference difference between the Porsche and the Honda is greater than the preference difference between the Ford and the Honda.

The use of a linear additive model implies the use of a *compensatory* approach. This assumes the effect of a high score on one criterion may be counteracted, or compensated for, by a lower score on another criterion. Where this is a poor assumption, non-compensatory techniques, which are outlined in Box 4, should be used to perform a multi-criteria analysis.

Box 4: Non-Compensatory Techniques

Non-compensatory techniques are used for multi-criteria analysis where it is not appropriate to make trade-offs. *Security* performance is an example of a criterion that some believe should not be substituted for by other measures, i.e., a weak security performance cannot be compensated for by a strong performance in travel time on an urban rail system, no matter what the weight assigned to these criteria. Non-compensatory techniques are less helpful for decision-making in practice as they often provide little distinction between alternatives, so informal judgment may be more helpful for determining a proper course of action.

The use of compensatory techniques assumes a mutual independence of preferences (MIP). Scores assigned to alternatives under one criterion cannot be affected by the scores assigned to another criterion for MIP to exist (ODPM DTLR). Mutual independence is weaker than statistical independence; it can hold even when options are correlated as long as the criteria express separate aspects of the value.

There are several other assumptions associated with using multi-criteria analysis as a decision-making tool that should be noted briefly before proceeding. These include:

- There is a single decision maker and the DM is undecided about the course of action. Even if there is a team of DMs who work together, this is still an assumption.
- Reason exists and functions in human behavior. If decision makers are not concerned with or capable of making rational decisions, they may have little interest in the results of an MCA.
- Formal analysis is appropriate for complex policy problems. Although there is subjectivity associated with quantifying weights and scores, this may not be more problematic than the quantification used in other evaluation techniques. One could argue that subjectivity is inherent in virtually all decision-making processes and is thus not specific to MCA.

5.2.2 Other MCA Techniques

Thus far, this chapter has dealt with linear additive multi-criteria analysis models, which are the traditional MCA method of combining scores and weights to produce overall preference scores for alternatives and will be used as the basis for RPDAT. Other methods for combining scores and weights that do not use linear-additive models are mentioned in this section to present alternative MCA techniques that could be used in subsequent versions of RPDAT. Some of these techniques are rather complex and take uncertainty and risk into account in the model, while others are very simple in application and in mathematical terms.

Outranking methods are sometimes credited with being more capable of capturing political realities and the effects of lobbying than other MCA models. As an example, the ELECTRE method tries to establish dominance relationships amongst alternatives using concordance and discordance indices to narrow the set of alternatives.[81] This methodology makes fewer assumptions about the process of creating preferences than linear-additive models, but the procedure is less transparent. Fuzzy set methods have also been developed in response to the idea that natural language is imprecise; however, this process is also less transparent.

Of all the MCA methodologies, Multi-Attribute Utility Models have the fewest critics, possibly as a result of their strong theoretical foundation. Keeney and Raiffa developed a set of procedures to generate a performance matrix, determine whether criteria are independent of each other, and estimate the utility of a DM's overall preference for an alternative. This approach

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[81] The dominance approach has its roots in graph theory. For additional information on the ELECTRE method, see: Nijkamp and Delft, Multi-Criteria Analysis and Regional Decision-Making.

formally considers uncertainty and allows criteria to interact with each other in relationships that are more complex than with linear-additive models. Although multi-attribute utility models have been applied in practice to a wide range of problems, their application may not be the most attractive for many decision-making problems because it is rather complex, resource-intensive, and less transparent than traditional MCA models.

Despite the analytical appeal of some of the models outlined in this section, the RPDAT framework uses a linear additive model to perform MCA because it is simple for decision makers to understand and the process is the most transparent.

There are strengths and weaknesses associated with all MCA methods, which are outlined in the following section.

5.2.3 Strengths and Weaknesses of MCA

There are several strengths and weaknesses inherent in multi-criteria analysis. One of the primary strengths associated with MCA is that it forces the DM to think about and clearly set forth the criteria that he/she will use to judge alternatives. This may lead to the inclusion of criteria that would otherwise be omitted from an evaluation. Additionally, documenting weights and scores shows why particular alternatives are chosen and allows for weights to be openly disputed, providing an important forum for discussion among stakeholders.

Linear-additive models in particular are attractive because they are very transparent. The algorithm used to combine weights and scores is very simple and there is little room for intentional bias to be hidden within the model. More complex MCA methods, such as the outranking method, fuzzy set method, and multi-attribute utility models, are less transparent and may be more difficult for stakeholders and analysts to understand, thus making them less attractive for many applications.

One notable weakness of MCA techniques is that there is no means to ensure there are net welfare gains from the action. BCA can ascertain whether benefits/costs > 1, while MCA cannot prove (in economic terms) that "no action" is not the best alternative.

In addition to this problem, the principal criticism and weakness of MCA is the subjectivity associated with weighting objectives. This weakness is far from unique to MCA, however, as there is subjectivity involved with most other economic evaluation methods as well.

In benefit/cost analysis, economists often dispute the choice of what constitutes a benefit or a cost as well as the magnitudes of these values.

The strengths of MCA warrant its use—especially if it can be performed quickly—for screening alternatives or as an evaluation technique to be used in additional to more detailed models. The following sections will discuss a tool (RPDAT) that performs MCA for road pricing strategies.

5.2.4 Section Summary

This section defines the basic processes and terminology associated with multi-criteria analysis. It explains the computational process and provides a sample application of MCA to an auto purchase problem.

The RPDAT framework, presented in Section 5.4, uses the linear-additive model form of multi-criteria analysis to evaluate road pricing strategies. Before the model framework is discussed, the decision-making context for the evaluation is presented in the following section.

5.3 The Decision-Making Context

The decision-making context for the RPDAT evaluation is regional planning, performed by an organization or group of DMs. Here, a region is defined as a *metropolitan area*. Metropolitan areas are the basic geographic unit for economic competition, economic growth, and environmental issues (Sussman, Perspectives on Intelligent Transportation Systems). Thus, this scale is appropriate for evaluating many transportation policies and measures.

Planning refers to the process of considering and making decisions to achieve objectives for the future. Therefore, regional planning is the process of identifying and then striving to achieve goals for a metropolitan area. The regional planning goals will, at minimum, depend on the region's political priorities and stage of development (Rietveld). Rietveld states that regional planning aims to integrate the following policies:

- Economic (income, wealth, differentiation of economic structure);
- Social (quantitative and qualitative aspects of the labor market);
- Spatial (location patterns, occupation rates, transport networks);
- Services (education, health, cultural); and
- Environmental (ecological quality, pollution, noise, quantity of natural areas).

Planning for these policies often occurs in a series of steps. Faludi (cited in Rietveld) states that planning theory consists of four phases:

1. The recognition of a problem
2. The generation of alternatives to meet the problem
3. The choice of an alternative
4. The implementation of the alternative chosen

Using Faludi's four planning phases, the initial problem that RPDAT addresses is deciding which, if any, form(s) of road pricing a region should pursue. In accordance with Faludi's second phase, RPDAT evaluates nine road pricing alternatives. The tool considers only road pricing alternatives and in fact, only a subset of all road pricing measures. The specific pricing measures evaluated by RPDAT are discussed in Section 5.4.

The primary objective of RPDAT is to assist DMs with Faludi's third phase of planning—the choice of alternatives. The tool is primarily intended for *sketch-planning* analysis, which is used to produce an indication of whether particular policies or strategies are worthy of further and more detailed consideration.[82] For sketch-planning, RPDAT can be used as a screening tool to decide which road pricing strategies should be evaluated further for a metropolitan area. This tool allows the user to trade-off several criteria, some of which may not be considered in classical transportation models but can still be important in decision-making (e.g., impact on the number and severity of traffic accidents). Though it is not intended for evaluating projects and it does not provide specific estimates of the impacts, RPDAT produces an index score for each indicating how well it compares with the other options, given the region's priorities.

Implementation, Faludi's fourth and final phase of planning, is not addressed with the model. Guidelines and experience, rather than a "black box tool," are more appropriate for assisting with the implementation process, which is situation-specific and arguably too complicated for quantitative analysis.

5.4   RPDAT Framework

The Road Pricing Decision Analysis Tool (RPDAT) performs MCA for road pricing strategies. It is a decision-making program intended to identify which road pricing alternatives

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[82] Sketch-planning refers to analysis that is more sophisticated than "back-of-the-envelope" planning yet can still be performed quickly, although it is less detailed than an in-depth analysis.

are the most appropriate, or worthy of further consideration, for a metropolitan area. Version 1.1 evaluates up to nine pricing strategies, depending on whether HOV lanes currently exist or not in the metropolitan area.[83] Network pricing, area-wide pricing, cordon pricing, facility pricing, conversion of HOV lanes to HOT lanes, adding HOT lanes, distance-based pricing, conventional tolling, and a "no pricing" alternative are considered in the model. The tool analyzes the alternatives as overall strategies rather than as they apply to specific projects.

RPDAT makes several assumptions about the characteristics of the metropolitan area to reduce the amount of information the user is required to input. These assumptions should be reasonable in most scenarios, especially for sketch-planning purposes. The assumptions of the tool are outlined below:

1. RPDAT can calculate the scores in the performance matrix on an interval from negative four to positive four using only the regional characteristics input by the user and the model's algorithms. It is also assumed that a scale ranging from negative four to positive four is appropriate for comparing alternatives.
2. The metropolitan area has an activity center, termed the "downtown/CBD," although other activity centers may also be evaluated.
3. Except in the case where the evaluation area is a particular corridor, the model evaluates the road pricing alternatives as if they were widely deployed throughout the metropolitan area. For example, a network of HOT lanes (one in each direction for all expressways) is evaluated rather than HOT lanes on several corridors. If the evaluation area is a single expressway corridor, the model assumes pricing will be deployed on that corridor only.
4. Demand will be induced when new capacity is added. In other words, capacity expansion will increase both the number of trips and vehicle miles traveled.
5. Increasing highway capacity encourages sprawl and increasing the financial cost of travel encourages "smart growth." These assumptions are used primarily to determine how the measures affect housing location decisions.
6. Road pricing policies have no effect on the number of traffic fatalities on city streets. Increasing vehicle speeds on expressways, however, is assumed to increase fatalities.
7. The scoring of the alternatives in the performance matrix is based on what the author defines as "theoretical best" values. RPDAT does not assume specific toll charges, but rather assesses how well a strategy could achieve objectives under a typical implementation.

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[83] RPDAT will evaluate eight alternatives if there are no HOV lanes in the region.

It makes inferences about the differences between toll rates and toll structures of the alternatives to calculate the scores of the alternatives in the performance matrix. Network pricing is assumed to have the highest toll charge of all the alternatives and facility pricing is assumed to have higher tolls than conventional tolling in the peak period but lower than or similar charges in the off-peak. The distance-based pricing toll is assumed to be high enough that it discourages some potential travel; however these charges are lower than network pricing tolls because they do not include congestion costs.

The following section identifies the basic RPDAT process. Each of these steps will be discussed in greater detail in the sections that follow Section 5.4.1.

5.4.1 RPDAT Basic Steps

RPDAT has four steps as well as an introduction step (step 0), which are outlined in Box 5. The model assumes there is a decision maker and an analyst who work together to perform the evaluation and that the DM is familiar with the policy objectives and the analyst is aware of the traffic/regional characteristics of the metropolitan area.[84] The DM and the analyst typically will be two different people, but they could be the same individual if that person is familiar with both sets of information. The DM performs the first two RPDAT steps and the analyst performs the third step. The fourth step is an output page, which presents the results and requires no information by the user.

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[84] The analyst inputs regional characteristic data into the model in step 3. This process and its role are described in greater detail in Section 5.4.4.

Box 5: RPDAT Steps

Step 0: Instructions. This page provides a brief description of the tool.
Step 1: Begin. The DM identifies the scope of the evaluation (i.e., the entire metropolitan area, downtown, or a specific corridor) and whether HOV lanes exist in the region.
Step 2: Weights. The DM identifies and weighs the policy objectives by assigning weights to the criteria.
Step 3: Regional Characteristics. The analyst inputs the regional data, which the model uses to calculate the scores for the criteria in the performance matrix.[85]
Step 4: Output. This page ranks the alternatives and displays the performance matrix.

Figure 5.1 shows the user paths and information flows within the model. Each of these steps will be explained in the following sections.

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[85] An example of a regional characteristic is the "peak-period average speed on the expressways." The value the user inputs into step 3 is used in conjunction with the "off-peak average speed on the expressways" value to determine how well each alternative "decreases average travel time for all peak-period trips on expressways," which is one of the criteria. As an example of how the performance matrix is calculated, the model uses these two values to calculate a score for how well facility pricing—one of the alternatives—meets the "decrease average travel time for all peak-period trips on expressways" criterion. The scores are documented in the performance matrix and the scoring system is described in Section 5.4.4.

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Step 0: Instructions Page. User reads the RPDAT instructions.

Step 1: Beginning Page. User selects the scope of the evaluation (entire region, downtown/CBD, or an expressway corridor) and answers whether HOV lanes are present in the region.

Step 2: Weights Page – Part B. If applicable, the decision maker assigns points among the criteria grouped under a high-level objective.

Step 2: Weights Page – Part A. Decision maker assigns points among the high-level objectives.

Weights Array

Criteria 1
Criteria 2
.
.
Criteria n

Denotes user-path

Denotes information flow

Step 2: Review Weights Page. User reviews the weights and decides whether to modify them.

OR

Step 3: Regional Characteristics Page. Analyst inputs regional characteristics and transportation data.

Weights

Performance matrix scores are combined with the weights to perform a multi-criteria analysis of the alternatives.

Performance Matrix

HOT Lanes   No Pricing

Criteria 1
Criteria 2
.
.
Criteria n

Scores

Step 4: Output Page. The index scores, performance matrix, and weights are presented to the decision maker.

Figure 5.1: RPDAT Flow Chart

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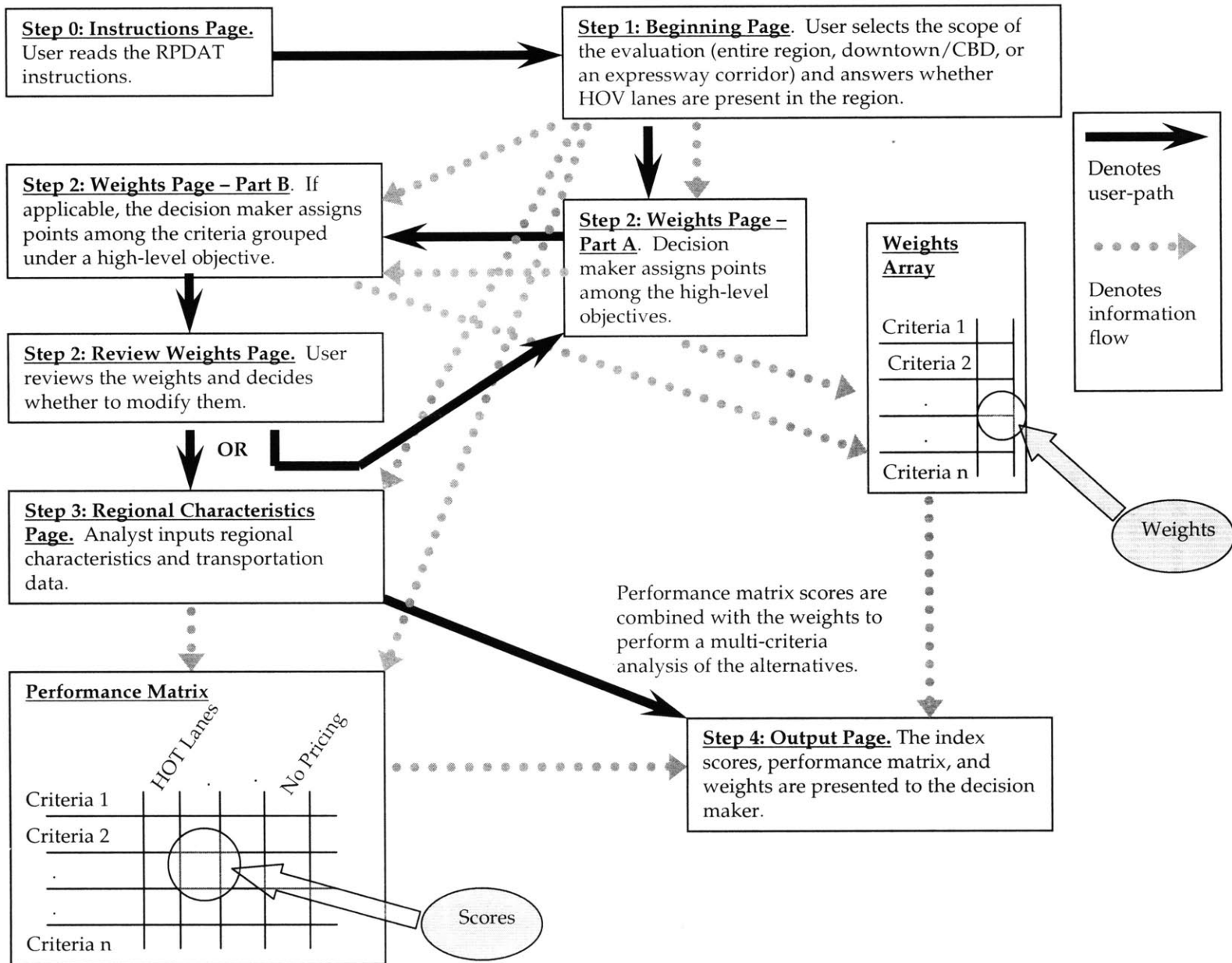
5.4.2 Identify the Decision-Making Problem and Evaluation Scope

Before the decision maker uses RPDAT, he/she should identify the decision-making context and problem he/she wishes to analyze. It is necessary to have clarity at the beginning stage; otherwise, unclear or improper objectives may be used in the analysis. The roles of the DM and the analyst must be identified, along with the role of the organization within the overall planning context. Identifying the current situation and who will be involved in the MCA should be performed before using RPDAT.

It is also necessary to identify the purpose of the appraisal. In other words, the DM should state the purpose of the evaluation and the problem to be solved. Because the topic of this particular MCA application is road pricing, RPDAT assumes the context is *decision-making for road pricing strategies in a metropolitan area*. Greater specificity in the context will likely differ between regions and agencies; however, some potential decisions may include:

- *Which forms of road pricing are best for our metropolitan area, if any?*
- *How can road pricing strategies help support our metropolitan area's objectives?*
- *What are the strengths of a particular road pricing strategy relative to others?*
- *Is there a better road pricing strategy than the existing one(s) used in our metropolitan area?*

In step 1 of RPDAT, the decision maker must identify the evaluation scope of the analysis. If the user is primarily interested in considering the impacts of road pricing measures in the downtown or an expressway corridor, he/she should select "downtown/CBD" and "an expressway corridor" evaluation scopes, respectively, in step 1. If the user wishes to consider the effects of road pricing at the metropolitan area-level, the user should select "entire metropolitan area" in this step. As will be discussed in Section 5.4.3 and Section 5.4.4, the choice of the evaluation scope affects which criteria the DM may consider in the analysis and the score of the alternatives in the performance matrix.

5.4.3 Identify Objectives and Assign Weights

After completing step 1, the DM should determine the objectives of the organization. This mental exercise will prepare the DM to assign weights to the criteria in step 2. If the DM is

directly involved with the MCA, he/she may identify, or work with others to identify, the objectives as they relate to the entity's overall mission and policies. If the DM is not involved, surveys or policy statements may be useful for this. Experts, or a panel of experts, could also perform this step. Care should be taken to ensure that the objectives are not defined too narrowly.

If a stakeholder outside the transportation organization is performing the evaluation, a vision for the future of the transportation system could also be identified to help determine policy priorities. A future vision could be compared with existing conditions or system projections if no measures are enacted, and the differences could be compared to provide insight regarding what needs to be achieved. A goal-oriented mindset helps DMs remember that strategies should be undertaken for the sake of reaching particular goals rather than merely implementing projects.

In step 2 of the model, the DM assigns weights to criteria in order to quantify the objectives. RPDAT has 29 criteria built into the model that reflect potential objectives associated with road pricing schemes. Because it is difficult for a DM to compare and assign weights to 29 criteria at the same time, RPDAT separates the process of assigning weights into two steps—part A and part B. Part A organizes many criteria under what are called *high-level objectives*. Here, similar criteria are grouped together, which reduces the number of criteria the DM must consider at one time. Points are allocated among criteria grouped under high-level objectives in part B. The high-level objectives are shown in Table 5.2.

Table 5.2: RPDAT High-Level Objectives

Reduce travel times (i.e., increase vehicle speeds)
Improve reliability of travel times
Improve road safety
Improve public transportation services
Enhance the natural environment
Gross revenue generation
Influence housing and business location choices
Reduce energy consumption and dependence
Influence auto ownership
Improve pedestrian-friendliness
Consider equity

Because some criteria do not group well with the other criteria, they are listed with the high-level objectives.[86] Gross revenue generation, reduce energy consumption and dependence, and improve pedestrian-friendliness are criteria that are listed with the high-level objectives.

An example of criteria grouping, "Reducing the number of fatalities" and "Reducing the number of accidents" are two different criteria that are grouped together under "Improving road safety" in part A. In part B, the user allocates "Improving road safety" points between "Reducing the number of fatalities" and "Reducing the number of accidents." Figure 5.2 shows all of the high-level objectives and criteria in the model; high-level objectives are on the left and the criteria grouped under them are on the right.

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[86] It should be noted that identifying a criterion as a high-level objective does not define any level of importance for that criterion (i.e., there could be a criterion listed with the high-level objectives that receives less weight that criteria listed under the high-level objectives).

Reduce travel times (i.e., increase vehicle speeds)	Decrease average travel time for all peak-period trips on expressway(s)
	Decrease average travel time for all mid-day trips on expressway(s)
	Decrease average travel time on city streets within CBD
	Decrease average travel time for peak-period arterial trips
	Create a lower travel time option for autos on expressway(s)
Improve reliability of travel times	Improve reliability for all peak-period trips on expressway(s)
	Improve reliability for all mid-day trips on expressway(s)
	Improve reliability on city streets within the CBD
	Improve reliability for peak-period trips on arterial(s)
	Create a reliable travel time option for autos on expressway(s)
Improve road safety	Reduce traffic fatality rate
	Reduce number of traffic accidents
Improve public transportation services	Decrease travel time of bus services operating on the expressway(s)
	Decrease travel time of bus services operating on city streets in the CBD
	Decrease travel time of bus services operating on city streets outside the CBD
	Improve reliability of bus services operating on expressway(s)
	Improve reliability of bus services operating on city streets in the CBD
	Improve reliability of bus services operating on city streets outside the CBD
Enhance the natural environment	Improve air quality
	Reduce greenhouse gas production
Reduce energy consumption and dependence	Reduce energy consumption and dependence
Gross revenue generation	Gross revenue generation potential
Influence housing and business location choices	Promote new housing developments on suburban or undeveloped land
	Promote "Smart Growth"
Influence auto ownership	Promote automobile ownership
	Reduce vehicle ownership growth rate
Improve pedestrian-friendliness	Improve pedestrian-friendliness
Consider equity	Availability of free or low-cost alternatives
	Internalize external costs (i.e., implement the "user-pay" principle)

Figure 5.2: RPDAT High-Level Objectives and Criteria

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Table 5.3 lists the full set of criteria and notes whether the model analyzes them for each evaluation scope. The number of criteria evaluated by the tool depends on the scope of the evaluation that the user selects. If the decision maker chooses to evaluate pricing for "the entire metropolitan area," all 29 criteria are applicable. If the user selects the "downtown/CBD" or "an expressway corridor" evaluation scopes in step 1, only some criteria are applicable and those that are not applicable are hidden from the user. For example, if a decision maker only wishes to evaluate the impacts of pricing on the downtown, he/she will not be concerned with "Decreasing average travel times for all peak-period trips on expressways," so in this case, this criterion will be omitted. In Table 5.3, the R column denotes "the entire metropolitan area" evaluation scope, the D column indicates "the downtown/CBD" evaluation scope, and the E column represents "an expressway corridor."

Table 5.3: RPDAT Criteria

Criteria	R	D	E
Decrease average travel time for all peak-period trips on expressway(s)	X		X
Decrease average travel time for all mid-day trips on expressway(s)	X		X
Decrease average travel time on city streets within CBD	X	X	
Decrease average travel time for peak-period arterial trips	X		X
Create a lower travel time option for autos on expressway(s)	X		X
Improve reliability for all peak-period trips on expressway(s)	X		X
Improve reliability for all mid-day trips on expressway(s)	X		X
Improve reliability on city streets within the CBD	X	X	
Improve reliability for peak-period trips on arterial(s)	X		X
Create a reliable travel time option for autos on expressway(s)	X		X
Reduce traffic fatality rate	X	X	X
Reduce number of traffic accidents	X	X	X
Decrease travel time of bus services operating on the expressway(s)	X		X
Decrease travel time of bus services operating on city streets in the CBD	X	X	
Decrease travel time of bus services operating on city streets outside the CBD	X		
Improve reliability of bus services operating on expressway(s)	X	X	X
Improve reliability of bus services operating on city streets in the CBD	X	X	
Improve reliability of bus services operating on city streets outside the CBD	X		
Improve air quality	X	X	X
Reduce greenhouse gas production	X	X	X
Reduce energy consumption and dependence	X	X	X
Gross revenue generation potential	X	X	X
Promote new housing developments on suburban or undeveloped land	X	X	X
Promote "Smart Growth"	X	X	X
Promote automobile ownership	X	X	X
Reduce vehicle ownership growth rate	X	X	X
Improve pedestrian-friendliness	X	X	
Availability of free or low-cost alternatives	X	X	X
Internalize external costs (i.e., implement the "user-pays" principle)	X	X	X
Public acceptability	X	X	X

The DM quantifies his/her objectives in two parts: first, the DM allocates 100 points among the high-level objectives in step 2 part A. Then, if the DM assigned any points to high-level objectives that have criteria grouped under them, the DM is prompted to allocate 100 points among each set of criteria that were grouped together under a high-level objective. RPDAT

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performs the arithmetic to determine the actual weight for each criterion.[87] When finished with part B, the user is directed to a page where he/she can review the weights calculated by the model. If the DM agrees with the weights, then he/she will proceed to step 3, but if he/she decides different weights should be used, the DM has the option to return to step 2 part A and re-enter the weights.

If the actual decision maker has limited participation in the analysis, the DM can be interviewed to derive weights. Techniques discussed up to this point produce the stated preference of the DM. If the relevant DM does not participate in the analysis, his/her revealed preference can be used to make inferences about future behavior and preferences, which is done by examining past actions. While such an implicit approach can be quite useful in some scenarios, it may be less useful in others. Many situations are unique; thus perfect examples of past behavior are not available. If neither technique can be performed, policy documents can be examined to derive the set of weights.

5.4.4   Score the Alternatives

After the DM completes step 2, he/she will presumably turn the model over to an analyst to input regional characteristics into the model in step 3. In this step, RPDAT calculates each alternative's score for each criterion using the model's algorithms based purely on the regional characteristics input into the model. The role of the regional characteristics will be explained further in the latter half of this section.

RPDAT calculates 783 scores for a given set of regional characteristics,[88] but the user will view no more than 261.[89] To avoid unnecessary confusion, the user will only view the scores that are applicable for the evaluation area selected in step 1. The arrays of scores are documented in the performance matrix.

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[87] Using the road safety example cited above, if the DM allocated 10 points to *Improve road safety* in part A, the DM would then need to allocate 100 points between *Reduce traffic fatalities* and *Reduce the number of traffic accidents*. Assuming the DM assigned 30 points to the first criteria and 70 points for the second, the weight for criterion *Reduce traffic fatalities* would be 10*30/100 = 3 points, and the weight for criterion *Reduce the number of traffic accidents* would be 10*70/100 = 7 points.

[88] 783 scores = (9 alternatives)*(29 criteria)*(3 evaluation scopes).
[89] 261 scores = (9 alternatives)*(29 criteria).

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The performance matrix in RPDAT Version 1.1 has 29 rows (one for each criterion) and nine columns (one for each alternative). RPDAT is a spreadsheet model, and the logic used to calculate each of the 783 scores is stored within the 261 cells.[90] Each cell contains the logic that determines the score for each of the three evaluation scopes.

In an MCA application, alternatives are scored according to a common rating scale. A description of potential rating scales is outlined in Appendix A4.

RPDAT uses a ratio scale with a maximum value of positive four and a minimum value of negative four for each score. The terminology used to describe how well each alternative meets the criteria is listed in Table 5.4. A scale with a fixed origin was chosen to allow positive and negative impacts to be represented in the model. For example, facility pricing may meet the "Decrease average travel time for all peak-period expressway trips" criterion well, which would give the alternative a positive score in the model. Under certain circumstances, however, it may meet the "Decrease average travel time for peak-period arterial trips" criterion poorly, implying it actually increases average travel times for peak-period arterial trips. In this case, facility pricing would receive a negative score for this latter criterion.

Table 5.4: RPDAT Performance Matrix Scoring Legend

4	Extremely well
3	Very well
2	Well
1	Somewhat well
0	Neutral or mixed
-1	Somewhat poor
-2	Poor
-3	Very poor
-4	Extremely poor

The limited scale with a magnitude of four was selected because a scale from 0-100 would imply the model is able to estimate the scores with more precision than what is possible. Implying such a precise scale would be misleading because a lack of data points makes it impossible for this model to be calibrated against real-world examples. On the other hand, a magnitude four scale allows more differences to be represented than a scale with extreme values

[90] Microsoft Excel is the spreadsheet application. Each cell stores three scores, one for each evaluation area.

of two or three. The author's judgment is that +4 to -4 is a reasonable balance between representational precision and ability to capture the differences among alternatives.

As mentioned earlier in this section, the values input by the analyst on the regional characteristics page are used in conjunction with the model's algorithms to calculate the scores in the performance matrix. The model automatically calculates the scores and the user does not input any information directly into the performance matrix. All of these values are numerical inputs except "Rate the availability of alternatives to the expressway(s)." To input this characteristic, the user selects either "No alternative routes," "Some alternative routes," or "Very good alternative routes" from a drop-down list. A list of the regional characteristics required by RPDAT is shown in Table 5.5.

Table 5.5: RPDAT Regional Characteristic Data Requirements

Peak-period average speed on expressway(s) (miles per hour)
Mid-day average speed on expressway(s) (miles per hour)
Off-peak average speed on expressway(s) (miles per hour)
Travel time safety margin index value for expressway(s) (reliability measure)[91]
Peak-period average speed in CBD (miles per hour)
Off-peak average speed in CBD (miles per hour)
Percent of air pollution derived from local transportation
Percent of metropolitan-area VMT that is on expressways
Size of the metropolitan area (hectares)
Size of the CBD or potential cordon area (hectares)
Percent of peak-period vehicle trips within the cordon that do not cross the cordon line (i.e., internal trips)
Percent of peak-period vehicle trips in the metropolitan area that cross the cordon, but neither originate nor terminate within the cordon area (i.e., through trips)
Percent of peak-period vehicle trips in the metropolitan area with origin or destination in the CBD
Percent of peak-period person trips in the metropolitan area crossing the cordon line that use public transportation
Percent of peak-period expressway corridor trips that are auto
Percent of HOV lane capacity utilized during peak-period
Rate the availability of alternatives to the expressway(s):
Number of expressway lanes in the peak direction

The number of scores calculated by RPDAT (783) prohibits enumerating all of the calculations in this section. A simple example, however, is presented for educational purposes.

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[91] This measures the extra travel time most travelers include when planning peak-period trips. For example, a value of 1.46 indicates travelers plan an additional 46 percent travel time than for off-peak travel times to ensure 95 percent on-time arrival.

The following Microsoft Excel formula represents the facility pricing scores that RPDAT calculates for the "Decrease average travel time for peak-period arterial trips" criterion:[92]

=IF(TargetLocationID=3,0,IF(AvailabilityOfAlternativesID=2,0,
IF(AvailabilityOfAlternativesID=3,IF(OffPeakToPeakExpressway
>=1.5,-3,IF(OffPeakToPeakExpressway>=1.3,-2,IF(
OffPeakToPeakExpressway>=1.05,-1,0))),IF(
AvailabilityOfAlternativesID=4,IF(OffPeakToPeakExpressway>=
1.75,-4,IF(OffPeakToPeakExpressway>=1.4,-3,IF(
OffPeakToPeakExpressway>=1.2,-2,IF(
OffPeakToPeakExpressway >=1.05,-1,0))))))))

Box 6 defines the variables used in the formula. To explain the formula above, a value of TargetLocationID = 3 signifies the evaluation scope is the downtown. Because this criterion is not applicable for a downtown evaluation, the value of the cell is equal to zero if that scope is selected by the user. The criterion is applicable to evaluations of the entire metropolitan area and an expressway corridor, so the rest of the formula logic applies to those cases.

Box 6: RPDAT Formula Example Variables

TargetLocationID = the scope of the evaluation area (selected by the user in step 1). A value of 2 implies the scope is the "entire metropolitan area," 3 implies the scope is the "downtown/CBD," and 4 implies the scope is "an expressway corridor."
AvailabilityOfAlternativesID = the quality of routes that are alternatives to the expressway. A value of 2 implies there are "no alternative routes," 3 implies there are "some alternative routes" and 4 implies there are "very good alternatives." The user selects one of these choices on the regional characteristics page.
OffPeakToPeakExpressway = the "off-peak average speed on expressways" divided by the "peak-period average speed on expressways," which are both regional characteristics input by the user.

If the analyst inputs that there are "no alternative routes" on the regional characteristics page, there will be no impact (i.e., a score of zero) on the average travel time for peak-period arterial trips because there is not any diversion. If there are "some alternative routes," there may be negative impacts, which would be represented by negative scores. In this scenario, the score is determined by the level of congestion on the expressway, which is approximated by the *OffPeakToPeakExpressway* variable. Higher congestion before the pricing measure would be implemented would imply there would be greater diversion after implementation than if there

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[92] Note that this formula calculates the scores for all three evaluation scopes.

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were little congestion on the expressway, and hence a greater magnitude negative score. If there are "very good alternative routes" the same logic applies, although the model assumes more diversion occurs when there are higher-quality alternative routes, explaining why the minimum threshold values for achieving the same score are lower for the "very good alternative routes" case than the "some alternative routes" case. This example represents one of the simpler of the 261 RPDAT cells in the performance matrix.

After the user has input all of the regional characteristics into the model, he/she is directed to the output page where the index scores, weights, and performance matrix are displayed.[93] The calculation and interpretation of the output is described in the following sections.

5.4.5 Determine Overall Preference of Alternatives

In step 4, the scores and weights are combined to obtain overall preference ratings of the alternatives, which are represented by index scores. An index score can be interpreted as the overall attractiveness of each road pricing alternative for the metropolitan area. As noted previously, RPDAT uses a linear-additive model. The (overall) index score for each alternative is simply:

$$S_i = \sum_{j=1}^{n} w_j s_{ij} \quad \text{where,}$$

S_i = the index score for alternative i;
w_j = the weight assigned to criterion j; and
s_{ij} = the score of alternative i for criterion j.

A higher index score represents a higher overall preference for an alternative. The user should review the results and conduct sensitivity analysis after reaching step 4.

5.4.6 Review and Conduct Sensitivity Analysis

The index scores should be compared against one another and reviewed by the user. If counter-intuitive results are produced by the process, the inputs should be reviewed and checked for errors.

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[93] Weights are input by the user, but the performance matrix is generated by the model. Both are presented on the output page to summarize the inputs and outputs.

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Sensitivity analysis may be helpful to test the robustness of the solutions obtained with the model. To determine the sensitivity, weights can be varied to determine the effect on the overall preference order of the alternatives. Individual stakeholders will often have different views of what the appropriate weights should be, and sensitivity analysis can demonstrate under what assumptions an outcome is the most preferred.

If used as a screening tool, the DM can use the output to select which alternative(s) should be pursued or (more likely) analyzed further. Because risk, uncertainty, and public acceptability are not accounted for in RPDAT Version 1.1, the DM should consider these factors in conjunction with the RPDAT results when making a final decision.

5.5 RPDAT User Interface

RPDAT uses the Microsoft Excel application with the Visual Basic language as the platform for the program. Users open an Excel file and RPDAT guides them through a series of pages. The user is instructed to input information and click a button when each step is completed, which will direct them to the next step. This section explains the user interface with a hypothetical example.

The program begins with an Instructions page (step 0), explaining what the program does, its intended use, what it evaluates, etc. A screenshot of this page is shown in Figure 5.3.
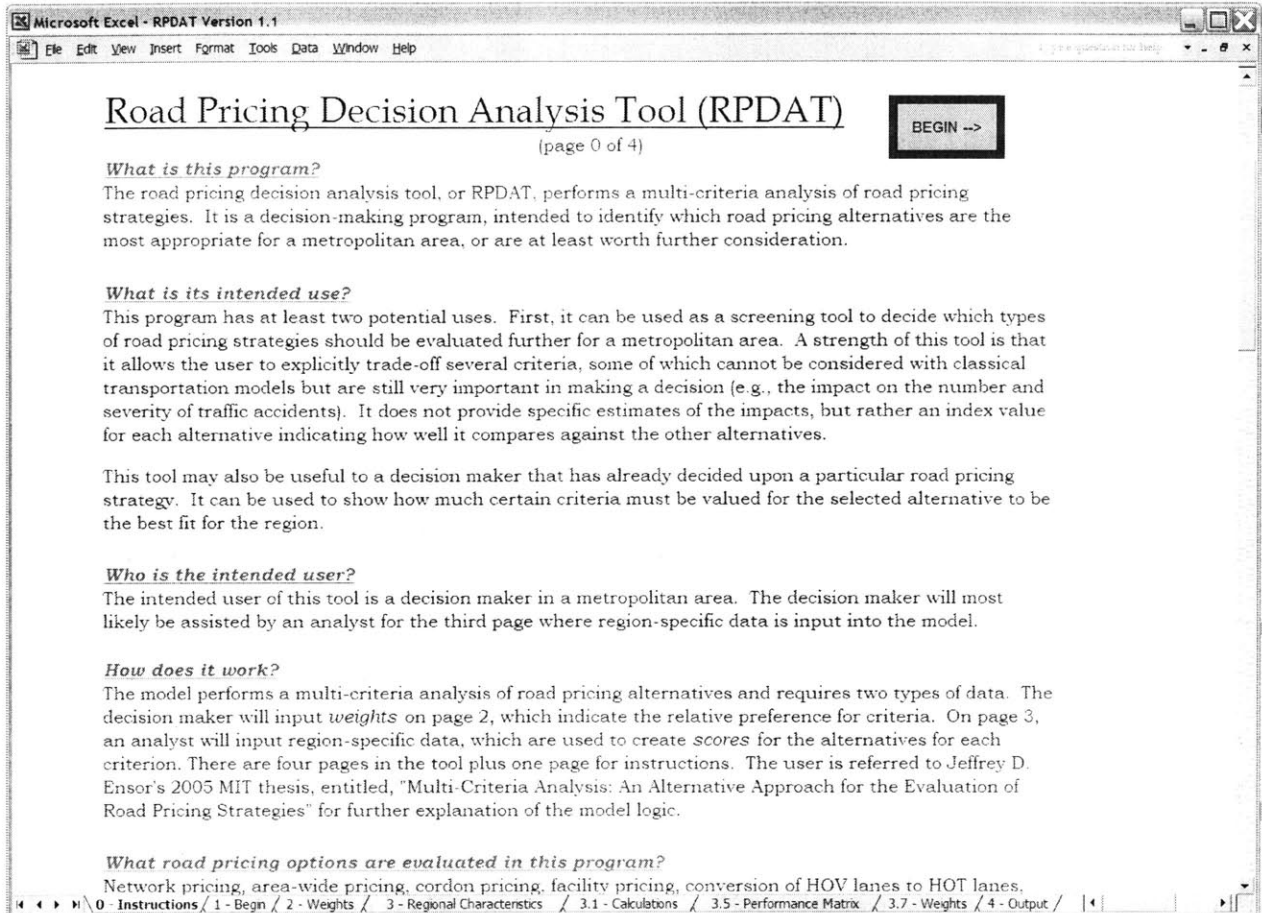
Figure 5.3: RPDAT Instructions Page

After the user has read the instructions, he/she will transfer to the first page by clicking the "Begin" button located in the upper right-hand corner of the page. This takes the user to the Beginning page, where the geographic scope of the study must be selected from a drop-down box. The choices are "entire metropolitan area," "downtown/CBD," and "an expressway corridor." In the second question, the user will input whether any HOV lanes are present in the metropolitan area. In this hypothetical example, it is assumed the evaluation is being performed for the entire metropolitan area and that HOV lanes are widely deployed. Figure 5.4 shows a user selecting these options from the drop-down list.
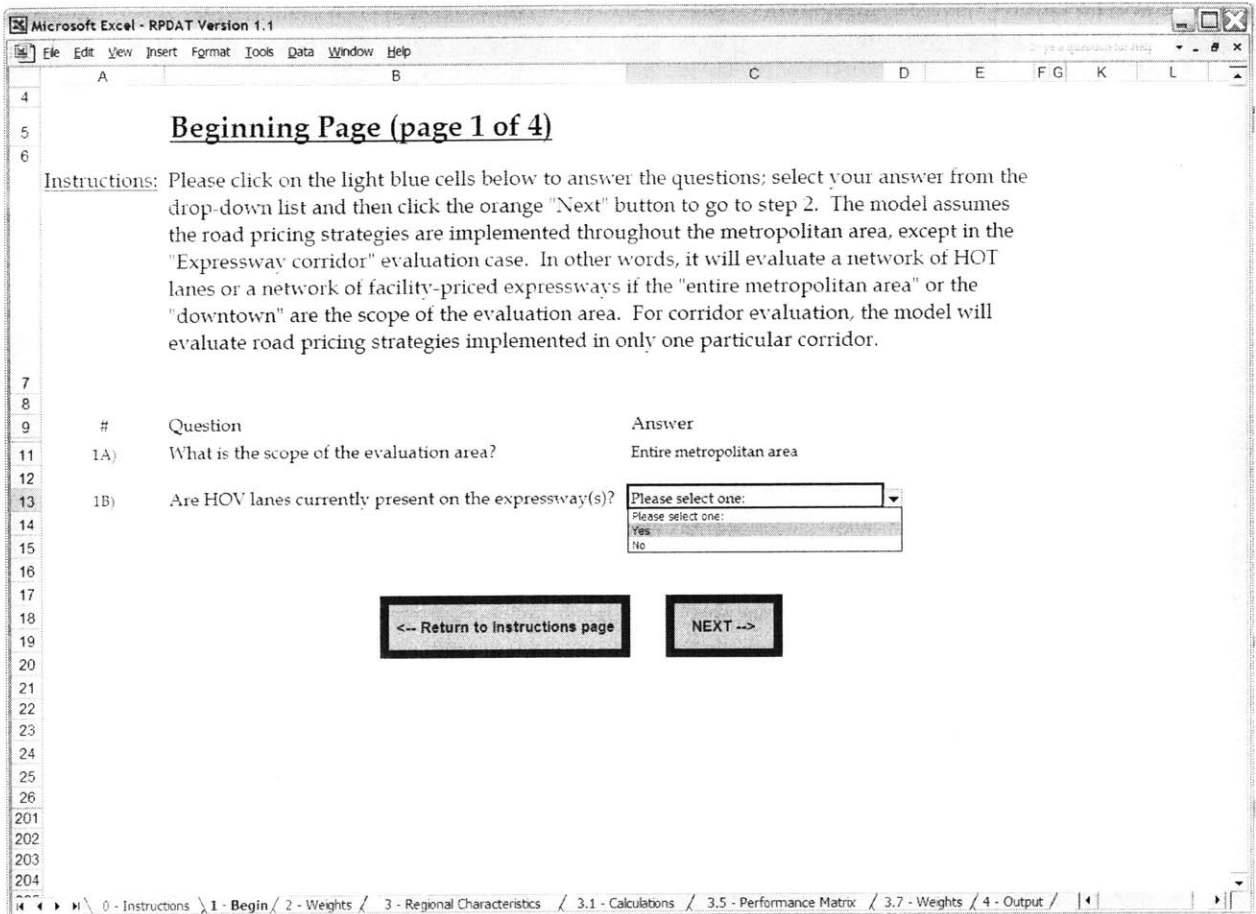
Figure 5.4: RPDAT Beginning Page

From this point, the user has the option to return to the instructions page or proceed to step two (Weights page), which is where the weights are entered into the model. This step is divided into two parts: A and B. In part A, the user assigns points to the high-level objectives (as described in Section 5.4.3). When 100 points have been assigned, the user is allowed to proceed to part B. In the example, it is assumed that the DM assigns values of 20, 25, 5, 30, 10, and 10 to reduce travel time, improve reliability of travel times, improve safety, improve public transportation services, enhance the natural environment, and gross revenue generation, respectively. In this example, zero weight is given to the other five high-level objectives. This process is presented in Figure 5.5.
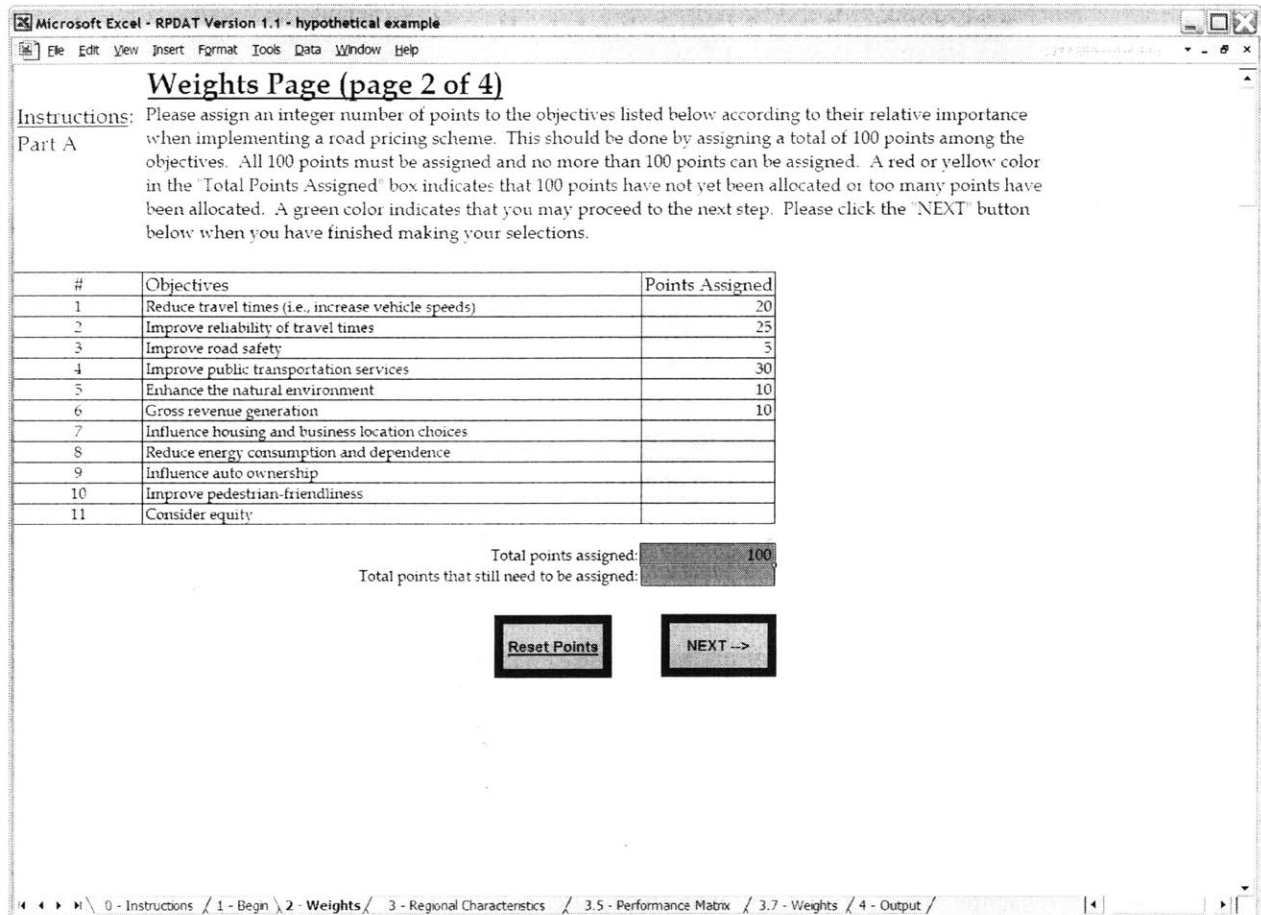
Figure 5.5: RPDAT Weights Page - Part A

After completing part A, the user goes to part B where he/she allocates points among criteria that were grouped under high-level objectives in part A. As discussed in Section 5.4.3, RPDAT determines which criteria will be displayed depending on the evaluation scope selected in step 1 and the points assigned in part A.[94] In the hypothetical example, assume that the user has allocated the point values listed in Table 5.6 for part B—high level objectives are shown in grey and criteria are shown in white. A screenshot of part B is shown in Figure 5.6.

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[94] Criteria grouped under high-level objectives are not displayed in part B if the high-level criteria they are grouped under received zero points in part A or if they are not applicable for the evaluation scope.

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Table 5.6: Step 2 Part B Criteria Points for Hypothetical Example

REDUCE TRAVEL TIMES CRITERIA	
Decrease average travel time for all peak-period trips on expressway(s)	20
Decrease average travel time for all mid-day trips on expressway(s)	0
Decrease average travel time on city streets within CBD	50
Decrease average travel time for peak-period arterial trips	0
Create a lower travel time option for autos on expressway(s)	30
IMPROVE RELIABILITY OF TRAVEL TIMES CRITERIA	
Improve reliability for all peak-period trips on expressway(s)	10
Improve reliability for all mid-day trips on expressway(s)	0
Improve reliability on city streets within the CBD	60
Improve reliability for peak-period trips on arterial(s)	0
Create a reliable travel time option for autos on expressway(s)	30
IMPROVE SAFETY CRITERIA	
Reduce traffic fatality rate	0
Reduce number of traffic accidents	100
IMPROVE PUBLIC TRANSPORTATION SERVICES CRITERIA	
Decrease travel time of bus services operating on the expressway(s)	15
Decrease travel time of bus services operating on city streets in the CBD	25
Decrease travel time of bus services operating on city streets outside the CBD	5
Improve reliability of bus services operating on expressway(s)	15
Improve reliability of bus services operating on city streets in the CBD	30
Improve reliability of bus services operating on city streets outside the CBD	10
IMPROVE THE NATURAL ENVIRONMENT CRITERIA	
Improve air quality	70
Reduce greenhouse gas production	30
GROSS REVENUE GENERATION CRITERIA	
Gross revenue generation	100
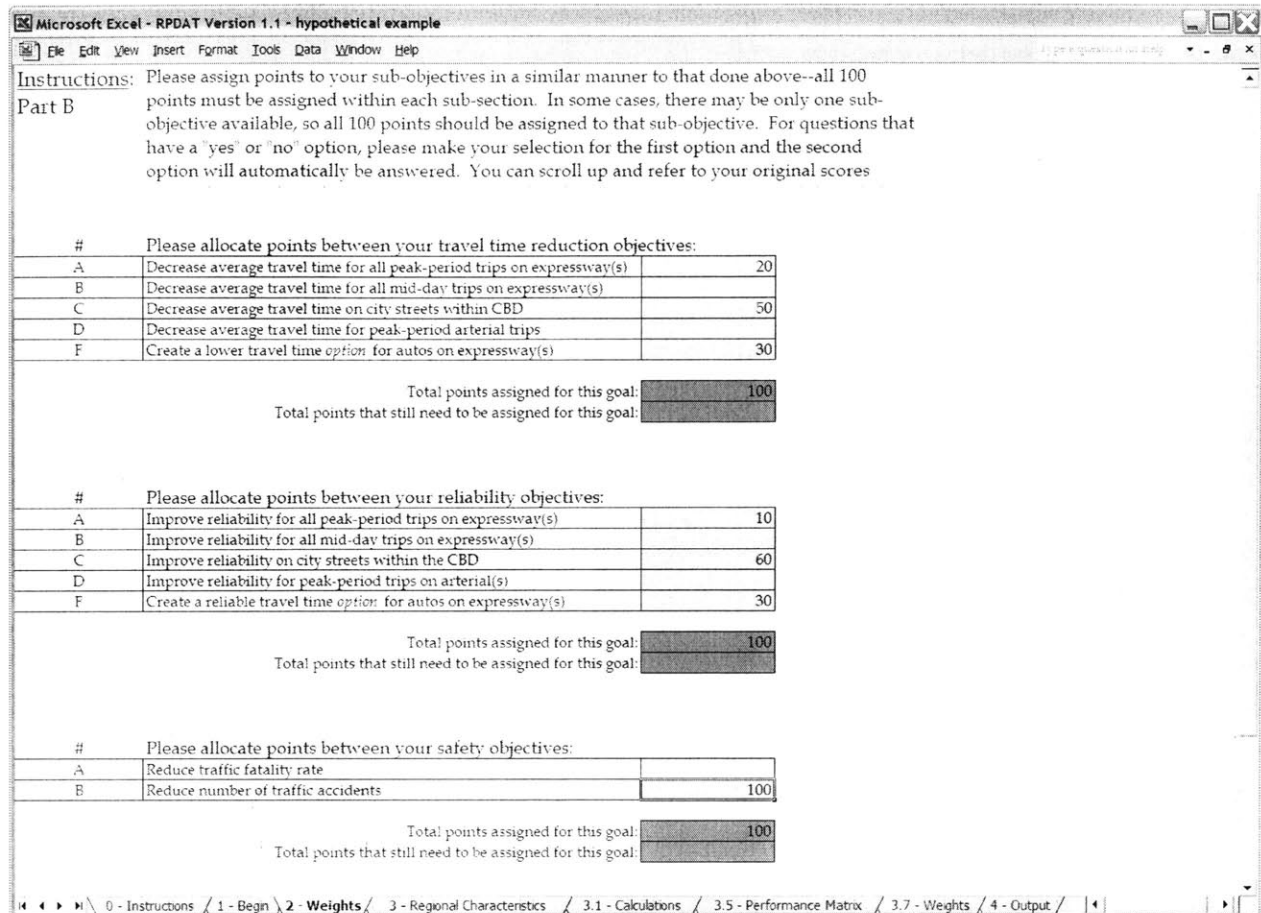
Figure 5.6: RPDAT Weights Page - Part B

After completing step 2 part B, the user is directed to the Review Weights page (Figure 5.7), which shows a summary of the weights calculated by the model based on the values input by the user in part A and part B. If the user determines a different set of weights should be used, he/she can return to step 2 part A and re-allocate points among the high-level objectives. If the user is satisfied with the weights, he/she then proceeds to the Regional Characteristics page.

You allocated the following weights among the criteria:

Criteria	Weight
Decrease average travel time for all peak-period trips on expressway(s)	4.0
Decrease average travel time for all mid-day trips on expressway(s)	
Decrease average travel time on city streets within CBD	10.0
Decrease average travel time for peak-period arterial trips	
Create a lower travel time option for autos on expressway(s)	6.0
Improve reliability for all peak-period trips on expressway(s)	2.5
Improve reliability for all mid-day trips on expressway(s)	
Improve reliability on city streets within the CBD	15.0
Improve reliability for peak-period trips on arterial(s)	
Create a reliable travel time option for autos on expressway(s)	7.5
Reduce traffic fatality rate	5.0
Reduce number of traffic accidents	
Decrease travel time of bus services operating on the expressway(s)	4.5
Decrease travel time of bus services operating on city streets in the CBD	7.5
Decrease travel time of bus services operating on city streets outside the CBD	1.5
Improve reliability of bus services operating on expressway(s)	4.5
Improve reliability of bus services operating on city streets in the CBD	9.0
Improve reliability of bus services operating on city streets outside the CBD	3.0
Improve air quality	7.0
Reduce greenhouse gas production	3.0
Reduce energy consumption and dependence	
Gross revenue generation potential	10.0
Promote new housing developments on suburban or undeveloped land	
Promote "Smart Growth"	
Promote automobile ownership	
Reduce vehicle ownership growth rate	
Improve pedestrian-friendliness	
Availability of free or low-cost alternatives	
Internalize external costs (i.e., implement the "user-pay" pricinciple)	

Re-allocate Points -->

NEXT -->

Click "Next" if you are satisfied with these weights and wish to continue. If you wish to revise your weights, please click "revise points."

Figure 5.7: RPDAT Review Weights Page

The Regional Characteristics page is the third step of RPDAT. Here, regional-specific information is input into the model—presumably by an analyst. In the hypothetical example, assume the values listed in Table 5.7 represent the characteristics of the metropolitan area. A screenshot of the regional characteristics page is shown in Figure 5.8.

Table 5.7: Regional Characteristics for Hypothetical Example

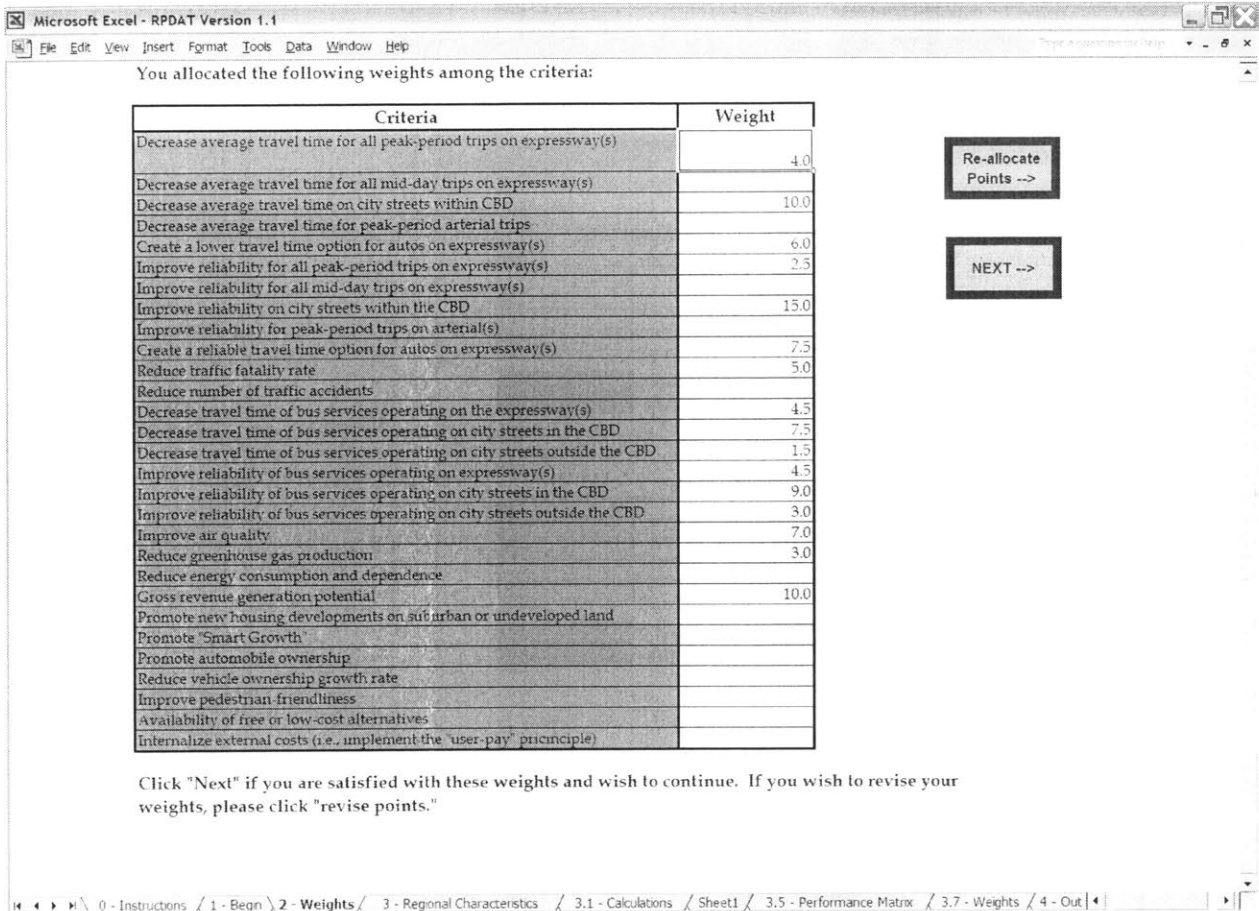|	
Peak-period average speed on expressway(s) (mph)	30
Mid-day average speed on expressway(s) (mph)	55
Off-peak average speed on expressway(s) (mph)	60
Travel time safety margin index value for expressway(s) (reliability measure)	1.6
Peak-period average speed in CBD (mph)	8
Off-peak average speed in CBD (mph)	25
Percent of air pollution derived from local transportation	20
Percent of metropolitan-area VMT that is on expressways	45
Size of the metropolitan area (ha)	100,000
Size of the CBD or potential cordon area (ha)	4,000
Percent of peak-period vehicle trips within the cordon that do not cross the cordon line (i.e., internal trips)	11
Percent of peak-period vehicle trips in the metropolitan area that cross the cordon, but neither originate nor terminate within the cordon area (i.e., through trips)	16
Percent of peak-period vehicle trips in the metropolitan area with origin or destination in the CBD	21
Percent of peak-period person trips in the metropolitan area crossing the cordon line that use public transportation	11
Percent of peak-period expressway corridor trips that are auto	90
Percent of HOV lane capacity utilized during peak-period	65
Please rate the availability of alternatives to the expressway(s):	Some alternative routes
Number of peak-direction expressway lanes	3

Regional Characteristics Page (pg. 3 of 4)

Instructions:
Part 3

Please enter the information requested below in the "Value" column. This data will be used to determine how well each alternative meets the criteria you selected in the previous step. Click the "Next" button after you have input all of the information to be directed to the output page.

	Value
Peak-period average speed on expressway(s) (mph)	30
Mid-day average speed on expressway(s) (mph)	55
Off-peak average speed on expressway(s) (mph)	60
Travel time safety margin index value for expressway(s) (reliability measure)	1.6
Peak-period average speed in CBD (mph)	8
Mid-day average speed in CBD (mph)	
Off-peak average speed in CBD (mph)	25
Percent of air pollution derived from local transportation	20
Percent of metropolitan-area VMT that is on expressways	45
Size of the metropolitan area (ha)	100,000
Size of the CBD or potential cordon area (ha)	4,000
Percent of peak-period vehicle trips within the cordon that do not cross the cordon line (i.e., internal trips)	8
Percent of peak-period vehicle trips in the metropolitan area that cross the cordon, but neither originate nor terminate within the cordon area (i.e., through trips)	16
Percent of peak-period vehicle trips in the metropolitan area with origin or destination in the CBD	21
Percent of peak-period person trips in the metropolitan area crossing the cordon line that use public transportation	11
Percent of peak-period expressway corridor trips that are auto	90
Percent of HOV lane capacity utilized during peak-period	65
Please rate the availability of alternatives to the expressway(s):	Some alternative route(s)
Number of peak-direction expressway lanes	3

<-- Return to beginning page   Reset values on this page   NEXT -->

0 - Instructions / 1 - Begin / 2 - Weights / weights values for hypo example \ 3 - Regional Characteristics / 3.1 - Calculations / 3.5 - Performance Matr
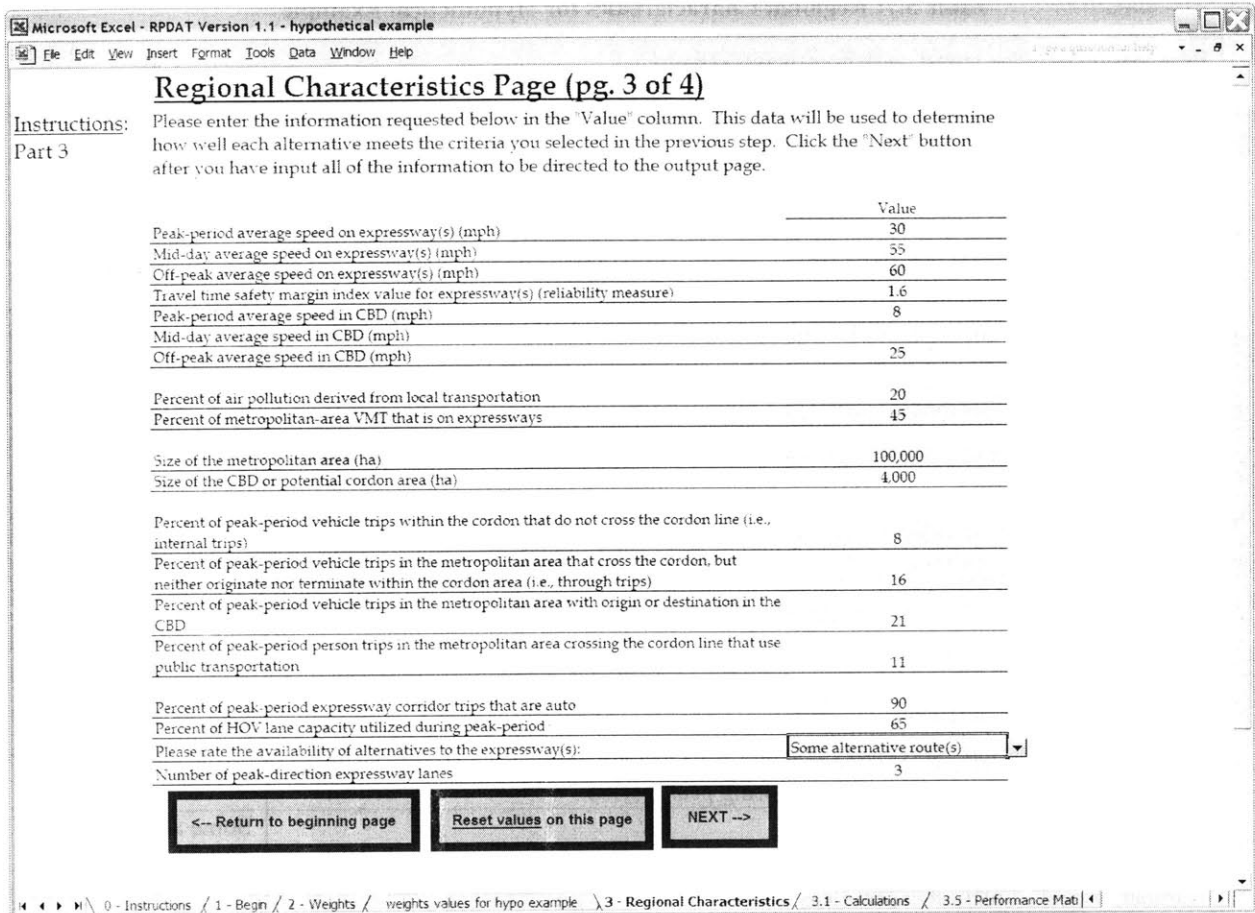
Figure 5.8: RPDAT Regional Characteristics Page

Figure 5.9 shows the Output page where the index scores, performance matrix, and weight values are presented to the user.

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Output Page (pg. 4 of 4)

This page presents *index scores* for each alternative, the weights associated with each criterion, and the *performance matrix*. The index scores suggest the attractiveness of each road pricing alternative; higher index scores imply the strategy is relatively more favorable than alternatives with lower index scores. When comparing index scores, the user must keep in mind that models make assumptions, and hence strong inferences should not be drawn from small differences in the index score values. For example, if conventional tolling, area-wide pricing, and network pricing have index scores of 52, 123, and 125 respectively, the model suggests area-wide pricing and network pricing are more attractive than conventional tolling, however, one should not infer network pricing is necessarily better than area-wide pricing.

The performance matrix rates how well each alternative meets each of the criteria; higher scores imply alternatives meet the criteria better, with a maximum score of +4 and a minimum score of -4. The weights column displays how much the user values each criterion; these weights reflect values input by the user in step 2. The performance matrix and weights are combined to calculate index scores for each alternative, thus demonstrating how the index scores were derived.

Strategy	Index Scores
Network Pricing	301
Area-Wide Pricing	222
Cordon Pricing	213
Facility Pricing	84
Distance-Based Pricing	74
Convert HOV to HOT Lane	67
Conventional Tolling	63
Add New HOT Lane	29
No Pricing	0

<-- Return to beginning page

<-- Return to weights page

PERFORMANCE MATRIX

Criteria	Network Pricing	Area-Wide Pricing	Cordon Pricing	Facility Pricing	Convert HOV to HOT Lane	Add New HOT Lane	Distance-Based Pricing	Conventional Tolling	No Pricing	Weight
Decrease average travel time for all peak-period trips on expressway(s)	4	2	2	4	2	3	3	4	0	4
Decrease average travel time for all mid-day trips on expressway(s)	1	0	0	1	0	1	0	1	0	0
Decrease average travel time on city streets within CBD	4	4	4	1	-1	-2	1	1	0	10
Decrease average travel time for peak-period arterial trips	4	2	0	-3	2	3	1	-3	0	0
Create a lower travel time option for autos on expressway(s)	0	0	0	4	4	4	0	0	0	6
Improve reliability for all peak-period trips on expressway(s)	4	0	0	4	2	3	0	1	0	2.5
Improve reliability for all mid-day trips on expressway(s)	0	0	0	0	0	1	0	0	0	0
Improve reliability on city streets within the CBD	4	4	4	0	-1	0	0	0	0	15
Improve reliability for peak-period trips on arterial(s)	4	0	0	-3	0	1	0	-3	0	0
Create a reliable travel time option for autos on expressway(s)	0	0	0	0	4	4	0	0	0	7.5
Reduce traffic fatality rate	-1	0	0	-1	0	-1	-1	-2	0	0
Reduce number of traffic accidents	4	3	3	1	0	1	0	1	0	5
Decrease travel time of bus services operating on the expressway(s)	0	0	0	0	0	0	0	0	0	4.5
Decrease travel time of bus services operating on city streets in the CBD	4	4	4	1	0	-2	1	1	0	7.5
Decrease travel time of bus services operating on city streets outside the CBD	4	0	0	-2	0	2	1	-2	0	1.5
Improve reliability of bus services operating on expressway(s)	4	0	0	4	0	4	0	1	0	4.5
Improve reliability of bus services operating on city streets in the CBD	4	4	3	0	0	-2	0	0	0	9
Improve reliability of bus services operating on city streets outside the CBD	4	0	0	-2	1	0	0	-2	0	3
Improve air quality	1	1	1	0	0	-1	1	0	0	7
Reduce greenhouse gas production	2	2	2	2	-1	-2	2	2	0	3
Reduce energy consumption and dependence	2	2	2	2	-1	-2	2	2	0	0
Gross revenue generation potential	4	2	2	1	1	3	2	0	0	10
Promote new housing developments on suburban or undeveloped land	-1	0	0	-1	1	2	-1	-1	1	0
Promote "Smart Growth"	1	0	0	1	-1	-2	1	1	0	0
Promote automobile ownership	-3	-1	-1	-1	0	1	-2	-1	0	0
Reduce vehicle ownership growth rate	3	1	1	1	0	-1	2	1	0	0
Improve pedestrian-friendliness	3	1	1	-1	0	-1	1	-1	0	0
Availability of free or low-cost alternatives	-4	0	0	-4	4	4	-4	-4	4	0
Internalize external costs (i.e., implement the "user-pay" pricinciple)	4	3	3	2	2	2	2	2	1	0
									Sum =	100

Figure 5.9: RPDAT Output Page

The index scores, which are listed in Table 5.8, indicate that network pricing, area-wide pricing, and cordon pricing are the top three alternatives (in that order) for this particular hypothetical combination of regional characteristics and weights.

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Table 5.8: Index Scores for Hypothetical Example

Strategy	Index Scores
Network Pricing	301
Area-Wide Pricing	222
Cordon Pricing	213
Facility Pricing	84
Distance-Based Pricing	74
Convert HOV to HOT Lane	67
Conventional Tolling	63
Add New HOT Lane	29
No Pricing	0

At the bottom of the output page, the user is able to see the values RPDAT calculated for the performance matrix, which are listed in Table 5.9. Table 5.10 lists the weights that were combined with the performance matrix to calculate the index scores.

Table 5.9: Performance Matrix for Hypothetical Example

CRITERIA	Network Pricing	Area-Wide Pricing	Cordon Pricing	Facility Pricing	Convert HOV to HOT Lane	Add New HOT Lane	Distance-Based Pricing	Conventional Tolling	No Pricing
Decrease average travel time for all peak-period trips on expressway(s)	4	2	2	4	2	3	3	4	0
Decrease average travel time for all mid-day trips on expressway(s)	1	0	0	1	0	1	0	1	0
Decrease average travel time on city streets within CBD	4	4	4	1	-1	-2	1	1	0
Decrease average travel time for peak-period arterial trips	4	2	0	-3	2	3	1	-3	0
Create a lower travel time option for autos on expressway(s)	0	0	0	0	4	4	0	0	0
Improve reliability for all peak-period trips on expressway(s)	4	0	0	4	2	3	0	1	0
Improve reliability for all mid-day trips on expressway(s)	0	0	0	0	0	1	0	0	0
Improve reliability on city streets within the CBD	4	4	4	0	0	-1	0	0	0
Improve reliability for peak-period trips on arterial(s)	4	0	0	-3	0	1	0	-3	0
Create a reliable travel time option for autos on expressway(s)	0	0	0	0	4	4	0	0	0
Reduce traffic fatality rate	-1	0	0	-1	0	-1	-1	-2	0
Reduce number of traffic accidents	4	3	3	1	0	1	0	1	0
Decrease travel time of bus services operating on the expressway(s)	0	0	0	0	0	0	0	0	0
Decrease travel time of bus services operating on city streets in the CBD	4	4	4	1	0	-2	1	1	0
Decrease travel time of bus services operating on city streets outside the CBD	4	0	0	-2	0	2	1	-2	0
Improve reliability of bus services operating on expressway(s)	4	0	0	4	0	4	0	1	0
Improve reliability of bus services operating on city streets in the CBD	4	4	3	0	0	-2	0	0	0
Improve reliability of bus services operating on city streets outside the CBD	4	0	0	-2	1	0	0	-2	0
Improve air quality	1	1	1	0	0	-1	1	0	0
Reduce greenhouse gas production	2	2	2	2	-1	-2	2	2	0
Reduce energy consumption and dependence	2	2	2	2	-1	-2	2	2	0
Gross revenue generation potential	4	2	2	2	1	1	3	2	0
Promote new housing developments on suburban or undeveloped land	-1	0	0	-1	1	2	-1	-1	1
Promote "Smart Growth"	1	0	0	1	-1	-2	1	1	0
Promote automobile ownership	-3	-1	-1	-1	0	1	-2	-1	0
Reduce vehicle ownership growth rate	3	1	1	1	0	-1	2	1	0
Improve pedestrian-friendliness	1	1	1	-1	0	-1	1	-1	0
Availability of free or low-cost alternatives	-4	0	0	-4	4	4	-4	-4	4
Internalize external costs (i.e., implement the "user-pays" principle)	4	3	3	2	2	2	2	2	1

Table 5.10: Weights for Hypothetical Example

CRITERIA	WEIGHTS
Decrease average travel time for all peak-period trips on expressway(s)	4
Decrease average travel time for all mid-day trips on expressway(s)	0
Decrease average travel time on city streets within CBD	10
Decrease average travel time for peak-period arterial trips	0
Create a lower travel time option for autos on expressway(s)	6
Improve reliability for all peak-period trips on expressway(s)	2.5
Improve reliability for all mid-day trips on expressway(s)	0
Improve reliability on city streets within the CBD	15
Improve reliability for peak-period trips on arterial(s)	0
Create a reliable travel time option for autos on expressway(s)	7.5
Reduce traffic fatality rate	0
Reduce number of traffic accidents	5
Decrease travel time of bus services operating on the expressway(s)	4.5
Decrease travel time of bus services operating on city streets in the CBD	7.5
Decrease travel time of bus services operating on city streets outside the CBD	1.5
Improve reliability of bus services operating on expressway(s)	4.5
Improve reliability of bus services operating on city streets in the CBD	9
Improve reliability of bus services operating on city streets outside the CBD	3
Improve air quality	7
Reduce greenhouse gas production	3
Reduce energy consumption and dependence	0
Gross revenue generation potential	10
Promote new housing developments on suburban or undeveloped land	0
Promote "Smart Growth"	0
Promote automobile ownership	0
Reduce vehicle ownership growth rate	0
Improve pedestrian-friendliness	0
Availability of free or low-cost alternatives	0
Internalize external costs (i.e., implement the "user-pays" principle)	0

This hypothetical example has attempted to illustrate the RPDAT user interface and the model steps. As this example demonstrates, the RPDAT process is quick, simple, and informative, making it a useful tool in determining which road pricing strategies a decision maker should pursue for a particular metropolitan area.

5.6 Chapter Summary

This chapter presented a new tool that can be used to evaluate road pricing alternatives for a metropolitan area. The Road Pricing Decision Analysis Tool (RPDAT) uses multi-criteria

analysis and is primarily intended to help decision makers narrow the range of road pricing alternatives to a set that can be examined in greater detail.

One of the main advantages of this tool is that it explicitly documents the policy priorities of the user. This method not only makes the decision-making process more transparent, but it also helps the user understand the trade-offs he/she makes when choosing among alternatives. Additionally, the RPDAT framework can act as a checklist, bringing to light alternatives or criteria that the user may not have considered previously.

The following chapter, Chapter 6, provides background information on Kuala Lumpur. This information is presented to establish the decision-making context for the application of RPDAT to Kuala Lumpur, which is performed in Chapter 7.

6 BACKGROUND INFORMATION ON KUALA LUMPUR

6.1 Chapter Purpose and Organization

This chapter presents an overview of transportation-related topics for the Kuala Lumpur Metropolitan Area (KLMA). Its purpose is to establish the decision-making context for the metropolitan area, which will provide the background information necessary to apply the RPDAT tool (discussed in Chapter 5) to the KLMA in Chapter 7.

The recent development history and socio-economics of Malaysia and the KLMA are presented first. Then, factors contributing to travel demand and travel demand management measures used in the metropolitan area are discussed. Next, the transportation infrastructure and transportation characteristics of the region are discussed, followed by assessments of transportation criteria (such as air quality and traffic accidents) and the national automobile and fuel policies. Finally, the state of road pricing in Malaysia is presented.

6.2 Introduction

Malaysia is located in Southeast Asia between Thailand, Singapore, and Indonesia. Kuala Lumpur (KL) is both the federal district and the largest city in Malaysia with a population of approximately 1.4 million people. The larger KLMA, shown in Figure 6.1, is home to 4.3 million residents, the center of economic activity in Malaysia, and an important economic force in the region. The KLMA plays a large role in Vision 2020, which is Malaysia's plan for becoming a developed nation by the year 2020.
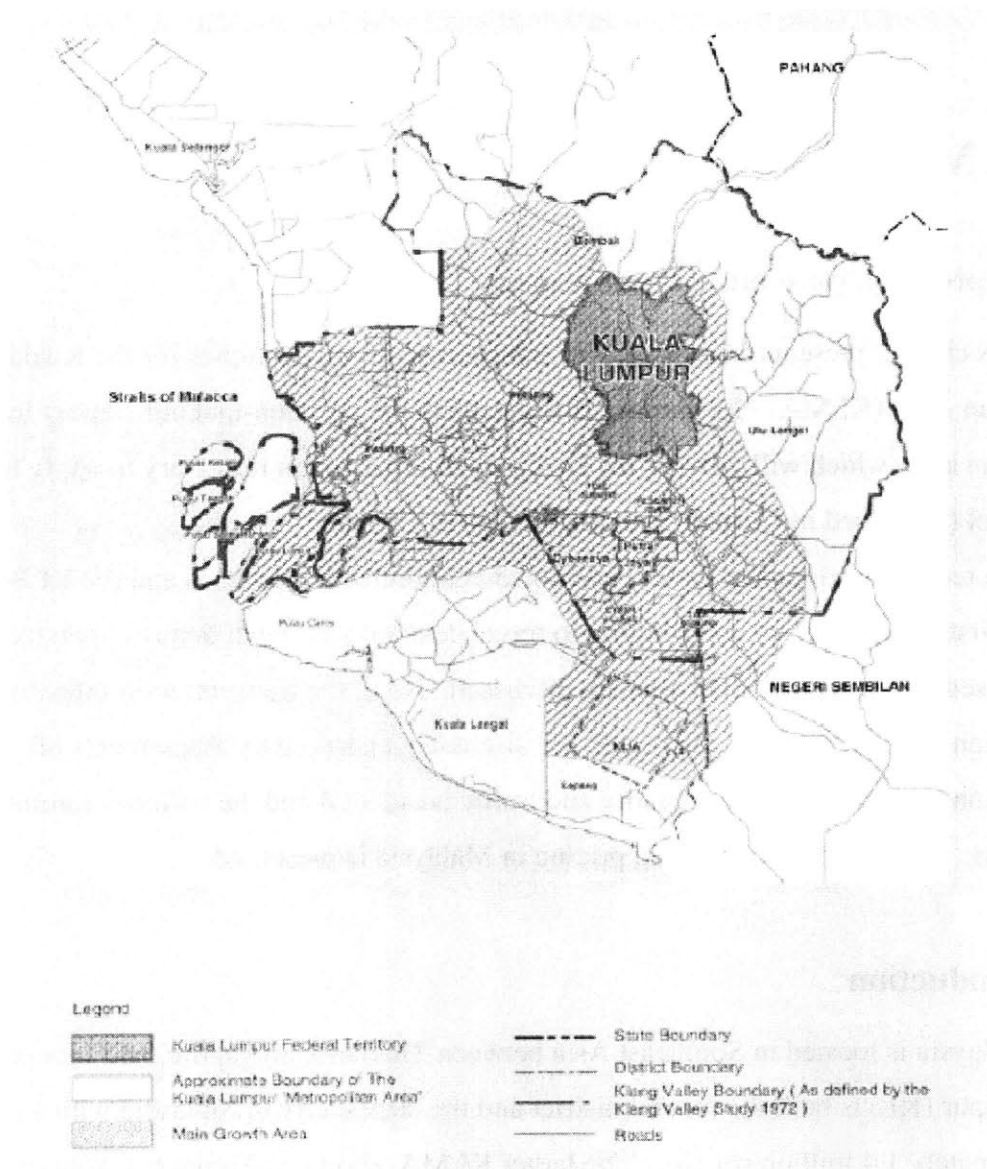
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Figure 6.1: Kuala Lumpur Metropolitan Area[95]

6.3 Recent Development History

Economic growth has been one of the major goals of Vision 2020. The Malaysian government recognizes the role of transportation in economic development and has constructed significant transportation infrastructure since the 1960s. Despite expanding the highways from

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[95] Source: City Hall Kuala Lumpur, <u>Draft Structure Plan Kuala Lumpur 2020</u>, First ed. (Kuala Lumpur: City Hall Kuala Lumpur, 2003).

15,400 kilometers in 1965 to 64,300 kilometers in 1995 (World Bank, Malaysia--Road Asset Management Project), the government has noted that infrastructure bottlenecks still exist.

The government made some efforts in the 1990s to address urban transportation problems, which included the construction of privatized light-rail facilities within the Klang Valley. Urban transportation infrastructure and policy in the KLMA was neglected in the past (Mody), which contributed to the poor traffic conditions in the Kuala Lumpur city center that still exist today. Malaysia has made a commitment to expanding the economy and the highway system, and has stated that it will "not let growth be retarded by excessive congestion" (EPU, The Way Forward (Vision 2020) 7). The worsening of congestion despite substantial capacity expansion highlights the extent of travel demand growth that has occurred in Malaysia.

Road investments were credited as a development catalyst for Malaysia during the 1990s; this policy continues to receive strong support. The country achieved and sustained an impressive rate of economic growth before the 1997 Southeast Asia financial crisis. The crisis created some unfavorable social impacts that threatened to reverse the pre-crisis gains. The government approached the World Bank to help with a recovery plan. The bank concurred that in order to continue medium- and long-term growth, Malaysia needed to expand highway capacity along high priority corridors suffering from high volume to capacity ratios (World Bank, Malaysia--Road Asset Management Project). Major road construction in new corridors was deemed a lower priority.

6.4 Socio-Economic Characteristics

6.4.1 Population, Employment, and Urban Structure

The population of Kuala Lumpur increased from 1.26 million in 1991 to 1.42 million in 2000 and is projected to reach 2.20 million by 2020. The KLMA contained 3.37 million residents in 1991 and more than 4.21 million in 2000. The number of KLMA inhabitants is projected to be just over seven million by 2020 (City Hall Kuala Lumpur).

Economic activities are concentrated in the Kuala Lumpur city center and follow major arterials radiating from the central business district (CBD). The total number of jobs in KL is estimated at 834,400 (City Hall Kuala Lumpur). Currently, a relatively high percentage are located in the CBD (24 percent) and inner areas of the city (53 percent) (Gakenheimer, Travel

Demand Drivers: Kuala Lumpur, Malaysia). Kuala Lumpur has a relatively high employment/population ratio with 59 jobs for every 100 residents, compared to 41 jobs for every 100 residents in the greater KLMA (City Hall Kuala Lumpur). Gakenheimer noted the employment/jobs ratio was 0.69 for the CBD.

The tertiary sector represents 83 percent of employment in KL, compared to 71 percent of employment in the KLMA. It is estimated that approximately 58 percent of KLMA service sector jobs are located in Kuala Lumpur. Employment in the manufacturing sector is declining (16.8 percent of total employment in 1980 and 10.5 percent in 2000), which reduces the range of employment opportunities (EPU, The Eighth Malaysia Plan).

Urban decentralization is occurring as residential and commercial activities are moving into the suburbs. A shortage of affordable housing in Kuala Lumpur contributed to the net emigration of approximately 5,000 per year between 1991 and 1997. The city center population decreased from 156,980 in 1980 to 128,720 in 2000; during the same time period, the share of KL's population living within the city center dropped from 17.1 to 9.0 percent (City Hall Kuala Lumpur). Large-scale residential developments are also occurring in the suburbs, as one might expect with rising incomes.

One indicator of employment decentralization is the relocation of federal government administrative offices to Putrajaya, which is one of the two major "smart cities" in the Multimedia Super Corridor (MSC) area of the KLMA. Car-oriented shopping malls and business parks are developing along major roads in the suburbs, without access to the urban rail network (Gakenheimer, Travel Demand Drivers: Kuala Lumpur, Malaysia).

6.4.2   Income Characteristics and Equity

Vehicle ownership is used by the Malaysian government as an indirect measure of income. The registered number of vehicles per 1,000 population in Malaysia grew from 339.2 in 1995 to 421.9 in 2000. In Kuala Lumpur, the number of registered cars and motorcycles per individual jumped 60 percent in just five years; there were 616.3 vehicles per 1,000 population in 1995 and 985.7 in 2000 (EPU, The Eighth Malaysia Plan).

Twenty-five percent of Kuala Lumpur households earn more than RM5,000 per month, compared to 9.8 percent for all of Malaysia. Approximately 8.1 percent of KL households earn less than RM1,000 per month, which places them in a category that is unable to afford a low-cost

house. In 1999, the incidence of poverty in KL was approximately 7.5 percent (City Hall Kuala Lumpur).

Equity is a concern in Malaysia. The following statement describes the typical feeling of citizens voiced in the media regarding the equity of KLMA transportation policies:

> *"[T]he rich and opulent residents of the elite addresses in the city*
> *like Taman Tun, Damansara Heights and Kenny Hills do not have*
> *to pay tolls like their poor cousins in Kepong and Cheras"*
> *(Malaysiakini).*

6.5 Travel Demand

While there is a range of estimates for the percentage of households that own vehicles, all studies suggest the KLMA is an auto-dependent region and appears to be further increasing its reliance on private vehicles. The Road Transport Department identified the ratio of registered cars and motorcycles in Kuala Lumpur as 985.7 per 1,000 population in the year 2000. A home interview survey performed by JICA in 1998 estimated there were 211 automobiles and 164 motorcycles per 1000 population (cited in City Hall Kuala Lumpur). According to Gakenheimer (Travel Demand Drivers: Kuala Lumpur, Malaysia), the motorization rate was 300 autos and 173 motorcycles per 1000 people in 2000, nearly double the 170 autos per 1000 just ten years prior and five times higher than the 1980 automobile ownership level. Using an average household size of 4.2 in the KLMA (Department of Statistics) and Gakenheimer's estimate, that averages out to 1.3 autos/household in addition to 0.7 motorcycles/household.

The Malaysia Highway Planning Unit (HPU, Quality of Roads in Malaysia: Road Safety) states that between 1970 and 1997, the vehicle population grew from 669,294 to 8,550,469—a factor of 13. This equates to an average growth rate of about 47 percent per year. Travel demand growth has been promoted by several factors, including:

- Population growth in the city of Kuala Lumpur itself is expected to be about two percent per year until 2015 while some of the outer areas are expected to grow eight percent per year (Gakenheimer, Travel Demand Drivers: Kuala Lumpur, Malaysia).
- Vision 2020 targets real GDP growth of seven percent per year between 1990 and 2020
- Average incomes are rapidly rising and female participation in the workforce is increasing. Average wages for Malaysian males and females increased 40 percent and 63 percent, respectfully, between 1992 and 1997 (United Nations).

- The Malaysian working age group (between 15 to 64 years) increased from 59.6 percent in 1991 to 62.8 percent in 2000, creating more demand during peak hours as drivers commute to work (Department of Statistics).
- Malaysia's urbanization increased from 50.7 percent in 1991 to 62 percent in 2000. Kuala Lumpur is 100 percent urbanized and Selangor has reached 87.6 percent urbanization (Department of Statistics). According to Gakenheimer (Travel Demand Drivers: Kuala Lumpur, Malaysia), the KLMA grew almost three times as much as KL itself between 1991 and 2000. The state of Selangor, which surrounds Kuala Lumpur, had the highest growth rate of 6.1 percent per year between 1991 and 2000 (Department of Statistics).

From 1985 to 1997, person automobile trips increased at an average annual growth rate of 4.2 percent in the Klang Valley while the population of Kuala Lumpur only grew at 1.1 percent per annum (City Hall Kuala Lumpur). Gakenheimer (Travel Demand Drivers: Kuala Lumpur, Malaysia) estimates the number of person auto trips will double 1997 levels by 2020 based on current trends.

It should also be noted that while the city center accounts for only 3.3 percent of the total population of the Klang Valley Region, approximately 19 percent of the 8.3 million trips per day are trips generated within the city center (City Hall Kuala Lumpur).

6.5.1 Travel Demand Management

Malaysia has recognized the need for travel demand management in the Eighth Malaysia Plan as seen in the following statement:

> "The increasing number of motor vehicles in all major urban centres will require the implementation of public transport priority measures, car parking control, local area traffic improvement schemes, restriction on heavy vehicles, greater pedestrianization and the application of ITS" (EPU, The Way Forward (Vision 2020) 289),

Travel demand management has been considered for Kuala Lumpur and is included in the Transport Master Plan for Putrajaya (REAM); however, few specific pricing measures are mentioned other than efforts to regulate car parking.

A carpooling program was attempted by Kuala Lumpur City Hall in the early 1990s but was deemed unsuccessful (Rahman). A survey of KL residents cited "different before/after work

schedules" as the number one reason why they felt carpooling would not be effective (Rahman 12). Interestingly, 95 percent of respondents from the same survey agreed traffic congestion in Kuala Lumpur was bad.

Additional efforts were made during the Seventh Malaysia Plan period to encourage public transportation and address urban congestion using traffic demand management. It appears these measures, although having the right idea, had mild effects (if any), and there remains much room for improvement. A 1997 survey noted travel speeds on most of the major radial roads in Kuala Lumpur were reduced to ten kilometers per hour or less during the morning peak hours due to high traffic volumes (EPU, The Eighth Malaysia Plan).

A 1999 study recommended numerous policies, strategies, and measures to alleviate urban congestion and enhance air quality in the KLMA.[96] Some measures implemented at that time included on-street parking restrictions, differential parking charges, one-way streets, pedestrianization, road system improvements, bus lanes, contra-flow, and restrictions on heavy vehicles entering the city center during peak hours (EPU, The Eighth Malaysia Plan). The level of enforcement for these measures is unknown.

Freight vehicles, often referred to as lorries, are not permitted to travel within Kuala Lumpur during the morning and evening peak hours (City Hall Kuala Lumpur). Most lorry trips either originate or terminate in the industrial areas peripheral to the city center, with concentrations in the south and passing through the region on a north-south axis. Instances of heavy goods and commercial vehicles parking in residential areas, which is illegal, are blamed on a lack of enforcement and proper parking facilities (City Hall Kuala Lumpur).

6.6 Transportation Infrastructure and Characteristics

Multiple urban expressways—controlled by different authorities—transport very high volumes of traffic within a narrow corridor and lack coordination or integration with the adjacent traffic networks. Urban road networks seem to lack a hierarchal system (e.g., mixture of local distributors and major arterials) and can have many demands for a single road (e.g., pedestrians, local traffic, through traffic, freight vehicles, motorcycles, and automobiles) (REAM).

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[96] The Study on Integrated Urban Transportation Strategies for Environmental Improvement.

There are no HOV lanes in the KLMA, although there are some bus priority lanes. The most-likely scenarios for creating HOT lanes include: (i) converting a bus priority lane, (ii) using existing general-purpose lanes for this purpose, (iii) adapting break-down lanes, or (iv) constructing additional lanes. It might make more sense to have reversible HOT lanes in developing countries because of the high peak-directional factors associated with many of their city centers, although this is a characteristic particular to individual corridors and would need to be considered on a site-by-site basis.

A Highway Network Development Plan (HNDP) for all of Malaysia was adopted in 1993. The HNDP highlighted three corridors that are "heavily trafficked," (i) the north-south trunk road on the west coast, (ii) the north-south trunk roads on the east coast, and (iii) the east-west link from Kuala Lumpur to Kuantan, (REAM). The HNDP also cited heavily concentrated traffic in Penang, the Klang Valley, and Joror Baru. These travel pattern forecasts are expected to remain essentially unchanged until 2010.

6.6.1   Public Transportation

The Malaysian government provides few direct references to the role of public transportation in the Eighth Malaysia Plan. A general theme in KL is that mass transportation lacks coordination between modes and transit providers. The poor integration of transit services contributes to its loss of mode share in recent years.

Bus utilization is low, primarily as a consequence of route duplication, unreliable service, low frequency, overcrowding during peak hours, and poor conditions of the vehicles (City Hall Kuala Lumpur). There are four major private bus companies in KL, all of whom have large amounts of debt and difficulty reaching profitability. Bus companies are not efficient feeder services for the LRT or monorail, limiting the number of suburban commuters who can realistically use public transportation to reach central Kuala Lumpur. Most bus routes are radial and terminate at the city center.

Population and commercial growth on the urban fringe is further increasing private automobile dependency, which is already quite high for a large Asian city. As noted previously, private transport dominates the KLMA with an 80 percent mode share of all motorized trips, leaving only 20 percent using mass transportation (Gakenheimer, Travel Demand Drivers: Kuala Lumpur, Malaysia).

The Malaysian government has recognized that a good public transportation system is necessary to reduce or discourage auto dependency. The Eighth Malaysia Plan states that "[e]mphasis will be on the need to have a more efficient, safe, and comfortable public transportation system to enable a modal shift from private car usage" (The Eighth Malaysia Plan 288). However, significant improvements in the public transportation system appear necessary if a city center congestion pricing scheme were to be implemented, as public transportation does not seem to be a realistic option for many households at this time.

6.6.2 Motorcycle Use

Motorcycles account for approximately 23 percent of all trips in Kuala Lumpur. They are principally used by the young and lower income groups. While many choose two-wheelers because they are fast and economical, they are quite dangerous; about 52 percent of fatal and serious accidents in KL involve motorcycles (City Hall Kuala Lumpur).

Motorcycles contribute significantly to noise and air pollution in KL. Noise emissions from motorcycles in the city center exceeds the permissible noise limits (Malaysia Environmental Quality Report, cited in City Hall Kuala Lumpur).

6.6.3 Parking

Parking fees are typically subsidized (directly or indirectly) in Kuala Lumpur. Most companies provide fringe benefits including free or subsidized transportation (MIDA). During the early 1990s, one carpooling program survey noted that 60 percent of respondents were provided with a parking space for their personal use (Rahman). Correspondingly, 64 percent of respondents felt that parking was not a problem. As of December 1999, on-street parking (legal and illegal) was a common contributor to urban congestion in Malaysia (REAM).

There are approximately 65,200 car parking spaces in the City center of Kuala Lumpur (City Hall Kuala Lumpur). Utilization of parking spaces is 71 percent for office buildings, 49 percent for retail spaces, and 47 percent for mixed-use locations. CHKL controls the number of parking spaces for new developments, but does not regulate parking charges. Parking costs in central Kuala Lumpur currently range from MYR 2 to MYR 5 per hour (USD 0.50 - 1.30) (Gakenheimer, Travel Demand Drivers: Kuala Lumpur, Malaysia). The Malaysian government

has already introduced differential parking charges (EPU, The Eighth Malaysia Plan).[97] It has also indicated it will take measures to enhance effective car parking control by limiting the duration of parking hours, reducing parking requirements for new projects, and imposing higher parking charges in specific areas (EPU, The Eighth Malaysia Plan). The effects of the limited parking management recently begun in the KLMA have yet to be quantified.

6.7 Air Quality and Noise Levels

According to the Air Pollution Index (API) for Kuala Lumpur, air quality is "good" 38 percent of the time, "moderate" 60 percent of the time, and "unhealthy" two percent of the time. The primary reason cited for unhealthy air quality in KL was "high levels of ozone," which is formed when nitrogen oxides (NO_x) react with volatile organic compounds (VOCs) in sunlight and heat. According to one study, vehicular emissions account for more than 70 percent of the total emissions in the Malaysia urban areas during the non-haze periods (Awang et al.).

Noise levels at schools and hospitals in Kuala Lumpur were found to be between 57.8 dB and 71.8 dB during the daytime, which exceeds the limit of 55 dB recommended by the World Health Organization (City Hall Kuala Lumpur).

6.8 Transportation Safety and Accidents

As illustrated in Figure 6.2, the number of vehicle fatalities has steadily increased with the vehicle growth rate in Malaysia. The fatality rate per 10,000 vehicles during the 1980s and 1990s is comparable to some Southeast Asian countries (Figure 6.3), but road safety is a problem frequently cited in the media. The national target is 2.0 deaths per 10,000 vehicles by 2020. The number of accidents, shown in Table 6.1, have also increased in recent years (HPU, Road Safety).

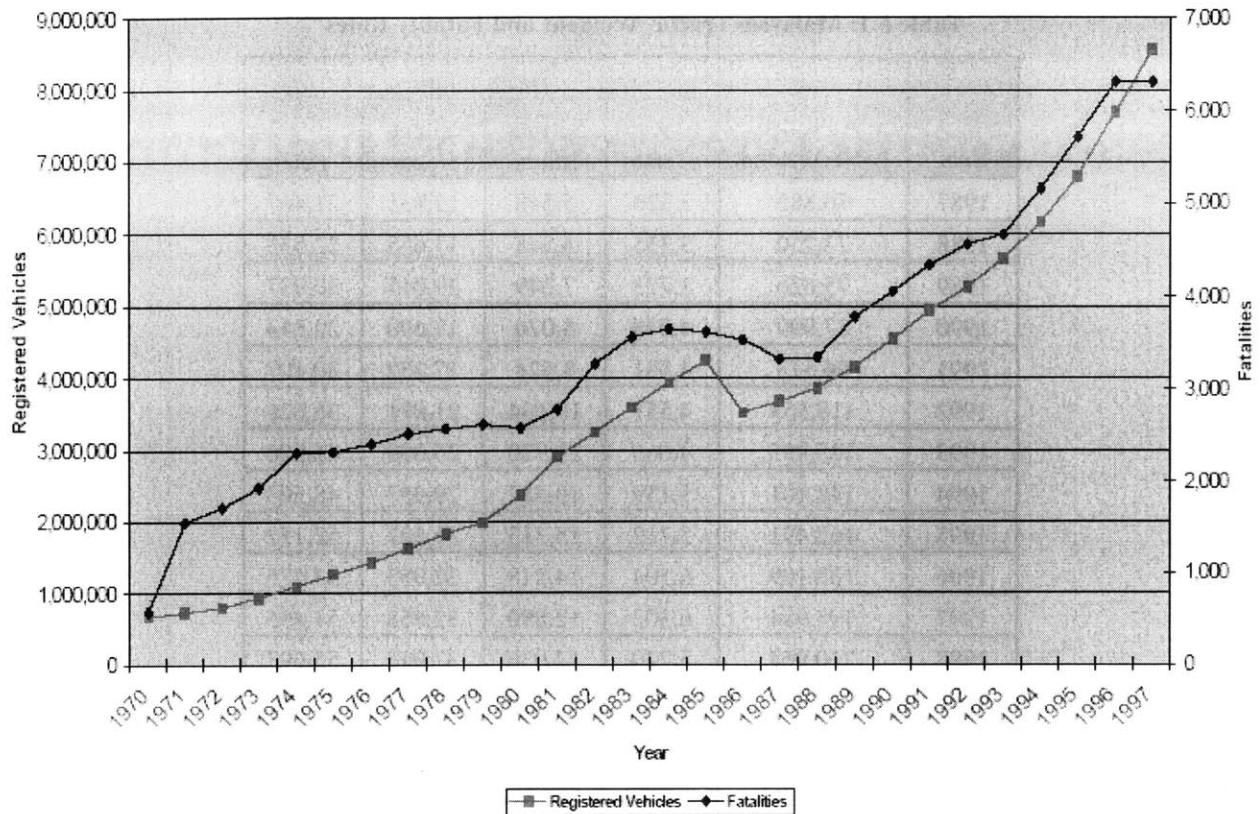[97] Differential parking charges may have a payment structure that favors short- over long-term use or HOVs over SOVs.

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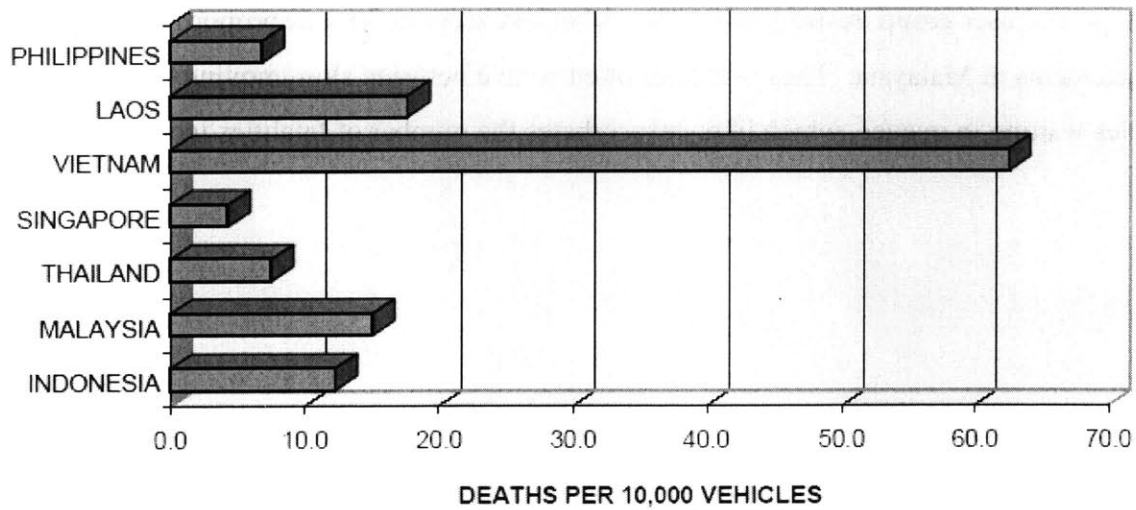**Figure 6.2: Malaysia Vehicle Growth and Fatality Trends[98]**

DEATHS PER 10,000 VEHICLES

Figure 6.3: Malaysia Motor Vehicle Fatality Rate in 1980s and 1990s[99]

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[98] Source: HPU, Road Safety, 2004, Ministry of Works Malaysia, Highway Planning Unit (HPU), Available: http://www.kkr.gov.my/bpj/safety/safety1.htm.
[99] Ibid.

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Table 6.1: Malaysia Traffic Accident and Fatality Rates[100]

Year	Total Accident	Death/Injury			
		Death	Serious Injury	Slight Injury	Total
1987	76,882	3,320	5,548	12,931	21,467
1988	73,250	3,335	5,548	13,655	22,538
1989	75,626	3,773	7,249	19,015	30,037
1990	87,999	4,048	8,076	17,690	29,814
1991	96,513	4,331	8,524	17,252	30,107
1992	118,554	4,557	10,634	21,071	36,626
1993	135,995	4,666	11,930	25,090	41,686
1994	148,801	5,159	13,387	29,957	48,503
1995	162,491	5,712	15,313	31,127	52,152
1996	189,109	6,304	14,218	32,953	53,475
1997	195,984	6,302	12,890	32,858	51,495
1998	210,964	5,740	12,036	37,917	55,697
1999	223,116	5,794	10,383	36,886	53,060
2000	250,429	6,029	9,790	34,375	50,194
2001	265,175	5,230	6,942	30,684	42,856
2002	279,641	5,886	8,414	35,149	49,449

Figure 6.4 and Figure 6.5 show the allocation of road fatalities in Malaysia according to road type and user group, respectively. Two-wheelers account for a disproportional share of all fatal accidents in Malaysia. These vehicles often weave between slow-moving or stationary vehicles waiting in queues, which likely exacerbates the number of fatalities incurred by this group.
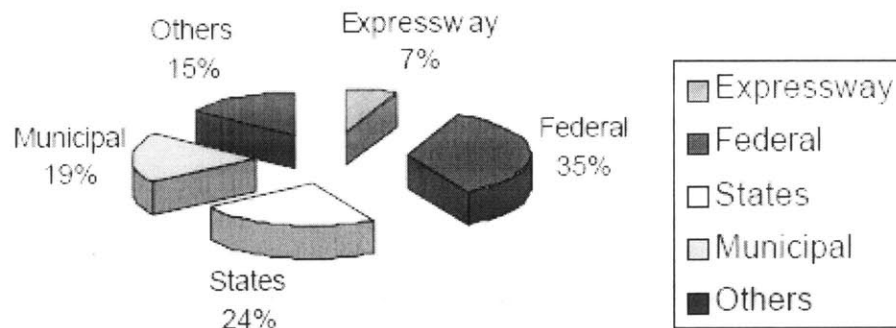
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[100] Ibid.

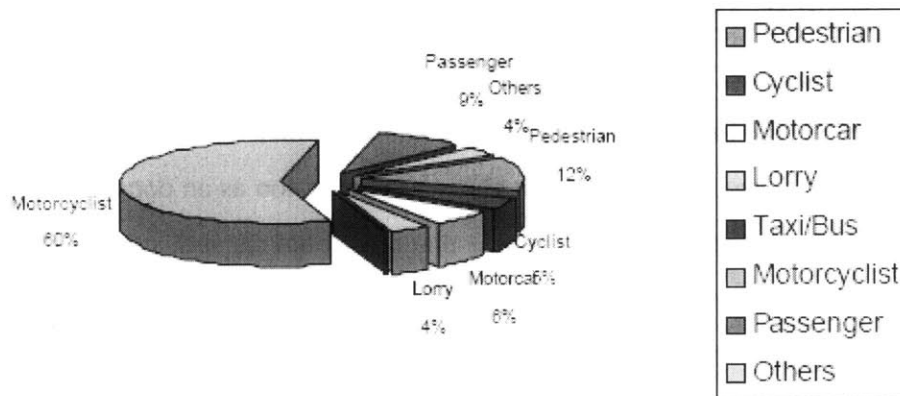**Figure 6.4: 1996 Road Fatalities in Malaysia[101]**

Figure 6.5: 1995 Malaysia Road Fatalities by User Group[102]

6.9 Law Enforcement

The average number of people for every police officer in Malaysia is 1:287, which is close to Interpol's recommendation of 1:250. In Kuala Lumpur, however, the ratio is 1:649—far below the recommended level (New Straights Times). The number of law enforcement officers is one indication of a city's ability to perform traffic enforcement, which can affect congestion levels and influence the viability of more sophisticated travel restraint measures such as area-wide pricing. Traffic enforcement is a common challenge for developing countries.

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[101] Source: HPU, Quality of Roads in Malaysia: Road Safety (Kuala Lumpur: Ministry of Works Malaysia, Highway Planning Unit (HPU), 1998).
[102] Ibid.

6.10 The National Automobile

Malaysia's national automobile plays a very large role in shaping the country's manufacturing and transportation policies. The national automobile is an integral part of Malaysia's economic strategies, making it necessary to understand the extent of its influence and importance.

Proton Holdings Bhd (Proton)—the national car company—is one of the largest government-linked companies in Malaysia. In efforts to develop a national car industry, the government has sheltered Proton with protectionist auto policies to give the national industry time to develop. Proton's market is primarily domestic—representing 45 percent of sales in Malaysia in the first half of 2003—but the company has also been trying to develop an export market with limited success. With recent trade liberalization in Malaysia, the future of Proton and the government's role in that future are important questions.

It is widely believed the government chose to use Proton as an economic catalyst for reaching developed nation status. The idea was that a national car industry would require a large network of supporting industries, such as engineering, research and development, distribution, and manufacturing, which would support the development of a knowledge-based economy and eventually result in increased trade exports. The project has succeeded in developing a network of supporting industries in Malaysia with 24 franchise holders, 350 component makers, and 250 vendor companies. Proton has invested nearly RM8 billion in the domestic market and it employs 9,500 people directly; it is estimated that almost 100,000 jobs have been created as a result of the company. Proton has clearly become a central part of the Malaysian economy and the government has considerable interest in seeing it flourish.

It is questionable whether the supporting industries can survive if Proton ceases to remain in existence or is not able to compete in the free market. China and Thailand have been able to develop successful vendor industries without national cars; however, it is not known if Malaysia can do the same without a national car policy. The international market for Proton has not developed to the extent many had hoped and the quality of Proton cars remains an issue. Many Malaysians own Proton cars, but the domestic market share has been decreasing in recent years.

There are several issues and challenges that need to be resolved if Proton is to thrive in the coming years. First, there are believed to be too many vendors—over 400 in the country—for each to bring in sufficient revenue. The vendor firms would be stronger financially if their

numbers were reduced. Second, Proton needs to improve the quality of its cars and vehicle service. Proton cars are perceived to handle poorly and do not meet international standards for quality and performance. The company's after-sales service is regarded as expensive and not as good as many neighborhood mechanics, so customers often lose loyalty after the warranty period of the car. Industry players have informally referenced an internal survey performed by Proton finding that less than 25 percent of its existing customers would consider buying another Proton car. Third, the company should release cars by the promised date to improve its image—the Gen.2 car that was recently released did not meet its delivery date, which did not help the company's image. Fourth, Proton needs to increase its export market. Proton sold about 15,000 cars in the UK in 1988 but sold less than 2,000 in the UK in 2003. The company is also considering exporting cars and technology to the Middle East and China, but it will need to be successful with increasing revenue from foreign sales for its future to be sustained—especially if domestic sales decrease. Fifth, Proton needs to find a way to abolish fake Proton parts in order to increase after-sales revenue; the company needs to offer quality parts at affordable prices. Sixth, Proton should reduce its costs so it can pass the savings on to consumers. Proton lost its discount on the excise duty on January 1, 2005 because of the ASEAN Free Trade Agreement, so the domestic cost of a new Proton has increased.

Many believe Proton needs to get a strategic foreign partner if it is going to survive in the long term. The thought is that forming an alliance will maximize Proton's potential and help ensure its survival. Nonetheless, it is apparent the national car industry has many issues that need to be resolved if it is to be able to continue to support the economic development of Malaysia.[103] Due to its importance to the overall economy, the national automobile is likely to be a factor shaping Malaysian transportation policies in the near future.

6.11 Fuel Policies

The Malaysian government fixes the price of fuel. Unleaded petrol costs range between MYR 1.10 to 1.25 (USD 0.29 - 0.33) per liter. Diesel and LPG cost 0.70 and MYR 1.28 per liter, respectfully (Gakenheimer, Travel Demand Drivers: Kuala Lumpur, Malaysia).

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[103] Primary source for section: L. Barrock, Special Report: Proton under a Microscope, 2004, The Edge Daily, Available: http://www.theedgedaily.com/cms/content.jsp?id=com.tms.cms.article.Article_236d189c-cb73c03a-23d27800-d2591310, January 2005.

The ratio of Malaysia's gasoline price to the world average was 0.46 for 1998-2000 MRYA (World Bank, 2002 Environmental Sustainability Index). The price of petrol is significantly less expensive in Malaysia than in its neighboring countries, Singapore and Thailand. Premium gasoline was about 40 percent more expensive in Thailand during this data period, while the price of petrol in Singapore is typically between 2-2.5 times more than the price in Malaysia.

The price of 'fuel and light' fell dramatically in relation to other goods during the 1990s in Malaysia. The consumer price index (CPI) for all items was 139.5 in 1999 (where 1990 = 100) while the CPI for fuel and light was only 102.8 in 1999.[104] Comparing these trends with the export price of crude oil in Malaysia is quite interesting. The export price quotation of crude petroleum rose from 405 ringgit per metric ton in 1992 to 525 ringgit per metric ton in 1999—a 30 percent increase (United Nations).[105] The CPI illustrates the need for real fuel prices to realign with previous levels, as fuel has become less expensive relative to other goods during this timeframe.

Fuel prices in Malaysia have decreased noticeably in absolute terms as well as relative to the "normal sale price," which is a hypothetical price that gas should be sold to neither raise revenue nor be subsidized by the national government (Metschies). The price of diesel fell from 26 to 19 U.S. cents per liter while the "normal sale price" climbed from 25 to 31 U.S. cents per liter. The price of super gasoline fell from 42 to 35 U.S. cents per liter while the "normal sale price" increased from 26 to 32 U.S. cents per liter. Metschies estimated Malaysia spends USD 390 million (2 percent of its tax revenues) on subsidizing transportation fuel and it could increase total government tax revenue by USD 868 million (5 percent of tax revenues) if the price of fuel increased 10 U.S. cents per liter on gasoline and diesel.

There are numerous potential reasons why the Malaysian government regulates fuel prices. The 1997 Southeast Asia financial crisis motivated the government to isolate itself from volatility and uncertainty as much as possible (Jaafar and Mohamad). Regulating commodity prices—such as fuel—reduces volatility and increased predictability. Malaysia has certain *controlled items* that have a price ceiling—fuel is one of them. One Malaysian paper justifies the

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[104] 1999 was the most recent consumer price index information available for 'fuel and light' in the reference.
[105] It is important to note that a major price increase occurred in the year 2000. The export price in 2000 was 854 ringgit per metric ton, which would create a +211 percent increase compared to the 1992 export price.

low fuel prices by saying Malaysia is trying to emulate the United States and as long as PETRONAS (the national petroleum corporation) and other energy companies remain profitable, this policy is appropriate. The paper also states, "Many developing countries use energy subsidies to encourage energy consumption to create economies of scale to reduce the unit cost" (Jaafar and Mohamad 2).

Low and predictable fuel costs encourage auto ownership and use, which may contribute to the projected increase of 8.7 percent per year for transportation energy demand (EPU, The Eighth Malaysia Plan). The Malaysian automobile industry has received quite favorable support from the government, with efforts led by the former Prime Minister (PM) Mahathir Mohamad. Mohamad supported steel plants, factories, and petrochemical industries in order to facilitate growth of the domestic automobile industry (Gakenheimer, ITS Deployment in Kuala Lumpur).

The government offers financial incentives to use natural gas as an alternative motor vehicle fuel. Exemptions on import duties and sales tax keep the price of natural gas vehicles lower than diesel vehicles. This policy discourages ownership of diesel vehicles, but inexpensive diesel prices are an opposing force and encourage excessive travel with vehicles already owned. Road tax reductions are also offered in the amount of 50 percent for mono-gas vehicles and 25 percent for bi-fuel or dual-fuel vehicles (Gakenheimer, Travel Demand Drivers: Kuala Lumpur, Malaysia).

Box 7: The Malaysian Deficit[106]

> The Malaysian budget deficit was recently about RM 20.40 billion, or 4.5 percent of GDP in 2004. Petroleum subsidies were RM6.80 billion in 2003, RM4.30 billion in 2002, RM7.40 billion in 2001, and RM8.4 billion in 2000. Year 2004 subsidies were expected to be RM9 billion in 2004 due to the sharp rise in oil prices. Economists are predicting petroleum prices may continue to increase.

The Malaysian fuel-tax policies appear to be sub-optimal from transportation demand management and economic efficiency perspectives. Government control of the national car industry and PETRONAS may be primary or contributing factors relating to the controlled low fuel prices. The Malaysian government could clearly raise significant revenues if they taxed

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[106] Source: J. Chin, Budget Likely to Be Prudent, 2004, The Edge Daily [Online], Available: http://www.theedgedaily.com/cms/content.jsp?id=com.tms.cms.article.Article_b45773ef-cb73c03a-940b8400-5dc1e6a6, September 2004.

petroleum at a reasonable level but it has chosen to keep fuel prices low. This may be to improve the mobility of low-income rural citizens, but future research into the motivation for this policy would be of value.

6.11.1 Road Taxes and Other Indirect Use Costs

The Malaysian government taxes the ownership of automobiles and motorcycles based on engine size (Gakenheimer, Travel Demand Drivers: Kuala Lumpur, Malaysia). Import duties were recently redesigned, but they have ranged from 42-80 percent for imported car components and were responsible for up to 300 percent of the purchase price of complete cars before the policy revisions (The Star Online). With the previous tax structure, imported automobiles were assessed higher excise taxes in attempt to promote the national car, but the tax differential was eliminated in January 2005 because of stipulations in the ASEAN Free Trade Agreement.[107] Purchasers of Proton and Perodua—the national cars—received a 50 percent discount on vehicle excise taxes under the old structure. The mandatory reduction of certain import duties has led the government to increase excise taxes.

Gakenheimer (Travel Demand Drivers: Kuala Lumpur, Malaysia) states that annual insurance fees range from USD 260 to 2,000. The insurance pricing and legal framework in Malaysia is unknown.

There are no vehicle quotas in Malaysia or the KLMA. It is unlikely vehicle quotas would be adopted in Malaysia, as it would be a direct contradiction with the policy of promoting the national automobile (discussed in Section 6.10).

6.12 Road Pricing in Malaysia

6.12.1 Overarching Pricing Policies and History

The Malaysian government does not appear to be an advocate of the user-pays principle or marginal-cost pricing for the transport sector. The Eighth Malaysia Plan states, "the Government will provide support to projects which have social implications and require large

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[107] For more information on the former taxation structure, see: J. Ward, "Toll Road Public-Private Partnerships in Malaysia: Using the Clios Process for Policy Improvements," Massachusetts Institute of Technology, 2005.

capital expenditure, in order to reduce tariffs and other charges to consumers" (EPU, The Eighth Malaysia Plan 183). Further, "the 'user-pay[s] principle,' though reflecting the economic costs of providing such services, will not be the guiding principle in the determination of tariff rates and charges. The government will continue to control tariff setting and reviews so as to ensure that the public will enjoy these services at affordable rates" (The Eighth Malaysia Plan 199). The true government intent with this statement is unknown, but one might infer that the government is trying to lower user costs in order to increase consumption and/or economic growth. Unsurprisingly, economic growth receives considerably more discussion in the Eighth Malaysia Plan than congestion abatement.

The World Bank strongly supported congestion pricing in its 1976 Urban Transport Policy paper after Singapore's successful Area Licensing Scheme was implemented. The World Bank suggested congestion pricing for Kuala Lumpur and Bangkok but it was not put into operation in either city. The implementation in Kuala Lumpur was deferred because the government felt improvements to public transportation and the development of the inner ring road were necessary before a scheme could be implemented (Armstrong-Wright). The scheme was considered again in the mid-1980s as part of the Master Plan Transportation Study for the city. A ring road has since been constructed in Kuala Lumpur and mass transportation services have been expanded, although the mode share of transit has decreased.

In Malaysia, it may be desirable to use urban toll revenue surpluses to cross-subsidize rural road construction and improve rural accessibility; a large portion of Malaysian poverty resides in rural areas. Eradicating poverty is one of the goals stated in Vision 2020 and additional support for rural infrastructure could have great social and economic benefits for low-income rural citizens. The government is likely to be responsible for financing rural roads because private companies serve high volume corridors where they can collect enough toll revenues to produce a profit. If the Malaysian government chooses not to reinvest revenues in transportation, socially progressive programs such as education and health care could benefit from the road pricing revenues, which would promote many of the objectives outlined in Vision 2020 and the Kuala Lumpur Structure Plan.

6.12.2 Road Pricing and Tolling

This section provides some insight as to the history, role, characteristics, and effects of road pricing in Malaysia. To date, tolling is the only form of road pricing known in Malaysia. The institutional agreements between the government and the toll concessionaires are a good indicator of the Malaysian road user charging policy as well as the ability of the Malaysian government to introduce congestion pricing.

Toll roads are most commonly inter-urban expressways in Malaysia. They are usually high capacity roads, but can be congested at toll plazas and some interchanges (REAM). There are approximately 1,230 km of expressways operated under concession in Malaysia as stated by the Malaysia Highway Authority, the principal regulator of the toll road transportation system (PLUS). There are about fifteen toll road concessionaires in Kuala Lumpur, but the focus of this section will be on PLUS Expressways. PLUS Expressways represents approximately 69 percent of all expressway kilometers operated under concession in Malaysia. It is a private corporation, but importantly, Khazanah—the investment holding arm of the government—had an aggregate direct and indirect interest of 86.4 percent in PLUS Expressways as of May 31, 2002 (PLUS).

PLUS Expressways and the government have been criticized for a lack of transparency in the awarded concessions. Two companies submitted bids that appeared more competitive than the one submitted by PLUS, but neither were awarded the contract. According to Gomez (cited in Mody), PLUS was set up by United Engineers Berhad, a company with connections to the ruling party.[108]

PLUS maintains and operates three interconnected expressways: (i) the 797 km North-South Expressway, (ii) the 35 km New Klang Valley Expressway, and (iii) a 16 km section of the Federal Highway Route 2. The North-South Expressway serves all major cities along Malaysia's west coast and runs from the Singapore border in the south to near the Thailand border in the north. In 2001, the North-South Expressway accounted for 82 percent of PLUS Expressways total toll receipts while the New Klang Valley Expressway and Federal Highway Route 2 produced the remaining 18 percent of total toll receipts (PLUS).

In their prospectus, PLUS Expressways states the following about their facilities:

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[108] United Engineers Berhad is owned by Danasaham, which is owned by Khazanah, which is owned by the Ministry of Finance Inc.

As at 31 May 2002, PLUS operated approximately 128 km of dual three-lane expressways, representing 15.1% of the [PLUS] Expressways, and approximately 720 km of dual two-lane expressways, representing 84.9% of the [PLUS] Expressways as well as 67 toll plazas, 78 interchanges, and 584 toll lanes.

PLUS declares annual traffic volume on the Expressways increased 4.1 percent per year on average between 1995 and 2001. An average of 840,790 vehicles used the Expressways each day in the year 2001. Class 1 vehicles (autos) are a significant portion of traffic, representing 88.1 percent of all traffic on the PLUS Expressways in 2001 (PLUS).

PLUS uses *open* and *closed* systems to collect tolls. In the toll collection context, motorists pay a fixed toll when they reach a toll plaza—regardless of distance traveled—in open systems. These systems are used in urban or semi-urban sections of the Expressways that have numerous intersections, including Federal Highway Route 2 and approximately six percent of the North-South Expressway. In closed systems, motorists collect a ticket when entering the facility and pay a toll upon exit based on the distance traveled. PLUS believes this system is best-suited for roads linking urban centers and uses it on the New Klang Valley Expressway and on 94 percent of the North-South Expressway (PLUS).

PLUS uses the "Touch 'n Go" and "SmartTag" systems for electronic toll collection. The Touch 'n Go is a contact-less smartcard that motorists can use to pay a toll. The complimentary SmartTag uses an on-board unit (costing RM 220) installed in the vehicle to allow drivers to pay the toll without stopping. Touch 'n Go and SmartTag became the Malaysian standard as of January 1, 2003. Touch 'n Go can now reportedly be used for bus and train fares (such as Putra LRT), on competing expressways, and in some car parks (PLUS). There were over 1.1 million Touch 'n Go smartcards in circulation as of April 2001 (Gakenheimer, ITS Deployment in Kuala Lumpur).

There are five vehicle toll classes, each with a different toll rate. The government sets the maximum toll rate PLUS can charge for Class 1 vehicles. Each vehicle class is then charged an amount relative to the Class 1 vehicle charge, which is determined by a toll rate multiplier. The toll rate multiplier for each vehicle class is listed in Table 6.2.

Table 6.2: PLUS Expressways Toll Rate Multipliers

Vehicle Class	Description	Toll Rate Multiplier
1	Vehicle with two axles and three or four wheels (excluding taxis)	1.00
2	Vehicle with two axles and six wheels (excluding buses)	1.50
3	Vehicles with three or more axles	2.00
4	Taxis	0.50
5	Buses	0.75

The government and the expressway operator negotiated allowable toll rates in a concession agreement. The government guaranteed to meet any shortfalls in forecasted traffic volume and any losses from adverse movements in the exchange rate or external loan interest rates for the first seventeen years (Hensley and Edward, cited in Mody). If the government ever imposes toll rates below those agreed upon in the concession agreement, the government is liable to compensate PLUS Expressways for the resulting shortfall (PLUS). This occurred during concession years 1996 to 2000 and the government gave the toll concessionaire cash compensation. PLUS stated the reason for lower imposed toll rates was the "result of economic pressure and negative consumer perceptions of high toll rates on the Expressways" (PLUS 103).

A supplemental concession agreement was executed on July 8, 1999, which imposed a revised toll rate lower than agreed upon in the original concession agreement. The government provided PLUS Expressways with an interest-free additional support loan for the years ended 1999 through 2001 and extended the concession period twelve years to May 31, 2030 as compensation. PLUS Expressways a second cash compensation of RM 280 million during this period (Kulasegaran).

The government again announced lower-than-agreed-upon toll rates for the remainder of the concession period in December 2001 and made new non-cash compensation agreements. A protest resulted when a ten percent increase in toll rates for the North-South Expressway was presented, even though the concessionaire was due a larger increase. New toll rates allowed by the government (gazetted toll rates) and the previously agreed toll rates are listed in Table 6.3 for Class 1 vehicles. A new and complicated set of concession agreements were reached in May 2002 to determine the formula for government compensation.

Table 6.3: Current and Previously Agreed Toll Rates for PLUS Expressways[109]

Year	Agreed Toll Rates (sen/km)	Gazetted Toll Rates (sen/km)	Year	Agreed Toll Rates (sen/km)	Gazetted Toll Rates (sen/km)
2001	11.91	11.24	2016	30.02	18.11
2002		12.36	2017		19.92
2003		12.36	2018		19.92
2004		12.36	2019		19.92
2005		13.6	2020		21.91
2006		13.6	2021		21.91
2007		13.6	2022		21.91
2008		14.96	2023		24.1
2009		14.96	2024		24.1
2010		14.96	2025		24.1
2011		16.46	2026		26.51
2012		16.46	2027		26.51
2013		16.46	2028		26.51
2014		18.11	2029		29.16
2015		18.11	2030		29.16

Toll rates in Malaysia might be considered inexpensive when one recognizes they are operated by for-profit companies. It currently costs Class 1 vehicles RM 4.20 (USD 1.11) to travel the entire length of the 35 km New Klang Valley Expressway, which begins at Bukit Raja and ends in Jalan Duta (Kuala Lumpur). Class 1 vehicles can also traverse the entire 797 km North-South Expressway for RM 97.80 (USD 25.74).

The government abolished toll charges for the Johor Baru-Senai stretch of the North-South Expressway effective March 1, 2004. According to Works Minister Datuk Seri S. Samy Vellu, the decision was made after numerous appeals from political parties, ministers, associations, and the Senai MP Datuk Lim Si Cheng (Lecthumanan). He also said, "The Cabinet also took note that there was no alternative road for the users other than [the] present highway." The government compensated the concession holder RM 331.68 million to eliminate the toll.

The World Bank (Malaysia--Road Asset Management Project) also cites public outcry against new toll roads and toll rate hikes in Malaysia. Two possible explanations are high concessionaire profits and public fears of corruption. The government essentially guaranteed high profits for PLUS in the original concessions, regardless of the toll rates. The public may believe the concessionaires are taking advantage of a near-monopolistic position based on the

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[109] Source: PLUS, Plus Expressways Company Prospectus (Company No. 570244-T, 2002).

lack of transparency in the concession awarding process because the terms are not always disclosed (Kulasegaran).[110] However, what the government has done by shifting the burden to taxpayers (with compensation to PLUS) in order to decrease tolls is less economically efficient than charging users the marginal cost or even something close to that. Lowering the cost of travel induces traffic demand and VMT. This may spur short-term economic growth with increased mobility, but creates sustainability and capacity issues for the transportation network—especially in the long term.

Box 8: Malaysian Toll-Road Subsidies

> The Malaysian government paid out RM1.04 billion in compensation to highway concessionaires as part of efforts to increase toll rates more gradually than the rates stipulated in the concession agreements over a five-year period from 1999. The companies were further compensated by the government, which extended their concession period, in the form of RM10.8 billion in toll charges. The government justification for this compensation was to "ease the burden of highway users" (Sennyah, Murugiah and Damis).

It is interesting to note that politicians have conceded to consumer demands to some extent. Gakenheimer (ITS Deployment in Kuala Lumpur) says the parliament has the ability to make beneficial—but politically unpopular—decisions because it has a degree of insulation from public opinion. Despite some public opposition to tolling, new toll roads and concession agreements continue to appear in Malaysia in efforts to expand and improve infrastructure.

The nature of privately-operated toll road companies increases the complexity of creating a viable overall transportation strategy that could include congestion pricing in Malaysia. As discussed in Section 3.4.1, congestion pricing revenues usually need to be transferred to other parts of the transportation system in order for a scheme to be politically acceptable. Transferring revenue from one privatized company to the government or to another company can make this option difficult, if not unviable.

6.13 Concluding Remarks

Urban congestion is a substantial problem in the KLMA and travel demand management strategies have not been well utilized. Prior surveys and media articles indicate that public

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[110] In fact, many transport documents in Kuala Lumpur are deemed confidential and are not available to the public.

support for demand management is likely to be low. Nevertheless, several immediate and long-term benefits could be realized for the KLMA with appropriate transportation pricing. A carefully planned, implemented, and operated scheme should have positive impacts on air quality, travel times, accessibility, land use, income distribution, and revenue.

There are several trends in Malaysia that are troubling from the perspective of travel demand management, namely the decreasing cost of automobile travel due to subsidies that distort mode choice. First, the price of fuel in Malaysia is approximately half the world average, significantly less expensive than its neighbor states, and is becoming less expensive relative to the cost of other goods. This encourages excessive and wasteful use of petroleum, which raises economic and environmental concerns. Second, the abundance of free or subsidized parking and government-subsidized tolls reduces the cost of auto travel, which encourages excessive demand and distorts mode choice in favor of the private automobile. Third, public transportation is generally of poor quality and has been losing mode share in Malaysia. Transit cannot attract riders to the system if it is not a viable option. Fourth, urban decentralization of residential and economic activities is making public transit even less of a realistic option for many households. Fifth, the promotion of the national car severely contradicts efforts to make public transportation a viable option.

The KLMA has become an auto-dependent city in part by policies adopted years ago in efforts to stimulate economic growth through the automobile manufacturing sector; the government has made numerous efforts to reduce auto-related costs for consumers in efforts to stimulate auto sales. Malaysia has chosen not to follow the user-pays principle, which can have negative transportation (and social) effects in the long term. Unless land use and travel demand management measures—including pricing—are taken, auto-dependency and congestion seem likely to increase in the future.

One of the public acceptance challenges associated with road pricing projects and policies is the use of revenue. Conventional beliefs suggest funds should be hypothecated to improving local public transportation and non-motorized alternatives. One obstacle with this approach is that the government does not directly own or operate many of the congested expressways or the transit systems. A better understanding of the legal and practical issues relating to this topic in Malaysia should be pursued to determine how revenues could be earmarked and transferred between transportation systems.

There are several road pricing strategies that could be implemented to address urban congestion or achieve other objectives in the KLMA. The following chapter will apply RPDAT to determine which road pricing strategies might make the most sense for the Kuala Lumpur Metropolitan Area.

7 APPLICATION OF RPDAT TO KUALA LUMPUR

7.1 Introduction

This chapter uses the Road Pricing Decision Analysis Tool (RPDAT) presented in Chapter 5 to determine which road pricing strategies might be most appropriate for a particular metropolitan area. The data and decision-making context established in Chapter 6 is used in conjunction with Kuala Lumpur's transportation policies (listed in Section 7.2) to apply RPDAT to the Kuala Lumpur Metropolitan Area (KLMA).

This application demonstrates the usefulness of the tool for regional strategic transportation planning (RSTP) purposes and tests the sensitivity of the tool to different criteria weights. Four scenarios are analyzed: the first infers objectives from a KLMA policy document and revealed preferences that were identified in Chapter 6; the second adds environmental considerations to the first scenario; the third uses a "pro-expressway" policy set of weights, reflecting policies that encourage expressway use and auto ownership; and the fourth adds environmental considerations to the third scenario.

7.2 Kuala Lumpur Policies

Because Malaysian decision makers were not available for interview, a policy document was used to help derive the set of RPDAT weights for the first scenario. Kuala Lumpur City Hall (CHKL) has outlined several objectives, policies, and proposals in the Draft Structure Plan Kuala Lumpur 2020, which is the main policy document for the metropolitan area. This section lists the relevant statements:

- *Provide a comprehensive and integrated transportation system that caters [to] the needs of inter- and intra-urban travel;*
- *Reverse the decline in public transport usage and to achieve a targeted public-private transport modal split of 60:40 by the year 2020;*
- *Optimize the road and rail transportation infrastructure so that it operates at its full capacity and maximum efficiency;*

- *Ensure that the overall configuration of land use is integrated with road and public transportation networks to optimize the development of land;*
- *Ensure that all areas within the City enjoy the same high quality and standard of provision of public transport services;*
- *Create a city that is highly accessible for all its occupants and users, in particular, one that is pedestrian and handicapped friendly;*
- *Enhance the working, living, and business environment of the City Centre; and*
- *Provide priority and incentives to development in areas around transit terminals.*

Interestingly, there are no policy statements in the environmental section of the Draft Structure Plan that aim to reduce transportation emissions; therefore, these criteria will be given weights equal to zero in the first scenario.

7.3 RPDAT Applied to Kuala Lumpur

7.3.1 Inputs

The first scenario applies RPDAT to Kuala Lumpur using the formal policy statements listed in Section 7.2 and implicit policies discussed in Chapter 6 to derive the set of weights. The high-level weights listed in Table 7.1 are assumed for this scenario.

Table 7.1: KLMA High-Level Weights

Reduce travel times (i.e., increase vehicle speeds)	20
Improve reliability of travel times	10
Improve safety	0
Improve public transportation services	30
Enhance the natural environment	0
Gross revenue generation	10
Influence housing and business location choices	10
Reduce energy consumption and dependence	0
Influence auto ownership	5
Improve pedestrian-friendliness	10
Consider equity	5
Public acceptability	0

For each high-level objective that has criteria grouped under it, points are allocated among the criteria in step 2 part B. Table 7.2 shows the weights used for this step.

Table 7.2: KLMA Weights Among Criteria Under High-Level Objectives

REDUCE TRAVEL TIMES CRITERIA	
Decrease average travel time for all peak-period trips on expressway(s)	20
Decrease average travel time for all mid-day trips on expressway(s)	10
Decrease average travel time on city streets within CBD	50
Decrease average travel time for peak-period arterial trips	20
Create a lower travel time option for autos on expressway(s)	0
IMPROVE RELIABILITY OF TRAVEL TIMES CRITERIA	
Improve reliability for all peak-period trips on expressway(s)	20
Improve reliability for all mid-day trips on expressway(s)	10
Improve reliability on city streets within the CBD	50
Improve reliability for peak-period trips on arterial(s)	20
Create a reliable travel time option for autos on expressway(s)	0
IMPROVE PUBLIC TRANSPORTATION SERVICES CRITERIA	
Decrease travel time of bus services operating on the expressway(s)	20
Decrease travel time of bus services operating on city streets in the CBD	20
Decrease travel time of bus services operating on city streets outside the CBD	20
Improve reliability of bus services operating on expressway(s)	15
Improve reliability of bus services operating on city streets in the CBD	15
Improve reliability of bus services operating on city streets outside the CBD	10
INFLUENCE HOUSING AND BUSINESS LOCATION CHOICES CRITERIA	
Promote new housing developments on suburban or undeveloped land	0
Promote "Smart Growth"	100
INFLUENCE AUTO OWNERSHIP CRITERIA	
Promote automobile ownership	100
Reduce vehicle ownership growth rate	0
CONSIDER EQUITY CRITERIA	
Availability of free or low-cost alternatives	100
Internalize external costs (i.e., implement the "user-pays" principle)	0

RPDAT uses the values in Table 7.1 and Table 7.2 to calculate the actual weights for each criterion, which are listed in Table 7.3.

Table 7.3: KLMA Criteria Weights

CRITERIA	WEIGHTS
Decrease average travel time for all peak-period trips on expressway(s)	4.0
Decrease average travel time for all mid-day trips on expressway(s)	2.0
Decrease average travel time on city streets within CBD	10.0
Decrease average travel time for peak-period arterial trips	4.0
Create a lower travel time option for autos on expressway(s)	0.0
Improve reliability for all peak-period trips on expressway(s)	2.0
Improve reliability for all mid-day trips on expressway(s)	1.0
Improve reliability on city streets within the CBD	5.0
Improve reliability for peak-period trips on arterial(s)	2.0
Create a reliable travel time option for autos on expressway(s)	0.0
Reduce traffic fatality rate	0.0
Reduce number of traffic accidents	0.0
Decrease travel time of bus services operating on the expressway(s)	6.0
Decrease travel time of bus services operating on city streets in the CBD	6.0
Decrease travel time of bus services operating on city streets outside the CBD	6.0
Improve reliability of bus services operating on expressway(s)	4.5
Improve reliability of bus services operating on city streets in the CBD	4.5
Improve reliability of bus services operating on city streets outside the CBD	3.0
Improve air quality	0.0
Reduce greenhouse gas production	0.0
Reduce energy consumption and dependence	0.0
Gross revenue generation potential	10.0
Promote new housing developments on suburban or undeveloped land	0.0
Promote "Smart Growth"	10.0
Promote automobile ownership	5.0
Reduce vehicle ownership growth rate	0.0
Improve pedestrian-friendliness	10.0
Availability of free or low-cost alternatives	5.0
Internalize external costs (i.e., implement the "user-pays" principle)	0.0

After the weights were calculated, the regional characteristics were input into the model. Due to the dearth of publicly-available data, many of the traffic characteristic values were assumed. If additional data were acquired the analysis could be performed again quickly, but these assumptions should be reasonable for sketch-planning purposes. Table 7.4 lists the regional characteristics used for the KLMA.

Table 7.4: KLMA Regional Characteristics

Peak-period average speed on expressway(s) (mph)	25
Mid-day average speed on expressway(s) (mph)	50
Off-peak average speed on expressway(s) (mph)	65
Travel time safety margin index value for expressway(s) (reliability measure)	3
Peak-period average speed in CBD (mph)	7
Mid-day average speed in CBD (mph)	11
Off-peak average speed in CBD (mph)	18
Percent of air pollution derived from local transportation	70
Percent of metropolitan-area VMT that is on expressways	30
Size of the metropolitan area (ha)	400,000
Size of the CBD or potential cordon area (ha)	1,813
Percent of peak-period vehicle trips within the cordon that do not cross the cordon line (i.e., internal trips)	15
Percent of peak-period vehicle trips in the metropolitan area that cross the cordon, but neither originate nor terminate within the cordon area (i.e., through trips)	10
Percent of peak-period vehicle trips in the metropolitan area with origin or destination in the CBD	20
Percent of peak-period person trips in the metropolitan area crossing the cordon line that use public transportation	20
Percent of peak-period expressway corridor trips that are auto	80
Rate the availability of alternatives to the expressway(s):	Some alternative routes[111]
Number of expressway lanes in the peak direction	3

The scope of this evaluation was "the entire metropolitan area," meaning the model examined the impacts of pricing measures at the regional scale. There are no HOV lanes in the KLMA, so the Convert HOV to HOT Lane alternative was not included/analyzed. The following section presents the results for the first policy scenario.

7.3.2 Outputs

RPDAT calculated the performance matrix based on the regional characteristics of the KLMA. These scores are presented in Table 7.5.

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[111] The choices for this characteristic are "Very good alternative routes," "Some alternative routes," and "No alternative routes."

Table 7.5: KLMA Performance Matrix

CRITERIA	Network Pricing	Area-Wide Pricing	Cordon Pricing	Facility Pricing	Add New HOT Lane	Distance-Based Pricing	Conventional Tolling	No Pricing
Decrease average travel time for all peak-period trips on expressway(s)	4	2	2	4	3	3	4	0
Decrease average travel time for all mid-day trips on expressway(s)	3	1	0	3	1	2	2	0
Decrease average travel time on city streets within CBD	4	4	4	1	-2	1	1	0
Decrease average travel time for peak-period arterial trips	4	2	0	-3	3	1	-3	0
Create a lower travel time option for autos on expressway(s)	0	0	0	0	4	0	0	0
Improve reliability for all peak-period trips on expressway(s)	4	0	0	4	3	0	1	0
Improve reliability for all mid-day trips on expressway(s)	4	0	0	4	2	0	1	0
Improve reliability on city streets within the CBD	4	4	4	0	-1	0	0	0
Improve reliability for peak-period trips on arterial(s)	4	0	0	-3	1	0	-3	0
Create a reliable travel time option for autos on expressway(s)	0	0	0	0	4	0	0	0
Reduce traffic fatality rate	-1	0	0	-1	-1	-1	-2	0
Reduce number of traffic accidents	3	3	3	1	1	0	1	0
Decrease travel time of bus services operating on the expressway(s)	4	0	0	4	4	3	4	0
Decrease travel time of bus services operating on city streets in the CBD	4	4	4	1	-2	1	1	0
Decrease travel time of bus services operating on city streets outside the CBD	4	0	0	-2	2	1	-2	0
Improve reliability of bus services operating on expressway(s)	4	0	0	4	4	0	1	0
Improve reliability of bus services operating on city streets in the CBD	4	4	3	0	-2	0	0	0
Improve reliability of bus services operating on city streets outside the CBD	4	0	0	-2	0	0	-2	0
Improve air quality	3	2	2	0	-1	3	0	0
Reduce greenhouse gas production	2	2	2	2	-2	2	2	0
Reduce energy consumption and dependence	2	2	2	2	-2	2	2	0
Gross revenue generation potential	4	2	2	2	1	3	1	0
Promote new housing developments on suburban or undeveloped land	-1	0	0	-1	2	-1	-1	1
Promote "Smart Growth"	1	0	0	1	-2	1	1	0
Promote automobile ownership	-3	-1	-1	-1	1	-2	-1	0
Reduce vehicle ownership growth rate	3	1	1	1	-1	2	1	0
Improve pedestrian-friendliness	1	0	0	-1	-1	1	-1	0
Availability of free or low-cost alternatives	-4	0	0	-1	4	-4	-1	4
Internalize external costs (i.e., implement the "user-pays" principle)	4	3	3	2	2	2	2	1

Because the first scenario did not assign weights to all criteria, scores for criteria that did not receive weight are not used in calculating the index scores for this scenario. However,

RPDAT calculates and presents these scores to the user regardless of whether he/she assigns weight to them. Further, all scores are presented here because subsequent scenarios will assign weights to additional criteria, and the scores will not change between policy scenarios.

RPDAT also calculated the following index scores (Table 7.6) for the KLMA based in the inputs listed in Section 7.3.1:

Table 7.6: RPDAT Index Scores for the KLMA

Strategy	Index Scores
Network Pricing	263
Area-Wide Pricing	135
Cordon Pricing	121
Distance-Based Pricing	80
Facility Pricing	66
Add New HOT Lanes	49
Conventional Tolling	32
No Pricing	20

7.3.3   Interpretation of Results and Recommendations

The RPDAT model suggests the KLMA should pursue network pricing, area-wide pricing, or cordon pricing strategies to meet its policy objectives. Political feasibility, risk, and uncertainty considerations were not accounted for in the model, but presumably should be when making a policy decision. The index score for network pricing is significantly higher than the other alternatives, which implies there is little ambiguity about its capacity to achieve the weighted criteria better than the other alternatives. However, network pricing may not be politically feasible in the region, which would suggest area-wide and cordon pricing might be the feasible alternatives that are best. Area-wide appears more preferable than cordon pricing—most likely because of the number of trips within the CBD that would not cross the cordon—but the two index scores are similar in magnitude so both should be explored in greater detail.

Interestingly, conventional tolling, which is the current form of pricing in the region, is the second-least preferable alternative—just ahead of no pricing. In Malaysia, conventional tolling is used by to fund infrastructure construction that the government could not otherwise finance, but the model suggests other road pricing strategies are capable of generating as much or more revenue and would be better suited to achieve other policy objectives as well.

7.4 Scenario Two: Including the Environment

The second scenario used the same weight proportions as the first, but assigned 15 points to the "Improve the natural environment" high-level objective and scaled all the other high-level objectives by approximately 85 percent. It was assumed that 70 percent of the "Improve the natural environment" points should be allocated to the "Improve air quality" criterion and the remaining 30 points were assigned to the "Reduce greenhouse gas emissions" criterion. The weights used in this scenario are listed in Table 7.7.

Table 7.7: KLMA Weights for Scenario Two

CRITERIA	WEIGHTS
Decrease average travel time for all peak-period trips on expressway(s)	3.4
Decrease average travel time for all mid-day trips on expressway(s)	1.7
Decrease average travel time on city streets within CBD	8.5
Decrease average travel time for peak-period arterial trips	3.4
Create a lower travel time option for autos on expressway(s)	0.0
Improve reliability for all peak-period trips on expressway(s)	1.8
Improve reliability for all mid-day trips on expressway(s)	0.9
Improve reliability on city streets within the CBD	4.5
Improve reliability for peak-period trips on arterial(s)	1.8
Create a reliable travel time option for autos on expressway(s)	0.0
Reduce traffic fatality rate	0.0
Reduce number of traffic accidents	0.0
Decrease travel time of bus services operating on the expressway(s)	5.0
Decrease travel time of bus services operating on city streets in the CBD	5.0
Decrease travel time of bus services operating on city streets outside the CBD	5.0
Improve reliability of bus services operating on expressway(s)	3.8
Improve reliability of bus services operating on city streets in the CBD	3.8
Improve reliability of bus services operating on city streets outside the CBD	2.5
Improve air quality	10.5
Reduce greenhouse gas production	4.5
Reduce energy consumption and dependence	0.0
Gross revenue generation potential	9.0
Promote new housing developments on suburban or undeveloped land	0.0
Promote "Smart Growth"	8.0
Promote automobile ownership	4.0
Reduce vehicle ownership growth rate	0.0
Improve pedestrian-friendliness	9.0
Availability of free or low-cost alternatives	4.0
Internalize external costs (i.e., implement the "user-pays" principle)	0.0

As shown in Table 7.8, the rankings did not change dramatically but one strategy moved down in rank. The index score for adding new HOT lanes fell while the index score for conventional tolling moved up, which switched the rank of these two alternatives. This is most likely because adding new HOT lanes increases capacity, which encourages more auto travel in the long-run.

Table 7.8: RPDAT Index Scores for Scenario Two

Strategy	Index Scores
Network Pricing	268
Area-Wide Pricing	146
Cordon Pricing	134
Distance-Based Pricing	111
Facility Pricing	65
Conventional Tolling	35
Add New HOT Lanes	22
No Pricing	16

The next section tests the sensitivity of the results further by analyzing a "pro-expressway" scenario.

7.5   Scenario Three: "Pro-Expressway"

A "pro-expressway" scenario was used to determine whether the results of the model changed if the Malaysian government adopted a set of policies that promoted auto ownership and expressway use. This third scenario assumed that priority would be given to creating fast and reliable travel time options for autos on expressways, generating revenue, promoting auto ownership, and maintaining free or low-cost alternatives. Other criteria were also given weight, which are shown in Table 7.9. The regional characteristics and scores in the performance matrix do not change in this sensitivity analysis—only the weights that reflect policy priorities of the decision maker.

Table 7.9: KLMA Weights for "Pro-Expressway" Scenario

CRITERIA	WEIGHTS
Decrease average travel time for all peak-period trips on expressway(s)	6.3
Decrease average travel time for all mid-day trips on expressway(s)	6.3
Decrease average travel time on city streets within CBD	0.0
Decrease average travel time for peak-period arterial trips	0.0
Create a lower travel time option for autos on expressway(s)	12.5
Improve reliability for all peak-period trips on expressway(s)	6.3
Improve reliability for all mid-day trips on expressway(s)	6.3
Improve reliability on city streets within the CBD	0.0
Improve reliability for peak-period trips on arterial(s)	0.0
Create a reliable travel time option for autos on expressway(s)	12.5
Reduce traffic fatality rate	3.0
Reduce number of traffic accidents	2.0
Decrease travel time of bus services operating on the expressway(s)	0.0
Decrease travel time of bus services operating on city streets in the CBD	0.0
Decrease travel time of bus services operating on city streets outside the CBD	0.0
Improve reliability of bus services operating on expressway(s)	0.0
Improve reliability of bus services operating on city streets in the CBD	0.0
Improve reliability of bus services operating on city streets outside the CBD	0.0
Improve air quality	0.0
Reduce greenhouse gas production	0.0
Reduce energy consumption and dependence	0.0
Gross revenue generation potential	15.0
Promote new housing developments on suburban or undeveloped land	0.0
Promote "Smart Growth"	0.0
Promote automobile ownership	15.0
Reduce vehicle ownership growth rate	0.0
Improve pedestrian-friendliness	0.0
Availability of free or low-cost alternatives	15.0
Internalize external costs (i.e., implement the "user-pays" principle)	0.0

The results of the second scenario are dramatically different from the first. Table 7.10 lists the index scores of the alternatives.

Table 7.10: KLMA Index Scores for "Pro-Expressway" Scenario

Strategy	Index Scores
Add New HOT Lanes	245
Facility Pricing	93
No Pricing	60
Network Pricing	52
Area-Wide Pricing	40
Cordon Pricing	34
Conventional Tolling	31
Distance-Based Pricing	-17

Comparing Table 7.6 and Table 7.10 reveals that the ranking of the alternatives is quite different between scenario one and scenario three. Adding new HOT lanes is the overwhelmingly best alternative for the pro-expressway scenario; facility pricing and no pricing are the next best alternatives.

Considering the different policy objectives of the two scenarios, it should not be too surprising that adding new HOT lanes is the preferred alternative. The pro-expressway scenario placed high priority on the availability of free alternatives, creating faster and more reliable travel time options for expressway users, promoting auto ownership, and generating revenue. Although adding new HOT lanes is not the best alternative for all criteria, it scores well for many of the highly weighted criteria, giving it the highest overall score.

7.6 Scenario Four: "Pro-Expressway" and the Environment

The final scenario re-examined the third, but assigned 15 points to the "Improve the natural environment" high-level objective and scaled the scenario three high-level objectives by approximately 85 percent. Similar to the methodology used in scenario two, it was assumed that 70 percent of the "Improve the natural environment" points should be allocated to the "Improve air quality" criterion and the remaining 30 points were assigned to the "Reduce greenhouse gas emissions" criterion. The weights used in the fourth scenario are listed in Table 7.11.

Table 7.11: KLMA Weights for Scenario Four

CRITERIA	WEIGHTS
Decrease average travel time for all peak-period trips on expressway(s)	5.3
Decrease average travel time for all mid-day trips on expressway(s)	5.3
Decrease average travel time on city streets within CBD	0.0
Decrease average travel time for peak-period arterial trips	0.0
Create a lower travel time option for autos on expressway(s)	10.5
Improve reliability for all peak-period trips on expressway(s)	5.3
Improve reliability for all mid-day trips on expressway(s)	5.3
Improve reliability on city streets within the CBD	0.0
Improve reliability for peak-period trips on arterial(s)	0.0
Create a reliable travel time option for autos on expressway(s)	10.5
Reduce traffic fatality rate	2.4
Reduce number of traffic accidents	1.6
Decrease travel time of bus services operating on the expressway(s)	0.0
Decrease travel time of bus services operating on city streets in the CBD	0.0
Decrease travel time of bus services operating on city streets outside the CBD	0.0
Improve reliability of bus services operating on expressway(s)	0.0
Improve reliability of bus services operating on city streets in the CBD	0.0
Improve reliability of bus services operating on city streets outside the CBD	0.0
Improve air quality	10.5
Reduce greenhouse gas production	4.5
Reduce energy consumption and dependence	0.0
Gross revenue generation potential	13.0
Promote new housing developments on suburban or undeveloped land	0.0
Promote "Smart Growth"	0.0
Promote automobile ownership	13.0
Reduce vehicle ownership growth rate	0.0
Improve pedestrian-friendliness	0.0
Availability of free or low-cost alternatives	13.0
Internalize external costs (i.e., implement the "user-pays" principle)	0.0

The index scores for this scenario are shown in Table 7.12. Comparing these index scores with those from scenario three, it is apparent that there are several changes. Adding new HOT lanes is still the best strategy, but its dominance has lessened because it may have long-term negative environmental impacts. No pricing fell from the third to the sixth most preferable alternative, most likely because it scores the highest on the "Availability of free or low-cost alternatives" criterion, which received less weight than in the third scenario. Although distance-based pricing is still ranked last, its score improved considerably because pollution and greenhouse gas charges can be incorporated into distance-based charges relatively easily, which would enhance the natural environment.

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Table 7.12: RPDAT Index Scores for Scenario Four

Strategy	Index Scores
Add New HOT Lanes	189
Facility Pricing	87
Network Pricing	83
Area-Wide Pricing	64
Cordon Pricing	58
No Pricing	52
Conventional Tolling	35
Distance-Based Pricing	25

The results of these four scenarios suggest that the overall ranking of the alternatives is quite sensitive to the weights input by the user, as one would expect.

7.7 Chapter Summary

This chapter applied the Road Pricing Decision Analysis Tool to the Kuala Lumpur Metropolitan Area. The results of the four policy scenarios suggest that RPDAT can be a useful tool to help decide which road pricing strategies are best for a metropolitan area; however, the weights chosen by the user can change the results considerably.

Using the set of weights associated with the first or second scenarios, the KLMA should consider network pricing, area-wide pricing, and cordon pricing schemes for the metropolitan area. If the government adopted a set of pro-expressway policies, adding HOT lanes would be the suggested alternative.

8   CONCLUSIONS

8.1   Conclusions

This thesis has identified the strengths and weaknesses of different road pricing strategies and demonstrated the value of multi-criteria analysis (MCA) as a technique to help determine which pricing alternatives are worthy of implementation or merit further consideration for a specific metropolitan area. MCA is an economic evaluation technique that allows decision makers to explicitly trade-off often-conflicting criteria to determine the most preferable alternatives. This approach can improve the decision-making process for selecting road pricing strategies to be implemented in a metropolitan area.

Many regions are considering implementing road pricing strategies, but the reasons for their consideration are varied. Often the agency or metropolitan area has multiple or unclear objectives. Congestion management, environmental improvement, and transportation finance are the three most common goals, but road pricing has impacts on other areas of concern to decision makers as well and pricing can change the way the transportation system operates. For example, some types of road pricing—such as HOT lanes—have the capacity to create fast and reliable travel time options for commuters, businesses, and leisure travelers who value their time highly for particular trips. Chapter 3 classified road pricing strategies according to six different forms, which allowed for generalized statements to be made regarding the strengths and weaknesses of each form.

There is evidence to suggest that analytical tools and data are not currently available to create accurate estimates of road pricing impacts with classical transportation models. Very few pre- and post-implementation studies have been performed to assess the accuracy of road pricing forecasts, but a lack of confidence in the models by some decision makers supports the thought that existing models could be improved. If model estimates are not trusted, then there may be little reason for using the models. The model most frequently utilized to evaluate pricing strategies is the four-step model (4SM), which has fundamental difficulties in capturing the most relevant characteristics of pricing. The model is being used for a purpose different from its

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original intent, which did not include the evaluation of policies involving little or no change to the infrastructure supply.

The Road Pricing Decision Analysis Tool (RPDAT) introduced in this thesis can help decision makers assess which forms of road pricing might be most regionally-appropriate and consistent with policy priorities. Version 1.1 of RPDAT performs MCA for nine different road pricing strategies and evaluates each according to 29 criteria. The tool can be used quickly with few data inputs, making it an excellent screening tool for sketch-planning purposes.

In Chapter 7, RPDAT demonstrated that network, area-wide, and cordon pricing respectively are the most appropriate road pricing options for the assumed policy priorities and regional characteristics of the Kuala Lumpur Metropolitan Area (KLMA). If the Malaysian government were to adopt a "pro-expressway" set of policies, however, the index scores would change significantly and the most preferred alternative would be adding HOT lanes.

As expected, the Kuala Lumpur application demonstrates that RPDAT is sensitive to input weights. The author believes that this phenomenon illustrates a very important concept— different forms of road pricing have different strengths and weaknesses and the "correct" road pricing strategy for a metropolitan area will depend greatly upon its objectives.

RPDAT Version 1.1 presents a generalized framework with which to evaluate road pricing strategies for metropolitan areas, but there are several improvements that could be made to the model. Additionally, this framework could also be integrated with other transportation planning methodologies. Section 8.2 identifies recommendations for further research with RPDAT and road pricing modeling.

8.2 Recommendations for Further Research

Three types of recommendations are presented: recommendations for improving the capacity of classical transportation models to estimate the impacts of road pricing, recommendations for improving RPDAT, and recommendations for integrating RPDAT with other transportation planning methods.

8.2.1 Improving Classical Transportation Models

Some approaches, such as bi-criterion traffic assignment, are theoretically more appealing than the classical traffic assignment models used in the 4SM, but there are still refinements necessary to make these techniques operational. An important research contribution would be to incorporate workable distributions of value of time into the four-step model.

Microsimulation is preferable to the 4SM in theory, but its estimates are only as good as the input assumptions. Currently, many academic researchers are working to develop more advanced microsimulation techniques, which may prove to be the most appropriate for modeling road pricing. These techniques merit further research.

The author is not aware of any forecasting models that incorporate the value of reliability. Evidence presented in Chapter 4 suggests this is an important factor considered by travelers and freight shippers/carriers when making a trip; therefore, its inclusion in a transportation model would be another valuable contribution.

There is much to be learned about the factors used by drivers as decision variables in the context of road pricing. The collection and analysis of empirical data from more pricing projects will be necessary to better understand the parameters used as decision variables and the aggregate impacts of strategies. This should advance the theory of driver behavior, which could contribute to more effective modeling and may help address equity issues of concern to decision makers.

Finally, several data insufficiencies need to be resolved to develop better pricing models. The travel characteristics and behavior of commercial vehicles are not understood well and more data is needed to estimate how this group will react to pricing policies. Commercial vehicles may be among the chief beneficiaries of priced facilities if they can increase productivity, but it is very difficult to estimate how many commercial vehicles will use a priced facility or their willingness to pay for the improved service. Other major problems include the poor quality of stated preference data and little documentation of reliability sensitivity.[112]

Finally, more accurate revenue and traffic diversion estimates might make more roads financially feasible by lowering the required rate of return from reduced risk. Increasing the

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[112] For more information on the freight impacts of congestion pricing, see: J. Waliszewski, "Toward Understanding the Impacts of Congestion Pricing on Urban Trucking," Massachusetts Institute of Technology, 2005.

accuracy—and consequently the trust—in models used to consider pricing could mitigate some of the major concerns associated with road pricing projects.

8.2.2 Improving RPDAT

Currently RPDAT Version 1.1 uses a metropolitan area's regional characteristics to calculate the scores of the alternatives in the performance matrix. The algorithms used to calculate the scores make the tool region-specific and are appropriate for sketch-planning analysis; however, refining the formulas to deliver more accurate scores would be a valuable next step. When more road pricing case studies and data are available, statistical analysis of factors that make a region better-suited for particular road pricing strategies could be performed. This evidence should create more accurate estimates of how well each alternative meets the criteria. Identifying these factors with current data would at least be intellectually challenging and may not even be possible; if they are identified, it may be difficult to determine the extent that a factor increases the attractiveness of a particular road pricing measure. Integrating demand elasticities into the performance matrix may also improve the sophistication of model scoring.

Incorporating more criteria and alternatives into the model would also increase its usefulness to decision makers. Some criteria, such as the cost of scheme operations and implementation, were not included in Version 1.1 even though they are important variables. These criteria were omitted because the choice of technology, network geometry, and other location-specific characteristics greatly influence the scores, thus accurate scoring was not possible. If more road pricing and some non-road pricing alternatives were included in the model, it would expand the scope of the tool, which could be an important next step.

It may also be helpful to determine if there is a minimum RPDAT index score value that indicates whether any of the strategies are worth pursuing. Of course, this would have to take into account the score of the current strategy of the metropolitan area.

RPDAT should be expanded so that it can evaluate bridges and tunnels. Some regions and agencies may wish to consider pricing on these facilities but cannot do so with Version 1.1. Another variation that could ideally be included in the model is the distinction between variable tolls versus dynamic tolls, but the differences may be unclear and too site-specific for the model. If it were able to provide specific estimates of the impacts, this modification might also expand the audience of potential users.

Risk, uncertainty, and public acceptability are not accounted for in the model and a more sophisticated multi-criteria method could be used to combine the scores and weights and incorporate these parameters. If this change were made in a subsequent version, however, it would be advantageous to retain the linear-additive model from Version 1.1 (as an option) because of its attractiveness as a transparent process.

8.2.3 Integrate RPDAT with Other Transportation Planning Methods

The RPDAT framework is useful by itself for evaluating road pricing measures, but it may be desirable to integrate the tool with other transportation planning methods such as Regional Strategic Transportation Planning (RSTP).[113] Both methodologies are concerned with regional transportation planning and perhaps RPDAT could be developed as a specific tool used with RSTP.

8.3 Concluding Remarks

Several technical and non-technical challenges remain for wider deployment of road pricing strategies. Political will, legal obstacles, perceived equity, and enforcement are just some of the challenges that need to be overcome before road charging is commonplace. The author neither advocates nor opposes road pricing measures, but hopes that this thesis advances the understanding of road pricing strategies for the traveling public, decision makers, researchers, and stakeholders.

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[113] For more information on RSTP, see: Sgouridis, "Integrating Regional Strategic Transportation Planning and Supply Chain Management: Along the Path to Sustainability."

9 APPENDIX A1: SECOND-BEST CONDITIONS AND PRICING

"Second-best" conditions are said to exist if at least one potential substitute, complement, or input is not priced at its marginal cost. This situation occurs in transportation as well as many other sectors, so economists have developed rules for pricing in second best conditions. If the mispriced services are supplements or complements to the service in question, denoted as service i, then the optimal price for service i is:

$$P_i - MC_i = -\sum_{j \neq i}[(E_{ij} / E_i) \cdot (Q_j / Q_i) \cdot (P_j - MC_j)] \quad \text{where,}$$

P_i = price of service i;
MC_i = marginal cost of service i;
E_i = price elasticity of demand for service i;
E_{ij} = cross price elasticity of demand for service j with respect to the price of service i; and
Q_i = quantity of service i.

This formula is valid with the condition that $P_i < MC_i$ if the other goods are all substitutes for it and the other goods are priced below marginal cost, and $P_i > MC_i$ if the other goods are all complements.

Despite being an attractive theory and interesting economic exercise, second-best pricing is rarely implemented because the rules for its application are rather complex.

10 APPENDIX A2: REVENUE HYPOTHECATION

While economic theory suggests welfare is maximized when revenues are not earmarked, urban policymakers strongly encourage that road pricing revenues be reinvested in the transportation system.[114] Past experiences suggest that public acceptance is likely to be higher if net revenues are hypothecated, i.e., earmarked, for local transportation improvements and investments. The public is often opposed to road pricing if they believe the revenues will contribute to the general government tax fund because they view the introduction of pricing measures as merely an increase in taxes. They are likely to be more supportive, however, if they believe the charge is giving them more value, hence the term *value pricing* that is used in the United States. Cases where net revenues are devoted to improving transportation on the facility from which they were collected—to transit in particular—are likely to have more public support. Unpriced alternative routes, such as a ring road around an area-wide scheme or arterials parallel to a priced expressway, should also be improved in order to avoid increasing congestion on these roads if travelers choose to bypass the priced area. Transit priority on approaches to the priced area are also recommended if the routes become congested.

In the event that net road pricing revenues were dedicated to regional transportation and used for the creation of a single area-wide transportation fund, one might expect the region to make more integrated investment decisions and improve the attractiveness of transit services. It is much more difficult to share revenues between transportation modes when each is operated by different agencies—even more so if one of the entities is a private operator. Public-private partnerships create complications because the motives (such as maximizing profit) of the private sector are different from those of the public sector and it is more difficult to ensure road pricing revenues are spent in a manner that is perceived as best for the public. Public support would likely be lacking for any such balance transfers unless there is transparency in government actions and public access to accounting records.

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[114] Road pricing on a new facility is less likely to be perceived as having negative impacts to existing users because there are no existing users. Therefore, revenue hypothecation is not as necessary to gain public support in this case; however, toll revenues might be secured for debt financing if revenue bonds are issued to finance the new construction, which is essentially a form of hypothecation to the facility for the lifetime of the bonds.

Singapore, London, the I-15 HOT lanes, and the German distance-based charging schemes have all earmarked revenues to improving transportation. As an example, an amendment to Section 11 of the HGV Act (regarding Germany's Toll Collect system) states that, "Expenditure for the operation, monitoring and enforcement of the tolling system shall be paid for out of the toll revenue. The remaining revenue shall be added to the transport budget and all of it shall be ring-fenced to improve transport infrastructure, predominantly federal highway construction."

11 APPENDIX A3: FOUR-STEP MODEL OVERVIEW

The four-step model (4SM) is the regional travel demand model used to evaluate most urban transportation planning projects in the United States. It is a long-range transportation planning tool originally developed over forty years ago, which is used to estimate changes in travel and utilization of the transportation system in response to changes in demographics, regional development, and the transportation supply (Caliper Corporation).

The 4SM estimates aggregate travel demand, meaning that it does not model the behavior of individuals. Instead, the model assumes homogeneous land use and demographic characteristics for sub-regions, which are referred to as traffic analysis zones, or TAZs; a metropolitan area will often have hundreds of TAZs. An example TAZ might be a four block by five block geographic area with low density single-family residential housing, high household income, and an average of 2.4 automobiles per household, among other characteristics. Demand for travel between TAZs is used in the 4SM process to determine the mode split and amount of traffic assigned to each link on the transportation network.

The 4SM is comprised of four sequential steps. *Trip Generation* determines how many trips will occur, *Trip Distribution* creates trip tables to see where those trips occur, *Mode Split* (a.k.a. Mode Choice) assigns the trips to a particular transportation mode, and then *Trip Assignment* (a.k.a. Route Choice or Traffic Assignment) assigns the trips to particular road links. A (user) equilibrium approach is used to assign traffic to the road network.

The 4SM steps are usually applied separately for different trip purposes because trip-making behavior varies across trip purposes (Caliper Corporation). Example trip purposes include home-based work, home-based shopping, home-based other, non-home based, and commercial vehicles. Trip rates are estimated on a 24-hour basis in many cases and then a time-of-day factor is applied to the 24-hour trip table to produce trip tables for different time periods (e.g., a.m. peak period, p.m. peak period, off-peak period) (Meyer and Miller).

The sequential nature of the model infers people first decide whether to make a trip, and then they determine where they will go, then they pick a transportation mode, and finally they choose which route to take. In reality, travelers obviously do not use this chronological

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methodology and more likely evaluate a combination of factors simultaneously; however, it is incredibly difficult to estimate the decision making factors and model such an analytically rigorous process. The 4SM does not claim to represent individual trip-making behavior, but takes a pragmatic approach to reducing the extremely complex phenomenon of travel behavior into analytically manageable components that can be dealt with using relatively simple techniques and reasonable amounts of data (Meyer and Miller).

12 APPENDIX A4: RATING SCALES

In a nominal scale, numerical values in the performance matrix represent a coded list of qualitative scores (e.g., 0 = 'yes' and 1 = 'no'), thus making numerical operations or aggregation inappropriate.

An ordinal scale represents a rank ordering of the alternatives. The differences between rankings can have significance if a descending preference rating scale (with the most preferable alternative assigned a value of n and the least preferred assigned a value of 1 when there are n alternatives) is used.

Interval scales do not have an origin, making absolute comparisons impossible, but this scaling system permits some numerical operations (e.g., averaging). An example would be a scale that ranks alternatives from zero to ten, where zero is the "least preferable" and ten is the "most preferable." The extreme values of the scale could be either real or hypothetical scores of the alternatives. This scale often works well if the analysis compares all alternatives at the same time. If hypothetical "best possible" and "worst possible" extreme values are not used in the original scoring, the scores of the original alternatives may have to be modified if another alternative is added.

A ratio scale has an origin and the absolute value of the number in the performance matrix has significance; more information can be inferred and all standard numerical operations can be performed with a ratio scale.

13 APPENDIX B: DEFINITIONS AND ACRONYMS

4SM: Four-step model. See Appendix A3.

AC: Average cost.

Alternative: One of the options evaluated in the multi-criteria analysis.

BCA: Benefit-cost analysis.

BRT: Bus rapid transit.

CBD: Central business district.

CC: (London) congestion charging scheme.

Congestion pricing: See Section 2.3.5.

Conventional tolling: Tolling on a limited-access expressway where all lanes are priced and the level of the charge does not vary by time-of-day or congestion-level. See Section 3.3.1.

CPI: Consumer price index.

Criteria: Criteria are used to reflect the decision maker's objectives in a multi-criteria analysis. See Section 5.4.3.

CV: Commercial vehicles.

Deadweight loss: A loss in social welfare derived from a policy or action that has no corresponding gain. Congestion costs are deadweight loss and the result of a flaw in the price-setting mechanism for roadway space. Deadweight loss represents economic inefficiency.

DM: Decision maker.

DOT: Department of Transportation.

Dynamic pricing: Tolls that vary by the level of traffic congestion to maintain free-flowing traffic conditions while making efficient utilization of the lane capacity (e.g., San Diego I-15 HOT lanes). Dynamic pricing is a form of congestion pricing.

ERP: (Singapore) electronic road pricing scheme. See Section 3.3.4.1.

ETC: Electronic toll collection.

Express lanes: Express lanes are a form of managed lanes where vehicles pay for a premium level-of-service. HOT lanes are an example of express lanes where discounts are given to HOVs. Other forms of express lanes may not give toll discounts. Express lanes are a form of managed lanes.

Externalities: See Section 2.3.2.

Facility pricing: Tolling on a limited-access expressway where all lanes are priced and the level of the charge varies by time-of-day or congestion-level. See Section 3.3.2.

FHWA: U.S. Federal Highway Administration.

First-best conditions: First-best conditions assume perfect competition; complete information; no externalities; no subsidies; and no indivisibilities of supply or demand.

Flat-rate tolling: See conventional tolling.

FTA: U.S. Federal Transit Administration.

GDP: Gross domestic product.

General-purpose (GP) lanes: Lanes on a roadway open to all classes of vehicles and have no special requirements.

GPS: Global Positioning Systems.

ha: Hectare.

HOT: High-occupancy/toll (lane). A lane that permits HOVs to travel at a free or discounted rate but charges low-occupancy vehicles a toll to use the same lane. HOT lanes manage demand by varying the toll by time-of-day or level-of-congestion in efforts to maintain a certain minimum level-of-service. HOT lanes are a form of express lanes.

HOV: High-occupancy vehicle (lane). An HOV has greater than or the same number of occupants in a vehicle than the HOV criterion specified for the facility. Many HOV lanes classify vehicles with two or more occupants as HOVs, although some facilities set more stringent criteria. HOV lanes are a form of managed lanes, and typically provide premium service relative to the general-purpose lanes.

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Hypothecation. Earmarking a revenue stream. See Appendix A2.

Index score: The final output of the multi-criteria analysis. Index scores indicate the overall preference of an alternative and can be used to rank the alternatives.

ITS: Intelligent transportation systems.

IU: In-vehicle unit. The toll transponder for the Singapore cordon pricing scheme is referred to as an IU.

J-I-T: Just-in-time (shipping).

Joint cost: See Box 2.

KL: Kuala Lumpur.

KLMA: Kuala Lumpur metropolitan area.

Long-run marginal cost (LRMC): The long-run marginal cost is the cost of accommodating an extra vehicle with infrastructure expansion such that congestion does not increase.

LOS: Level-of-service.

LOV: Low-occupancy vehicle. LOVs have fewer occupants than the HOV criterion. LOVs are typically SOVs.

LRT: Light-rail transit.

Managed lanes: Managed lanes are lanes other than general-purpose lanes, which have special requirements for vehicle use. Special requirements may relate to vehicle type (e.g., allow hybrids or prohibit trucks), vehicle occupancy (i.e., HOVs only), or payment of an additional toll. HOV lanes, HOT lanes, and express lanes are examples of managed lanes.

MC: Marginal cost.

MCA: Multi-criteria analysis. See Section 5.2.

MCP: Marginal-cost pricing. See Section 2.3.3.

Microsimulation: Microsimulation models transportation choices at a disaggregate level.

mph: Miles per hour.

MPO: Metropolitan planning organization.

Performance Matrix: Where alternative scores for multi-criteria analysis are documented. See Section 5.4.4.

Public good: A public good must be non-excludable and there must be non-rival consumption. Once non-excludable goods are provided, others cannot be prevented from enjoying them. If non-rival consumption exists, additional people can consume the good without reducing other consumers' enjoyment. Pure public goods are rare, and transportation does not meet these criteria. Only the public sector will provide public goods. A lighthouse and national defense are classic examples of public goods.

Ramsey Pricing: See Section 2.3.4.

Regional Characteristics: See Section 5.4.4.

RP: Revealed preference (data). This is empirical data derived from actual experiences and projects. RP data is more preferable to SP data because it more accurately represents actual choices and is less subject to perception errors of people being surveyed.

RPDAT: The Road Pricing Decision Analysis Tool. See Chapter 5 for description.

RSTP: Regional Strategic Transportation Planning.

RZ: Restricted zone for the Singapore electronic road pricing scheme. The RZ is the area within the cordon.

Scores: Scores are used to indicate how well alternatives meet the different criteria in a multi-criteria analysis.

Second-best: See Appendix A1.

Short-run marginal cost (SRMC): The short-run marginal cost is the cost of accommodating an additional vehicle with extra congestion.

SOV: Single-occupancy vehicle. SOVs are a vehicle with only one person.

SP: Stated preference (data). This is hypothetical data derived from surveys distributed prior to the policy change about how people think they would respond to a change in policy. This data is less desirable than RP data because it is less accurate.

TAZ: Traffic analysis zone. A small geographic unit within a region assumed to have homogeneous demographic and land use characteristics. It is used in the 4SM. An example of a TAZ would be a 3 block x 3 block low density residential zone where all households are assumed to have the same socio-economic characteristics (i.e., same household income, same car ownership, etc.).

TDM: Traffic demand management.

TfL: Transport for London.

U.S. DOT: United States Department of Transportation.

OST: U.S. DOT Office of the Secretary of Transportation.

Variable pricing: Tolls that vary by time-of-day and/or day-of-the-week according to a pre-determined and published toll schedule (e.g. California SR91). Variable pricing is a form of congestion pricing.

VMT: vehicle miles traveled.

VOR: Value of reliability.

VOT: Value of time.

vphpl: Vehicles per hour per lane.

Weights: Used to document the policy priorities of the decision maker in a multi-criteria analysis. See Section 5.4.3.

ZEV: Zero-emissions vehicle.

14 BIBLIOGRAPHY

Armstrong-Wright, A. "Road Pricing and User Restraint: Opportunities and Constraints in Developing Countries." Transportation Research Part A: General 20.2 (1986): 123-27.

Awang, M., et al. "Air Quality in Malaysia: Impacts, Management Issues and Future Challenges." Respirology 5 (2000): 183-96.

Barrock, L. Special Report: Proton under a Microscope. 2004. The Edge Daily. Available: http://www.theedgedaily.com/cms/content.jsp?id=com.tms.cms.article.Article_236d189c -cb73c03a-23d27800-d2591310. January 2005.

Ben-Akiva, M., and S. Lerman. Discrete Choice Analysis. Cambridge: MIT Press, 1985.

Blau, J. High-Tech Truck Toll System Finally Launched in Germany. 2005. Computer World. Available: http://www.computerworld.com/industrytopics/transportation/story/0,10801,98679,00.ht ml. February 2005.

Brownstone, D., and K. Small. Valuing Time and Reliability: Assessing the Evidence from Road Pricing Demonstrations: University of California at Irvine, 2003.

Bureau of Labor Statistics. Consumer Expenditures in 2002. Washington: U.S. Department of Labor, Bureau of Labor Statistics, 2004.

Caliper Corporation. Caliper Introductory Travel Demand Forecasting Workshop Software. Newton, MA: Caliper Corporation, 2003.

Carter, J. ""the President's Proposed Energy Policy." 18 April 1977." Vital Speeches of the Day Vol. XXXXIII.No. 14 (1977): 418-20.

CBS Broadcasting. "Taxing by the Mile." CBS Evening News. Sandra Hughes. Corvallis, OR, 2005.

Chin, J. Budget Likely to Be Prudent. 2004. The Edge Daily [Online]. Available: http://www.theedgedaily.com/cms/content.jsp?id=com.tms.cms.article.Article_b45773ef-cb73c03a-940b8400-5dc1e6a6. September 2004.

City Hall Kuala Lumpur. Draft Structure Plan Kuala Lumpur 2020. First ed. Kuala Lumpur: City Hall Kuala Lumpur, 2003.

Cracknell, J. Experience in Urban Traffic Management and Demand Management in Developing Countries: World Bank, Department for International Development, UK, 2000.

DeCorla-Souza, P. An Evaluation of "High Occupancy Toll" and "Fast and Intertwined Regular" Networks. Washington: Transportation Research Board Annual Meeting, 2003.

---. Using Smite-ML 2.2 to Evaluate Road Pricing Alternatives. Washington: Federal Highway Administration, 2005.

Department of Statistics. 2004. Malaysia Department of Statistics. Available: http://www.statistics.gov/my. January 2004.

Dial, R. "Bicriterion Traffic Assignment: Basic Theory and Elementary Algorithms." Transportation Science 30.2 (1996): 93-111.

Downs, A. Traffic: Why It's Getting Worse, What Government Can Do. Washington: Brookings Institution, 2004.

EFTE. Congestion Pricing in London--a European Perspective. Brussels: European Federation for Transport and Environment (EFTE), 2003.

EPU. The Eighth Malaysia Plan. 2001. Economic Planning Unit (EPU) of Malaysia. Available: http://www.epu.jpm.my/RM8/front_RM8.html. January 2004.

---. The Way Forward (Vision 2020): Economic Planning Unit (EPU) of Malaysia, 1991.

Estache, A., L. Trujillo, and E. Quinet. Forecasting the Demand for Privatized Transport: What Economic Regulators Should Know, and Why. Washington: World Bank, 2000.

European Commission. External Costs--Research Results on Socio-Environmental Damages Due to Electricity and Transport. Brussels: European Commission, 2003.

FHWA. Report on the Value Pricing Pilot Program (Submitted to Congress). Washington: Federal Highway Administration (FHWA), 2000.

Fielding, G., and D. Klein. High Occupancy/Toll Lanes: Phasing in Congestion Pricing a Lane at a Time: Reason Public Policy Institute (RPPI), 1993.

Fitch Ratings. Bliss, Heartburn, and Toll Road Forecasts. New York: Fitch Ratings, 2003.

Gakenheimer, R. ITS Deployment in Kuala Lumpur: Massachusetts Institute of Technology, 2003.

---. Travel Demand Drivers: Kuala Lumpur, Malaysia: Massachusetts Institute of Technology, 2003.

Gómez-Ibáñez, J. "Externalities, Public Goods, and Commons." Cambridge: Harvard University, Kennedy School of Government, 2005.

---. "The Political Economy of Highway Tolls and Congestion Pricing." Transportation Quarterly 46.3 (1992): 343-60.

---. "Pricing." Essays in Transportation Economics and Policy: A Handbook in Honor of John R. Meyer. Washington: Brookings Institution, 1999. 99-136.

Hendrickson, C., and M. Wohl. "Efficient Prices for Roadways and Transit Services." Transportation Quarterly 36.3 (1982): 433-49.

Highway Communication Exchange. Priced New Lanes: California - Extension of I-15 HOT Lanes in San Diego. April 16 2004. Available: http://knowledge.fhwa.dot.gov/cops/hcx.nsf/0/4bc5cb5d5824a28085256e77006a74cc?Op enDocument. February 2005.

"HOT Networks: A New Plan for Congestion Relief and Better Transit." Joint Economic Committee. Washington: Poole, R. Jr., 2003.

HPU. Quality of Roads in Malaysia: Road Safety. Kuala Lumpur: Ministry of Works Malaysia, Highway Planning Unit (HPU), 1998.

---. Road Safety. 2004. Ministry of Works Malaysia, Highway Planning Unit (HPU). Available: http://www.kkr.gov.my/bpj/safety/safety1.htm.

ICF Incorporated. Opportunities to Improve Air Quality through Transportation Pricing Programs. Fairfax: Report for the U.S. Environmental Protection Agency, 1997.

Ingram, G. "Patterns of Metropolitan Development: What Have We Learned?" Urban Studies 35.7 (1998): 1019-35.

Jaafar, M., and R. Mohamad. "Is There a Need for Energy Subsidy Reform? A Malaysian Perspective." Asia Workshop on Energy Subsidy Reform. Bangkok: Pusat Tenaga Malaysia (PTM), 2001.

Keeney, R., and H. Raiffa. Decisions with Multiple Objectives: Preferences and Value Tradeoffs. New York: John Wiley & Sons, 1976.

Knight, F. "Some Fallacies in the Interpretation of Social Cost." Quarterly Journal of Economics 38 (1924): 582-606.

Kulasegaran, M. "No Basis for Increase in Toll Charges and Jelapang Toll Plaza Must Be Relocated." Ampang Toll Plaza, Ipoh, Perak, Malaysia, 2001.

Lecthumanan, A. Toll for Senai-Johor Baru Stretch Abolished. 2004. The Star Online. Available: http://www.star-motoring.com/research/review.asp?file=/editorial/2004/usedhope.html. February 2004.

Lijphart, A. "Unequal Participation: Democracy's Unresolved Dilemma." The American Political Science Review 91.1 (1997): 1-14.

Malaysiakini. "Ring Road: Minister Running Rings around Us." http://www.malaysiakini.com/letters/29202, 2004.

Matsuda, W., Y. Tsukada, and M. Kikuchi. Analysis of the Demonstration Project Results Concerning Diverse and Flexible Charge Measures for Toll Roads to Promote Road Policy. Washington, D.C.: Transportation Research Board (TRB), 2005.

McNally, M. The Four Step Model. Irvine: Institute of Transportation Studies, University of California, 2000.

Menon, A. "ERP in Singapore--a Perspective One Year On." tec (2000): 1.

Metschies, G. International Fuel Prices: GTZ, 2003.

Meyer, M., and E. Miller. Urban Transportation Planning. New York: McGraw-Hill, 2001.

MIDA. The Cost of Doing Business in Malaysia: Malaysia Industrial Development Authority (MIDA), 2002.

Mody, A. Infrastructure Strategies in East Asia: The Untold Story. Washington: The World Bank Group, 1997.

Mohring, H. "Congestion." Essays in Transportation Economics and Policy: A Handbook in Honor of John R. Meyer. Washington: Brookings Institution, 1999. 181-221.

NCHRP. Road Pricing for Congestion Management: A Survey of International Practice. Washington: National Cooperative Highway Research Program (NCHRP), 1994.

New Straights Times. Police Corruption. 2004. New Straights Times. Available: http://www.nst.com.my/Current_News/NST/Tuesday/Frontpage/20040810074429/Articl e/indexb_html. August 2004.

Nijkamp, P., and A. Delft. Multi-Criteria Analysis and Regional Decision-Making. Studies in Applied Regional Science. Ed. P. Nijkamp. Vol. 8. Leiden: Martinus Nijhoff Social Sciences Division, 1977.

Oak Ridge National Laboratory. Transportation Energy Databook. Oak Ridge: Prepared for the U.S. Department of Energy, 2004.

OCTA. 91 Express Lanes Fiscal Year 2003 Annual Report. Orange: Orange County Transportation Authority (OCTA), 2003.

---. 91 Express Lanes Homepage. 2005. Orange County Transportation Authority (OCTA). Available: www.91expresslanes.com. March 2005.

ODPM DTLR. Multi-Criteria Analysis Manual. London: United Kingdom, Office of the Deputy Prime Minister (ODPM), Department for Transport Local Government and the Regions (DTLR), 2005.

Orski, K., and R. Poole. Paying for Roads. 2003. Innovation Briefs. Available: http://www.innobriefs.com/cditor/20030326payingforroads.html. May 2005.

Pigou, A. The Economics of Welfare. London: Macmillan, 1920.

PLUS. PLUS Expressways Company Prospectus: Company No. 570244-T, 2002.

Poole, R., Jr. "Vehicle Emissions Will Soon Be a Non-Problem." Surface Transportation Innovations.22 (2005).

Rahman, A. "Car Pooling in Kuala Lumpur: Public Perception." Conference Transport and Communication for Urban Development. Singapore: United Nations Habitat, 1997.

Ramsey, E. "A Contribution to the Theory of Taxation." Economic Journal 37.March (1927): 47-61.

REAM. ITS Strategic Plan for Malaysia: A Way Forward: Road Engineering Association of Malaysia (REAM), 1999.

Replogle, M., and D. Reinke. Estimating the Effects of Transportation Pricing Policies on Traveler Behavior: Current Techniques and Future Direction, 1998.

Rietveld, P. Multiple Objective Decision Methods and Regional Planning. Studies in Regional Science and Urban Economics. W. Isard. Vol. 7. Amsterdam: North-Holland Publishing Company, 1980.

Ruidisch, P. "The German Truck Charge." ECMT Conference on Managing Transport Demand through User Charges. London, 2004.

Samuel, P. GPS-Based Toll Collect in Germany Is Collecting. January 2, 2005. Available: http://www.tollroadsnews.com/cgi-bin/a.cgi/rwXBNl0REdmcElJ61nsxIA. March 2005.

Schrank, D., and T. Lomax. 2004 Urban Mobility Report. College Station: Texas Transportation Institute, 2004.

Sennyah, P., C. Murugiah, and A. Damis. Compensation to Ensure Gradual Toll Increases. 2004. New Straights Times. Available:

http://www.nst.com.my/Current_News/NST/Wednesday/National/20040929084928/Arti
cle/indexb_html. September 2004.

Sgouridis, S. "Integrating Regional Strategic Transportation Planning and Supply Chain
Management: Along the Path to Sustainability." Massachusetts Institute of Technology,
2005.

Small, K., et al. Valuation of Travel-Time Savings and Predictability in Congested Conditions
for Highway User-Cost Estimation. Washington: National Cooperative Highway
Research Program (NCHRP), 1999.

Small, K., and C. Winston. "The Demand for Transportation: Models and Applications." Essays
in Transportation Economics and Policy: A Handbook in Honor of John R. Meyer.
Washington: Brookings Institution, 1999. 11-56.

Small, K., C. Winston, and J. Yan. Uncovering the Distribution of Motorists' Preferences for
Travel Time and Reliability: Implications for Road Pricing: University of California
Transportation Center, 2002.

Standard & Poor's. Traffic Forecast Risk: Study Update 2004. New York: Standard & Poor's,
2004.

STPP. Mean Streets 2002. 2002. Executive Summary. Surface Transportation Policy Project
(STPP). Available: http://www.transact.org/library/reports_html/ms2002/exec_sum.asp.
April 2005.

Sussman, J. Introduction to Transportation Systems. Boston: Artech House, Inc., 2000.

---. Perspectives on Intelligent Transportation Systems. New York: Springer, 2005.

Sussman, J., S. Sgouridis, and J. Ward. A New Approach to Transportation Planning for the 21st
Century: Regional Strategic Transportation Planning as a CLIOS. Cambridge:
Massachusetts Institute of Technology, 2004.

TCRP. Road Value Pricing. Washington: Transportation Research Board, Transit Cooperation
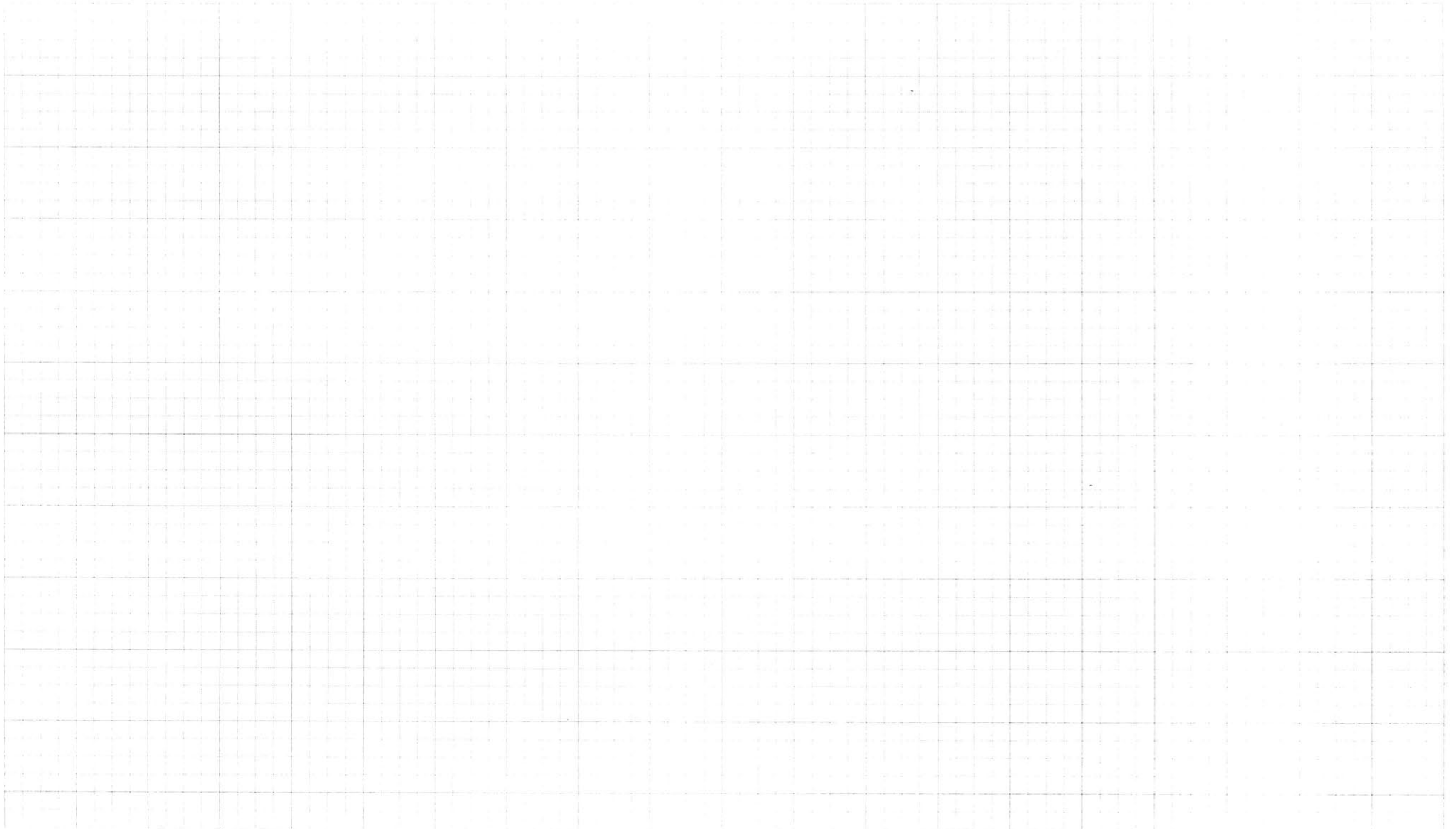Research Program (TCRP), 2003.

The Star Online. Prices of Foreign Cars 'May Not Come Down'. 2002. Available:
      http://www.star-motoring.com/research/review.asp?file=/editorial/2002/afternot.html.
      December 2002.

Toll Collect. Toll Collect. 2005. Available: http://www.toll-
      collect.de/frontend/HomepageVP.do;jsessionid=F27DB1064AB1E3893FEECC3EAE499
      90F. March 2005.

Transport for London. Central London Congestion Charging Scheme - Impacts Monitoring, First
      Annual Report. London: Transport for London (TfL), 2003.

---. Central London Congestion Charging Scheme - Impacts Monitoring, Second Annual Report.
      London: Transport for London (TfL), 2004.

---. Central London Congestion Charging Scheme - Impacts Monitoring, Summary Review
      January 2005. London: Transport for London (TfL), 2005.

---. "Press Release - Congestion Charge to Increase to £8; Fleet and Regular Users to Receive
      Discounts." April 1, 2005.

TTI. "Houston Value Pricing Pilot Program Pamphlet." Texas Transportation Institute (TTI),
      2003.

U.S. Census Bureau. Government Finance and Employment Classification Manual. Washington:
      U.S. Census Bureau, Government Division, 2000.

U.S. EPA. The U.S. Greenhouse Gas Inventory. Washington: U.S. Environmental Protection
      Agency (EPA), 2002.

U.S. EPA and U.S. DOE. "www.fueleconomy.gov."
      http://www.fueleconomy.gov/feg/oildep.shtml, April 2005.

United Nations. Statistical Yearbook for Asia and the Pacific. New York: United Nations, 2002.

Vickrey, W. "Congestion Theory and Transport Investment." The American Economic Review
      59.2 (1969): 251-60.

---. "Pricing in Urban and Suburban Transport." American Economic Review 53 (1963): 452-65.

---. "A Proposal for Revising New York's Subway Fare Structure." Journal of the Operations Research Society of America 3.1 (1955): 38-68.

Victoria Transportation Policy Institute. Transportation Cost and Benefit Analysis: Techniques, Estimates, and Implications. 2003. Victoria Transportation Policy Institute. Available: http://www.vtpi.org/tca/. February 2005.

Waliszewski, J. "Toward Understanding the Impacts of Congestion Pricing on Urban Trucking." Massachusetts Institute of Technology, 2005.

Ward, J. "Toll Road Public-Private Partnerships in Malaysia: Using the CLIOS Process for Policy Improvements." Massachusetts Institute of Technology, 2005.

Wilbur Smith and Jurutera Konsultant. Kuala Lumpur Master Plan Transportation Study: Wilbur Smith and Associates and Jurutera Konsultant (S.E.A.) SDN. BHD., 1981.

World Bank. 2002 Environmental Sustainability Index. Washington: The World Bank Group, 2002.

---. Cities on the Move: A World Bank Urban Transport Strategy Review. Washington: The World Bank Group, 2002.

---. Malaysia--Road Asset Management Project. Washington: The World Bank Group, 1999.

Wylie, M. Transportation Planners Innovate with Toll Systems. 2005. Newhouse News Services. Available: http://www.newhousenews.com/archive/wylie021005.html. February 2005.

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