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Technical Methods for Analyzing Pricing Measures to Reduce Transportation Emissions

Dear Colleague:

State transportation and air quality planners have requested the Environmental Protection Agency (EPA) and the Department of Transportation (DOT) for assistance in how to quantify the impacts of transportation pricing measures in their regional transportation models. They need this assistance to develop regional transportation plans, transportation improvement programs, and state implementation plans. This report, jointly funded by EPA and DOT, responds to those inquiries and provides technical assistance on best practice approaches for analyzing various transportation pricing policies.

This document is intended strictly to provide technical recommendations and does not advocate the use of any specific policy measures. Individual states and regions are always encouraged to select those policies that best match local priorities in meeting National Ambient Air Quality Standards.

Transportation pricing mechanisms have been recognized as having the potential to significantly improve air quality, reduce congestion, bolster transit, and improve regional economic performance. Despite this potential, implementation of pricing measures has been limited and substantial institutional barriers remain. This report will assist non-attainment and maintenance areas in the demonstration of the emission reduction and travel impacts of various market-based transportation policies.

Many of the techniques outlined in this document are not commonly used by Metropolitan Planning Organizations (MPOs). However, incorporation of these techniques into regional transportation models would allow the explicit analyses of pricing options. The recommendations in this report provide a means for areas to receive credits in State Implementation Plans (SIPS) for pricing measures. The modeling enhancements may also be useful for demonstrating conformity.

The methods discussed in this report are not required for areas considering the adoption of market-based strategies, but are thought to be useful tools to help areas assess the impacts of such measures. We hope that transportation and air quality modelers using this document find it useful and productive for assessing the impacts of various transportation pricing options. Please let us know of any improvements or additonal information that might be useful as we strive to develop technical assistance for state and local planners.

Sincerely yours,

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Director, Office of Policy Development

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1.0 Introduction

1.1 Guidance Purpose

State transportation and air quality planners have requested the Environmental Protection Agency (EPA) and the Department of Transportation (DOT) for assistance in how to quantify the impacts of transportation pricing measures in their regional transportation models. They need this assistance to develop regional transportation plans, transportation improvement programs, and state implementation plans. The modeling enhancements may also be useful for demonstrating conformity. This report, jointly funded by the EPA and the DOT, responds to those inquiries and provides technical assistance on best practice approaches for analyzing various transportation pricing policies.

This document is intended strictly to provide technical recommendations and does not advocate the use of any specific policy measures. Individual states and regions are always encouraged to select those policies that best match local priorities in meeting National Ambient Air Quality Standards.

Market-based approaches to transportation policy can provide many potential benefits ranging from reduced congestion and improved regional economic performance to reductions in emissions of criteria pollutants. These policies have often not been analyzed since many existing transportation planning models are not able to provide adequate analyses of these issues. This document will enable regional and state transportation planners to consider a broad selection of innovative market-based policy measures that may provide significant air quality benefits.

Although market mechanisms can be applied in all areas of environmental policy, this guidance is rooted in EPA s authority for implementation of the Clean Air Act Amendments of 1990. It thus discusses only methodologies for assessing air quality benefits. Specifically, this guidance describes methodologies cities and states can use to analyze the air quality benefits of market-based transportation policies. The intent of the guidance is to:

- Assist transportation, planning, and air quality professionals at state and local levels in analyzing the emissions reduction potential of market-based approaches; and
- Provide state air agency and U. S. EPA field staff with technical guidance for reviewing analyses of market-based measures proposed as part of state and local air quality planning processes.

Neither consumer nor traveler response to new policies is ever perfectly predictable. Nonetheless, both traditional and more recent travel demand modeling provide powerful tools for analyzing the likely response to changes in transportation prices. This guidance discusses those tools, and highlights analytical steps necessary to assure that policies are well-formulated and evaluated properly from a technical standpoint. It then briefly discusses non-technical implementation issues.

Proper use of methodologies described in this document will generally satisfy EPA that appropriate analysis has been conducted. EPA has no intent to limit areas from using other methodologies that might also provide an accurate assessment of the consequences of market-based measures, so long as these methodologies are fully described in an application for SIP credits. No guidance can anticipate all local conditions and EPA is eager to help potential implementers of market-based measures solve any challenges they face. Because this guidance cannot cover all topics related to market-based policies, it also refers readers to studies that provide more detailed information on particular topics. As guidance, this document describes expected practices, but establishes no legally binding requirements.

It should be noted that any analytical method used to estimate emissions benefits for SIP credits must meet all requirements for SIP purposes. It should be further noted that any credits granted for implementation of market-based mechanisms will reflect the uncertainty inherent in the methods used.

1.2 Definition of Market-Based Measures

The term market-based measures here refers to *pricing* mechanisms which reduce transportation emissions. That is, they harness the *marketplace*.

This guidance document discusses five major categories of measures:

1. **Parking Pricing** removing or reducing subsidized or free parking privileges;
2. **Modal Subsidies** reducing the cost of non-single occupancy vehicle (SOV) modes;
3. **At-the-Pump Charges** (hereafter abbreviated to *Pump Charges*) changing prices at the fuel pump to increase the marginal cost of auto use (including vehicle miles traveled fees);
4. **Emissions Fees** levying fees directly on vehicles or their use in a way that reflects their emissions production; and
5. **Roadway Pricing** charging road users directly for travel on specific roadways, with potential price differentials based on time of day, congestion levels, or miles traveled.

Market-based measures typically include actions that either (1) change the cost of specific trips (e.g., roadway pricing, parking charges, and transportation subsidies) or (2) change more general or cumulative characteristics (e.g., charges on vehicle emissions or miles traveled).

1.3 Guidance Organization

Effectively using market forces in setting transportation policy requires careful work in policy design, community involvement, planning, and implementation. This guidance addresses prospective analysis and discusses other considerations only as they affect EPA s ability to approve a SIP containing market-based measures. Specifically, this guidance describes:

- The scope and nature of market-based measures that affect travel patterns; and
- Methodological approaches for estimating the impacts of market-based measures on travel emissions when these measures are included in State Implementation Plans submittals.

Following this introduction, the guidance is made up of three substantive chapters and two technical appendices, described below and in Table 1.1.

Chapter 2 is directed to persons in *managerial* and *decision-making* positions with regard to the planning or implementation of air quality improvement measures. This audience includes state and regional transportation officials, planning directors, members of air quality or transportation steering/review committees, and EPA regional staff.

Chapter 2 also provides a summary of key points for more technically-oriented readers too busy to review the full guidance document. Chapter 2 defines and describes market-based measures, reviews the analytic challenges involved in estimating travel and air quality impacts of market-based measures, describes characteristics of current planning and analysis techniques, and summarizes standards of accepted basic practice, including suggestions for more advanced practices that would yield greater accuracy and confidence.

Chapter 3 is directed at the *practitioner* and is much more specific in its technical guidance on evaluation techniques for market-based approaches. Interested managers and decisionmakers also are encouraged to read this chapter. Analogous to Chapter 2, Chapter 3 describes five groups of market-based measures, and discusses how these measures are presumed to affect travel behavior and emissions. The subsequent discussion presents detailed, step-by-step methodological guidelines and procedures that can be used to evaluate the transportation and emissions impacts of each measure. With these analytical recommendations, Chapter 3 describes the expected impact and treatment of the measure at each stage of the travel behavior modeling hierarchy.

Chapter 4 discusses implementation issues. Topics include: putting market-based measures into the public policy context; addressing issues of legal authority, administrative capacity, and technology availability; and consideration of revenue generation and reinvestment opportunities.

Appendices A and B provide technical examples of (A) a traditional modeling approach, and (B) an advanced modeling approach. Appendix B also discusses some policy issues as part of its discussion of how to approach modeling questions.

Table 1.1 Guidance Overview

Audience	Key Chapters to Read	Goals
Managers/ Decisionmakers	Chapter 2	Provide overview on measures and summarize analytical issues
Practitioners/ Modelers	Chapter 2, Chapter 3, Appendix A, Appendix B	Compare measures and give step-by-step guidelines on analysis
All	Chapter 4	Address implementation issues: legal, administrative, and technological

2.0 Overview of Measures and Analysis Requirements

■ 2.1 Introduction

This chapter serves several purposes. It first provides an introduction to market-based measures: what they are, specific examples and applications, and how they are effective in reducing emissions. Second, this chapter discusses the importance of accurate evaluation of the impact of these measures, with specific attention to the challenges that may be posed by current analysis tools and data. Third, the chapter presents guidelines for effective evaluations, both to support local assessment and acceptance and to allow EPA to grant emissions credit for these measures should they appear in a State Implementation Plan submittal.[1]

This chapter is specifically directed to persons in *managerial* and *decisionmaking* positions in planning or implementing air quality improvement measures, including state and regional transportation officials, planning directors, members of air quality or transportation steering/review committees, and EPA regional staff. This chapter discusses the importance of considering market measures, articulates EPA s understanding of the methodologies used to evaluate their impacts, and offers insights and suggestions as to methods and procedures that should lead to enhanced evaluations. This chapter does not directly address *implementation* issues; these are covered in Chapter 4.

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[1] This guidance manual does not deal directly with emissions from freight transportation. This is an important emissions source, particularly of NO_x and particulate matter. While many measures in this manual would affect freight, the manual does not discuss the models and data for evaluating freight impacts. See Federal Railroad Administration, Federal Highway Administration, and US Environmental Protection Agency, *Air Quality Issues in Intercity Freight: A Guidebook for Estimating the Travel and Emissions Impact of Intercity Truck and Rail Intermodal Freight Activity and Effects of Improvement or Control Strategies,* draft final report, prepared by Cambridge Systematics, Inc., *et al.*, December, 1996.

2.2 Overview of Market-Based Measures

2.2.1 Description of Market-Based Measures

In general, a market-based measure adjusts the price of a given commodity in the marketplace to accurately reflect the actual cost of producing and using that commodity. In the realm of public policy and emissions programs specifically, this means incorporating air quality costs in prices paid by consumers.

The prices currently paid for transportation deviate from full cost pricing in two ways. First, prices are distorted by financial subsidies, such as employer subsidies for employee parking, transit subsidies from non-transit revenue sources, and taxes collected from non-highway drivers and used to underwrite highway infrastructure. Prices also are distorted from failure to include external costs, such as air quality and health costs.

Mechanisms offered for consideration in this report are *once-removed* from the ideal, since it is difficult to alter all policies that affect the current marketplace all in one step. These strategies are more properly regarded as *pricing mechanisms*, which *begin* showing users the true cost of travel and emissions.

A number of strategies apply pricing to influence travel and other emissions-related decisions. This guidance document discusses five major categories of measures. Summarized in Table 2-1 and discussed in greater detail in the text below, they include:

- **Parking pricing;**
- **Modal subsidies;**
- **Pump charges;**
- **Emissions fees; and**
- **Roadway pricing.**

The magnitude of the impacts of these measures could be considerable. Estimated impacts of a sample of market mechanisms are presented in Table 2-2.[2]

Not all of these measures are purely market based. For example, subsidies reduce prices to below economic costs. Such subsidies may, however, alter comparative prices to better reflect relative social benefits and/or differences in social and economic costs.

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[2] See Greig Harvey et. al., Transportation Pricing for California: An Assessment of the Air Quality, Congestion, Energy, and Equity Impacts, Vol. 1: Summary Report, Draft, California Air Resources Board, 1995. This article can provide further details on the potential magnitudes of pricing strategy impacts. The numbers presented in Table 2-2 are based on tables prepared in this document.

This section describes various categories of pricing strategies and presents their major features; it is followed by a discussion (Section 2.2.2) of how these measures are expected to affect travel behavior and emissions.

Table 2.1 Overview of Market-Based Measures

Measure Category	Overall Intent	Major Variations	Emissions-Related Travel Effect
Parking Pricing	Remove/reduce subsidized parking privileges.	Employee parking fees Rates to favor short-term parking over long-term	Shift work trips to alternate modes, work arrangements (telecommuting, compressed work weeks) or off-peak periods, leading to reduced peak-period vehicle trips and VMT.
		General parking fees	Shift travel to alternate modes and/or destinations, leading to reduced vehicle trips and VMT.
Modal Subsidies	Improve attractiveness of non-SOV modes by reducing their cost.	Parking cash out HOV subsidies Non-motorized mode subsidies	Increase use of subsidized non-SOV modes, leading to reduced vehicle trips and VMT, particularly in peak period.
Pump Charges (including their relative, VMT fees)	Raise cost of fuel to reflect actual costs to construct or maintain infrastructure.	Per gallon fuel prices reflecting different cost allocations	Raise overall cost of driving for all travelers, causing shift in modes, reduced trip lengths, and more grouping of trips, leading to reduced vehicle trips and VMT.
Emissions Fees	Impose charges on vehicle owners proportional to vehicle emissions production.	Age-based registration fees (periodic fee indexed to vehicle age and VMT)	Reduce ownership and use of older, higher-emitting vehicles.
		Emissions fee (VMT x measured emissions rate)	Reduce ownership and use of higher-emitting vehicles and encourage better vehicle maintenance.
Roadway Pricing	Impose direct charges for use of transportation facilities.	Full-time facility tolls/fees	Shift travel to alternative modes, routes, or destinations, leading to reduced vehicle trips and VMT.
		Congestion pricing: variable prices linked to congestion levels or time of day	Shift travel to alternative modes, routes, destinations, and time of day, leading to reduced vehicle trips and VMT; also improved flow/speeds.

Table 2.2

Potential Magnitude of Impacts

	Estimated Decreases from 1991 Mobile Source Baseline (in percent) [1]						
Market Mechanism	*VMT*	*Trips*	*Time*	*Fuel/CO2*	*ROG (VOC)*	*CO*	*NOx*
1) Regionwide Congestion Pricing	0.6 - 2.6	0.5 - 2.5	1.8 - 7.6	1.8 - 7.7	1.5 - 6.2	1.6 - 6.3	0.7 - 2.9
2) Regionwide Employee Parking Charges							
2a) $1.00 per day	0.8 - 1.1	1.0 - 1.2	1.0 - 1.1	1.1 - 1.2	0.9 - 1.2	0.9 - 1.2	0.8 - 1.0
2b) $3.00 per day	2.3 - 2.9	2.6 - 3.1	2.5 - 3.0	2.6 - 3.0	2.5 - 3.1	2.6 - 3.1	2.4 - 2.8
3) Gasoline Tax Increase							
3a) $0.50 per gallon	2.3 - 2.8	2.1 - 2.7	2.4 - 2.8	5.8 - 7.4	2.2 - 2.7	2.1 - 2.7	2.1 - 2.5
3b) $2.00 per gallon	8.1 - 9.6	7.6 - 9.2	8.4 - 9.7	24.3 - 27.3	7.8 - 9.5	7.6 - 9.4	7.8 - 9.2
4) Mileage and Emissions-based Registration Fees [2]							
4a) Fee Range from $40-$400 annually[3]	0.2 - 0.3	0.1 - 0.2	0.2 - 0.3	3.4 - 4.4	7.4 - 9.5	7.5 - 9.6	6.6 - 8.5
4b) Fee Range from $10-$1,000 annually[4]	2.9 - 3.6	2.7 - 3.3	2.7 - 3.5	6.3 - 7.9	15.8 - 19.3	15.6 - 19.4	13.1 - 17.3
5) VMT fee of $0.02 per mile	4.6 - 5.6	4.4 - 5.4	4.8 - 5.7	4.8 - 5.7	4.5 - 5.5	4.4 - 5.6	4.3 - 5.4
Example of combined effects: moderate impact							
Mechanisms 1, 2a, 3a, and 4a							
Current levels of transit service	4.6 - 6.3	4.4 - 6.2	5.7 - 11.1	13.8 - 18.5	13.9 - 17.6	14.2 - 17.9	11.0 - 13.6
Example of combined effects: high impact							
Mechanisms 1, 2b, 3b, and 4b							
Extensive investments in transit service	16.2 - 19.1	15.5 - 18.4	19.0 - 24.0	39.2 - 44.1	31.1 - 36.3	31.1 - 36.7	26.4 - 32.3

(1) Effects forecast for San Francisco, Los Angeles, Sacramento, and San Diego by DHS, "Transportation Pricing for California," prepared for CARB, October 1994.

(2) Fees would be paid annually at the time of registration, based on an estimate of annual emissions.

(3) Effects based on annual mileage and average model year emissions as reflected in EMFAC7F.

(4) Effects based on -actual odometer readings and in-use tailpipe measurements.

Parking Pricing

Parking Pricing removing or reducing subsidized or free parking privileges that serve as an incentive to drive.

Free or discounted vehicle parking creates a strong incentive for vehicle ownership and driving for all types of travel, both work and non-work. National data suggest that nine out of 10 workers in metropolitan areas park for *free or at below-market prices,* yet employer-paid parking is treated as a tax-exempt fringe benefit by federal and state tax laws, a subsidy value of up to $170 per month.[3] Free parking provides a similar attraction for non-work travel for shopping and other purposes in suburban and outlying areas, in contrast to parking in downtowns and activity centers which is priced, but where there also exist alternatives to driving. Internalizing the cost of parking would reduce the demand for private vehicle travel in favor of alternatives.

There are many ways in which parking pricing can be introduced, the major variation being whether it is applied exclusively to work travel, or to non-work travel as well.

Pricing *commuter parking* is perhaps the most common application of parking pricing. Employees may be seen as more captive to their location than non-work travelers, and because of their repetitive travel to the same site during peak hours, they usually have access to the best transportation alternatives. In many instances, employees already pay a parking charge if they work in a downtown or activity center; a small percentage may experience some parking cost as a result of the employer's involvement in a trip reduction program. Employee parking pricing as a regional pricing mechanism can take many forms, including:

- Imposing a parking tax on all or a portion of the parking supply;
- Shifting public policy to eliminate or reduce tax exemption of parking subsidies;
- Eliminating early bird/all-day discounts, or replace these with peak-period surcharges;
- Introducing a *minimum* parking charge for all employees (i.e., where all parking is raised to some threshold level, say $3 per day);
- Requiring parking charges at sites that meet certain criteria (e.g., with 100 or more employees, where vehicle trip rates exceed a standard, etc.);
- Replacing free parking with a transportation allowance applicable to various modes, coupled with introduction of parking rates;
- Offering the value of the subsidized parking space back as a cash credit to persons who would agree not to drive (popularly termed Cash Out);
- Offering discounted parking for High Occupancy Vehicles (HOVs); and

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[3] This amount is adjusted periodically by the IRS in $5 increments to adjust for inflation.

- Levying area entry fees on Single Occupancy Vehicles (SOVs), particularly in peak periods (these are generally considered more of a congestion pricing action).

Attaching parking prices to *non-work* travel is more problematic. Parking charges for non-work travel include:

- Imposing [higher] charges at major traffic generators, such as malls and activity centers, shopping centers, hospitals, educational institutions, and entertainment sites;
- Levying a parking tax on public or private parking operators;
- Restricting off-site parking in residential areas and/or installing meters or increasing metered rates; and
- Restricting parking supply or raising parking costs at residential locations.

Modal Subsidies

Modal Subsidies: Underwriting part of the cost of non-SOV modes, thus reducing their price relative to SOV modes to increase their attractiveness.

By lowering the cost of alternative modes such as transit or ridesharing relative to the automobile or by providing direct (or indirect) incentives for non-motorized modes (bicycle and walking), the attractiveness of these modes increases and their usage would be expected to increase. As alternative mode use increases, a reduction in vehicle trips and vehicle miles traveled (VMT) would be expected to reduce emissions. If subsidies lead to proportionately higher use of alternative modes for work trips in peak periods, then congestion relief also might occur, potentially with additional emissions benefits.

There are a number of ways in which modal subsidies can be introduced or enhanced through public policy initiatives:

- Lowering the usage cost of non-SOV alternatives, for example, reducing transit fares, or exempting HOV users from various tolls and fees;
- Allowing employers to grant (or employees to *receive)* tax-exempt subsidies for carpool or non-motorized mode use, or to grant larger subsidies to transit or vanpool users;
- Offering tax credits to employers to cover their cost of providing subsidies; and
- Directing implicit subsidies to rideshare users in the form of gasoline allowances, parking discounts, vanpool capital or insurance assistance or maintenance, etc.

Reliance on modal subsidies as an emissions reduction strategy has two major problems. First, they require a *net outlay* of resources to support, which if not financed by a specific revenue source, will fall as a burden on employers or state/local governments. Second, they may further distort current imperfections of the marketplace, by adjusting for existing subsidies through the addition of new subsidies, and potentially inducing demand on highways with freed-up capacity. While this may, in principle, begin to equal out the subsidy treatment across modes, it does not serve the purpose of making current prices a better reflection of costs, and hence, may just further skew the operation of the marketplace. While these limitations are important, subsidies are advantageous in that travelers view them as a benefit, rather than a cost.

At-the-Pump Charges (and their relative, VMT fees)

At-the-Pump Charges—Using the pump price of fuel to increase the price of driving and thus discourage private vehicle (especially SOV) use.

By raising the price of fuel, this measure reduces emissions by increasing the overall cost of travel for all private vehicle trips, thus affecting the frequency and length of such trips. A pump-based charge can be based on numerous factors. For example, pump-based charges can be:

- Structured to cover a more complete proportion of the cost of road construction and maintenance;
- Used as a medium to collect insurance payments under a pay-as-you-go insurance coverage policy, as is being considered in some states; and/or
- Structured to account for social costs, such as emissions (often through links to VMT).

Experience has demonstrated that fuel price increases can be controversial at both the national and state levels. Some states may, however, see some benefits in designing systems that more accurately reflect the marginal social costs of vehicle usage. As with all the policies discussed in this document, state and regional decision makers are encouraged to develop the best strategies for meeting emissions reduction targets.

Emissions Fees

Emissions Fees—Levying fees directly on individual vehicles or their use in a manner that reflects their emissions production.

This category of pricing measure consists of charges based on vehicle characteristics, including emissions production, rather than on travel behavior. It attaches a higher cost to owning high-emitting vehicles, discouraging ownership and usage, as well as encouraging proper maintenance. Exactly which is affected more—ownership or use—depends on the structure of the particular mechanism.

Emissions fees may be based on:

- Vehicle age;

- Vehicle type; and/or
- Vehicle emissions, using:
  - *Estimated* emissions; or
  - M*easured* emissions, as determined at an annual emissions test.

In most cases, emission fees also would be linked to VMT, based on odometer readings.

Generally, emissions fees are imposed as part of a vehicle registration fee, and tied to required emissions tests. While annual fees may be most common, fees also may be assessed on a more frequent basis or in the form of a VMT-based emissions fee at the fuel pump. This version of the measure potentially could have a greater impact on travel.

Roadway Pricing

Roadway Pricing—Imposing direct user charges for travel on specific roadways, with potential price differentials depending on time of day or congestion levels.

Fuel taxes and vehicle registration fees are the conventional means for traveler financial support of the highway system. These measures, however, neither cover the entire *cost of supplying* that transportation capacity, nor serve as any indicator of the *level of service* which is being demanded from the transportation system at any given time.

Road pricing establishes a more direct and immediate link between the cost of roadway use and payment for that use through:

- On-the-spot collection of fees or tolls;
- Pre-paid permits; or
- Electronic monitoring and periodic billing.

Manually collected tolls may be somewhat counterproductive as the resulting delays at toll booths can increase emissions levels. However, electronic toll collection systems solve this problem.

Roadway pricing can be narrowly focused, such as installation of tolls on individual bridges or tunnels. Alternatively, roadway pricing can be more broadly implemented by, for example, applying them to a system of facilities that define a corridor, to a particular functional class of facilities such as all expressways, or—in its most extensive form—to all travel into, within, and through an area.

In the specific case of *congestion pricing*, the usage fee is assessed at the marginal cost for each additional vehicle. This places a premium on the privilege of travel during peak demand periods. Travelers may face fee schedules ranging from peak-only fees to fees that are variable by time of day, facility, or level of use. Congestion pricing provides incentives for travelers to take congestion costs into account when making trip decisions, thus leading to more efficient use of facilities and avoiding construction of expensive new capacity. By reducing congestion, such pricing also provides higher levels of service to those willing to pay for it as well as auxiliary benefits, such as providing better access for public safety vehicles.[4]

Seeing an increase in travel cost based on roadway prices, the traveler may either pay the increase in cost or opt for alternatives. For *work travelers*, where the destination is largely fixed in the short run, the choices include different modes, different routes, or, in the case of congestion pricing, different times of day. *Non-work travelers* face the same options, as well as the ability to choose destinations that can be reached without payment of tolls, or that provide more services for the given outlay.

2.2.2 Impacts of Market-Based Measures on Travel and Vehicle Use

In response to a properly designed and implemented program of market-based measures, travelers can be expected to do any or all of the following:

- Change travel mode to walk, bike, transit, carpool;
- Change destination;
- Change travel route;
- Change time of day of travel;
- Change the pattern of trip making (e.g., consolidate trips or group them into chains);
- Substitute telecommunications for travel;
- Adopt alternative work schedules or other arrangements to reduce the number of trips;
- Shift patterns of vehicle use in multi-vehicle households and change maintenance practices; and
- Make changes in residence and employment location (and thus change pattern or rate of growth of community).

Each of the described market-based measures, with the exception of emissions fees, affects emissions by first affecting vehicle travel and usage patterns. Emissions fees, if

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[4] Congestion pricing creates greater economic efficiency in the sense that it increases the net benefits to society. This is because congestion results in significant costs to society, and these costs can be greatly reduced if fees are used to reduce congestion. The funds collected through fees then can be returned to the public in another form. The fee is thus not a true cost to society, but simply a transfer, while the cost of congestion has been reduced. Those road users who value their trips the most are willing to pay congestion fees in return for reduced congestion and will benefit from the fees on balance. Those road users less willing to pay for peak-period travel will prefer switching modes, routes, or time of travel, and the disbenefits they experience under congestion pricing will be smaller than the net benefits to the first group of users. Regardless of the equity implications of this approach, it generates net benefits to society.

imposed through an annual or periodic fee, would be expected to have only an indirect impact on travel patterns, primarily by affecting vehicle ownership. Although the other four measures influence travel patterns, they nonetheless vary in the specifics of their impacts on travel and emissions. In brief:

- **Parking pricing** reduces or redirects vehicle trips by increasing costs at destinations, often through the levy of visible out-of-pocket charges at the site. Parking pricing is most effective when it is applied regionally.
- **Modal subsidies** increase the use of less-polluting modes through a reduction in their relative price.
- **Pump charges** reduce total vehicle travel by raising the price of fuel.
- **Roadway pricing** reduces vehicle trips along given roadways by raising the *en-route* cost of travel, either on a per-mile, per-facility, or per-entry basis (Roadway pricing also can affect total travel if it is implemented on all roadways in a given area).
- **Congestion pricing** is a variation of roadway pricing that reduces vehicle travel on congested facilities at congested times of day.

There is ample evidence to substantiate that travelers *do respond* to cost changes. Much depends on the *level of the charge* and the availability of substitutes. The higher the income of travelers, the less likely travelers are to respond to modest changes in the price of fuel, parking, or vehicle ownership.

The relative impact of pricing mechanisms depends on the pricing instrument itself and *how direct a signal* it provides; charges which are periodic and disassociated with travel behavior are unlikely to be linked in a conscious decision-making process. The *availability of realistic options* also is an important consideration, although more options exist (e.g., carpooling, deliveries, telecommuting) than are commonly acknowledged and options would increase substantially if driving prices are raised. Revenues derived from pricing also can enhance the number and quality of these options. Under the current system of subsidized and indirect pricing, however, these options are not likely to develop.

The balance of this section summarizes the key assumptions underlying market-based measures and describes expected impacts of each measure in greater detail.

Impacts of Parking Pricing

Parking pricing provides direct signals to the traveler on the cost of driving. Because a parking charge is often collected at the point of use, it has an explicit linkage to the particular trip. Many studies have concluded that such an out-of-pocket cost has a greater impact on decisionmaking than costs that are averaged over a longer time period or multiple uses.

If parking pricing is implemented at a site that *must* be accessed (e.g. a work site) it is difficult to avoid or ignore, particularly in the short run. Faced with new or increased parking charges, *work travelers* would be expected to consider shifting to non-SOV modes, telecommuting, and/or compressed work week arrangements. The effect on emissions would be through reduced vehicle trips and VMT, primarily during congested peak travel periods.

Non-work travelers faced with parking charges would be expected to shift modes or travel less, such as by grouping trip functions to accomplish more on the same trip tour, (the effect is likely to be stronger if there are no free parking areas). However, non-work parking charges also may be avoided simply by traveling to another destination, which may entail *more* travel as a result of being further away.

It can be physically difficult to institute parking charges at a high proportion of destinations, particularly for small employers and for non-work situations. Ensuring that the charges are actually implemented, and not diminished by employer or merchant subsidies, requires enforcement. One other characteristic of parking pricing is that it has less impact on longer trips, since parking charges represent a smaller proportion of overall trip costs; this may be advantageous in addressing certain pollutants since pricing would have a greater impact in reducing short trips and associated cold starts.

The effectiveness of any parking pricing arrangements depends on the level of the price change and the uniformity of the application. Major differences in rates across a region (e.g., suburb versus core) or exemption of many sites from pricing are expected to encourage shifts in choice of destination to avoid or minimize the charge, *even if such a change involved more travel.* This is particularly a concern with non-work travel. Such a result could have an undesirable effect on total emissions.

Impact of Modal Subsidies

Modal subsidies have the advantage that they are comparatively easy to implement. The traveling public is not likely to resist being offered a discount, in contrast to paying a charge.

The disadvantage of modal subsidies is that they must be paid for from some source, thus raising the question of who bears this cost (employers, governments, taxpayers, etc.), although revenues raised through other pricing measures could serve as the funding base for these subsidies (potentially a mechanism for addressing equity concerns). A troubling aspect of subsidizing alternative travel modes is that it may exacerbate current market pricing distortions, by trying to overcome one subsidy with another. Evidence also suggests that travel behavior is less influenced by a cost *incentive* than a disincentive. In light of these characteristics, modal subsidies are best seen as a strategy supportive of some other *active* pricing mechanism.

Impact of Pump Charges (including VMT fees)

Pump charges are one of the most broad-reaching pricing strategies available. Implemented directly through the cost of fuel, a pump charge closely tracks vehicle usage rates, bears upon the travel decisions of all travelers and trip purposes, and can be implemented with relative technological and administrative ease. In general, fuel price surcharges cause travelers to:

- Switch modes;

- Restructure travel to emphasize shorter trips or grouping of trips;
- Seek a wider variety of options for satisfying activity needs, including non-travel alternatives and locational preferences for more compact and integrated developments; and/or
- Purchase more fuel-efficient vehicles.

The last of these will tend to eventually offset the VMT benefits of higher fuel prices, although decreased energy consumption is still beneficial.

For *work travel*, the primary response of a pump-based charge is a shift from driving to other modes or to alternative work arrangements (e.g., telecommuting or shortened work weeks). For *non-work travel*, destination shifts or errand/trip chaining might be more common.

Because fuel price surcharges increase cost burdens in direct proportion to the number of miles traveled, they would be expected to affect longer trips more than shorter ones. As such, they can be complementary to fixed charges like parking pricing, which diminish in influence as trip length increases as parking prices become a smaller proportion of total trip costs. Higher pump charges also could encourage less rapid acceleration, better maintenance and other driving-style improvements to reduce fuel consumption.

Impact of Emissions Fees

Emissions fees vary in their impacts, depending on how they are designed. Most simply, a surcharge is added to the standard vehicle registration fee that reflects vehicular emissions. In simple applications, requiring almost no additional administration, the fee is indexed to the type and year of vehicle as a proxy for contribution to air-borne pollutants. Depending on the level of the surcharge, this approach would be expected to discourage ownership of older and presumably higher-emitting vehicles.

More targeted applications link charges to each vehicle s annual VMT, or base charges on emissions rates as actually measured at the time of inspection. These approaches have a more direct effect on ownership and usage rates of high-emitting vehicles. Any effect on daily travel behavior, however, would depend on how closely and with what impact the owner links the fee to the level of travel; fees that are administered infrequently have a more tenuous tie to daily travel decisions. The primary advantage of emissions fees is that they target emissions production directly, and cut across all ownership and use situations. The primary disadvantage is that the simpler applications may not produce the desired results, while the more complex (e.g., real-time emissions rate and VMT) are more challenging to implement.

Addressing particulate emissions through emissions fees poses a unique challenge, because reentrained dust emissions depend on the location and road type (e.g. unpaved versus paved) more than the vehicle type. Emissions fees tailored to these particulates would be difficult to design. Fees based on VMT could impact particulates, but could not be readily targeted to high-emitting activities or vehicles in the same way NO_x or VOC-based fees could be, for example.

Depending on the specific fee structure to be implemented, the following consumer responses to emissions fees might be anticipated:

- Consumers will replace high-emitting vehicles with cleaner ones (also creating greater pressure on manufacturers to produce such vehicles);
- If the ownership fee is very high, households will reduce the number of vehicles owned;
- Multi-vehicle households will make greater use of their cleaner vehicles; and
- Where fees are based on actual *measured* emissions rates, consumers will maintain vehicles to the highest possible standards.

Reductions also may occur in overall rates of travel, depending on how much of the fee is based on VMT usage, and how frequently the fee is levied and/or people are reminded of the fee (infrequent/periodic fees may not be strong disincentives to daily use).

Impact of Roadway Pricing

Roadway pricing is an attractive approach because it is a classic application of direct user charges. Travelers are charged for the number of trips they make and, in the case of congestion pricing, for the congestion cost that they impose on the transportation system. Road pricing serves as a fairly immediate signal to travelers to consider alternatives to driving, including travel by a different mode, time of day, or route. *Congestion pricing* offers one of the few direct mechanisms to reduce congestion and to address the emissions impacts specifically caused by congestion.[5]

Road pricing schemes are most effective when they have full coverage of the road system (including collectors and local roads). However, it is probably more feasible to price controlled-access facilities. Pricing systems need to consider possibilities for route diversion onto un-priced arterials and local streets. Traffic-calming strategies and changes in signalization could reduce the efficiency of alternatives and make the priced alternative clearly superior and worth the price.

To avoid road pricing, travelers may shift to any of the following:

- Unpriced routes that are ill-equipped to accept such traffic or entail greater VMT to reach intended destinations; or
- Other destinations that are further away and/or not as serviceable by non-SOV options.

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[5] It should be noted that there might be cases where congestion relief allows speeds to increase to levels where emissions rates are actually higher, at least for some pollutants. In other cases, speeds may increase such that emissions rates are reduced.

Comparison of Characteristics Among Measures

Table 2-3 summarizes the major characteristics of the market-based measures described above. Each measure has distinct strengths and weaknesses. No single measure adopted by itself is likely to achieve all program objectives. In fact, the most effective program will be one that combines complementary measures, thus improving overall traveler acceptance and maximizing emissions impact.

Moreover, impacts can vary among the different specifications of an individual measure and differences in implementation. This calls for careful definition and evaluation of individual measures, identification of potential benefit-cost synergy among measures, and analysis of how individual measures can be integrated into an overall system plan.

2.2.3 Relationships Between Travel and Emissions

Market-based measures are implemented to achieve two types of social objectives: increased travel mobility, measured in terms of transportation access, level of service and travel trip time; and reduced vehicular emissions. The ultimate impact of market-based measures on emissions is closely tied to program setting and pollutants to be addressed.

Areas attempting to achieve compliance with or maintain National Ambient Air Quality Standards (NAAQS) need plans to reduce ozone, carbon monoxide (CO), or particulate matter (PM). Areas with ozone violations must reduce the component pollutants of volatile organic compounds (VOCs), oxides of nitrogen (NO_x), and CO. These pollutants have different characteristics, stem from different sources and conditions, and are typically addressed by slightly different strategies. Program design is complicated by pollutants different relationships to factors such as speed range, flow conditions, number of cold starts, VMT, and vehicle ownership or use characteristics.

Only careful analysis can identify and evaluate the overall air quality impacts of pricing measures. However, knowing the particular circumstances that affect the various pollutants is important in defining the group of strategies likely to be most effective in meeting a particular area s objectives. This section describes the emissions that are commonly the focus of market-based measures and identifies transportation variables associated with each, thus pointing out the travel behavior that must be influenced to best reduce emissions of each type of pollutant.

Table 2.3 Characteristics and Comparative Advantages of Pricing Measures

Measure	Method of Achieving Impact	Advantages	Disadvantages
Parking Pricing	Cost pressure at destination reduces vehicle use	• Relatively direct signal • Relatively strong signal (out-of-pocket cost) • Affects shorter trips more than longer (limiting cold starts) • Results in better trip planning (less inefficient chaining use)	• Difficult to implement in many locations • Creates demand for lower-priced destinations, which could be more distant (causing higher VMT) • Relatively easy to evade • Difficult to enforce
Modal Subsidies	Pull to alternate modes through lower comparative prices	• Easy to implement (through benefit rather than cost) • Shift to modes that pollute less per person trip	• Requires societal outlay • Further distorts market pricing signals by making modes cheaper than cost • Can cause sub-optimal shift in mode choice (e.g., transit to carpool) • Incentive may be less effective than a disincentive
Pump Charges	Raise cost of vehicle travel on per-mile basis to affect VMT	• Technologically easy to implement, minimal administrative costs • Affects all travel (non-work, as well as work) • Encourages shorter, grouped, or non-motorized trips • Increases fleet efficiency	• Must be substantial to have travel impact • VMT impact can be diminished as more efficient vehicles replace current fleet.
Emissions Fees	Fees on high-emitting vehicles; reduce use and/or improve maintenance High registration fees to discourage vehicle ownership	• Direct impact on source of emissions • Reaches all vehicle owners/users • Technical implementation not difficult for simple versions • Encourages better maintenance, thus improves emissions rates	• Infrequently levied fees weak as daily travel signal • More effective fees are difficult to implement
Roadway Pricing	Per-mile fee reduces VMT	• Relatively direct signal of usage cost • Peak-pricing affects peak-period travel and congestion directly • Improves mobility	• Complex/expensive to implement on all roads • If manual payment, may produce delays that increase emissions • In incomplete pricing network, traveler can evade by using alternate routes, destinations, or times of day

Volatile Organic Compounds (VOCs)

VOCs are unburned hydrocarbons (HC), typically generated by gasoline combustion engines. VOC emissions per vehicle have been substantially abated through automobile technology and fuels programs over the last decade, though it remains a problem in many areas and threatens to be a long-term issue as both VMT and the number of vehicular trips continue to rise. VOC emissions are influenced by speed range, flow conditions, number of vehicle trips and, VMT.

Engines produce VOCs in these elements of operation:

- *Cold Start Emissions* Cold start emissions occur when a vehicle is first started and the catalytic converter is cold. For a given vehicle and weather conditions, cold start VOC emissions are the same for all trip lengths, thus they are higher as a percentage of total VOC emissions for short trips. As noted in the table below, cold start emissions represent about 65 percent of total VOC emissions for a 5-mile trip, 53 percent of total VOC emissions for a 10-mile trip, and 39 percent for a 20-mile trip.
- *Running Emissions* Running emissions occur once the catalytic converter has warmed up. VOC running emissions vary with the number of miles driven and the speed of travel. Assuming the same speed conditions, a 10-mile trip would produce twice the VOC emissions of a five-mile trip. VOC emissions generally decline rapidly with speeds up to about 25 mph, fall more gradually up to 55 mph, and then rise moderately over 55 mph. A vehicle traveling in free-flowing traffic emits only one-third as much VOC emissions as one in congested traffic. As VOC running emissions are proportionately related to trip length, they increase as a proportion of total emissions as trip length increases. The running emissions for a 5-mile trip are roughly 21 percent of total trip emissions, 35 percent for a 10-mile trip, and 52 percent for a 20-mile trip.
- *Hot Soak* Hot soak emissions occur after the vehicle is turned off when residual heat in the engine causes fuel in the gas line and carburetor to evaporate. These emissions also are independent of trip length; they therefore represent a greater share of short-trip than long-trip emissions (approximately 14 percent of a 5-mile trip, 12 percent of a 10-mile trip, and 9 percent of a 20-mile trip).

While longer vehicle trips produce less emission per mile, they still, of course, produce more *total* emissions. A 20-mile trip, for example, produces 35 percent more emissions than a 10-mile trip and 64 percent more than a 5-mile trip.

Table 2.4 VOC Emissions for Typical 1987 Automobile, Normal Operating Conditions (grams of HC)

	5-Mile Trip	10-Mile Trip	20-Mile Trip
Cold Start	9	9	9
Running Exhaust	3	6	12
Hot Soak	2	2	2
Total	**14**	**17**	**23**
Grams/mile	**2.8**	**1.7**	**1.2**

Source: California Assembly Office of Research, Exhausting Clean Air: Major Issues in Managing Air Quality. Sacramento, CA (1989) p.4

Carbon Monoxide

CO is formed during incomplete combustion, and occurs when carbon in fuel is partially oxidized rather than fully oxidized to form carbon dioxide (CO2). CO is an odorless and colorless gas. High concentrations can be found in confined spaces like parking garages, poorly ventilated tunnels, or along roadsides during periods of heavy traffic ("CO hotspots").

CO interferes with the absorption of oxygen by hemoglobin in the blood. Lack of oxygen impairs the cardiovascular and nervous system, with symptoms including chest pain, headaches, dizziness, nausea, fatigue, and slower reflexes. In addition, CO impairs visual perception, work capacity, manual dexterity, learning ability and performance of complex tasks. CO can affect fetal growth and tissue development, and results in death at extremely high concentrations.

In 1992, the transportation sector produced about 77 percent of all CO emissions nationally, or about 75 million short tons. Highway vehicles contributed about 80 percent of transportation sector CO emissions. Carbon monoxide is produced at a significant rate by heavy-duty diesel (HDD) trucks and at an even higher rate by gasoline-powered vehicles. As of 1993, heavy-duty diesel vehicles contributed about 1.5 percent of all CO emissions nationally, and highway vehicles overall contributed about 62 percent of all CO emissions nationally.[6]

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[6] National Research Council, *Expanding Metropolitan Highways: Implications for Air Quality and Energy Use*, Special Report 245, National Academy Press, Washington, DC, 1995.

In general, CO emissions increase as the proportion of fuel in the air-fuel mixture increases. Cold-starts, heavy engine loads, and high speeds are major causes of incomplete oxidation of the carbon present in fuel.

Nitrogen Oxides

Nitrogen oxide (NO_x) is an important pollutant in the generation of ozone and in some cases of PM. Although NO_x emissions are a product of gasoline-powered engines for vehicles, diesel engines are the most significant producers of NO_x emissions. Diesel engines power heavy-duty trucks and also a variety of off-road sources, including rail, air, and marine transportation. Buses are also powered by diesel engines, and contribute heavily to NO_x emissions. HDD trucks contribute as much as 35 percent to 50 percent of regional mobile source NO_x emissions, and 10 percent to 25 percent of *total* regional NO_x.[7]

While NO_x emissions from passenger vehicles have been substantially curtailed by catalytic converters, commercial diesel vehicles are still significant NO_x emitters. Given progress in reducing VOCs for the 1996 15 percent reduction demonstration, NO_x has now become a problem focus in many areas.

NO_x emissions obey different travel relationships than VOCs. NO_x emissions are high at speeds under 10 mph, fall slightly to speeds of about 20-25 mph, rise slowly to speeds of about 45 mph, and then increase rapidly with speeds above 45 mph. Hence, strategies that relieve congestion and improve operating speeds to over 10 mph are generally effective in reducing CO, VOCs and NO_x emissions; programs that increase speeds above 25 mph will reduce CO and VOCs but may increase NO_x emissions (depending on pre-program speeds); and speeds over 45 mph result in substantial NO_x emissions, though VOCs and CO emissions continue to decline until speeds of 55 mph are reached. Current models indicate that PM emissions are not much affected by speed, except that higher speeds lead to more travel and therefore more PM.

Selection of an emissions-reduction strategy based on travel patterns and speed must accommodate divergent effects across pollutant types. Moreover, the *ratio* of NO_x to VOC reductions is important. As the ratio between a region s VOCs and NO_x increases, the appropriate strategy for controlling ozone changes. At a VOC/NO_x ratio of 10 or less, for example, VOC controls are more effective, but at VOC/NO_x ratios of 20 or more, NO_x control is more effective. In between these extremes, NO_x and VOC policies are more comparable in their effectiveness. These variations also must be taken into account in program design and evaluation of program impacts.

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[7] Air Quality Issues in Intercity Freight, see footnote 1.

Particulate Matter

EPA estimates show that about 26.4% of PM-10 sources are due to transportation. This excludes miscellaneous sources and is based on direct emissions, but road dust kicked up by traveling vehicles is another significant source. Tailpipe emissions also create secondary PM-10 emissions from the oxidation of NO_X and SO_X to nitrates and sulfates in the atmosphere; also, some of the VOC compounds are also oxidized to secondary particulates.

PM-2.5, or fine particulates, result from two major types of sources: 1) the incomplete combustion of fossil and biomass fuels in motor vehicles, boilers, furnaces and open burning sources and 2) gaseous emissions such as SO_2, NO_X, and VOCs from boilers and other fossil fuel combustion processes that transform in the atmosphere to form sulfate and nitrate particles. The resuspended soil component of PM-2.5 is generally less than 5-15%. EPA is continually reviewing and improving estimates of the emission factors and inventories of PM-2.5.

Revisions to the particulate matter standard were announced on July 18, 1997. The review of hundreds of peer-reviewed scientific studies, published since the original PM-10 standards were established, provided evidence that significant health effects are associated with exposure to ambient levels of fine particles (PM-2.5) allowed by the previous standard. These new standards are available in 62FR 38652 or at the following world wide web address: http://www.epa.gov/ttn/oarpg/rules.html.

Pricing strategies to reduce sources of particulates would probably vary based on the sources within a region and various climatic factors. In general, reductions in VMT, rather than specific congestion reduction strategies or emissions fees tailored for other pollutants, may be more effective.

2.2.4 Overall Advantages and Disadvantages of Market-Based Measures

Consumers who have grown accustomed to subsidized prices (i.e., prices that do not reflect the full social and economic costs of their decisions) are likely to oppose any change in the status quo unless it can be demonstrated that they will be made better off (or not worse off) as a result of the change. Travelers are no different from other consumers and thus the introduction of market-based measures to date has been unpopular with the public and their elected representatives.

Demonstrating the advantages of market-based pricing measures is critical to gaining their ultimate acceptance. Some important advantages of market-based measures, which may be used to increase support for their introduction, include the following:

- Applying market-based measures to achieve program objectives (in contrast to regulatory actions that compel governments or individuals to assume particular courses of action), provide considerable latitude for individual *freedom of choice.*
- By reducing driving subsidies and shifting costs to those who are responsible for them, market-based measures give *individuals more information* about their transportation costs and choices.
- Consumers can make *more rational trade-offs* between how much they want to pay and how and when they want to travel under a pricing system based on true costs; the current system of indirect taxes and subsidies obscures the information necessary for such choices.
- Rather than locking in current institutional and service concepts, market-based measures support *creativity to develop new and more efficient solutions* to travel and access needs currently met mainly through private vehicle travel.
- Market-based measures can be applied to *all types of travel and* trips, not just employment-related travel. This is in contrast to TCMs, which have been criticized as having a limited (and perhaps inequitable) impact because they affect only a portion of travel activity.
- Market-based measures are typically *self-financing*, and in fact may provide revenue to support their implementation, as well as other transportation improvements.
- Market-based measures can *substantially reduce the cost* of transportation (both direct and indirect). Reduced vehicle dependency can result in improved travel time and reliability in movements of people and goods, reduced construction and maintenance costs, lower taxes, and fewer accidents in addition to lower health costs, less environmental damage and clean up across a range of media: water, climate, noise, solid and hazardous wastes, and habitat.
- Market-based measures can help states and local areas *delay or offset the need for expensive new transportation capacity*, help finance that capacity when it is needed, and result in more efficient usage. They also can help cut costs for maintenance and government services.
- Longer-term, structural changes induced by market-based measures are critical to the *sustainability* of transportation and air quality plans, and can help areas avoid recurring updates of their SIPs in search of new and stronger controls to offset VMT growth.

Market-based measures are not, of course, without their shortcomings. Perceived disadvantages include:

- *Political resistance,* as noted above, to any form of direct transportation pricing, elimination of subsidies, or imposition of new taxes.
- *Technological and administrative challenges* and uncertainties in implementation.
- Concerns about *fairness and equity,* including, for example, whether travelers have reasonable alternatives and whether they impose increased burdens on the poor or other disadvantaged groups.

These concerns are important to consider in program design, and should not be dismissed by local decision-makers. Political consensus on complementing policy changes at the local level will be required. This document will allow decision-makers to evaluate the costs and benefits of alternative market-based policy options. (Issues of implementation and practical acceptance are discussed in Chapter 4).[8]

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[8] Issues related to public involvement, public acceptance, and equity are also discussed in: USEPA, *Opportunities to Improve Air Quality through Transportation Pricing Programs (EPA 420-R-97-004)*, September 1997. This document is also available at the following world wide web address: http://www.epa.gov/OMSWWW/gopher/Market/pricing.pdf

2.3 Evaluation of Market-Based Measures

Real-life examples that demonstrate how pricing can influence transportation choices exist: transit ridership clearly fluctuates with fare changes; bridge and tunnel usage demonstrate sensitivity to toll changes; HOV usage responds to exclusion from tolls; and automobile owners respond to fuel price levels by changing their driving behavior. Currently, planners and decision-makers do not have system-wide implementations of pricing initiatives at their disposal (such as those discussed in this guidance document) to furnish detailed empirical evidence of their effectiveness and related impacts. DOT's Value Pricing Pilot Program (formerly the Congestion Pricing Pilot Program) is generating valuable experience and research into the potential effectiveness of pricing policies. For the immediate future, however, estimation of the impacts of these measures will likely come from simulation tools and other analytical approaches described in this section. There also are examples from other countries upon which evaluations can be based.

2.3.1 Analytical Process

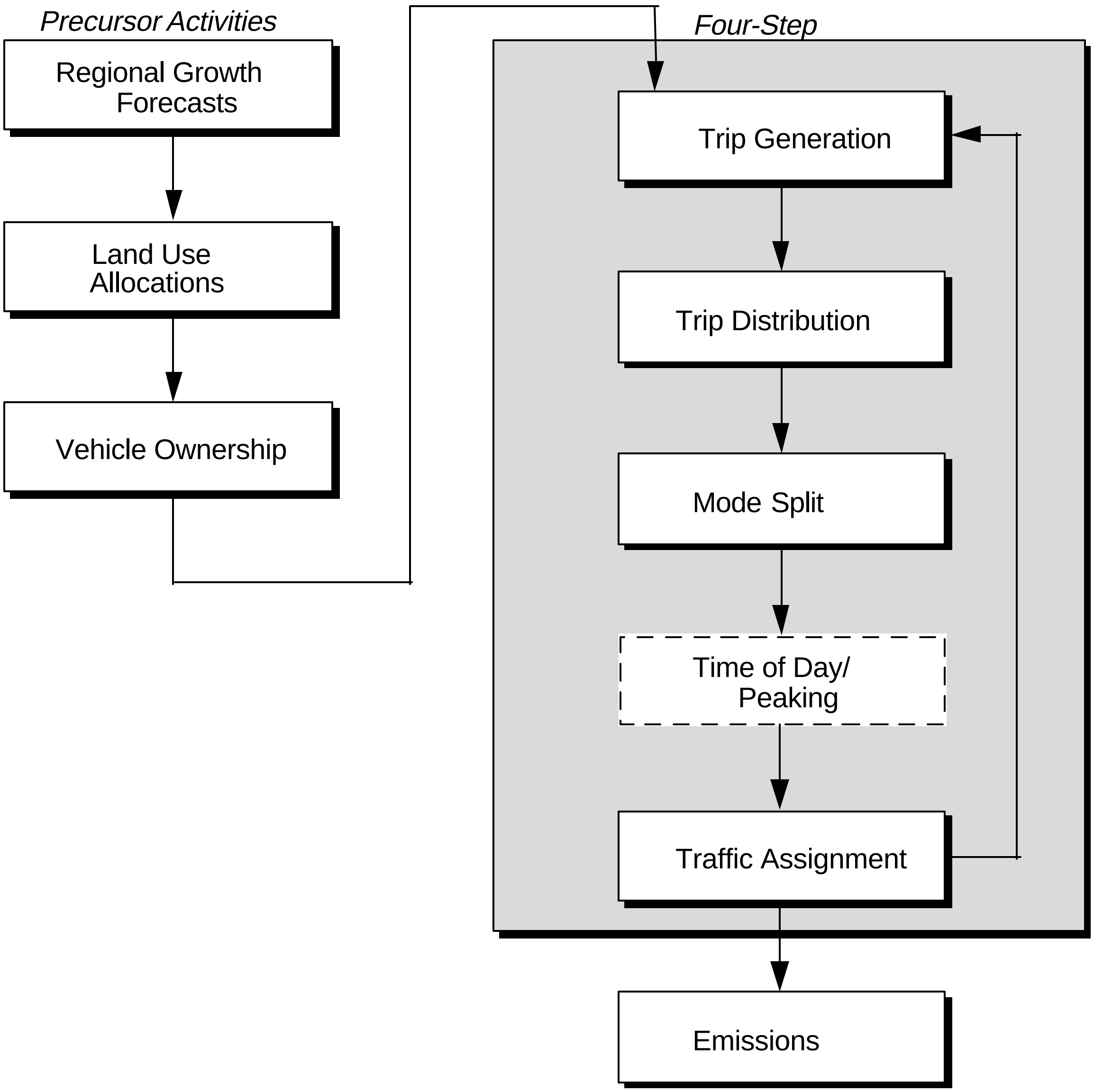
Most major metropolitan areas perform transportation planning analysis through some variation of the four step process, which derives its name from the four basic analysis modules through which it assesses travel demand: Trip Generation, Trip Distribution, Modal Split, and Traffic Assignment. This process, which is pictured in Figure 2.1, methodically translates spatial activity patterns into trip flows, which are then represented on a transportation network to reflect specific travel volumes on facilities, with respective speeds and levels of congestion.

Supporting these major elements are important upstream functions, such as land use/activity allocations, detailing of the transportation network, and vehicle ownership forecasts, which provide essential starting inputs to the process. Although these sub-functions may not be thought of as *demand estimation* procedures, they have an important role in profiling travel demand. Allocation of trips to peak and off-peak time of day is also an important function.

Emissions are calculated as an end product of this process. Analysts extract information on vehicle trips, miles of travel and speeds from the transportation model and link it with information on the regional vehicle fleet mix and emissions characteristics. This typically is accomplished through application of EPA s MOBILE model (version 5a), or in California, the EMFAC model developed by the California Air Resources Board (CARB). PM_{10} emissions are calculated using EPA s PART 5 Model.

This section describes the steps in the analysis hierarchy and issues associated with these analyses. This serves as a prelude to the subsequent discussion on analysis of specific market-based measures.

Figure 2.1 Schematic Overview of Four-Step Planning Process



2.3.1.1 Steps in the Analysis Hierarchy

Nine steps comprise the analysis hierarchy, including three precursor activities (regional growth forecasts, activity allocations, vehicle ownership), the components of the four step process (Trip Generation, Trip Distribution, Modal Split, and Traffic Assignment), as well as its implied time of day/peaking component, and, last, the emissions evaluation.

Regional Growth Forecasts

The regional planning process begins with forecasts of population and economic growth. Usually, economic growth, stated in terms of basic employment, is estimated first, followed by estimation of the population growth that would be stimulated by those jobs. Then, population-serving employment and attendant population increases are estimated. Frequently, these estimates are keyed to federal and state control totals.

Activity Allocations

Once jobs and population information is compiled, they are located spatially across the region, based on development trends, master plans, incomes/economic criteria, or a variety of other factors. Specific allocations of jobs and households are made to geographic units, generally traffic analysis zones that loosely conform to groupings of census tracts. This process may involve analytic techniques (so-called land use models which reflect transportation access and cost issues), but most commonly are the result of an iterative negotiating process.

Vehicle Ownership

Travel activity forecasts are driven by the economic resources available to households. Most travel models represent this through the number of vehicles owned by a household, which are then used throughout the process. Some model systems rely directly on income figures, and do not estimate vehicle ownership. Vehicle ownership estimates are typically done through simplistic cross-classification models, reflecting differences by income, location and other socioeconomic characteristics. The estimates usually ignore land use and alternative mode availability as explicit factors.

Trip Generation

From the information on population and employment activity, actual trip making is estimated through trip generation analysis techniques. Factors are applied to the population/economic activity levels to estimate productions and attractions, where households are assumed to *produce* trips and employment and commercial activity are assumed to *attract* trips. These estimates of household trip making are generally cast in terms of person trips, though in most models these are *motorized vehicle* person trips only and exclude walk/bike trips. Some model systems are even more limited and forecast only *private vehicle* trips. Trip estimates also are developed for each major trip purpose (work, shopping, personal business and social/recreational). Trip production rates are based on such factors as household size, income/vehicle ownership, location, etc. Trip attractions are based on the type of employment activity and other factors. Again, land use, density, and transportation facilities and price/source levels are frequently not entered into the forecasting process.

Trip Distribution

The next step is to match the trip *productions* and *attractions* to create connected trips for each zone-to-zone (origin-destination) pair. This usually is done using a *gravity model*, where productions and attractions for each trip purpose are matched based on the size of the relative production/attraction and inversely to the separation or travel difficulty between the two zones. This step tends to represent destination choice.

Mode Choice

The next step in the process projects a traveler s choice of desired travel mode for the given trip**.** Generally, this entails choices among automobile, automobile passenger, and transit, since trips which would be candidates for walking or bicycle have been separated out at the trip generation stage. A small number of models do include non-motorized modes among the choice options. Typically, this assessment is made for each trip purpose and each zone pair using a statistical model that considers the relative attractiveness of each alternative, expressed in terms of its travel time and cost, and weighted by the characteristics (income, vehicle ownership, etc.) of the traveler, and estimates the probability with which each mode is likely to be chosen. Some models relate mode choice and destination choice, but this is not common at present.

Time of Day

Most travel models attempt to account for the time of day that travel occurs, which is obviously critical to portraying peak versus off-peak travel conditions. However, rather than treat this as an active travel choice, the models handle this phenomenon through peaking factors. These factors simply proportion a certain percentage of trips into the peak and off-peak periods, based on survey observations. A separate travel network and assignment is necessary to reflect peak and off-peak conditions. It should be noted that a fair number of areas do not have a peak (i.e., a constrained flow) network, and work only with 24-hour conditions.

Traffic Assignment

Once blocked into time-of-day groups, trips are then placed into the actual transportation network using a statistical procedure that *assigns* them to routes that represent the most desirable path to their chosen destination (generally the least time path). This simulates the choice of travel route by the traveler, although like time of day, it is a decision that the process makes for them through a procedure that shifts trips around until the resulting volumes on the links best represent observed traffic levels. Traffic assignment also is important as the part of the process where level of service and congestion is determined, from which travel speeds are calculated for use elsewhere in the process.

The realism of the forecasts from this multi-step procedure depends on the extent to which the various steps are operating with the same information. Thus, a fair amount of cycling of information among the steps is required. It is necessary to pass information from later steps (e.g., travel times as calculated during traffic assignment) to earlier steps (e.g., trip distribution or modal split) as inputs to the calculations (i.e., traveler decisionmaking) at those stages. Thus, preceding steps contribute inputs to succeeding steps, with the process continuing until a defined state of equilibrium is reached. Model systems vary greatly in the degree and sophistication with which they feedback information among steps and reach a satisfactory equilibrium.[9]

Emissions Estimation

This step is not part of the conventional transportation modeling approach, but is necessary when estimates of vehicle emissions are required for air quality analysis. Typically, this procedure is performed through a special model, such as MOBILE or EMFAC, which takes information on vehicle trips, vehicle miles of travel, and speeds, by facility type, combines it with information on the composition of the local vehicle fleet and its emissions characteristics, and generates estimates of emissions by type of pollutant. MOBILE is used to estimate VOC, CO and NO_x emissions, while a similar model, PART5, is used to estimate PM_{10}. EMFAC also includes PM_{10} for tail pipe, brake wear, and tire wear emissions, while PART5 is used for re-entrained dust emissions. Future EMFAC versions may incorporate re-entrained dust emissions (It should be noted that MOBILE produces emission *factor* estimates rather than estimates of emissions *amounts*).

2.3.1.2 Issues

Two sets of issues are raised concerning the suitability of these analytic tools in performing evaluations of market-based mechanisms. The first issue is that the four-step process has various limitations as a tool for examining the impacts of market-based approaches in general, and pricing measures in particular. The second issue is that the analytic capabilities of candidate regions and agencies vary widely.

It is generally acknowledged that the four-step process was not developed as a tool for performing sensitive policy testing. It was originally developed and has been primarily used for generating vehicle traffic volumes for highway planning and sizing purposes. Over time, enhancements have been made that increase its capabilities and sophistication, but a number of shortcomings still exist that raise concerns when examining pricing actions:

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[9] Work is underway in several regions under the U.S. DOT/FHWA s Travel Model Improvement Program to develop a new generation of travel models that more effectively integrate these steps, considering individual activity scheduling, the changing of trips into tours, and the potential for trip sequencing and time of day of travel, as well as recognizing the effects of transportation on growth patterns. Many of these improvements are already available to local agencies through the Texas Transportation Institute.

- Pricing is often not rigorously included in the model's structure. Typically, the only choice dimension that is sensitive to cost is mode choice.
- The accuracy of the pricing relationship in the models is challenged by the heavy emphasis on travel time in model development, and the relative lack of good variation in pricing conditions in most U.S. urbanized areas when compiling input data.
- It is expected that travelers will respond differently to pricing actions depending on their income status, although this is not explicitly accounted for in most models.
- Based on a structure that approximates behavior through zonal averages, and the specification of the models themselves, it often is necessary to restrict consideration of a measure to the most basic definition.
- Commercial and through (external-external) travel is generally not addressed in the application of policy actions, especially pricing.
- Whereas pricing actions would be expected to have a pervasive effect on travel behavior, ranging from changes in destination, route, time of day, or even location choice, most models consider price only in relation to mode choice. Also, these decisions would be expected to have some interdependency, whereas the models usually represent behavior as a sequential-step process.

Added to these inherent limitations, there is the further complication that overall capability varies widely by location. The model systems of areas like Portland, Oregon or San Francisco are fairly progressive and have many of the features that would raise confidence in their use for pricing measure analysis. However, there are many other major metropolitan areas whose models are fairly rudimentary or which have acknowledged flaws or limitations. Added to this are a number of areas that might choose to look at pricing measures, but which have little or no modeling capability at all. These might be counties or urban areas that are too small to have sophisticated transportation planning capabilities. The planning process for many of these areas, for example, may be only a three-step process (excluding mode choice) or less.

This guidance document has been developed with appreciation for the demand that pricing measures place on the analytic process and the wide range of analytic capabilities that exist. It is EPA's desire that areas that need additional help in reaching their attainment goals consider market-based measures. In this regard, the candidate area should endeavor to perform the most accurate and realistic assessment possible, within its capabilities, when submitting such measures for emissions credit. EPA s decision as to how much credit to grant will be based on: (1) whether the analysis supports the requested credit; and (2) whether the steps leading to implementation are realistic. Obviously, the greater the significance and contribution of the measure to the area's attainment goals, the more carefully the analysis procedures must be reviewed when deciding to grant credit. However, EPA will work cooperatively with the performing agency to support its efforts and help achieve an accurate determination of credit.

2.3.2 Identifying and Assessing Areas of Impact

This section presents how each measure is expected to affect travel and emissions. Discussion is organized by area of impact, presented in the same order as the analysis hierarchy. This section also describes the analytical tools that may be used to assess those impacts.

Table 2-4 lists each of the five market mechanisms, as well as an assessment of where in the travel demand hierarchy they would be likely to have impact. Regional growth forecasts have been excluded as a step, since their value is almost always exogenously determined. Vehicle ownership appears in two ways: (1) conventional vehicle ownership, which represents the *number* of vehicles owned by households as a factor in travel decisionmaking for many model systems; and (2) vehicle mix (shown as a component of the emissions generation step), which represents the *types* of vehicles owned and their composition in the vehicle fleet mix.

Table 2-4 indicates where a pricing measure would have an impact in this structure, and the expected level of importance of that impact. Impact importance is rated using the following scale:

- **Primary:** The impact is major and basic to the measure; every effort should be made to evaluate its effects.
- **Secondary:** The impact is judged to be an important effect which may even exceed the primary effect and thus must be considered; however, while its formal *analytical* evaluation (i.e., a complete regional travel demand modeling analysis) may not be possible, an area should provide documentation to show that the effect has been considered in the most reasonable manner possible.
- **Trace:** Some impact would be expected, but its implications for emissions would be minimal and no evaluation would be required.
- **None:** For practical purposes, no impact would be expected.

A draft version of the impact hierarchy outlined above was originally developed as the result of a meeting that included EPA and DOT staff and contractors involved in the production of this report. Subsequently, the draft hierarchy was reviewed by EPA and FHWA staff and modified. EPA and FHWA review and modification led to the hierarchy outlined above.

Table 2-4 should be used with several caveats in mind. First of all, *level of importance* valuations in the table are not linked to time periods. For example, while the land use impacts are often, long-term the distinctions among primary, secondary and trace effects are generally linked to the ultimate level of impact expected, rather than how long it takes for that impact to fully materialize.

Table 2.5 Anticipated Impact of Measures in Analysis Hierarchy

Area of Impact	**Measure Category**				
	Parking Pricing	**Modal Subsidies**	**Pump Charges (VMT fees)**	**Emissions Fees**	**Roadway Pricing**
Land Use/Activity Allocations	Secondary	Trace	Secondary	Secondary	Secondary
Vehicle Ownership	Secondary	Trace	Trace	*Primary*	Secondary
Trip Generation	Primary for work, trace overall*	Trace*	Secondary*	Trace*	Primary if area-wide, trace otherwise*
Trip Distribution	Secondary	Secondary	Secondary	Trace	*Primary*
Mode Choice	*Primary*	*Primary*	*Primary*	Trace	*Primary*
Time of Day	Secondary	Secondary	None	None	*Primary* (through congestion pricing)
Traffic Assignment	Trace	Trace	Trace	None	*Primary*
Emissions/Vehicle Mix	None	None	*Primary* (change vehicle mix)	*Primary* (change vehicle mix or emissions factors)	None

* *An issue if Trip Generation does not include non-motorized modes.*

Second, *level of importance* valuations do not account for major differences in price levels. For any of the measures to have an effect on behavior, the level of the price applied would have to be sufficient to be felt. At low price levels, all of the instruments would be expected to function primarily as revenue generators, and have only marginal effects on travel behavior. However, the relative level of impact implied by the importance valuations would be expected to stand across a wide range of price levels.

The analytical tools or approaches described in this section are categorized as *basic analysis* or *advanced analysis*, according to how they are rated by EPA submission requirements:

- **Basic Analysis:** Procedures that EPA suggests be used when formal analysis is required if the measure is to be considered for emissions credit (that is, when the measure is expected to have a primary and direct impact or a significant indirect effect).
- **Advanced Analysis:** *Suggested* procedures beyond the basic analytical procedures that EPA believes would result in better estimates of the travel and emissions impact of the measure if applied. Use of Advanced Analysis Techniques will enhance the acceptability of an application for SIP credits.

In many cases, the same analytical technique is considered basic in one circumstance (e.g., when the measure will have a primary impact), but advanced in another analytical context (e.g., when the measure will have a secondary or trace impact); these techniques are thus categorized as *basic or advanced analysis*. This consolidated discussion of analytical techniques helps avoid undue repetition in Section 2.3.3, below, on analytical requirements for individual market-based measures.

2.3.2.1 Land Use/Activity Allocations

Some pricing measures can affect long-term locational decisions and land use patterns and both short and long-term individual decisions. These measures might either induce more concentrated growth patterns that might be favorable for longer term transportation and emissions management, or could produce divergent trends toward dispersed land use patterns and greater automobile dependence.

Effects of Market-Based Measures on Land Use/Activity Allocations

Much depends on the level and type of cost impact of the particular measure, but most of the measures could conceivably have an impact on this underlying aspect of travel behavior. Despite the potential impact of a change in land use/locational choice, these impacts are listed as *secondary* in Table 2-4 because of the uncertainty associated with projecting these changes with current modeling tools.

Parking pricing would be expected to induce a locational effect, with greater preferences for locations that provide more concentrated amenities and services and better transportation alternatives. If applied differentially, businesses and households might be expected to show preferences for locations with lower parking rates. For example, should the policy be to raise downtown rates relative to suburban rates, this would be expected to increase the attractiveness of suburban development. If parking were implemented *uniformly*, and resulted in some areas having better design/amenity or offering better access through non-SOV modes, the measure also might induce locational shifts to these areas.

Modal subsidies would be expected to have only a *trace* effect on land use decisions, unless they were of significant size and the public perceived them to be permanent (in availability and in relation to the cost of other modes). At high levels, dedicated subsidies might shift locational preferences to areas where these price advantages could be exploited, that is, where transit or other subsidized modes are more available and useful in reaching desired destinations.

Pump charges would be expected to have a concentrating (*secondary*) effect on land use, since they function to visibly raise the cost of driving for all travel purposes. Thus, households might be expected to locate in areas where less dependence on private vehicle travel was required.

Emissions fees, if scaled primarily to emissions output and not VMT, would have little more than a *trace* effect on locational decisions. However, an emissions fee that is substantial, or based heavily on VMT, could encourage households to own fewer vehicles and thus prefer areas with mixed land uses and which otherwise provide better access to desirable locations without private vehicles.

Roadway pricing might have an important (*secondary*) effect. Widespread pricing would tend to encourage locating where there is less reliance on private vehicles. Assuming *only selected facilities* would be priced, households and businesses would be expected to locate so as to minimize long-term reliance on these facilities. The impact of this on air quality is uncertain. *Area-wide* implementations of road pricing would tend to reduce VMT and encourage a greater mixing of uses. Congestion pricing would be limited in influencing location choice, particularly if fees were peak-only. To the extent that congestion pricing leads to travel time decreases, it could lead to more dispersed new development, could allow better access to currently congested centralized developments, or both. Area cordon fees may lead to more transit-oriented development, provided the priced area remains attractive relative to other locations.

Analytical Techniques for Land Use/Activity Allocations

Advanced Analysis

Two approaches are generally applicable for evaluating the impacts on land use/activity allocation of market-based measures:

- Estimate impacts using a land use model that is sensitive to transportation costs (through incorporation of generalized cost, for example);[10] or

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[10] The DRAM/EMPAL model, for example, developed by University of Pennsylvania s Dr. Stephen Putman, is commonly used in the United States to model land use changes.

- Develop one or more growth scenarios to depict the alternate ways in which regional growth might respond to changes in transportation costs of the type proposed. This might be done in conjunction with application of land use models, and involve development and integration of alternative land use/urban design configurations supportive of alternatives (e.g., subsidized) modes.[11]

Because land use/activity allocation effects are identified as secondary impacts, no formal analysis is called for, although a statement of anticipated impacts should be included in most cases.[12]

2.3.2.2 *Vehicle Ownership*

Effects of Market-Based Measures on Vehicle Ownership and Vehicle Mix

Pump charges would encourage drivers to shift to owning and/or using more fuel-efficient vehicles. This would have an important *primary* effect on vehicle types, which should be captured in the emissions modeling step, in terms of the fleet mix used to calculate regional emissions factors. These more efficient vehicles might or might not be lower-emitting.

Pump charges that serve as a medium for pay-as-you-go insurance might have an effect on vehicle ownership, although the direction of the effect would be hard to predict. Such charges would significantly boost the cost of vehicle ownership and use for groups that do not carry insurance (a legal violation in most cases, acting to discourage ownership). Pay-as-you-go charges, however, may be more economical for owners currently insured and could encourage ownership.

Emissions fees, if significant enough, could affect the number of vehicles owned (hence a *primary* impact). Emissions fees would likely cause households to shift ownership to (and possibly use) newer and/or lower-emitting vehicles. This would be an important *primary* effect that would need to be reflected in the emissions modeling step through adjustments to the fleet mix.

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[11] An outstanding example of this approach is Portland, Oregon s Region 2040 planning process, and a closely related analysis process by 1000 Friends of Oregon, the Land Use, Transportation, and Air Quality Connection (LUTRAQ). Region 2040 information is available from Portland Metro, and LUTRAQ information from 1000 Friends of Oregon See, for example, 1000 Friends of Oregon, Making the Connections: A Summary of the LUTRAQ Project, February 1997.

[12] In a relevant recent case, a US District court ruled that as part of planning for a major new highway, Illinois DOT would need to develop a separate set of socioeconomic/land use forecasts based on what would likely occur with vs. without construction of the road. A single set of socioeconomic/land use assumptions for both build and no-build scenarios for evaluation of ozone precursors was deemed to fail the legal requirements of the National Environmental Policy Act. US District Court (Northern District of Illinois, Eastern Division), Case No. 96 C 4768. Sierra Club, Illinois Chapter; South Corridor Against the Tollway, Inc.; Environmental Law and Policy Center of the Midwest; and Business and Professional People for the Public Interest *vs.* US DOT/FHWA, Illinois FHWA, Illinois DOT, and Illinois State Toll Highway Authority.

No other market-based measures would be expected to have a major *direct* effect on the *number of vehicles* owned by households. The primary effect on vehicle ownership levels for these other measures would be a result of induced shifts in location (land use/activity allocations) to areas where fewer vehicles were required.

Analytical Techniques for Vehicle Ownership and Vehicle Mix

Basic or Advanced Analysis

Analytical tools used for evaluating ownership patterns apply primarily to vehicle mix because that is the factor expected to be most affected by market-based measures. Approaches include:

- Analytic procedures such as hedonic models to forecast shifts in ownership patterns;
- Research studies on shifts in vehicle ownership in response to price, and application of factor methods to estimate shifts; and
- Special analyses, such as stated preference surveys, to investigate likely responses to ownership that might result from alternative fee structures.

2.3.2.3 Trip Generation

Market-based measures can have a range of impacts on the generation of trips from households. Probably the key factor in terms of the impact on trip generation is the overall scope of the measure and its comprehensiveness in increasing the overall cost of travel by single-occupant vehicles. Ideally, trip generation should account for all person-trips. Non-motorized trips are generally not accounted for in current modeling systems, which could constitute an important limitation when evaluating pricing systems.

Effects of Market-Based Measures on Trip Generation

Many analysts assume that the number of trips generated by a household is not particularly sensitive to transportation factors, including cost. They suggest that a household's propensity to travel is determined by its need to satisfy specific activities, which are dictated by its size and socioeconomic composition. Rather than forego activities and make fewer trips in response to higher prices for vehicle travel, households would be expected to make less severe changes in their pattern of trip making — for example, more trips to closer/different destinations or, shift to other modes. These are important effects, but are generally dealt with elsewhere in the travel analysis hierarchy.

There are growing challenges to this view, however, particularly in light of new information and telecommunications systems that are reshaping our economy and communities. For example, an increasing number of workers are opting to work at home under telecommuting arrangements; many others have shifted to a modified work schedule. In these cases, the number of trips made to a physical work site is reduced and/or the time of travel changed, suggesting that the household might make fewer total trips as a result.

Similarly, shopping and entertainment needs are being increasingly satisfied through cable TV, the Internet, video movie rentals, deliveries, etc. There also are other ways in which households could shift their activity patterns to group trips together into trip chains, possibly accomplishing multiple functions in a single trip. Such adjustments to activity patterns could show up in overall trip rates in response to higher travel costs, although their impact is presently not well understood.

Parking pricing could influence trip generation in many different ways and depends heavily on the details of the pricing changes. For example, requiring employers to charge employees for parking (or instituting a cash-out program) could have primary impacts on work trips but, probably, virtually no impacts on non-work trips. If non-work parking were priced, one could expect far larger impacts, though their character might differ. Impacts of non-work parking pricing might emphasize long-term land use changes by retail locations. Since land use effects are captured elsewhere in the modeling system, trip generation would probably only have a trace impact for non-work trips.

Modal subsidies would only have a trace impact on trip generation. This would probably tend to affect work travel more than non-work travel. Minor increases in carpooling and transit use would be likely.

Pump charges could have a secondary impact on trip generation. In the short run, this would be reflected by better scheduling of activities and vehicle usage within households (often a household with more than one vehicle will increase use of the more fuel efficient vehicle).

Roadway pricing could have a primary impact on trip generation if applied area-wide. An increase in the overall cost of travel would be expected to result in household activities being more efficiently scheduled and coordinated. Limited roadway pricing, such as tolls on individual facilities or limited congestion pricing would only be expected to have a trace impact.

Emissions fees are not expected to have more than a trace impact on trip generation. Note that if these fees are mileage-based, and if the mileage-based component of fees is significant, they could have a greater effect.

Analytical Techniques for Trip Generation

Basic Analysis

Aside from uncertainty regarding the actual impacts, practical concerns have been raised regarding the modeling conventions used to assess impacts. Frequently, trip generation models estimate only those household person trips that may be served by vehicle. They do not include trips that would be made by walking or bicycle. Therefore, in situations where a household may respond to a change in travel conditions by shifting some trips to pedestrian or bike travel, this shift would not be captured accurately in the trip generation analytical step.

Some regions employ models that are even more restrictive; they consider only trips made *in vehicles*, not person trips. Typically, these are smaller areas where the private vehicle is the overwhelmingly dominant mode and the planning process is less complex in that they are not concerned with transit or non-motorized alternatives. Thus, if a region's trip generation model estimates *all* person trips, the effect of pricing on trip generation would be expected to be at a *trace* level, since allowance would be made for vehicle trips to shift to non-motorized modes.

However, if trip generation analysis is based only on *vehicle* or *vehicle-eligible* trips, then pricing would be expected to show at least a *secondary* effect, at least in the case of *pump charges*, but possibly also for *parking pricing* and *modal subsidies*, because vehicle trips would shift to non-motorized modes would disappear from the inventory.

Advanced Analysis

In general, if the trip generation analysis deals only with motorized-vehicle trips, then an adjustment should be made to the vehicle trip generation estimates to reflect shifts to non-motorized or non-automobile-driver options. Wherever possible, trip generation analysis should be performed separately for each purpose and income strata, to support subsequent analysis of trip distribution and mode choice.

Moreover, if land use analysis suggests shifts in activity or land use patterns, then the vehicle ownership and trip generation analytical steps should be repeated to reflect relocation of activity and its association with potentially different rates of trip making and vehicle ownership.

2.3.2.4 *Trip Distribution*

Effects of Market-Based Measures on Trip Distribution

All market-based measures, except emissions fees, would be expected to influence choice of destination, that is, trip distribution. As noted earlier, if emissions fees are mileage-based, and if the mileage-based component of these fees is significant, they could have a greater effect. The same caveat applies to all references to the effects of emissions fees throughout this section. **Parking pricing** would be expected to influence destination choice at a *secondary* level. Increased parking rates would increase the attraction to destinations that provide better access to desirable locations without private vehicles. If parking rates were *uneven* in their application, travelers would be attracted to comparable destinations with zero or lower parking rates, unless the priced area also offered better access, more services or a higher level of amenities.

Modal subsidies would be expected to have a *secondary* effect. Lowered costs of selected non-SOV modes (through subsidies) would be expected to increase the attractiveness of those destinations accessed by subsidized modes.

Pump charges would have a *secondary* effect on destination choice. By raising the comparative costs of private vehicle travel, this measure would be expected to increase the attractiveness of closer destinations and/or destinations easily reached by alternative modes.

Emissions fees could have a *trace* effect on choice of destination. If the mileage-based component of the charge were significant, then it could encourage travel patterns that would reduce VMT, although the imposition of this fee on a periodic/annual basis would be expected to dampen its effect as a signal to daily travel.

Roadway pricing would be expected to have the largest effect of all pricing measures on destination choice, constituting a *primary* impact. Prices would tend to induce consumers to reduce vehicle trips, to reduce the length of trips, and also to consolidate destinations. If prices were imposed on *select* facilities, travelers would be expected to re-examine their options (particularly for non-work travel) and choose to:

- Travel to alternative (possibly more distant) destinations not subject to pricing;
- Travel to alternative destinations served by priced facilities that offer good alternatives, special amenities, or are closer than their original choices; or
- Travel to the same or alternative destinations, where they obtain quicker access at an acceptable price using priced facilities (more likely among higher income travelers).

Area-wide road pricing would result in shifts to closer destinations. Isolated road-pricing systems could, in some cases, result in increased travel.

Analytical Techniques for Trip Distribution

Basic or Advanced Analysis

Areas that have trip distribution models that incorporate price sensitivity directly through a *generalized cost* procedure can account for the effects of market-based measures explicitly. Many trip distribution models are sensitive to travel time but not cost. Some agencies address this in their models by incorporating *a generalized cost* formula. This characterizes the full cost of travel by private vehicle from each origin to each destination in terms of both the *travel time* cost and the *monetary* cost (use of travel time equivalents is discussed in Section 3.3.5.3.). Some models also consider the time and money cost of transit, where it is available, and *average* it into the overall measure of generalized cost.

If an agency has a model system with a *generalized cost* procedure that can be made to reflect the cost of market-based measures, this should be used to perform a revised trip distribution analysis that incorporates the proposed cost measures. Moreover, trip distribution analysis should be performed separately by trip purpose and income strata.

2.3.2.5 Mode Choice

Effects of Market-Based Measures on Mode Choice

All of the pricing measures, with the exception of emissions fees, would be expected to have a *primary* effect on the choice of travel mode.

Parking pricing would clearly serve to discourage driving, and, in particular, driving alone, in favor of other alternatives, and will shift some shorter trips to walking or biking if suitable alternatives and access exist.

Modal subsidies would create a direct attraction to the mode or modes being subsidized.

Pump charges would encourage use of alternative modes that would allow the traveler to avoid or reduce the higher cost of private vehicle travel.

Emissions fees could have a *trace* effect on mode choice through the mileage-based component of the charge. Again, however, the effect would be greatest if fees are collected frequently and/or there are frequent education and reminder efforts.

Roadway pricing would encourage use of alternative modes to avoid or reduce the cost of priced facilities, although this effect would be in combination with consideration of alternative destinations, routes and times of day at a much higher level than with the other measures.

Analytical Techniques for Mode Choice

Basic or Advanced Analysis

With the exception of emissions fees, all market-based measures would be expected to have a primary effect on mode choice. The performing agency can conduct the basic analysis with any of the three following options:

- Accepted mode choice model;
- Accepted quick response methods; or
- Elasticity methods.

An agency with access to a *mode choice model* is expected to use that model to conduct any required analyses of the impact of market-based measures. It may be permissible to adjust the factors included in these models or their coefficient values, provided adequate documentation is supplied on the nature of and need for the adjustment.

Areas without a mode choice model but with access to person trip tables may consider acquiring one of several *quick response methods,* which are widely available. These include: the TDM Evaluation Model from the Federal Highway Administration, the QRS planning system, and various methodologies developed to support CMAQ project analyses. Information on these tools is given in Section 3.3.6.9.

If an agency does not have reasonable access to either a mode choice model or one of the above surrogate procedures, analysis may be based on *application of elasticities* from research studies or from the mode choice model of similar urban areas. Section 3.3.6.9 provides references on sources for such elasticities and guidance toward their proper application.

Advanced Analysis

Advanced analysis of impacts on mode choice would use current generation, more sophisticated, mode choice models such as nested multinomial logit models, which permit testing of a wide array of alternative modes. The range of transportation service and socioeconomic variables that they incorporate offers greater flexibility in relating strategies and more realistic estimates of travel response. Some models have separate coefficients for categorically different cost items, such as transit fares, parking subsidies or parking costs, and HOV costs, and should result in more accurate estimates of response to corresponding policies. Models that reflect the interaction of mode choices and destination choices are desirable and EPA encourages their development.

More realistic analysis will result from application of separate models for each primary trip purpose, including home-based work, home-based other, and non-home based trips. Many agencies, however, do not have mode choice models for non-work travel. Accuracy would be further enhanced by accounting for effects by income strata, as well as trip purpose, in order to reflect differences in cost sensitivity by income level. This would also help analyze the equity-related issue of differential impact by income group.

Finally, model accuracy can increase if models can capture the attractiveness of an area to other travel options, including non-auto travel. Just as the design of the road system increases or decreases the impedance a driver experiences, so the walking and cycling infrastructure helps determine whether, how often, and how far people walk or bicycle. And just as impedance for drivers can be quantified, new work has significantly improved the quantification of determinants of walking and bicycling. Recent work on Pedestrian Environment Factors and Urban Density Factors has helped improve modeling in Portland, for example.[13]

2.3.2.6 *Time of Day*

Effects of Market-Based Measures on Time of Day

Only three of the described market-based measures would be expected to have any effect at all on travel time of day; neither pump charges nor emissions fees would influence time patterns since assessment is not linked to specific trips.

Parking pricing could have a *secondary* effect on time of day if the differential between peak rates and off-peak rates were sufficient to shift users with flexibility to off-peak travel. In many cases, however, impacts would be at a *trace* level.

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[13] See, for example, 1000 Friends of Oregon, *Making the Land Use, Transportation, Air Quality Connection: Volume 4A, the Pedestrian Environment*. 1993. Portland: 1000 Friends of Oregon.

Modal subsidies that favor alternatives (mode and/or specific service within that mode) used primarily in peak periods could shift users from unsubsidized modes/services used off-peak to the subsidized service during peak periods. Nonetheless, only *trace* effects would be expected for the level of subsidies generally proposed unless subsidies vary by time of day.

Roadway pricing in the specific case of congestion pricing would be expected to have a *primary* effect on time of day choice. Higher peak-period prices would be expected to shift lower-valued trips to off-peak travel and would draw some trips into the peak if a higher level of service becomes available as a result of the pricing program.

Analytical Techniques for Time of Day

Basic or Advanced Analysis

Time-of-day analysis procedures are still uncommon in transportation planning practice. Some agencies have time-of-day models. For those that do not, analysis could be based on procedures borrowed from another location or based on a special analysis at the affected site to identify relationships and estimate behavioral factors. More specifically, analysis of the impacts of market-based measures expected to have a measurable impact on time of day could be based on any of three approaches:

- Use of a time of day choice model acquired from another location (see Section 3.3.7);
- Consultation of references on time of day sensitivity, which could include analyses of other area programs, transit or parking peak pricing results, or other special analyses; or
- Performance of a special *stated preference* survey analysis to develop a model for the area under investigation.

2.3.2.7 Traffic Assignment/Route Choice

Effects of Market-Based Measures on Traffic Assignment/Route Choice

While *all* of the pricing measures affect traffic assignment in terms of revised traffic patterns, only roadway pricing directly targets route choice.

Roadway pricing forces travelers to make conscious decisions about spatial patterns and, as such, has a *primary* impact on traffic assignment. Travelers may have a choice between routes that are tolled but that offer a higher level of service/travel time and another set of routes that are not tolled but that have a lower level of service/travel time. As with destinations, the choices ultimately made depend on the specific characteristics of the pricing scheme and the available travel alternatives.

Analytical Techniques for Traffic Assignment/Route Choice

Basic or Advanced Analysis

Roadway pricing explicitly forces travelers to evaluate and respond to the trade-off between tolled roadways that may have a higher level of service and toll-free routes that may be more congested. They also may choose shorter trips or forego some trips that would previously have been taken. The anticipated close links between roadway pricing and traffic assignment (route choice) mandate analysis of these effects. Yet, traveler route choice is not directly handled by most traffic assignment models. There are various options for addressing anticipated impacts, including:

- Use of procedures that represent toll and free path opportunities to travelers in an assignment routine. These are relatively advanced techniques, however (see Section 3.3.8.5); or
- Representation of the effect of tolls for a given facility as an increase in travel time through use of *value of time* relationships to estimate the appropriate value. This raises the cost of a tolled facility to a traveler considering its use (also see Section 3.3.8.5).

2.3.2.8 Emissions /Vehicle Mix

Effects of Market-Based Measures on Emissions /Vehicle Mix

All market-based measures should ultimately affect the level of emissions generated. Two market-based measures pump charges and emissions fees could directly affect vehicle mix and, through that, emissions rates.

Pump charges could induce shifts in favor of vehicles with greater fuel economy. The net effect on emissions is the result of two factors: lower fuel consumption per mile traveled (and potentially overall) and possibly different emissions characteristics (rate of emissions per mile). The overall relationship between pump charges and vehicle mix/emissions could be considered *primary*, though the indirect link of pump charges working through increased efficiency and lower total fuel consumption could be considered *secondary*. Pump charges would induce travelers to shift to more efficient vehicles, partially offsetting the benefits of fuel price increases.

Emissions fees would act similarly to the pump charge, except that by inducing a shift in the vehicle fleet toward cleaner vehicles, it would constitute a *primary* effect. Influence of a VMT component of emissions fees would also show up in lower aggregate mileage rates within the fleet.

Analytical Techniques for Emissions /Vehicle Mix

Basic Analysis

Agencies should use an approved emission factor model to calculate emissions, with factors computed to reflect any program-induced adjustments in the regional vehicle mix. Areas without formal emissions factor models would be expected to explain how the average emissions rates would change with the induced shifts in vehicle fleet composition and/or use.

Basic or Advanced Analysis

Analysis of anticipated shifts in vehicle fleet composition or usage can utilize the following approaches:

- Use of hedonic models (models of consumer satisfaction with particular vehicle attributes) to project changes in vehicle ownership in relation to cost differences;
- Consultation of research studies on shifts in vehicle ownership in response to price, and application of factor methods to estimate shifts; or
- Performance of special analyses (using revealed or stated preference survey methods) to forecast possible shifts in vehicle ownership and use.

These methods are further detailed in Chapter 3, Section 3.3.3.

2.3.3 Analysis Guidance

This section presents EPA s recommendations for evaluation of market-based mechanisms and describes the types of analyses that EPA expects to see accompany submissions of the respective measures for emissions credit. The guidance descriptions in this chapter are at a *general* level, designed to communicate to managers and decision-makers EPA s general thinking; specific step-by-step guidance suitable to direct technical staff in the actual evaluation practices is provided in Chapter 3, further supported by examples in Appendices A and B.

The table on the following page summarizes rules of thumb for submissions to EPA; impacts are assessed for individual market-based measures at each stage of the analysis hierarchy (refer to Table 2.3 for description of anticipated impacts). Clearly, the more careful the analysis, the more credit EPA can be expected to approve.

Rules of Thumb for Submissions to EPA on Market-Based Measures	
Expected Impact	**Acceptable Analysis**
Primary effect	*Formal analysis* expected for impact on that step of analysis hierarchy.
Secondary effect	Must include *some treatment* of impact on that stage of analysis hierarchy, though requirements are less formal.
Trace effect	Agency expected to *take note of possible side effects*, which could occur under special applications of the measure.

In laying out its recommendations for effective analysis, EPA has taken into consideration the wide range of capabilities that are available to those considering market-based measures. Because of the strong likelihood that there will be sites with minimal analysis capabilities, the guidance recommendations have been made flexible enough to allow these states to respond.

This flexibility does not take away from the position, however, that an accurate, comprehensive analysis is extremely important. Accuracy and completeness are important to EPA's review and decision to grant emissions credit. Therefore, agencies proposing pricing measures should consult with a wide range of parties to get as much assistance as possible in developing good analytical approaches. Furthermore, an accurate analysis also is essential to the performing agency's ability to assess the impacts and tradeoffs that are critical to local acceptance and implementation. EPA's position is to support the best possible analysis, to make allowances for states with limited capabilities, but to expect that states will take every reasonable step to perform the best analysis within their ability.

The remainder of this section presents analysis recommendations for each of the five measure groups: parking pricing, modal subsidies, pump charges, emissions fees, and road pricing. To avoid repetitive discussion of analytical approaches, EPA submission components are often noted only briefly with reference to the more extended discussion of basic or advanced analysis organized by impact category in Section 2.3.2. Recommendations for analysis are separated into *basic analysis* and *advanced analysis* and, within each of these, according to expected level of impact from *primary* to less important effects.

Advanced analysis is optional from the standpoint of EPA guidance. This reflects an acknowledgment of current limitations, but also willingness on EPA s part to work with all areas in exploring advanced strategies to deal with long-term air quality concerns. Nonetheless, EPA expects that those areas with advanced planning tools will use those tools to their best ability. Areas that do not have such tools or capabilities are encouraged to strive to acquire those advanced capabilities, both to serve their own current needs and to support other air quality and planning requirements that are likely to be part of future planning and funding tests.

In addition to attention to analysis tools and procedures, EPA places importance on the quality of data used to conduct the analyses, particularly with regard to data age, coverage, and accuracy.

The level of scrutiny applied by EPA to analyses that accompany submissions of market-based measures will be tailored to each circumstance. In particular, the level of credit claimed for the measure and its importance in achieving a given area s attainment or maintenance goals will be a factor considered by EPA in its review. More rigorous scrutiny can be offset through a more accurate and defensible analysis.

2.3.3.1 Parking Pricing

Suggestions for basic analysis and advanced analysis pertaining to parking pricing are illustrated in Figure 2.2a.

Basic Analysis for Parking Pricing Measures

Mode Choice: The *primary* effect of parking pricing on travel and emissions would be through its impact on mode choice. A submission that seeks emissions credit for parking pricing must pay particular attention to the shift of travelers from private vehicles, especially single-occupant vehicles, to transit, ridesharing or non-motorized alternatives.

Given the importance of parking pricing on mode choice, submitting agencies should use the most sophisticated procedures available to them, following the order of preference described in Section 2.3.2.5 on analytical techniques for mode choice basic or advanced analysis (i.e., mode choice models, quick response techniques, elasticity analysis).

In performing appropriate analysis, the performing agency must address, either explicitly in its analysis or through a listing of assumptions, how it has accounted for the following types of questions:

- What percentage of parking situations and consumers are affected by the proposed policy, and how is this reflected in the tested rate?
- What travel groups are affected by the proposed price (e.g., commuters, shoppers, etc.) and how is this reflected in the trip populations to which the analysis is applied?

Figure 2.2a Elements of Analysis for: *Parking Pricing*

ELEMENTS of *Basic Analysis*	ANALYSIS STEP (Type of Impact)	RECOMMENDATIONS for *Advanced Analysis*
Formal analysis not required; Statement of possible effects if rates are applied with geographic differences.	**LAND USE ALLOCATION** (Secondary)	Develop alternative growth scenarios or apply land use models capable of considering changes in transportation access and cost; Integrate alternative land use/urban design supportive of alternative modes into land use models, or adjust subjectively to evaluate.
None	**VEHICLE OWNERSHIP** (None)	Re-run if shifts in land use (above).
None	**TRIP GENERATION** (Trace)	Re-run if shifts in land use or vehicle ownership; Try to incorporate change in cost; Run separately by purpose and income; If using motorized vehicle trip tables only, adjust trip rates to reflect shifts to non-motorized and non-automobile driver modes using market share analysis or other model.
Formal analysis not required; Statement of possible effects if differential rates are applied.	**TRIP DISTRIBUTION** (Secondary)	Run separately by time of day if time-variant rates; Run separately by purpose and income; Explicitly model to reflect impact of change in parking cost.
Analyze through mode choice model, if available; Elasticity factor or quick response analysis if no model; Document sources and assumptions.	**MODE CHOICE** (Primary)	Use separate models for each purpose; Run separately by purpose and income; Separate coefficient for parking cost; Account for pass-through effect and HOV exemption/ discount; Estimate shift to non-motorized/ non-travel modes.
None	**TIME OF DAY/ PEAKING** (Secondary)	Try to model if parking prices vary by time of day or short/ long term; Model by trip purpose and income.
Standard assignment analysis, if capability exists.	**TRAFFIC ASSIGNMENT** (Trace)	Standard analysis
None	**EMISSIONS RATE/ VEHICLE MIX** (None)	None
Standard analysis, if emissions model available; If no model, apply emissions factors to the change in vehicle trips and VMT.	**EMISSIONS ANALYSIS**	Standard analysis.

- What proportion of the tested fee is assumed to be passed through to the traveler (affects tested rate)?
- Does the policy provide for exclusion of or parking discounts to HOVs?
- Is the dollar value of the policy being tested consistent with the year in which the elasticity was developed?
- What other factors are likely to be introduced or changed during the evaluation period that could affect the implementation or traveler response to the proposed application?

Traffic Assignment and Emissions Analysis/Vehicle Mix: Subsequent to the required mode choice analysis, areas with full model systems are expected to perform traffic assignment analyses and apply an emissions factor model to determine the resulting change in emissions. If these procedures are not available, emissions impacts may be estimated by applying emissions factoring methods to estimated net changes in vehicle trips and VMT, taking cold start effects into account if they are considered significant.

Land Use and Trip Distribution: Parking pricing that is applied evenly in an area could have important secondary impacts on land use/activity allocations and trip distribution. Mode shifts would tend to shift people to locations with more available services. Parking pricing that is applied unevenly in an area also could have important *secondary* impacts on land use/activity allocations and trip distribution. If the proposed parking pricing strategy will not be uniform across different geographic and travel purpose markets, then the performing agency should address this concern in its submission.

While a formal analysis of these effects is not required, the submitting agency should provide at least a statement of the potential impact from the proposed strategy on near-term choice of destination and longer-term land use trends, and the anticipated implications of these shifts for air quality. This statement should include acknowledgment by decision-makers of the anticipated impact.

Suggestions for Advanced Analysis of Parking Pricing Measures

Use of the following advanced analysis techniques could produce a more comprehensive and accurate analysis of the impact of parking pricing; these are listed in approximate order of presumed importance of effects (most important first).

Mode Choice: More advanced evaluation of mode choice impacts would utilize more sophisticated models (described in Section 2.3.2.5 as advanced analysis for mode choice) such as nested multinomial logit models, incorporating parking cost coefficients (where possible), and differentiating among income strata and trip purpose.

Trip Distribution: Enhanced analysis would be based on use of a trip distribution model sensitive to trip costs such as parking pricing, or on a model that uses time-equivalencies to account for such costs (see Section 2.3.2.4 on advanced analysis for trip distribution).

Land Use/Activity Allocations: Programs that introduce major changes in the level or pattern of parking prices could affect longer term land use and activity patterns. Advanced analysis may be warranted, using procedures such as a land use model sensitive to cost and/or growth scenarios (see Section 2.3.2.1 above on advanced techniques and, for a more technical discussion, Section 3.3.1 of the following chapter).

Vehicle Ownership and Trip Generation: If the trip generation procedure deals only with motorized-vehicle trips, then an adjustment should be made to the vehicle trip generation estimates to reflect shifts to non-motorized or non-automobile-driver options; the analytical approaches described in Section 2.3.2.3 are appropriate for advanced analyses of parking pricing effects.

***Time of Day*:** Unless the parking policy results in major changes in cost structure between peak and off-peak periods, it is unlikely that a sufficient time-of-day travel shift would occur that would be discernible by analysis. Advanced time of day analysis, if warranted, would follow those approaches described in Section 2.3.2.6, above (see also the more technical discussion in Section 3.3.7); these include choice models, other references, or special surveys.

2.3.3.2 Modal Subsidies

Suggestions for both the basic analysis and the advanced analysis pertaining to Modal Subsidies are illustrated in Figure 2.2b and described below.

Basic Analysis for Modal Subsidy Measures

***Mode Choice*:** Because the only *primary* effect of modal subsidies on travel and emissions is through mode choice, to be acceptable, an analysis should demonstrate a convincing evaluation of the modal split effect of the proposed subsidy. (Some effects on trip distribution may be likely with mode shifts).

The options for completing the basic analysis include, in order of preference, use of: accepted mode choice model; accepted quick response methods; or elasticity methods (see basic or advanced analysis, Section 2.3.2.5).

The performing agency also is expected to relate how it has accounted for the following types of questions:

What percentage of travelers will be affected by the proposed policy, in terms of receiving a subsidy, and how is this reflected in the tested rate?

- What travel groups are affected by the subsidy (e.g., commuters, shoppers, etc.) and how is this reflected in the travel base which has been used for analysis?
- What is the actual subsidy that is expected to be passed through to the traveler?

- Does the policy reward different groups at different levels (e.g., ridesharers versus transit users) and how does the analysis represent the competition among modes?
- Is the dollar value of the policy being tested consistent with the year in which the elasticity was developed?

Figure 2.2b Elements of Analysis for: *Modal Subsidies*

ELEMENTS of *Basic Analysis*	ANALYSIS STEP (Type of Impact)	RECOMMENDATIONS for *Advanced Analysis*
Formal analysis not required; Statement of possible effects if subsidy levels are significant.	**LAND USE ALLOCATION** (Trace)	If significant impact on inter-mode cost relationships, develop alternative growth scenarios or run land use models with consideration of cost; Integrate alternate land use/ urban design supportive of alternative modes.
None	**VEHICLE OWNERSHIP** (Trace)	Re-run if shifts in land use. (If significant mode shift, ownership should drop).
None	**TRIP GENERATION** (Trace)	Re-run if shifts in land use or vehicle ownership; Try to incorporate change in subsidies; Run separately by purpose and income; If vehicle-based trip generation, account for non-motorized/ non-automobile driver shifts.
Formal analysis not required; Statement of possible effects if subsidies are at significant level.	**TRIP DISTRIBUTION** (Secondary)	Run separately by purpose and income strata; Try to reflect impact of change in cost among alternatives and mode shift.
Analyze through mode choice model, if available; Elasticity factor or quick response analysis if no model; Document sources and assumptions.	**MODE CHOICE** (Primary)	Use separate models for each purpose; Run separately by purpose and income; Make certain models appropriately sensitive to the different subsidized modes/ instruments; Perform supplemental analysis to assess effects on use of subsidized or non-motorized modes.
Formal analysis not required; Statement of possible effects if subsidies are significant.	**TIME OF DAY/ PEAKING** (Secondary)	Perform supplemental analysis to account for peak/ off-peak effect of subsidies.
Standard analysis if have assignment procedure.	**TRAFFIC ASSIGNMENT** (Trace)	Standard analysis
None	**EMISSIONS RATE/ VEHICLE MIX** (None)	None
Standard analysis if have emissions model; If no model, apply emissions factors to the change in vehicle trips and VMT.	**EMISSIONS ANALYSIS**	Standard analysis

- What other factors are likely to be introduced or changed during the evaluation period that could affect the implementation or traveler response to the proposed application?

Traffic Assignment and Emissions Analysis/Vehicle Mix: Subsequent to the required mode choice analysis, areas with full model systems are expected to perform traffic assignment analysis and apply an emissions factor model to determine the resulting change in emissions. If these procedures are not available, emissions impacts may be estimated by applying emissions factoring methods to estimated net changes in vehicle trips and VMT, taking cold start effects into account if they are considered significant.

Land Use, Trip Distribution and Time of Day: Modal subsidies also may have *secondary* impacts on land use/activity allocations, trip distribution, and time of day. Impacts on land use trends and trip distribution would be anticipated only from *significant* levels of subsidy. Time of day impacts might occur if subsidized rates drew travelers into or out of peak periods. In such cases, although a formal analysis would not be required, EPA expects a statement of anticipated impacts.

Suggestions for Advanced Analysis of Modal Subsidy Measures

Expanding the evaluation to include the following components would generate a more comprehensive and accurate analysis of the impact of modal subsidies; these suggestions are listed in descending order of importance.

Mode Choice: More extended analysis would incorporate those approaches described as advanced analysis in Section 2.3.2.5 above (i.e., mode choice models that specifically break out and allow for interactions among each of the candidate travel modes), may include separate coefficients for parking costs, transit fares, etc., and are preferably run for each primary trip purpose, including home-based work, home-based other, and non-home based trips. Mode choice should be performed separately for each purpose and income strata.

Trip Distribution: Extended evaluation would incorporate those procedures described under advanced analysis in Section 2.3.2.4 on trip distribution (i.e. models that are sensitive to cost considerations and that distinguish among trip purposes and income strata).

Time of Day: Only if the subsidy policy results in major changes in cost structure between peak and off-peak should a formal analysis be attempted of time of day travel shifts. Such analyses are described in Section 2.3.2.6 (and Section 3.3.7) and include models borrowed from other locations, previous research, or conducting special surveys.

Land Use/Activity Allocations: If significant levels of modal subsidy suggest a different cost structure for regional travel, estimating this effect may be important. Because modal subsidies would result in across-the-board changes in the cost of travel, *significant* subsidies could lead to longer-term shifts in residential and employment locations to areas that require less automobile dependence. Approaches for extended evaluation include those described in Section 2.3.2.1 on advanced analysis for land use/activity allocations, including land use models sensitive to such costs and growth scenarios.

***Vehicle Ownership and Trip Generation*:** On their own, modal subsidies would not be expected to cause households to own fewer vehicles or make a different number of trips. If alternative land use patterns are determined in the previous step, then the vehicle ownership and trip generation steps should be re-run to reflect the relocation of activity and its association with the respective vehicle ownership and trip rates in the new location.

If the trip generation procedure deals only with motorized-vehicle trips, then an adjustment should be made to the vehicle trip generation estimates to reflect shift to non-motorized or non-automobile-driver options.

Wherever possible, trip generation analysis should be performed separately for each purpose and income strata, to support the subsequent analysis of trip distribution and mode choice.

2.3.3.3 Pump Charges and VMT Fees

Suggestions for both the basic analysis and the advanced analysis pertaining to pump charges are illustrated in Figure 2.2c. The *primary* effects triggered by pump charges would be on mode choice and vehicle mix. Higher fuel prices would be expected to reduce the demand for private vehicle travel and increase ownership and use of higher-mpg vehicles or alternative-fuels/electric cars.

Basic Analysis for Pump Charges

Mode Choice: Basic analysis includes those techniques described as basic or advanced analysis in Section 2.3.2.5 on mode choice impacts, that is (in order of preference): mode choice models, quick response methods, or elasticity methods.

The performing agency also is expected to indicate how it has accounted for the following factors or concerns:

- What percentage of regional travelers will be affected by the increased pump price, versus those who would be expected to evade the price increase by purchasing fuel outside the area; how is this reflected in the assumptions regarding the tested price?
- What average cost per mile is being assumed, and upon what average mpg is it based?
- Is the dollar value of the policy being tested consistent with the year in which the elasticity was developed?

Figure 2.2c Elements of Analysis for: *Pump Charges*

ELEMENTS of *Basic Analysis*	ANALYSIS STEP (Type of Impact)	RECOMMENDATIONS for *Advanced Analysis*
Formal analysis not required; Statement of possible impacts.	**LAND USE ALLOCATION** (Secondary)	Develop alternative growth scenarios; or run land use models with change in transportation access and cost considered; Integrate alternative land use/urban design supportive of alternative modes into land use models.
None	**VEHICLE OWNERSHIP** (Trace)	Re-run if shifts in land use.
If trip generation for vehicle trips only, account for non-motorized and non-automobile driver modes.	**TRIP GENERATION** (Trace)	Re-run if shifts in land use or vehicle ownership; Try to incorporate change in cost; Account for non-motorized or non-auto driver trips; Run separately by purpose and income.
Formal analysis not required; Statement of possible effects.	**TRIP DISTRIBUTION** (Secondary)	Run separately by purpose and income; Explicitly model to reflect impact of change in costs.
Analyze through mode choice model, if available; Elasticity factor or quick response analysis if no model; Document sources and assumptions.	**MODE CHOICE** (Primary)	Use separate models for each purpose; Run separately by purpose and income; Supplemental analysis to assess any effects of shift toward higher mpg vehicles; Supplemental analysis to assess demand for non-motorized modes.
None	**TIME OF DAY/ PEAKING** (None)	None
Standard assignment analysis if have assignment procedure.	**TRAFFIC ASSIGNMENT** (Trace)	Standard analysis
Indicate assumptions regarding change in vehicle mix to reflect shift in mpg anticipated.	**EMISSIONS RATE/ VEHICLE MIX** (Primary)	Adjust vehicle fleet mix to reflect changes in ownership and use.
Standard analysis if have emissions model; If no model, apply emissions factors to change in vehicle trips and VMT.	**EMISSIONS ANALYSIS**	Adjust vehicle fleet mix to reflect changes in ownership and use.

Trip Generation: If the trip generation process forecasts only vehicle trips, an attempt should be made to estimate the shift to non-motorized or non-automobile-driver modes as a result of higher fuel prices, following the recommendation for advanced analysis in Section 2.3.2.3 on analytical techniques for trip generation.

Traffic Assignment: Following mode choice analysis, areas with appropriate capability are expected to perform a revised traffic assignment for input to the emissions analysis.

***Emissions/Vehicle Mix*:** The performing agency should relate its assumptions on changes in average mpg due to shifts in vehicle mix, the impact this would have on the effective cost per mile used in each of the analysis steps, and whether this would be expected to result in important differences in impacts for different market groups, particularly by income level. Analysis requirements can be met with use of an emission factor model that incorporates vehicle mix impacts or, if that is not available, a narrative description that details program-induced changes in emissions rates in response to increased fuel prices.

Suggestions for Advanced Analysis of Pump Charges

A more comprehensive and accurate analysis of the impact of pump charges could be achieved with more extended analysis, using the following techniques (listed in descending order of importance).

Mode Choice: Appropriate evaluation is described under advanced analysis in Section 2.3.2.5 on analytical techniques for mode choice (i.e., mode choice models such as nested logit models, with attention to differentiation among trip purposes and income levels).

Emissions/Vehicle Mix: Extended evaluation of emissions/vehicle mix effects is described as basic or advanced analysis in Section 2.3.2.8, and includes hedonic models, research studies, and/or special surveys.

***Trip Distribution*:** Extended evaluation of trip distribution effects would incorporate the advanced analysis approach described in Section 2.3.2.4; that is, a trip generation model sensitive to cost, used to perform a revised trip distribution analysis (performed separately by trip purpose and income strata if possible), which also reflects changes in attractiveness of destinations (and purposes) due to fuel-price based overall increases in travel costs.

Land Use/Activity Allocations and Trip Distribution: Because fuel price increases would result in across-the-board changes in the cost of private vehicle travel, *significant* increases in price could lead to near-term shifts to closer trip destinations and longer-term shifts in residential and employment locations to areas that require less automobile dependence. Because these are *secondary* impacts, no formal analysis is *required,* but the performing agency would be advised to perform such an analysis if it has the capability, or at a minimum, state its assumptions as to the anticipated impacts this price change would have on trip distribution and land use/activity allocations.

If significant levels of fuel prices suggest a different cost structure for regional travel, it may be important to estimate this effect on long-term land use locational preferences.

Two options are described under advanced analysis in Section 2.3.2.1 on land use/activity allocations, that is: land use models sensitive to cost, and growth scenarios to depict the alternate ways in which the growth patterns might adjust to an overall change in pricing. Scenarios might be developed in conjunction with application of the land use model, and involve development and integration of alternative land use/urban design configurations supportive of subsidized modes.

***Vehicle Ownership and Trip Generation*:** If shifts in land use patterns are determined in the step above, then the vehicle ownership and trip generation steps should be re-run to reflect the relocation of activity and its association with potentially different rates of trip making and vehicle ownership. Wherever possible, trip generation should be performed separately for each purpose and income strata, to support the subsequent analysis of trip distribution and mode choice.

In general, an increase in fuel price would not be expected to have a major impact on the overall *number* of trips made by households. However, if the local planning process considers vehicle-serviceable trips rather than person trips in trip generation, then the evaluating agency should investigate any impact of higher fuel prices on shifts to non-motorized or non-automobile-driver modes, and to closer destinations.

2.3.3.4 Emissions Fees

Suggestions for both the basic analysis and the advanced analysis pertaining to emissions fees are illustrated in Figure 2.2d and discussed below. (If there is a significant VMT component, then address also the Pump Charges guidance).

Basic Analysis for Emissions Fees

The *primary* effects of emissions fees would be on vehicle mix and emissions. If the proposed fees imposed a significant cost on vehicle ownership, then impacts on land use and vehicle ownership also could be important. Because emissions fees (as defined here) would be assessed on a periodic basis, they would not be expected to affect daily travel choices.

***Vehicle Mix/Emissions Analysis*:** Fees levied on vehicles in relation to their age and/or emissions production (emissions rate, perhaps coupled with VMT) would have the *primary* effect of encouraging replacement of higher emitting/older vehicles and/or encouraging higher use of lower-emitting vehicles in multi-vehicle households.

Evaluation required in submissions to EPA includes the basic or advanced analyses techniques described in Section 2.3.2.8, above; that is, hedonic models, research studies, and/or special surveys (these methods are further detailed in Chapter 3, Section 3.3.3). The agency also should make an effort to indicate emissions fee impacts on relative usage patterns of particular vehicles, accompanied by a statement on assumptions relating impacts to market segment (income). For fees based on actual (measured) emissions rates, evaluation should include an estimate of the effects on improved maintenance.

Figure 2.2d Elements of Analysis for: *Emissions Fees*

ELEMENTS of *Basic Analysis*	ANALYSIS STEP (Type of Impact)	RECOMMENDATIONS for *Advanced Analysis*
If measure affects vehicle ownership/ use, submit statement that assesses effects on locational patterns.	**LAND USE ALLOCATION** (Secondary)	If price significantly affects vehicle ownership or VMT, then consider development of alternate growth scenarios or application of land use models to reflect change in costs on number of vehicles.
Assess if measure affects number of vehicles owned, following procedures for vehicle mix analysis.	**VEHICLE OWNERSHIP** (Primary)	Re-run if shifts in land use; Possible supplemental analysis to estimate change in vehicle mix and possibly usage patterns favoring cleaner vehicles.
Investigate impacts if land use or vehicle ownership affected.	**TRIP GENERATION** (Trace)	Re-run if shifts in land use or vehicle ownership; If trip generation does not include non-motorized, non-automobile driver modes, adjust to assess impact; Run separately by purpose and income.
Investigate impacts if land use or vehicle ownership affected, or if VMT fee significant; Otherwise, no analysis.	**TRIP DISTRIBUTION** (Trace)	Run separately by purpose and income; If significant VMT cost effect, incorporate cost modeling.
Investigate impacts if land use or vehicle ownership affected, or if VMT fee significant; Otherwise, no analysis.	**MODE CHOICE** (Trace)	Use separate models for each purpose; Run separately by purpose and income; Supplemental analysis to assess any effects of shift toward higher mpg vehicles; Assess demand for non-motorized modes, or impact of periodically-assessed charge on daily travel.
None	**TIME OF DAY/ PEAKING** (None)	None
Investigate impacts if land use, vehicle ownership, distribution or mode choice changes; Otherwise, no analysis.	**TRAFFIC ASSIGNMENT** (None)	Standard analysis
Indicate assumptions to account for shift in vehicle mix to cleaner vehicles.	**EMISSIONS RATE/ VEHICLE MIX** (Primary)	Adjust vehicle fleet mix to reflect change in ownership and use; Adjust emissions rates for better vehicle maintenance, if a feature of measure.
Standard analysis if have emissions model; If no model, apply emissions factors to change in vehicle trips and VMT.	**EMISSIONS ANALYSIS**	Adjust vehicle fleet mix to reflect change in ownership and use; Adjust emissions rates for better vehicle maintenance, if a feature of measure.

Areas with emissions factor models are expected to use these to assess the result of the proposed strategy on emissions and to incorporate the effect of emission fees on vehicle mix and/or improvements in maintenance.

In the absence of an emissions factor model, agencies may apply emissions factor relationships to changes in vehicle trips and VMT, with appropriate supporting documentation of their analysis and assumptions for emissions factors that reflect anticipated shifts in fleet mix and maintenance levels.

Vehicle Ownership: If proposed emissions fees lead to significant cost increases in automobile ownership, household ownership rates may be reduced, particularly ownership of high-emitting vehicles. Evaluation would follow that described under vehicle mix/emissions analysis above.

Land Use/Activity Allocations: If vehicle ownership is affected by a sizable emissions-based increase in registration fees, or if the VMT component of emissions fees is significant, households could shift to locations where fewer vehicles and/or less dependence is required. This effect should be investigated.

Suggestions for Advanced Analysis of Emissions Fees

Listed in declining order of importance, the following analyses could help generate a more comprehensive and accurate evaluation of emissions fee impacts.

***Vehicle Mix and Emissions Analysis*:** Because the primary impact of emissions fees is expected to be on vehicle ownership patterns, enhanced evaluation of emissions/vehicle mix effects could be achieved through more sophisticated application of the same techniques described above under basic analysis (i.e., hedonic models and/or secondary analyses, such as stated preference surveys to explore vehicle ownership and usage). In addition, the agency could use the above techniques to investigate whether the VMT aspect of the fee produces any change in daily travel behavior, how large a fee would have to be applied, and how frequently it would have to be assessed.

The most accurate emissions analysis will probably use an accepted emissions factor model adjusted to account for these changes, rather than application of emissions factors to net trip and VMT changes.

Vehicle Ownership and Land Use: Vehicle ownership would be affected by significantly higher emissions-based registration fees. Agencies proposing such fees should estimate vehicle ownership patterns, by income group if possible. In turn, revised ownership rates should then be incorporated in a revised land use analysis that reflects the impact of fewer vehicles and higher costs, using models, if available, or best professional judgment.

Mode Choice, Trip Distribution, Trip Generation: Generally, emissions fees collected through infrequent periodic assessments would not be expected to lead to major adjustments in daily travel behavior. If the VMT component of the fee is either significant or controlling, however, investigate its effects on mode choice, trip distribution, and trip generation by consulting research studies or performing a supplemental analysis of relative impact on daily behavior of annual (or periodic) fees.

Any changes in vehicle ownership and household location also would have an indirect effect on trip generation, distribution, and mode choice, and should be assessed. Trip generation analysis should reflect total person trips, and allow for shifts to non automobile-driven and non-motorized modes.

2.3.3.5 Roadway Pricing

Suggestions for both the required and advanced analysis pertaining to roadway pricing are illustrated in Figure 2.2e and discussed below.

Basic Analysis for Roadway Pricing

Because it is a fairly complex measure in terms of travel behavior impacts, there are more *primary* effects associated with roadway pricing than any of the other measures. Roadway pricing would be expected to have a primary impact in relation to mode choice, trip distribution, and traffic assignment, and, if peak period or congestion pricing is instituted, time of day choices as well.

Trip Distribution: Travelers would be expected to respond to the pricing of specific transportation facilities by favoring comparable destinations which can be reached without payment of a toll (where such a substitution can occur). There are several options for approaching this analysis. The more rigorous approaches are described in Section 2.3.2.4 as basic or advanced analysis techniques for trip generation, which include cost-sensitive trip generation models and generalized cost procedures.

Sites that do not have formal trip distribution modeling capabilities should formulate a statement that reflects a careful assessment of the anticipated impacts of the road pricing scheme on shifts in travel patterns.

Traffic Assignment (Route Choice): Traffic assignment becomes particularly important in the case of road pricing since travelers can choose between tolled routes that may have a higher level of service, and toll-free routes that may be more congested.

This choice is not directly handled by most traffic assignment models. The options for addressing anticipated impacts, described in Section 2.3.2.7 on basic or advanced analysis techniques for traffic assignment, include assignment routines for toll and free paths, or use of travel time equivalency estimates (see also Section 3.3.8.5).

If an area cannot perform traffic assignment analysis, or if the tolled facility can be easily avoided, then it may not be possible to consider the emissions impacts of roadway pricing because the impacts would be too uncertain.

Mode Choice: Mode choice is still an important factor in considering road pricing. Analytical options include those detailed above in Section 2.3.2.5 as basic or advanced analysis techniques for mode choice (i.e., mode choice models, quick response methods, or elasticity methods).

Figure 2.2e Elements of Analysis for: *Roadway Pricing*

ELEMENTS of *Basic Analysis*	ANALYSIS STEP (Type of Impact)	RECOMMENDATIONS for *Advanced Analysis*
Formal analysis not required; Statement of possible effects due to pricing of select facilities.	**LAND USE ALLOCATION** (Secondary)	Develop alternative growth scenarios or run land use models to reflect cost related to priced network; Integrate alternative land use/urban design supportive of alternative modes.
None	**VEHICLE OWNERSHIP** (Trace)	Re-run if shifts in land use.
None	**TRIP GENERATION** (Trace)	Re-run if shifts in land use; Run separately by purpose and income; Consider shifts to non-motorized alternatives, if area-wide pricing and vehicle-only trip generation.
Analyze if have trip distribution model; If no model, provide estimates of expected impacts; Account for non-motorized trips if vehicle trips only.	**TRIP DISTRIBUTION** (Primary)	Run separately by purpose and income; Explicitly model to reflect change in cost and travel time changes.
Analyze through mode choice model, if available; Elasticity factor or quick response analysis if no model; Document sources and assumptions.	**MODE CHOICE** (Primary)	Use separate models for each purpose; Run separately by purpose and income; Directly represent price for trip (rather than travel time equivalent); Possible supplemental analysis to ascertain response to electronic/ periodic charge assessment.
Must analyze if apply time of day pricing; Document sources and assumptions.	**TIME OF DAY/ PEAKING** (Primary)	Acquire/ develop model to simulate response to time of day pricing; Possible supplemental analysis to gauge time of day shifts.
Must analyze if pricing applies to selected facilities; Can use elasticity factor methods; Document sources and assumptions.	**TRAFFIC ASSIGNMENT** (Primary)	Develop and use toll diversion model to reflect toll/ free path options; Possible side analysis to gauge route choice shifts.
None	**EMISSIONS RATE/ VEHICLE MIX** (None)	None
Standard analysis if have emissions model; If no model, apply emissions factors to the change in vehicle trips and VMT.	**EMISSIONS ANALYSIS**	Standard analysis; Possibly adjust emissions rates for major speed changes on facilities.

Most likely, an area considering road pricing would have a reasonably sophisticated modeling system, complete with a mode choice model. Application of elasticity techniques would only be expected to be valid where simple pricing schemes are being considered (i.e., a bridge or tunnel with few/no parallel routes).

Important issues that should be addressed in the analysis include:

- Will the toll be paid to toll booth operators, to exact change machines, or electronically through advanced vehicle identification (AVI) transponder technology? What are the queuing and delay impacts of the chosen method?
- Are HOV users exempt from the toll, or charged discounted rates?
- Is the dollar value of the policy being tested consistent with the year in which the elasticity was developed?
- What other factors are likely to be introduced or changed during the evaluation period that could affect the implementation or traveler response to the proposed application?

Time of Day: Peak-period congestion pricing versions of road pricing would be expected to affect time of day choices as well as route choice and, if such strategies are being considered, the agency should attempt to estimate the impact of the fee on peak versus off-peak travel demand by trip purpose and income group.

Options for conducting this analysis are described above in Section 2.3.2.6, basic or advanced analysis techniques for time of day, and include: time of day choice models, references to other research, and survey analysis. Under extenuating circumstances, the area may be allowed to use assumptions to suggest the degree of change, but it is expected to provide documentation as to the assumptions and their degree of impact on the result.

Land Use/Activity Allocations: Implementation of toll pricing on selective transportation facilities would be expected to cause a shift in locational trends, which could reduce use of these facilities. Because these are *secondary* impacts, no formal analysis is required. Nonetheless, the performing agency is expected to state its assumptions (and show the concurrence of decision-makers) regarding the anticipated impacts that the system of road pricing would have on land use/activity allocations. This is particularly important in the context of partial-network pricing.

Suggestions for Advanced Analysis of Roadway Pricing

In descending order of importance, the following analyses would contribute to a more comprehensive and accurate evaluation of roadway pricing impacts.

Traffic Assignment (Route Choice): The best analysis would use a procedure including both toll and free paths as options to travelers, taking into consideration the fact that traveler choice will be sensitive to type of trip and traveler income level (see Section 2.3.2.7 for a more extended discussion, and Section 3.3.8 for a more technical presentation).

Time of Day: Time of day choice flexibility is particularly important in assessing the impacts of congestion pricing schemes. Shifts in time of day would be expected to vary significantly by trip purpose and income level. Time of day transportation modeling is a relatively uncommon practice; options described above in Section 2.3.2.6 include time of day choice models, references to other research, and surveys (Section 3.3.7 describes appropriate models).

Trip Distribution**:** Shifts to alternative destinations induced by road pricing could be important, particularly with partial-network pricing and numerous travel or route alternatives; impacts are likely to vary by trip type and traveler income levels. Include distribution effects of reduced congestion.

Application of a trip distribution model which is sensitive to cost through a *generalized cost* relationship to individual trip purposes and income strata would be essential to an effective analysis.

Mode Choice: Mode choice analysis would be most accurate if it were accompanied by the described advanced analyses of trip distribution, route choice, and time of day alternatives. It also would be most accurate if performed with separate models of each trip purpose and evaluated separately for each income strata.

Land Use/Activity Allocations: Road prices would be expected to make some areas more attractive than others in terms of future locational preferences. Options for approximating and accounting for these trends include use of land use models that incorporate sensitivity to cost, and/or the development of alternative growth scenarios. It would be particularly meaningful to develop land use and urban design scenarios which would complement travel alternatives to those sites with priced facilities/access.

Vehicle Ownership and Trip Generation: If alternative land use patterns are anticipated, the vehicle ownership and trip generation steps should be re-run to reflect the relocation of activity and its association with potentially different rates of trip making and vehicle ownership. When possible, trip generation analysis should be performed separately for each purpose and income strata, to support the subsequent analysis of trip distribution and mode choice.

2.4 Packaging Measures for Best Effect

The preceding discussion of market-based measures and guidelines for their evaluation necessarily provide a somewhat one-dimensional view of the nature and impact of these strategies. In reality, such measures would seldom be deployed in isolation, as described here. Rather, they would be deployed as part of a carefully considered package of different market measures and other actions to complement and support the market-based measure(s). Market-based measures serve as signals and incentives to change; other actions provide the appropriate setting and options necessary to complete the process.

There are two major benefits from packaging market-based measures into balanced programs:

- Balanced programs offer ***synergy*** that will generally produce a greater impact than a market-based measure acting alone; and
- Balanced programs that offer tangible and attractive ***choices*** are more likely to foster public acceptance of the proposed pricing measure component of the program.

This guidance manual cannot offer hard and fast rules detailing the most effective packaging strategies to accompany pricing initiatives, given the wide variation in settings, needs, and circumstances. In general, however, pricing measures are expected to work best if the following general principles are applied:

1. ***Match actions to consumer responses*** Anticipate the types of responses consumers are likely to make in response to a particular pricing measure. Analysts can use the guidance presented in the preceding sections, coupled with the performing agency s knowledge and experience. Analysts also should evaluate reciprocal actions that could be mated with these responses.
2. ***Identify realistic alternatives*** Where a measure is likely to raise interest in an alternative mode of travel, identify alternatives that will be attractive and appropriate in that setting. For example, consider transit service improvements if a high density corridor or downtown area is involved. If the impact area is more suburban, transit may still have a role, but actions to stimulate carpooling or vanpooling may be more suitable.
3. ***Consider non-motorized modes*** Broaden the analysis to include non-motorized alternatives such as walking and biking, which are often overlooked when options are considered. A fair portion of shorter trips may be amenable to walking or biking under the appropriate circumstances; shifting these trips from private vehicles to non-motorized modes could eliminate substantial emissions associated with vehicle cold-starts. More specifically, consider enhancing circumstances associated with bike and pedestrian modes such as: improving sidewalks; and

pedestrian access to buildings; providing frequent, safe pedestrian crossings; alleviating vehicle/pedestrian design conflicts; separating vehicles from pedestrians and reducing speeds; and providing bicycle lanes, paths, suitable lockup/storage facilities, and lockers or change facilities at destinations. Also consider approaches that encourage mixed use land development, such as reduced taxes for development that reduces transportation costs.

4. ***Consider positive incentives for desirable alternatives*** Identify and evaluate incentives for users of the more environmentally efficient modes. Incentives such as fare subsidies to transit or vanpool users, parking subsidies for HOVs, and equipment rebates can provide a powerful economic complement to market-based measures that primarily increase the cost of travel for driving or use of high-emitting vehicles.

5. ***Consider barriers to counter-productive traveler choices*** Articulate strategies to limit or direct the choices of travelers who might select counter-productive alternatives in response to the market-based measure. Depending on who they are and the purpose of their travel, many travelers have flexibility in their choice of route, destination, and time of day. When faced with market-based incentives, these travelers would be expected to consider and use that flexibility in their own best interest. Analysts should anticipate these responses and, unless these secondary responses support emissions reduction objectives, should propose complementary actions that reinforce desired behavior patterns. Mechanisms include: limitations on off-street parking coupled with site parking charges; and limitations on use of secondary/neighborhood roads as alternatives to a priced facility.

6. ***Explore outreach and indirect support*** Consider complementary actions in addition to financial incentives and physical alternatives that support travelers faced with changes in their travel context. For example, information outreach, education, and marketing can ease barriers to use of alternative travel modes. They can also explain and demonstrate the problems caused by driving and the virtues of walking, bicycling, and telecommunications. Effective matching programs can put people into acceptable ridesharing arrangements. Employers can play a very valuable role in supporting employee travel choices, including: guaranteed rides home in event of late work nights or family emergencies; assistance with dependent care; preferential or covered parking for ridesharing employees; and assistance with vanpool formation and operation. Employers also can offer opportunities to work at home through telecommuting arrangements, or introduce modified work schedules to reduce the number of physical trips to work sites.

7. ***Promote land use planning that supports alternative travel*** Recognize the importance of an environment that supports the use of alternative travel patterns. If persons are expected to travel to targeted destinations without

their personal vehicles, they must be confident that they can achieve their objectives at that location without a car at their disposal. This calls for innovation in urban design that allows people to circulate and accomplish activities pleasantly through walking, biking, transit or through shuttle services. This also means designing those centers so that the mix of uses is varied, complementary and attractive. Street space should be managed in these areas to provide pedestrians with safety from motor vehicles, freedom of movement, attractive visual surroundings, and comfortable settings for conversation, rest and shopping.

8. ***Use program revenues to support transportation and emissions goals*** Clearly and explicitly link the revenues that are collected through application of a pricing action with the use of those revenues. If the public perceives that the revenues extracted from them are used for the direct enrichment of their environments, rather than diverted to other uses, they should show stronger support for those programs since they are getting something back from their contribution. Revenues from pricing programs are often a convenient and adequate source to finance a variety of supporting strategies.

For more information on techniques for effective packaging, the reader is referred to other information sources, such as *Implementing Effective Travel Demand Management Actions,* which is recommended as a comprehensive source for packaging and impact information and contains considerable information on a wide variety of strategies and packaging tips, as well as a significant number of references to other sources on specific related topics.[14]

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[14] COMSIS Corporation et al., *Implementing Effective Travel Demand Management Measures: Inventory of Measures and Synthesis of Experience,* prepared for the Federal Highway Administration and the Federal Transit Administration, U. S. Department of Transportation, Washington, D.C., September 1993 (DOT-T-94-02).

3.0 Guidelines for Analysis of Market-Based Measures

■ 3.1 Introduction

This chapter provides guidelines and suggestions for those responsible for performing the actual evaluation of market-based measures for emissions credit. Whereas the preceding chapter was designed for managers and those without a technical background, this chapter was developed for those versed in the basic principles of transportation modeling and analysis. Expanding on topics discussed in Chapter 2, this chapter employs terminology and concepts that assume greater familiarity with transportation and emissions modeling tools and procedures. The intent is to provide fairly specific language as to EPA s expectations when reviewing credit submissions.

The chapter is divided into two main sections. The first section, Section 3.2, presents guidance on each of the five basic groups of market-based measures (parking pricing, modal subsidies, pump charges, emissions fees, and road pricing). The second section of the chapter, Section 3.3, is a reference compendium on methods and procedures suitable for the types of analyses suggested in Section 3.2. The reference compendium is organized according to steps in the analysis process. The methodological guidelines in Section 3.2 refer extensively to the methodological discussions of Section 3.3, many of which also list external references for further details.

This document has been prepared more as guidance than traditional requirements. EPA recognizes that that no single approach can work for all sites and that areas vary widely with respect to analytic tools, data, and staff capabilities. It is EPA's intention to suggest analytic approaches for *best practicable evaluation* of the proposed market-based measures.

EPA will use this guidance when evaluating an area's submission of a measure for credit. However, EPA also desires to work cooperatively with any area that is seriously considering market-based measures and will support reasonable best efforts to introduce such measures. EPA expects those areas with more sophisticated analytical tools to use them to the best possible advantage in performing an accurate assessment. At the same time, areas with limited analytic capability should not be discouraged from investigating market-based measures, and are encouraged to use this interest as a basis for upgrading their analytical tools for future investigations.

This chapter was designed to give direction to technical staff and, as such, goes beyond basic description of analytical approaches. Nonetheless, some practitioners may want additional information, such as clear-cut examples or instructions on how to make particular changes to their models or how to apply their models in specific circumstances. Appendices A and B address these needs by providing detailed technical procedures on model applications.

Appendix A describes a Case Study Model, which involves practical modification of a conventional four-step model system to improve its sensitivity to pricing. In addition to a description of the modification itself, the appendix demonstrates model applications to test market-based measures. Appendix B describes a somewhat different approach that uses household data and sample enumeration methods to obtain increased flexibility and potentially greater accuracy in evaluating pricing measures.

Performing sites are encouraged to contact their respective EPA regional offices for more information. In the course of undertaking an evaluation of market-based measures, agencies also are advised to:

- Establish and maintain a dialogue with EPA and other organizations with approval authority;
- Confer with appropriate agencies to coordinate assumptions and data;
- Consult with state and local air agencies and EPA on planned analytic approaches to obtain agreement on the proposed approach; and
- Consult with transportation agencies, environmental and community groups, and possibly consultants or academics to make sure that analyses and assumptions are reasonable and accepted.

■ 3.2 Evaluation Guidance for Individual Pricing Measures

This section provides step-by-step guidance for evaluation of each of the following five types of market-based measures:

- **Parking Pricing (Section 3.2.1);**
- **Modal Subsidies (Section 3.2.2);**
- **Pump Charges (Section 3.2.3);**
- **Emissions Fees (Section 3.2.4); and**
- **Road Pricing (Section 3.2.5).**

The discussion of each follows a common four-part format. Each of the five segments begins with an introductory table that summarizes the relationship between the given measure and each of the nine steps in the analysis hierarchy with regard to the following:

- *Form of impact* expected at that step that is, how the market-based measure will work to affect transportation factors analyzed in that step of analysis;
- *Type of impact* expected primary, secondary, trace, none and derivative (i.e., it must be addressed as a result of impacts in other steps); and
- *Impact indicator* that is, measures of performance that should be employed in the evaluation of each step.

Discussion begins with a statement of *Anticipated Impacts*, or those effects that are expected to be important in evaluating the specified measure. This is followed by a short summary statement of the *Basic Analysis*. The third component is *Guidelines for Analysis*, which presents step-by-step procedures or considerations that EPA would expect to see applied in evaluating the given measure. Analysis recommendations progress from basic analysis to advanced analysis, which is more likely to result in the granting of maximum emissions credit.

3.2.1 Parking Pricing

3.2.1.1 Anticipated Impacts

The primary impact of parking pricing would be on Mode Choice. Parking prices raise the cost of vehicle trips and thus increase the attractiveness of alternative modes, including transit, ridesharing and non-motorized options. They may also affect trip distribution, shifting destination to those more accessible without private vehicles. The degree to which other options become more attractive depends very much on attendant factors, such as:

Table 3.1 Impacts of Parking Pricing

Analysis Step	Impact Form	Impact Type	Impact Indicator
Land Use/ Activity Allocation	Greater attractiveness of areas with lower prices (uneven application) or with better alternatives & supportive land use/density	Secondary	Population and/or employment, by zone
Vehicle Ownership	None	None	Vehicles per household per zone
Vehicle Mix	None	None	Percent of vehicles by VMT
Trip Generation	Possible effect on attractions	Primary on work-trips, trace overall	Number of person trips to/from each zone
Trip Distribution	Diversion to destinations with lower prices or better alternatives	Secondary	O/D patterns (average trip length)
Mode Choice	**Decreases private vehicle use**	**Primary**	**Person trips by mode; % transit; % walk/bike; # vehicle trips; average vehicle occupancy**
Time of Day	Shift time of day	Secondary (if time of day differs)	Trips by time period
Traffic Assignment	Shift in trips and VMT as result of mode choice & distribution	Derivative effect	Link volumes; VMT
Emissions	Reduced vehicle trips and VMT	Derivative effect	Tons or kg. of VOC, NO_x, CO, PM

- Importance of reaching the particular destination;
- Amenity/design characteristics of that location; and
- Service/quality of the options that serve that location.

Parking pricing collected as a daily fee may have a greater effect than other pricing measures, since it is directly associated with the cost of the particular trip. Parking pricing is expected to have a greater effect on shorter trips, for which it represents a higher proportion of overall trip costs. This has important implications for affecting cold starts and micro-level traffic problems.

Parking pricing policies also raise practical concerns about distributional impacts. It often is difficult in practice to:

- Apply parking pricing uniformly with regard to geography (e.g., suburb versus city), type of site (site size and accessibility, on-street versus lots or spillover options, etc.), and
- Eliminate employer or merchant discounting.

Travelers with flexibility in choice of destination may shift away from locations with increased parking costs. This could apply to many non-work trips, and also to work and other fixed-location destinations in the longer run. In turn, this could have an effect on land use as the comparative advantages/disadvantages of various locations shift in response to pricing levels and uniformity, quality of alternatives, amenities, etc.

If parking pricing is applied at different rates to different travel markets (e.g., commuters versus non-commuters, or peak versus off-peak), then travelers with time flexibility can be expected to shift their chosen time of travel.

3.2.1.2 Basic Analysis for Parking Pricing

Aside from the standard analysis of emissions, parking pricing analysis should include a careful assessment of the impacts on mode choice (person trips by mode) and the resultant effects of mode choice changes on overall vehicle trips, VMT, and emissions. If parking rates are to be implemented non-uniformly across the region, the effect on shifts in trip distribution (particularly for non-work travel), land use, and time of day (if applicable) should be assessed, either through formal analysis/assumptions or through a discussion that describes the anticipated impacts on travel and emissions.

3.2.1.3 Guidelines for Analysis

1. Parking Pricing and Land Use/Activity Allocations

Parking pricing can affect long-run locational patterns by decreasing vehicle trips, particularly to locations affected by the policy. EPA does not require a formal analysis of parking pricing s effects on land use, although it would be more important to consider land use impacts if pricing is not uniform. If parking prices are not applied uniformly across the region, businesses and employers might shift to areas with lower charges or areas with better travel alternatives (e.g., transit) and supporting density. Households are expected to make long-term shifts in residence to areas that support lower cost travel patterns—that is, access to work/non-work destinations that have parking with low or no fees or that offer effective travel alternatives.

If an area's planning process includes a *land use allocation model* that incorporates transportation cost through a measure such as *composite impedance,*[1] the area may wish to consider using this model to investigate parking price impacts on long-term development trends. However, these results should be interpreted with caution given the limited accuracy of such models and the existence of other factors that can affect location trends. Section 3.3.1.2 provides more information on the nature and use of land use models.

Agencies may wish to consider formulating *alternative growth scenarios* based on various anticipated effects that development shifts might have on regional travel and emissions. This approach is particularly relevant for agencies that do not use models for land use analysis. This option, detailed in Section 3.3.1.1., involves defining alternative land use/urban design schemes that support the alternative modes and/or travel patterns encouraged by the proposed parking pricing policy.

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[1] Composite impedance is a measure that combines the time and cost of highway and transit (and perhaps other) modes into one statistic; see Section 3.3.5.1.

If the proposed parking policy entails major disparities in regional coverage or level, and the agency cannot perform a formal analysis of its impacts, the agency should provide a statement that reflects local decisionmakers appraisal of (1) the long-term consequences such a policy would be expected to have on regional development, travel trends, and emissions; and (2) what impact, if any, this will have on other land use and transportation investment analyses.

2. Parking Pricing and Vehicle Ownership

Because parking pricing is expected to have little or no direct impact on vehicle ownership, no formal analysis is required. Indirect impacts on vehicle ownership could occur as a result of household location shifts described in (1) above; in this case, advanced analysis would include re-running the vehicle ownership analysis.

3. Parking Pricing and Vehicle Mix

Parking pricing is not expected to have a direct impact on ownership vehicle mix, thus no formal analysis is required. Given that parking pricing is likely to affect short trips more than long trips, however, parking pricing could affect vehicle usage patterns; this should be taken into consideration in determining vehicle distribution used for the emissions estimation step.

4. Parking Pricing and Trip Generation

It is unlikely that parking pricing will have a measurable impact on the overall *number* of person trips made by households as forecast in trip generation analyses, thus formal analysis is not required.

Household vehicle trip rates could be affected by parking pricing in the following ways:

- Higher numbers of workers involved in telecommuting or compressed work weeks;
- Increased errand chaining to reduce the number of stops at priced destinations; and/or
- More use of telecommunications for non-work activities.

While these responses may affect the pattern of household tripmaking, it is unclear whether they affect the overall *number* of trips or simply trip *characteristics*, such as destination, trip length, mode, or time of day. Because there are no formal existing methods for dealing with these responses, however, no formal analysis is required (see Section 3.3.4.5).

There is some concern regarding what types of trips are depicted by the trip generation process used for analysis—*total person trips* or only those trips that are *vehicle serviceable.* Because the latter approach excludes walking and bicycle trips, important shifts in household trips from vehicular to non-motorized modes are likely to be underestimated; Section 3.3.4.4 discusses this aspect in greater detail.

Areas that do not currently forecast total person trips are encouraged to upgrade to such a framework as a future goal; for the present, these areas should try to consider these effects in their analysis as best they can. Section 3.3.6.6 suggests ways in which areas currently unable to project non-motorized modes can account for these effects later in the mode choice step.

Smaller urban areas without mode choice models may have an *even more restricted* definition of trip generation, considering only *vehicle trips* (i.e., only those person trips that are made in *private vehicles*, excluding transit). Trip tables limited to private vehicles inhibit analysis of pricing strategies, although options for overcoming this constraint are discussed in the mode choice segment below.

Parking pricing may have an effect on trip *attraction* rates, although there are no known models that are directly sensitive to parking pricing in this way. For example, suburban shopping sites tend to have higher vehicle trip attraction rates than downtown areas, although this may simply derive from a failure to account for transit and non-motorized trips. Areas are advised to be sensitive to these differences in their trip generation analyses.

Parking pricing is not expected to have a major (or predictable) impact on freight/commercial traffic, except in the event that parking supply itself also becomes more restricted, for example, due to limitations on curb parking. It also is unlikely that parking pricing would have a tangible effect on through (or external-external) traffic—that is, trips originating from and destined for locations outside the area of the pricing scheme.

5. Parking Pricing and Trip Distribution

Parking pricing is expected to have only a secondary effect on trip distribution; thus, no formal analysis is required. If parking pricing is applied differentially, however, a statement of possible effects should be included.

Trip distribution analysis can be a particularly important element in assessing the travel/ emissions response to parking pricing in the following ways:

- *Trip purpose:* Travelers who have the flexibility to shift to alternative destinations for some trip purposes, such as shopping and social/recreation, would be expected to consider and perhaps shift to destinations which serve more needs and/or are accessible without a private vehicle and if parking charges increase in only some locations to those with free or lower parking charges (unless there are offsetting amenity or utility circumstances). Travelers are less likely to shift destinations on trips with more rigidly determined destinations, such as work, school or personal business, at least in the short run.

- *Trip length*: Parking charges will have a higher proportionate effect on shorter trips, which also are strong candidates for transit or non-motorized alternatives (see mode choice discussion below).

Advanced analysis for areas with appropriate modeling capability includes evaluation of the effect of parking pricing on trip distribution, both for non-uniform and uniform pricing applications. This is best done with a gravity model that incorporates cost in its measure of separation through a feature such as *composite impedance* (see Section 3.3.5.1). If parking price is added to overall cost of travel to the respective destination, a different pattern of destination choices in the trip table can be expected to result. If the separation measure in the gravity model does not directly incorporate cost, then it may be reasonable to transform the parking cost into a travel time equivalent (see Section 3.3.5.3).

This analysis should be done independently for each trip purpose and income strata, or done with an equivalent income-sensitivity procedure (see Sections 3.3.6.3 and 3.3.6.4). If parking pricing varies by time of day, trip distribution analysis should be performed separately for each period.

Users are cautioned that in typical gravity models, which are *doubly constrained*, the model tries to allocate (through iterations) the same number of trip attractions to each zone that the trip generation model has estimated would be attracted to that zone. If the relative attractiveness of a zone decreases because of an increased parking price, the gravity model will still try to force a certain number of attractions to go to that zone. This could cause unintended distortions in trip patterns. That problem could be minimized by including some type of price-based variable (like composite impedance) in the attraction model. Another option is to switch to a logit destination choice model to allocate attractions, as is done in Portland, Oregon or San Francisco, for example (see Section 3.3.5.4).

Areas without trip distribution modeling procedures will have difficulty accounting for the impacts that would result from differential application of parking pricing. In this case, there are two options:

1. Assume only applications of parking pricing that would affect all areas at the same level, and avoid applications to non-work travel; or
2. If the above option is not realistic, then clearly state assumptions on how the proposed implementation is expected to affect the pattern of regional trip origins and destinations and how this is reflected in the estimated emissions reductions.

6. Parking Pricing and Mode Choice

Changes in choice of mode is the principal impact expected from parking pricing. All areas considering parking pricing are expected to furnish estimates of:

- Probable impact on number of person trips by mode; and
- Change in number of vehicle trips and average vehicle occupancy.

Areas with Mode Choice Models

Areas with mode choice models in their planning systems are expected to (1) use them for this analysis, or (2) explain to EPA their reasons for not doing so. In the absence of appropriate models, agencies should use elasticity factor or quick response analysis. Advanced analysis includes disaggregating analysis by purpose and income, applying separate coefficients for parking costs, and estimating shifts to non-motorized modes and non-travel.

EPA offers the following guidelines for the best possible mode choice analysis results:

- **Type of Model:** Multinomial logit (or similar probability-based) models are expected to provide the most realistic estimates of impact; models with a nested choice structure are among the most advanced of these (see Section 3.3.6.5 for more information). An ability to represent different automobile occupancy levels as modes increases accuracy in estimating the response to parking charges, particularly if special exceptions in parking fees are made for HOVs. An ability to account for non-motorized modes and multi-modal (e.g. park and ride) options will increase realism of modeling, subject to the capabilities and information furnished by the overall model system.
- **Parking Cost Coefficient:** Some models carry a separate coefficient value for parking cost, which suggests that parking cost carries more weight than routine operating cost (typically by a factor of 1.5 to 2.0). Agencies may wish to incorporate such a coefficient in their models (see Section 3.3.6.1).
- **Non-Work Mode Choice Models:** There should be a mode choice model for each separate trip purpose. Some areas model only work trip mode choices and estimate non-work mode choice through a factoring process; this is not likely to yield a credible result for non-work trips (see Section 3.3.6.4).
- **Income Stratification:** Mode choice analysis should be performed separately for different income levels (strata), both to allow for different cost sensitivity and to later account for distributional impacts. An acceptable alternative approach would be to base the analysis on mode cost prices divided by traveler income (see Section 3.3.6.3).
- **Program versus Effective Rates:** Agencies should not take it for granted that travelers will bear the full weight of program-based increases in parking prices. Effective rates may be altered by employer subsidies or other discounts. Unless the policy explicitly assumes full rate pass-through, some assumption should be made regarding effective rates paid per zone. It also is desirable to develop models that consider the distribution of parking costs by site, rather than using zonal averages. The STEP approach discussed in Appendix B offers such a capability.
- **Cost Basis:** Mode choice modeling is typically based on the comparison of costs for a one-way trip. Thus, it is generally appropriate to apply half of the daily parking to each one-way work trip. For non-work trips, where rates may be hourly, or for trip chains with multiple destinations, the relevant price per trip may be less clear and analysis will require explicit assumptions.

- **Adjustment for Inflation:** The dollar value implied in the suggested parking price must be consistent with the base year for which the model coefficient was developed. Generally, this requires *deflating* the tested parking price with a time-inflation factor that makes parking costs compatible with the coefficient in real terms (see Section 3.3.6.2).
- **HOV Special Rates:** Few, if any, mode choice models permit testing of different parking prices for different automobile occupancy levels. Such distinctions are important if the proposed pricing strategy provides incentives to carpools or vanpools. The TDM Evaluation Model (discussed in Section 3.3.6.9) may be useful to areas that wish to perform such an analysis.

Areas without Mode Choice Models

Areas that do not have mode choice models will have a more difficult time assessing parking pricing impacts, but may still do so. Suggestions for evaluations by these areas include:

- **Areas with Person Trip Tables:** Areas with person-trip tables (by individual trip purpose), can obtain an estimate of modal shifts by applying one of the following methods:
    - <u>Quick Response Methods:</u> Mode choice analysis can be achieved with a number of techniques that use sketch planning or pivot-point methods. These include the FHWA's TDM Evaluation Model and the QRS software system (see Section 3.3.6.9 for more information).
    - <u>Elasticities:</u> Mode choice analysis can be approached through application of pricing elasticity estimates from empirical studies or from mode choice models of similar areas (see Section 3.3.6.9 for more information and references). It must be stressed that elasticities will vary widely from region to region, depending on base costs, travel times, urban-design factors, and mode shares as well as socio-economic factors.
- **Areas with Vehicle Trip Tables (not Person Trip Tables):** Some areas perform analysis using only vehicle trip tables. It is still possible to evaluate mode choice responses to parking pricing if the agency first generates an estimate of person trips and then uses the derived estimates with either of the methods identified above. Person trips can be derived by (1) dividing vehicle trips by average vehicle occupancy, or (2) using a technique such as the TDM Model to produce a starting person trip table (note that the TDM model does not include non-motorized trips, however).
- **Areas with No Trip Tables:** Areas without trip tables have fewer analysis options, but can develop at least a rough estimate of mode split response to parking pricing if they can estimate total person trips, total vehicle trips (or average vehicle occupancy), and VMT through HPMS or another source. Elasticity methods can then be used to factor the base trip rates to reflect the

change in parking. Segmenting the base population by average trip length, if possible, may increase accuracy.

Generally, if an area's planning tools and data are limited to trip tables or gross trip and VMT measures, the range of policy options that can be evaluated is also limited. Only the most simplistic definitions can be considered, such as a uniform charge on all parking, which also raises questions as to realism of the assumptions and assessment of the impact (both locally and to EPA).

7. Parking Pricing and Time of Day

Parking pricing effects on time of day of travel are likely to be minimal in most cases; thus, no formal analysis is required. Shifts in travel time of day are anticipated only if parking rates varied substantially by time of day, in which case the analysis should be treated more like congestion pricing (Section 3.2.5-7). Presumably, most parking schemes directed at work travel would be in effect all-day, and thus traveling off-peak would offer no advantage. Restructuring daily rates vis-à-vis hourly rates away from all-day discounts for commuters and toward more favorable short-term rates, however, could induce non-work travelers to shift time patterns. Analysis of such effects is quite complicated and requires either fairly specialized tools or off-line methods (see Section 3.3.7).

8. Parking Pricing and Traffic Assignment/Route Choice

Parking pricing is likely to have limited or no direct effect on traffic assignment. Parking pricing applied in a special geographic pattern (e.g., downtown peripheral parking zones) may, in some cases, generate micro-level traffic concerns. If these threaten to be significant, then traffic microsimulation procedures should be considered (see Section 3.3.8.3 for more information).

Areas with traffic assignment as part of their transportation analysis process are expected to perform a new assignment to reflect the impacts of mode choice and trip distribution analyses on vehicle trip patterns and their corresponding VMT levels in the travel network. These inputs are necessary for application of the emissions model in the next step. Areas lacking traffic assignment capability must rely on net changes in vehicle trips and VMT to perform emissions analysis.

9. Parking Pricing and Emissions

All analyses of parking pricing should conclude with an estimate of the net changes in VOC, NO_x, and CO. Areas with PM_{10} attainment problems also should evaluate changes in anticipated PM_{10} emissions. Parking pricing is not expected to alter emissions rates or emissions analysis factors related to baseline vehicle mix. However, because shorter trips are likely to be most affected by parking pricing, emissions analysis cold start factors should be adjusted or evaluated separately to account for changes.

Areas with traffic assignment capability are advised to use results from the traffic assignment process in an emissions factor model, such as MOBILE or EMFAC (PART5 where appropriate), to generate estimates of emissions (see Section 3.3.9). Areas without traffic assignment capability are limited to application of emissions factors to net changes in vehicle trips and VMT (also see Section 3.3.9), again accounting for possibly disproportionate changes in cold starts.

3.2.2 Modal Subsidies

3.2.2.1 Anticipated Impacts

Modal subsidies are expected to have their primary impact on Mode Choice. The reduced cost of the subsidized mode increases its attractiveness relative to all other modes, particularly driving alone. Subsidies could include reductions in cost for transit users, rideshare travelers, walkers, and cyclists. Modal subsidies also might include incentives for alternative work arrangements (e.g., telecommuting, compressed work weeks).

Impacts depend on the subsidy level (and its net value to the recipient), mode or modes subsidized (modal competition), and quality of the alternatives (service/coverage). Subsidies can increase the attractiveness of destinations where the alternatives are best deployed, which could affect trip distribution and long-term land use decisions.

Subsidies that affect peak/off-peak differences could trigger time of day shifts. Significant subsidies could possibly influence vehicle ownership decisions, but probably more as a secondary result of household relocation.

Table 3.2 Impacts of Modal Subsidies

Analysis Step	Impact Form	Impact Type	Impact Indicator
Land Use/ Activity Allocation	Areas where subsidy applied can be more attractive	Trace (Secondary level if significant)	Population and/or employment by zone
Vehicle Ownership	May eliminate need for multiple vehicles	Trace	Vehicles per household per zone
Vehicle Mix	None	None	Percent of vehicles by VMT
Trip Generation	Could induce non-motorized trips or alternate work schedules	Trace	Number of person trips to/from each zone
Trip Distribution	Destinations reachable by subsidized mode more attractive	Secondary	O/D patterns (average trip length)
Mode Choice	**Encourages use of subsidized modes**	**Primary**	**Person trips by mode; % transit; no vehicle trips; Average vehicle occupancy**
Time of Day	Shift trips to periods with most subsidy benefit	Secondary (if time of day differs)	Trips by time period
Traffic Assignment	Shift in trips and VMT as result of mode choice & distribution	Derivative effect	Link volumes; VMT
Emissions	Reduce vehicle trips and VMT	Derivative effect	Tons or kg. of VOC, NO_x, CO, PM

3.2.2.2 Basic Analysis for Modal Subsidies

In addition to the standard analysis of emissions, agencies should carefully assess the impacts on mode choice (person trips by mode) and, in turn, mode choice effects on overall vehicle trips, VMT, and emissions. If subsidies are mode-oriented, submitting agencies should investigate the effects on other modes. If subsidies favor particular locations, in terms of modal access or other amenities, agencies also should address the indirect impacts on trip distribution and land use.

3.2.2.3 Guidelines for Analysis

1. Modal Subsidies and Land Use/Activity Allocations

Modal subsidies are unlikely to affect long-run locational patterns unless they are substantial, considered permanent, and linked to concurrent investment in alternative mode and/or land use/urban design strategies that complement the subsidy; these latter also would add to the sense of permanence. EPA does not require a formal analysis of subsidy impacts on land use unless the nature of the subsidy suggests an obvious impact on long-term trends; in this latter case, EPA requires a statement of possible effects.

2. Modal Subsidies and Vehicle Ownership

Modal subsidies are expected to have little or no direct impact on vehicle ownership and, thus, no formal analysis is required. If an agency feels its subsidy program will directly affect vehicle ownership levels, the agency should present appropriate assumptions or analysis to support this claim.

There may be an indirect effect on vehicle ownership, however, if modal subsidies are expected to affect land use through household shifts to areas with lower rates. Advanced analysis could then include a re-run of vehicle ownership evaluation to reflect anticipated land use impacts.

3. Modal Subsidies and Vehicle Mix

Modal subsidies are expected to have little or no impact on vehicle mix and, thus, no formal analysis is required. Since modal subsidies can have differential effects on different trip types and lengths, however, shifts in usage patterns may be important in determining the regional fleet mix used in the emissions estimation step.

4. Modal Subsidies and Trip Generation

It is unlikely that modal subsides will have a measurable impact on the overall number of *person trips* generated by households. However, an analytical problem arises if trip generation is only performed for vehicular trips since the overall vehicle trip reduction effects will be understated if a subsidy draws travelers from private vehicle to transit, non-motorized or telecommuting modes.

Modal subsidies might influence household trip generation, and estimates of trip generation, through:

- Shifts to or from non-motorized modes, if those modes are not reflected in trip generation estimates; and/or
- Attraction of non-work trips to subsidized transit that may have not been made previously, or were made by non-motorized mode (and not included in the trip generation rate).

While a formal analysis is not required, the performing agency may wish to estimate modal subsidy impact on trip generation if the proposed subsidy:

- Stimulates alternative work arrangements;
- Involves transit or non-motorized modes; and
- Is set at a significant level (e.g., free off-peak transit).

While there are no known formal methods (i.e., methods typically included in a complete regional travel demand modeling analysis) for dealing with these impacts, the user may consider off-line or sketch planning techniques such as described in Section 3.3.6.6 (Special Modes) and 3.3.6.9 (Off-line Methods). If the agency does not perform an analysis, it should offer an assessment of the anticipated impact of the subsidy on vehicle trip generation.

5. Modal Subsidies and Trip Distribution

Subsidies that favor travel to particular destinations can affect destination choices. The effects on destination choice for work-related trips would only be realized in the longer term; the effects for non-work trips, however, could well be realized in the shorter term. Trip lengths also may be affected, depending on the nature of the subsidy (whether it is fixed or distance-based).

As these effects are likely to be secondary, a formal analysis is not required. If subsidies are significant, however, agencies should provide a statement of possible effects on trip distribution. Agencies with trip distribution models can perform an analysis of modal subsidy effects on destination choices.

Models that incorporate a *composite impedance* measure (see Section 3.3.5.1) can estimate the effect of most subsidies directly, by altering the respective generalized travel costs for each affected origin-destination pair. This approach is generally effective for motorized modes. Current techniques, however, do not deal well with subsidies that greatly influence the choice between non-motorized and motorized mode destination choices.[2]

If subsidies vary by destination, a different pattern of destination choices in the trip table would be expected to result. Analysis should be disaggregated by trip purpose and should account for differences in income though income stratification or other techniques (see Section 3.3.5.2).

Areas without trip distribution models of the type described here will not be able to perform this analysis. These areas are advised to exercise caution when interpreting the modal choice effects of subsidy policies and should state how failure to account for changes in trip distribution might affect their final analysis.

6. Modal Subsidies and Mode Choice

Because modal subsidies are expected to have their greatest impact on mode choice, formal analysis should be used. All areas considering modal subsidies should furnish an estimate of the change in the number of person trips by mode, the change in number of vehicle trips and average vehicle occupancy, and the change in the percent of travelers using transit as a result of the particular policy.

Modal subsidies alter the relative cost and attractiveness between subsidized and unsubsidized modes, thus altering competition among the modes for person trips. Modal subsidies are expected to have limited or no impacts on commercial travel or through travel. Because the relationships are complex, areas with mode choice models in their planning systems are encouraged to use them for this analysis.

EPA offers the following guidelines to help agencies develop the best possible mode choice analysis:

Areas with Mode Choice Models

- **Type of Model:** Multinomial logit (or similar probability-based) choice models will provide the best estimates of impact, provided the relevant modes are included in the model structure. Nested models are expected to provide the most accurate estimates (see Section 3.3.6.5).

- **Suitable Modes/Coefficients:** Since most mode choice models include cost relationships for transit fare and automobile operating cost, they can accommodate many subsidy policies. Coefficients suitability is addressed in Section 3.3.6.1. If subsidies for HOV travel involve parking discounts, then

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[2] It would be necessary to incorporate measures of bike/pedestrian generalized cost measures into the models. Initially, such models would need to be estimated where there is a large difference in non-motorized mode utility and use, with a transfer of coefficients to regions lacking such diversity, using choice model coefficient scaling (see section 3.3.6.8).

use of a parking coefficient may be appropriate (see Sections 3.3.6.9 and 3.2.1.6).

- **Accommodation of Modes:** In order to test the full range of modal pricing options, the mode choice model should incorporate different costs for each sub-mode (e.g., walk to transit, drive to transit, drive alone, 2-person carpool, 3-person carpool, 4-person carpool, and perhaps even vanpool, walk and bike). Not all models accommodate such refinements. Alternatives include use of the TDM Evaluation Model (Section 3.3.6.9), which allows subsidies to be targeted individually to various carpool levels, vanpools, and transit, and distinguishes between direct out-of-pocket and less direct per-mile costs. Most model systems (including the TDM Model) do not accommodate non-motorized modes. Areas considering subsidies to these modes will need to consider off-line methods for their evaluation (see Sections 3.3.6.6 and 3.3.6.9).
- **Non-Work Mode Choice Models:** Mode choice analysis of modal subsidy impacts should be performed separately for each separate trip purpose; use of factoring methods is discouraged (see Section 3.3.6.4).
- **Income Stratification:** The performing agency should perform mode choice analysis separately for each income stratum, or use an alternative approach to address income group differences in sensitivity and impact (see Section 3.3.6.3).
- **Cost Basis:** Costs should be specified on the basis of a (daily) one-way trip.
- **Adjustment for Inflation:** The dollar value implied by the proposed subsidy should be deflated for consistency to model coefficient's year of calibration (see Section 3.3.6.2).
- **Special Policy Definitions:** Certain subsidies may be difficult to test with existing models because they may require specialized information; for example, parking cash out requires knowing whether the commuter currently has free parking, whether the employer leased the parking, and what the value would be to the employee back as a subsidy. Policies of this nature can sometimes be addressed through *sample enumeration methods* (see Section 3.3.6.7) or use of *stated preference* methods (see Section 3.3.6.8).

Areas without Mode Choice Models

Areas that do not have mode choice models will have a more difficult time assessing subsidy policies, but may still do so. Suggestions for these areas are as follows:

- **Areas with Person Trip Tables:** If agencies have access to trip tables based on person trips (by individual trip purpose), they can estimate the impact of modal subsidies on modal shifts through application of one of the following methods:
    - Quick Response Methods: Mode choice analysis can be achieved with a number of techniques that use sketch planning or pivot-point

methods. These include the FHWA's TDM Evaluation Model and the QRS software system (see Section 3.3.6.9 for more information).

  - Elasticities: Mode choice analysis can be approached through application of pricing elasticity estimates from empirical studies or from mode choice models of similar areas (see Section 3.3.6.9 for more information and references). It must be stressed that elasticities will vary widely from region to region, depending on base costs, travel times, and mode shares as well as socio-economic factors.

- **Areas with Vehicle Trip Tables (not Person Trip Tables):** Some areas perform analysis using vehicle trip tables only. It is still possible to evaluate mode choice responses to parking pricing if the agency first generates an estimate of person trips and then uses the derived estimates with either of the methods identified above. Person trips can be derived by (1) dividing vehicle trips by average vehicle occupancy, or (2) using a technique such as the TDM Model to produce a starting person trip table (note that the TDM model does not include non-motorized trips, however).
- **Areas with No Trip Tables:** Areas without trip tables have fewer analysis options, but can develop at least a rough estimate of mode split response to parking if they can estimate total person trips, total vehicle trips (or average vehicle occupancy), and VMT through HPMS or another source. Elasticity methods can then be used to factor the base trip rates to reflect the change in parking. Segmenting the base population by average trip length, if possible, may increase accuracy.

Generally, areas that are limited to trip tables or gross trip and VMT measures can evaluate only a limited range of policy options and consider only the most simplistic policy definitions.

In all cases, more advanced analysis includes the use of separate models for each purpose, disaggregated by income levels, and an accompanying supplemental analysis to assess the effects on the use of subsidized or non-motorized modes.

7. Modal Subsidies and Time of Day

Modal subsidies can have secondary effects on time of day of travel, but, in most cases, the effects are expected to be minimal and formal analysis is not required.

Subsidies that entail major peak/off-peak differentials may trigger migration into or out of peak periods, particularly for non-work trips. Since ridesharing is almost exclusively a commuter mode, ridesharing subsidies are not expected to produce much of a shift in time of day unless time of day differentials include off-peak periods close to conventional work day beginning and end.

Subsidy-induced differentials in transit pricing by time of day, however, could produce travel time shifts—lower off-peak fares would be expected to attract non-work riders and a small number of workers, while relatively lower peak fares might draw some non-work trips into the peak, as well as some work-based transit trips.

If time of day impacts are considered possible, methods such as those described in Section 3.3.7 may be of use. In the particular case of transit, time of day demand information may be available through studies (possibly local) of transit peak/off-peak fare adjustments.

8. Modal Subsidies and Traffic Assignment

Modal subsidies are not expected to exert any special influence on traffic assignment. Areas that have traffic assignment as part of their transportation analysis process, however, should perform a new assignment analysis to reflect the impacts of mode shifts on vehicle trip and VMT levels, and to accommodate these changes in the travel network pattern. These inputs are necessary for application of the emissions model in the next step.

Areas which do not have traffic assignment capability must rely on net changes in vehicle trips and VMT to perform emissions analysis.

If HOV subsidies are high enough, demand may justify new or expanded HOV facilities. Regarding analytical procedures, this would require some additional effort in network coding and assignment procedures; however, this would be a categorically different policy from a straight HOV subsidy and would argue for a formal HOV analysis.

9. Modal Subsidies and Emissions

All analyses of modal subsidies should conclude with an estimate of the net changes in the major pollutants for which they are claiming credit. Modal subsidies are not expected to affect emissions through emissions rates or through changes in regional vehicle fleet distribution; thus, no special attention need be paid to these impacts in the emissions analysis process.

Areas with traffic assignment capabilities are strongly encouraged to use an emissions factor model, such as MOBILE or EMFAC or PART5, to furnish estimates of emissions, using the results from the traffic assignment step (see Section 3.3.9).

Areas without traffic assignment capability are limited to application of emissions factors to net changes in vehicle trips and VMT (see Section 3.3.9), accounting for the possibly disproportionate changes in cold starts.

3.2.3 Pump Charges

3.2.3.1 Anticipated Impacts

Pump charges (or similar VMT-based fees) increase the per-mile cost of driving. This is expected to reduce the demand for private vehicle travel. The expected primary impact is on mode choice, though significant price increases also could affect trip distribution, long-term locational decisions (land use), and possibly trip generation. Households also are expected to react to higher fuel prices by shifting to ownership and/or use of higher-mpg vehicles, thus affecting vehicle mix.

Table 3.3 Impacts of Pump Charges

Analysis Step	Impact Form	Impact Type	Impact Indicator
Land Use/ Activity Allocation	Causes location in less auto-dependent areas	Secondary	Population and/or employment by zone
Vehicle Ownership	If shifts in location encouraged	Trace	Vehicles per household per zone
Vehicle Mix	**Shift to higher mpg vehicles**	**Primary**	**Percent of vehicles by VMT**
Trip Generation	Overall higher cost of travel	Secondary	Number of person trips to/from each zone
Trip Distribution	Causes shorter trips/closer destinations	Secondary	O/D patterns (average trip length)
Mode Choice	**Decreases private vehicle use**	**Primary**	**Person trips by mode; % transit; no vehicle trips; Average vehicle occupancy**
Time of Day	None	None	Trips by time period
Traffic Assignment	Change in trips and VMT; may affect speeds	Derivative effect	Link volumes; VMT
Emission Analysis	Reduces vehicle trips and VMT; may affect speeds	Derivative effect (possible change in vehicle mix)	Tons or kg. of VOC, NO_x, CO, PM

3.2.3.2 Basic Analysis for Pump Charges

Aside from the standard analysis of emissions, analysis of pump charges should include mode choice (person trips by mode) and the effect of mode choice shifts on overall vehicle trips, VMT, and emissions. Agencies also should address the implications of a potential shift to higher-mpg vehicles on effective operating cost and vehicle mix (which, in turn, affects factors used in emissions analysis).

3.2.3.3 Guidelines for Analysis

1. Pump Charges and Land Use/Activity Allocations

Pump charges (or VMT fees) influence long-run locational patterns by favoring locations that support reduced dependence on private vehicles (e.g., better walk access, availability of transit, etc.). Because this is designated as a secondary impact, a formal analysis is not required; however, EPA expects some acknowledgment of the long-range impacts.

If pump charges (or VMT fees) are significant, they may influence land use/locational effects. Although a formal analysis is not required, any agency anticipating major changes in pump prices should submit at least a statement of likely long-term impacts on regional development trends, travel, and emissions. The agency may or may not support this statement with a more rigorous analysis of anticipated impacts.

Areas with *land use allocation models* (see Section 3.3.1.2) that incorporate transportation cost through some measure like *composite impedance* (see Section 3.3.5.1) may wish to use these models to investigate potential land use impacts as part of their advanced analysis. Another approach would be to consider one or more alternative growth scenarios that: (1) are based on a system of higher travel costs, (2) incorporate alternative transportation investments, and (3) include various land use/urban design elements (Section 3.3.1.1).

2. Pump Charges and Vehicle Ownership

Pump charges (or VMT fees) are unlikely to directly affect overall levels of vehicle ownership and, thus, no formal analysis is required. If shifts in land use/locational patterns are projected in Step 1, however, then these changes should be carried forward into a revised assessment of vehicle ownership.

3. Pump Charges and Vehicle Mix

Given the primary impacts anticipated, submitting agencies should indicate their assumptions regarding the effects of pump charges on vehicle mix.

Assuming that program-based pump charges are proportional to gallons of fuel purchased (rather than set as fixed fees per transaction or based on recorded VMT), households can be expected to respond by gradually shifting ownership and/or use to higher-mpg vehicles.[3] Shifts to higher-mpg vehicles could have two effects:

1. Offset some of the gains from pump-based charges by reducing cost-per-mile of surcharges; and
2. Shift the mix of vehicles reflected in the emissions model, thus the effective emissions rate.

If the increase in fuel price will be significant, the performing agency should assess the shift in ownership and usage to higher-mpg vehicles. This assessment could employ:

- Forecasting tools, such as hedonic or other vehicle share models (see Section 3.3.3.1);
- Scrappage models and studies (see Section 3.3.3.2);

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[3] If ongoing emissions charges are pure VMT-based charges (using smart-card or other mileage tracking technology) where fuel consumption is not used as a proxy or intermediate variable, there is no incentive to shift to higher-mpg vehicles.

- Empirical/research studies or trend data (see Section 3.3.3.3);
- Stated preference analyses (see Section 3.3.3.4); and
- Elasticity methods (see Appendix A discussion related to Vehicle Registration Fees).

Clearly, this assessment has applicability beyond those agencies that employ vehicle ownership as a formal part of their planning system, since this assessment gauges the changes in average mpg, cost per mile of driving, and vehicle distribution variables used for emissions analysis.

4. Pump Charges and Trip Generation

Because pump charges increase the overall cost of vehicle usage for all trips regardless of purpose, they could have an impact on the number of activities that households support with trips, i.e., trip generation. More likely, however, households would adjust *trip characteristics* without altering the *number of trips*, for example, by favoring other modes, shorter trips, and increased trip chaining. Thus, formal analysis of the impact of pump charges (or VMT fees) on trip generation is not needed.

In general, EPA encourages agencies to do the following:

- Re-assess trip generation if land use or vehicle ownership shifts are projected in earlier steps *and* the agencies have trip generation models based on these inputs; and/or
- Perform an assessment of the impact of increased pump charges (or VMT fees) on trip generation if the agencies have trip generation models able to reflect cost through a measure such as *composite impedance* (see Section 3.3.5.1).[4]

Agencies basing trip generation on *vehicle serviceable* or *vehicle only* person trips rather than all person trips may face concerns regarding accuracy in this step since higher fuel prices can shift trips to non-motorized modes. These agencies may use off-line methods to approximate mode-choice shifts (see discussion below in sub-section 6). EPA encourages these agencies to upgrade their models to deal specifically with non-motorized trips in the future.

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[4] A difficulty in modeling the influence of an increase in the cost per mile of automobile travel is that at the trip generation stage of a four-step model, there is no specific trip length from which to gauge the actual increase in the user cost of travel. Also, for transit users and bicyclists, there would be no increased user cost. One way around this is to use the mode choice model to calculate a composite accessibility variable which reflects changes in the generalized price of reaching all destinations via all modes. There are few current trip generation models that are sensitive to user cost (see Section 3.3.4.1.).

5. Pump Charges and Trip Distribution

Vehicle *per mile* charges will have a secondary effect on the distribution of trips. By increasing the effective separation between zones, *longer-distance trips* will have a higher price and thus be discouraged. The impact on work trips is expected to be long term, while the impact on non-work trips could be realized in the near term.

Although formal analysis is not needed, submitting agencies should submit a statement of possible effects. Agencies that anticipate significant increases in pump prices as a result of the proposed policy should perform a trip distribution analysis in relation to the higher fuel prices if they have trip distribution models that:

- Accommodate costs through measures such as *composite impedance* (Section 3.3.5.1); or
- Incorporate travel time approximation techniques (Section 3.2.5.3.).

Where possible, this analysis should be performed separately by trip purpose and income level. In addition, if the price per gallon is likely to trigger a shift to higher-mpg vehicles, agencies should consider the effect of this shift on cost per mile.

Areas that do not have trip distribution model capability, or that anticipate only insignificant changes in prices, should document their assumptions and effects on final results.

6. Pump Charges and Mode Choice

Because pump charges (and VMT fees) are expected to have a primary effect on mode choice, a formal assessment of anticipated effects should be conducted.

Pump charges (or VMT fees) increase the per-mile cost of private vehicle travel both absolutely and relative to other modes; this should increase the demand for alternative modes. Transit and non-motorized modes would be exempt from price increases, thus improving their comparative cost position. Although rideshare modes would be assessed as private vehicles, this mode would still enjoy a cost advantage over solo driving since the increased price would be distributed among several travelers. Although the comparative cost positions of bike and walk modes also are improved, these modes may be less affected because of the short trip length (small total cost impact for competing automobile trips). However, significantly higher fuel prices could generate more non-motorized trips to closer destinations. Commercial vehicle trips could be affected depending on the nature of the business activity.

Areas with Mode Choice Models

Areas with mode choice models should use them to evaluate mode choice effects of pump prices (see Section 3.3.6 for model characteristics). In using these models, agencies should increase operating costs for all private vehicle modes by the increase in cost per mile times the origin-destination trip length as determined from the highway distance matrix. The following guidelines should be applied to this analysis:

- **Calculation of Cost Impact:** For a VMT fee, the increase in cost per mile is direct. For pump charges, the incremental cost per mile must be determined by first dividing the change in price per gallon by the average mpg of the regional vehicle fleet. *In the event of significant price increases yielding a shift in the vehicle mix toward higher mpg vehicles, the revised average mpg should be used to estimate the tested per-mile cost impact.*
- **Control for Inflation:** Agencies should ensure that the cost increase input to the model has been inflation-adjusted to match the year of calibration of the model coefficient (see Section 3.3.6.2).
- **Income Stratification:** The mode choice analysis should be performed separately by income strata, or with an acceptable alternative approach (see Section 3.3.6.3).
- **Trip Purpose Distinctions:** Separate mode choice models should be applied for each trip purpose (see Section 3.3.6.4).

Areas without Mode Choice Models

Areas without mode choice models may estimate mode choice impacts from pump charge or VMT fee policies using less formal methods. Suggestions for these areas include:

- **Quick Response Methods,** which include computer software methods like the FHWA TDM Model and the QRS system (particularly useful for areas with trip tables); and/or
- **Elasticity and Sketch Planning Methods,** which include various pivot-point methods and elasticity estimates that may be applied to either a trip table base or more aggregated travel estimates.

These techniques and their application are detailed in Section 3.3.6.9. Areas that do not formally account for non-motorized modes in mode choice may wish to do so by considering one of the off-line methods listed in Section 3.3.6.9.

Areas without formal mode choice models or trip tables are cautioned that their analyses may have questionable accuracy with respect to differences among travelers regarding trip purpose, trip length, modal alternatives, and income level.

7. Pump Charges and Time of Day

There could be a second-order effect on peak/off-peak travel distribution to the extent that total vehicle trips, VMT, and congestion are reduced by pump charges (or VMT fees). This effect, however, is not expected to be measurable; and no analysis is needed.

8. Pump Charges and Traffic Assignment

Most of the impact from pump charges (or VMT fees) on traffic assignment is likely to come from reductions in length and number of vehicle trips. However, increases in the per-mile cost of driving also may affect route selection for given origin-destination pairs. If the additional cost is high enough, it will encourage drivers to select paths that minimize cost as well as time (e.g., selecting shorter but less speedy routes). In general, these effects are expected to be at the trace level, and standard assignment analysis is expected only of those agencies with assignment procedures.

Agencies with appropriate capabilities can estimate traffic assignment impacts of pump charges by building highway paths based on a combination of travel time and user cost, using the per-mile user cost of vehicle operation and an assumed average value of travel time to motorists. All major software packages are believed to provide this capability.[5]

Areas without traffic assignment capability must rely on net changes in vehicle trips and VMT to perform emissions analysis.

9. Pump Charges and Emissions

All analyses of pump charges (or VMT fees) should conclude with an estimate of net changes in VOC, NO_x, and CO (and PM_{10} for areas with PM_{10} problems). The impacts on emissions are expected to derive from projected changes in vehicle trips and VMT (without shifts in emissions rates), and shifts in mpg and possibly speeds from the traffic assignment step (with concomitant changes in emissions rates).

Areas with traffic assignment capability and with emissions factor models, such as MOBILE or EMFAC, are expected to use these procedures to estimate the emissions changes. PART 5 should be used if particulates are a problem. If analysis in Step 3 indicates a change in the regional vehicle fleet mix, then the agency should use the new vehicle distribution results to alter the distribution in the MOBILE or EMFAC model and resultant emissions factors (see Section 3.3.9).

Areas without emissions model capability, that is, areas that rely strictly on emissions factor estimates, should detail their assumptions and the procedures they used if they have modified their base emissions rates to reflect the shift in vehicle fleet mix.

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[5] It may be possible to make this analysis sensitive to income groups by first building (skim and assign) separate paths for each income group, so that low-income drivers are assumed to use routes that minimize vehicle operating cost and high-income drivers to use routes that minimize travel time.

3.2.4 Emissions Fees

3.2.4.1 Anticipated Impacts

Emissions fees, as defined for this guidance, consist of increases in vehicle registration fees based on some combination of vehicle emissions characteristics (age and/or emissions rate) and usage (odometer reading). The emissions element rather than VMT is presumed to be dominant; that is, emissions would account for the greatest variation in the level of the fee. (VMT-based fees are addressed as a variation of pump charges in Section 2.2.3.)

The primary impact anticipated is increasing ownership and greater usage of newer, low-emitting vehicles. If emissions fees are significant, they also could affect the number of vehicles owned. In turn, this could influence land use/locational patterns, which then affects trip generation.

If emissions fees are assessed infrequently, it is unlikely that they would have direct effects on *travel* unless education campaigns make people aware of the charges.

Table 3.4 Impacts of Emission Fees

Analysis Step	Impact Form	Impact Type	Impact Indicator
Land Use/ Activity Allocation	Lowers demand for auto-dependent environments	Secondary (if vehicle ownership is affected.)	Population and/or employment by zone
Vehicle Ownership	**Reduces demand for vehicle ownership**	**Primary**	Vehicles per household per zone
Vehicle Mix	**Increases ownership & use of newer/ low-emitting vehicles**	**Primary**	**Percent of vehicles by VMT**
Trip Generation	If vehicle ownership affected	Trace	Number of person trips to/from each zone
Trip Distribution	If vehicle ownership affected	Trace	O/D patterns (average trip length)
Mode Choice	If vehicle ownership affected	Trace	Person trips by mode; % transit; no vehicle trips; average vehicle occupancy
Time of Day	None	None	Trips by time period
Traffic Assignment	None	None	Link volumes; VMT
Emissions	**Changes vehicle mix, maintenance**	**Primary**	**Tons or kg. of VOC, NO_x, CO, PM**

3.2.4.2 Basic Analysis

Agencies proposing to introduce emissions fees should analyze the effects of this measure on regional vehicle mix and the subsequent effects on emissions attributable to a change in vehicle mix. Additional assessments should be used if significant impacts are anticipated for vehicle ownership and, from that, for land use and other secondary effects.

3.2.4.3 Guidelines for Analysis

1. Emissions Fees and Land Use/Activity Allocations

Two instances in which emissions fees could trigger land use/locational impacts, are:

1. *Major VMT component in fee:* If the emissions fee has a major VMT component, the cost per mile for vehicle use could deter vehicle use. In this case, analysis should follow the guidelines for pump charges as well (Section 3.2.3).
2. *Significant increase in automobile ownership costs:* If the emissions fee significantly increases the cost of vehicle ownership, it may deter vehicle *ownership*. A reduction in household vehicle ownership could increase the demand for location-efficient areas.

If the nature or magnitude of emissions fees are considered sufficient to affect vehicle ownership rates, EPA suggests that the performing agency address the potential impact on land use/locational patterns with a land use allocation model, if one is available and suitable, or through scenario testing. Agencies should prepare a statement that reflects the agency s assumptions of the potential impacts on long term location patterns and the overall impact on emissions if the agency (1) does not have appropriate analysis tools, or (2) elects to declare this impact to be insignificant.

2. Emissions Fees and Vehicle Ownership

Emissions fees can trigger a reduction in vehicle ownership if the fees cause a significant increase in costs of vehicle ownership. The performing agency should account for shifts in vehicle ownership if the agency (1) thinks that its proposed emission fee may have an impact on vehicle ownership levels and (2) uses vehicle ownership in its modeling process. The agency may use analytic methods or the best possible assumptions. Techniques suitable for this analysis include:

- Forecasting tools, such as hedonic or other vehicle share models (see Section 3.3.3.1);
- Scrappage models and studies (see Section 3.3.3.2);
- Empirical/research studies or trend data (see Section 3.3.3.3);
- Stated preference analyses (see Section 3.3.3.4); and
- Elasticity methods (see Appendix A discussion related to vehicle registration fees).

3. Emissions Fees and Vehicle Mix

Emissions fees are expected to have their primary effect on vehicle mix. Households would be expected to either replace high-emitting vehicles with cleaner ones, and/or shift use within multi-vehicle households in favor of low-emitting vehicles.

In some circumstances, such as in a revenue-neutral feebate approach, an emissions fee program could actually increase the number of motor vehicles by encouraging diversification in favor of low-emissions vehicles. This would be in contrast to recent trends toward vehicles with high weight/power/performance characteristics. If the agency s proposed strategy is likely to encourage net expansion in vehicle fleet size, the agency should address the effect of its proposed emissions fee program on overall vehicle ownership levels as well as on distribution.

Emissions fees also may affect the composition or use of commercial vehicle fleets registered in the affected jurisdiction. Emissions fees would not, however, affect through traffic or external travel vehicles.

Section 3.3.3 provides options that may be used to estimate shifts in vehicle mix.

4. Emissions Fees and Trip Generation

In general, emissions fees are expected to have only trace effects on trip generation. (Recall that infrequent assessment of emissions fees would mean limited direct impact on daily travel decisions.). Nonetheless, emission fee effects on the costs of vehicle ownership could lower the number of vehicles owned by households. In turn, this could affect trip generation analysis in jurisdictions that use models based on vehicle ownership. These agencies may wish to estimate the impacts on trip generation of changes in vehicle ownership.

Higher annual costs of ownership and operation of high-emitting vehicles also could discourage their use in favor of low-emitting vehicles in multi-vehicle households, thereby altering household interactions and travel decisionmaking. This could generate more errand chaining, and/or use of non-motorized modes, thus affecting trip generation for motorized trips and trip characteristics. It also could induce various other effects that influence mode choice, destination, or trip timing. Formal procedures to evaluate these impacts are not in common use; off-line techniques are the only realistic approach for addressing them (see recommendation under emissions fees and vehicle ownership above).

5. Emissions Fees and Trip Distribution

Emission fees are expected to have only trace effects on trip distribution. Although formal analysis is therefore not needed, some investigation of effects should be undertaken by agencies anticipating impacts on land use and vehicle ownership and by agencies contemplating fees with a significant VMT component.

Reduced vehicle ownership could have an effect on trip distribution results in models that employ vehicle ownership to estimate trip generation. If earlier steps in the analysis indicate changes in automobile ownership, areas with such models are advised to repeat the trip distribution step to account for ownership changes.

There are no known techniques, however, that permit direct assessment of trip distribution effects in response to changes in vehicle availability (i.e., vehicle ownership). One possible technique is to use a composite impedance approach (as defined in Section 3.3.5.1), stratified by vehicle availability. If the coefficients are arranged so that households with fewer vehicles are more sensitive to trip cost (as a surrogate for distance), then such households' trips would be more likely to be distributed to closer destinations, yielding a revised pattern of trips by origin-destination.

Trip distribution also might be affected by the VMT component of an emissions fee if that component is significant enough. It is difficult, however, to analyze the VMT-based impact because the relationship between a *periodic*—typically annual—fee and *daily* travel is uncertain.

In the absence of documented relationships, areas that believe the VMT component of their emissions fee to be significant are advised to use the same methods as they would for pump charges (Section 3.2.3.5), which are VMT-sensitive. Alternatively, such areas might consider one of the off-line techniques described in Section 3.3.6.

6. Emissions Fees and Mode Choice

Emissions fees are not expected to produce a major impact on mode choice. If the proposing agency believes the *VMT component* of a proposed fee will be a substantial element in mode choice, however, the agency should undertake a mode choice analysis similar to that specified for pump charges, incorporating the cost from the emissions fee as a change in operating cost.

Caution should be taken in treating the emissions fee as a cost element if the fee is administered infrequently (i.e., annually), since there is little information on travelers translation of periodic fees into daily/per mile costs. If the performing agency chooses to evaluate a mode choice effect in this instance, its assumptions regarding periodic fee assessment and its effect on behavior should be clearly documented.

Emissions fees can affect mode choice indirectly through changes in vehicle ownership. If prior analysis indicates an impact on vehicle ownership, agencies with a mode choice model that includes vehicle ownership in its specification may revise their estimates of mode distribution of person trips.

7. Emissions Fees and Time of Day

Emissions fees are not expected to have any measurable effect on the time of day of travel. Therefore, no analysis is needed.

8. Emissions Fees and Traffic Assignment

In general, emissions fee measures are not expected to exert any special effect on traffic assignment and, thus, no formal analysis is needed.

If travel changes are calculated in any of the preceding steps, for example, land use, vehicle ownership, trip distribution, or mode choice, then agencies with assignment procedures should use them to determine changes in vehicle trips and VMT. Areas without traffic assignment capability must rely on net changes in vehicle trips and VMT to perform the subsequent emissions analysis.

9. Emissions Fees and Emissions Calculations

Given the anticipated impact of emissions fees on emissions, EPA requires proposing agencies to (1) indicate how the vehicle fleet mix and VMT distribution will be changed by the particular fee structure, and then (2) revise the appropriate parameters in the emissions model (MOBILE or EMFAC; PART5 for PM areas) to reflect the impact on average emissions factors (see Section 3.3.9 for information on procedures to effect this change).

Emissions fees based on direct measurement of vehicle emissions output by inspection may result in improved maintenance and reduced emissions rates. EPA s Office of Mobile Sources has developed a methodology for estimating emission reductions from inspection/maintenance (I/M) programs. The methodology is based upon the observed effectiveness of different I/M short tests for identifying high-emitting vehicles and the observed emission reduction associated with commercial repairs resulting from I/M programs.

Areas without emissions model capability, which rely strictly on emissions factor estimates, must detail their assumptions and the procedures they use to modify existing emissions rates to reflect the shift in vehicle fleet mix.

If the proposed emissions fee policy is expected to generate changes in travel, resulting in a new travel assignment in Step 8 (or revised vehicle trips and VMT for areas without models), the submitting agency should calculate the revised levels of VOC, NO_x, CO, and PM_{10} (where it is an issue) due to these changes in travel and in fleet mix/emissions factors.

3.2.5 Roadway Pricing

3.2.5.1 Anticipated Impacts

The impact of roadway pricing on travel and emissions is complex. Traveler responses to roadway pricing are conditioned by roadway coverage (i.e., the extent and number of facilities that are priced), availability of alternatives, and trip purpose. Traveler responses include changes in destination, route, mode, and, under congestion pricing, time of day of travel. Activity planning may be effected to schedule trips more efficiently to minimize costs.

The impact on emissions depends on reduction in VMT and changes in flow conditions (reduced congestion). Location and land use can be affected in the long term by the pricing scheme.

Table 3.5 Impacts of Roadway Pricing

Analysis Step	Impact Form	Impact Type	Impact Indicator
Land Use/ Activity Allocation	Changes relative attractiveness based on pricing and alternatives to driving	Secondary	Population and/or employment by zone
Vehicle Ownership	Depends on type of location shift	Trace	Vehicles per household per zone
Vehicle Mix	None	None	Percent of vehicles by VMT
Trip Generation	May reduce vehicle trips if location shift or “area” fees	Primary if area-wide—otherwise, trace	Number of person trips to/from each zone
Trip Distribution	**Pricing affects access (cost/ time) of particular destinations**	**Primary**	**O/D patterns (average trip length)**
Mode Choice	**Use alternatives to avoid road price**	**Primary**	**Person trips by mode; % transit; %walk/bike; no vehicle trips; average vehicle occupancy**
Time of Day	**Congestion pricing causes time shifts**	**Primary (if congestion pricing)**	**Trips by time period**
Traffic Assignment	**Compound: reduces trips & VMT; causes route shifts**	**Primary**	**Link volumes; VMT**
Emissions	Reduces vehicle trips and VMT; also congestion & speeds	Derivative effect	Tons or kg. of VOC, NO_x, CO, PM

3.2.5.2 Basic Analysis

Submitting agencies should analyze the impacts of roadway pricing on mode choice, trip distribution and route choice through traffic assignment. Agencies considering congestion pricing forms of roadway pricing also should evaluate the anticipated impact of the measure on time of day of travel. Emissions analysis should reflect changes in vehicle trips, VMT, and speeds.

Roadway pricing is expected to have a secondary, rather than primary, impact on land use; thus, formal analysis is not needed. However, submitting agencies should include a statement that describes their assumptions and the measure s anticipated impacts on long-term land use.

3.2.5.3 Guidelines for Analysis

1. Roadway Pricing and Land Use/Activity Allocations

In the long term, roadway pricing is likely to affect locational patterns, particularly if roadway pricing is applied only to selected facilities. However, if a large number of facilities are priced then it becomes very difficult to make longer trips without paying. In that case there is a strong incentive to avoid vehicle trips, particularly longer ones. In turn, businesses and households have an incentive to shift to locations that either (1) are not dependent on priced roadways or (2) will benefit from higher levels of service on the priced roads. Area-wide pricing reduces or even eliminates incentives to re-locate. The degree and pattern of relocation depend on roadway pricing rates and scope of the coverage. Substantial improvement of alternatives and supportive land use planning together with roadway pricing, would positively reinforce these trends.

Although a formal analysis of roadway pricing effects on land use is not needed, submitting agencies should include either (1) an assessment of the implications of the proposed policy on travel and emissions or (2) a statement that describes the area's assumptions and interpretation of potential impacts. This statement should reflect the appraisal of area decisionmakers as to the impact on long-term land use and transportation plans and programs.

Performing agencies with access to *land use allocation models* (Section 3.3.1.2.) that incorporate transportation cost through a measure like *composite impedance* (see Section 3.3.5.1) may use such models to investigate roadway pricing impacts on long-term development trends. Results should be treated with caution, however, in view of the analytical limitations of these procedures.

Submitting agencies (particularly those that do not use models for land use analysis) might consider formulating *alternative growth scenarios* (Section 3.3.1.1) to account for the effects on regional travel and emissions from roadway-pricing induced development shifts. These scenarios also should reflect any complementary actions with regard to land use alternatives or urban design.

2. Roadway Pricing and Vehicle Ownership

No direct impact is anticipated on vehicle ownership as a result of roadway pricing and, thus, no formal analysis is needed. If land use and household location shifts are projected in Step 1, however, these shifts may translate to revised vehicle ownership levels; agencies should account for these effects.

3. Roadway Pricing and Vehicle Mix

Roadway pricing is expected to have only limited impacts on the types of vehicles used by households and, therefore, regional vehicle fleet distribution; no formal analysis is suggested.

4. Roadway Pricing and Trip Generation

Roadway pricing can have a measurable direct impact on household person trip generation. This is particularly true when an area-wide pricing policy is pursued. EPA suggests, when an area-wide pricing policy is pursued, that analysis of trip generation should be conducted. Areas with trip-generation models that incorporate a measure of generalized transportation cost (i.e., composite impedance) are encouraged to use those methods to assess the impact on trip generation (see Section 3.3.5.1.). Use of these techniques is likely to show significant impacts on total trip generation, and it would be beneficial for areas to develop this capability if they are considering area-wide pricing. Shifts in land use and vehicle ownership should be carried through to the trip generation stage when area-pricing is being modeled.

Roadway pricing that focuses on a single corridor or facility is less likely to have major impacts on trip generation. In these cases, most of the impact will be from mode and route shifting, changes in destinations, and time-of-day (if congestion pricing is used). At a minimum, areas modeling single corridor pricing effects should document assumptions used for any anticipated changes in trip generation.

5. Roadway Pricing and Trip Distribution

Roadway pricing is likely to have a primary impact on trip distribution; thus, a formal analysis of anticipated effects is suggested. In the *short term*, roadway pricing is likely to affect only non-work trips through shifts in destinations selected in response to pricing patterns. In the *long term*, work as well as non-work trips could be affected as workers change their work and/or home locations to avoid the additional road price (These latter effects may be more appropriately modeled through the land use allocation step.).

Areas with trip distribution models that can account for the effect of cost through a measure such as *composite impedance* (Section 3.3.5.1) are encouraged to use those models to assess the impact of roadway pricing on the origin-destination patterns of non-work trips (both short-run and long-run) and work trips (long-run). Agencies should perform independent analyses for each trip purpose by income strata or use some other approach to account for income differences (Section 3.3.5.2).

Areas with trip distribution models that do not incorporate cost directly in their measure of separation may consider using a travel time approximation for the increased link cost (see Section 3.3.5.3).

Areas without trip distribution models will have difficulty accounting for roadway pricing impacts; these agencies may not be able to perform a realistic analysis given the complexity of roadway pricing programs. Pricing applications considered by these agencies would likely be limited to situations where chances for toll-avoidance are minimal (e.g., pricing of a strategic bridge or tunnel).

In contrast to some of the other market-based measures considered, road pricing can have a fairly important effect on commercial and through traffic. For commercial users, the existence of a road user charge may actually prove to be an advantage, given anticipated impacts on road congestion on priced roadways and the importance of travel time to commercial users. The ultimate net benefits depend on the nature of the goods or services being transported.

When travel time is of higher value than the anticipated increase in cost, local commercial traffic (as well as personal traffic) will be drawn to the priced facility if pricing results in higher levels of service. If pricing-induced increases in travel cost are considered important, however, trips will shift to unpriced facilities; this, in turn, may generate local traffic congestion and emissions problems.

Like local commercial traffic, through traffic will also weigh the toll costs against the value of time saved on priced facilities. Price sensitive through-travelers will shift to non-priced alternative routes or be inclined to pick an alternative route around the given region unless they simply know of no alternatives. Traffic response to trade-offs between time and money are difficult to assess with currently available methods, although new methods are under development.[6] Agencies wishing to assess these impacts are encouraged to do so within the limits of their analytic tools and data. All assumptions should be clearly documented.

6. Roadway Pricing and Mode Choice

Roadway pricing is likely to have a primary impact on mode choice. Agencies should submit a formal assessment of the impact of roadway pricing on person trips by mode, change in vehicle trips, and average vehicle occupancy and change in transit trips.

Areas with mode choice models in their planning systems are encouraged to use them for this analysis. However, it should be noted that the analysis of roadway pricing presents several important modeling issues and special requirements:

- **Network Representation of Tolls:** Modeling the pricing of specific roadways requires a concerted effort to represent the price in the highway network. This is equivalent to properly coding a toll value on all affected individual links. When coding is completed, the path-building and skimming software must be alerted to the presence of the toll and must be capable of creating a matrix that reflects the total toll cost of traveling on all

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[6] Three recent studies have directly addressed air quality and travel impacts of freight transportation.

Cambridge Systematics, Sierra Research, and Jack Faucett Associates, Air Quality Issues in Intercity Freight, prepared for the FRA, the FHWA, and U.S. EPA, draft final report, December 1996

Cambridge Systematics et al., A Guidebook for Forecasting Freight Transportation Characteristics Demand, NCHRP Report 388, National Academy Press, Washington, DC, 1997.

Cambridge Systematics, COMSIS Corporation, and Alan Horowitz, Freight Planning Manual, developed for the Federal Highway Administration.

origin-destination pairs. It is somewhat simpler to model area-wide pricing since the matrix manipulation program in most modeling software packages can build a cost matrix representing the additional cost of traveling into the affected area from any origin zone.

- **Mode Cost Sensitivity to Tolls:** Few mode choice models are set up to accept toll costs explicitly; most deal only with automobile operating cost and possibly parking cost. This leaves open the issue of what coefficient value to assign to tolls. If the toll is paid *physically* at the point of charge, it may be reasonable to treat it as an out-of-pocket cost comparable to parking and apply a parking cost coefficient (see Section 3.3.6.1). If the toll cost is determined *electronically*, with billing issued periodically, then it may be more appropriate to treat it as an operating cost. The agency should state the assumptions underlying its choice of coefficient. The agency also may wish to consider *stated preference* methods to ascertain the relevant sensitivity (see Section 3.3.6.8).
- **Queuing and Delay:** If tolls are collected through automatic identification methods (i.e., no toll booths), delays related to toll payment would be minimal. When tolls are collected manually, however, toll booth operations may well produce queue delays that affect (1) travel time on the facility and (2) micro-level traffic effects that contribute to emissions. Agencies may consider using traffic microsimulation methods to assess these effects (see Section 3.3.8.3).
- **Type of Model:** Multinomial logit, especially nested logit models, provide the most realistic estimates of mode choice impacts, particularly when toll treatment differs across modes (see Section 3.3.6.5).
- **Non-Work Mode Choice Models:** There should be a mode choice model for each separate trip purpose (see Section 3.3.6.4).
- **Income Stratification:** The mode choice analysis should be performed separately by income strata, or through an equivalent method that accounts for income differences (see Section 3.3.6.3).
- **Adjustment for Inflation:** It is important that the dollar value of the toll price be adjusted for compatibility with the base year for which the model coefficient was developed. This generally means *deflating* the tested price by a time-inflation factor that makes the costs compatible with the coefficient in real terms (see Section 3.3.6.2).
- **HOV Special Rates:** If the policy incorporates toll exemptions or discounts for HOVs, few mode choice models will provide sufficient analytical support. Off-line methods, such as the TDM Evaluation Model, are suggested for assessing this effect (see Section 3.3.6.9).

Areas *without mode choice models* will have a difficult time adequately assessing a measure as complex as roadway pricing. Off-line methods, which include quick-response techniques and sketch-planning/elasticity approaches (see Section 3.3.6.9), may be used with caution; agencies using such methods must document their assumptions regarding potential limitations of the analysis.

7. Roadway Pricing and Time of Day

If roadway pricing is applied evenly throughout the day, then only limited impacts on travel time of day would be expected. However, if the implementation involves peak/off-peak congestion pricing differentials, time of day shifts are anticipated; and these should be analyzed.

Current time of day analysis methods that employ peak factors are probably not sufficient to capture time of day effects. Modified procedures, such as those described in Section 3.3.7, may be considered. Analysts should estimate the specific sensitivity of travelers' start times to price differentials at different times during the day. Non-work trips are likely to exhibit greater sensitivity than work trips because of their greater flexibility (and perhaps cost sensitivity), although some workers may be able to shift hours outside the peak. The sensitivity of travelers' trip times to price differentials is uncertain in current practice, but it may be possible to make an assessment that can be refined subsequently using observed data. Such initial estimates may be based on empirical sources or on stated preference surveys (see Section 3.3.7.4).

All applications of roadway pricing that involve time of day price differentials *should* make an estimate of the time of day shift in travel, using approximation methods such as those described above for *broad* applications of the policy. However, agencies introducing more complex applications are expected to use more sophisticated analysis methods.

8. Roadway Pricing and Traffic Assignment

Roadway pricing has a special effect on traffic assignment because pricing of specific links in the highway network is likely to induce some shifting to alternative routes, particularly by cost sensitive travelers with some flexibility (lower income and non-work travelers). This would probably constitute the policy s primary effect and should be evaluated. Evaluating agencies should be careful to ensure that *all* alternative paths to the tolled network are represented in order to address the diversion issue.

Areas with traffic assignment models may perform an analysis of roadway pricing impacts on revised vehicle trips, VMT, and speeds using one of the following methods:

- **Toll Diversion Model:** Some areas have developed models that specifically offer travelers a choice of a *toll* or *free* path during assignment. This approach is described in Section 3.3.8.5.
- **Travel Time Equivalent:** A less accurate, but acceptable, approach is to translate the impact of the toll into a travel time equivalent (also described in Section 3.3.8.5). This approach, however, disregards the likelihood that travelers with a higher value of time will opt to use a tolled facility even at higher cost simply to take advantage of the improved travel time. That is, this method assumes away traveler willingness to pay for time saved.

Areas without traffic assignment capabilities will probably not be able to evaluate roadway pricing options unless alternative route choice options are greatly limited (e.g., isolated bridge or tunnel).

9. Roadway Pricing and Emissions

All analyses of roadway pricing should conclude with an estimate of the net changes in the major pollutants for which credit is being claimed.

If roadway pricing has an effect on emissions *rates,* it would be through changes in congestion levels, rather than through impacts on vehicle mix. That is, roadway pricing implemented as congestion pricing can affect emissions rates if it significantly affects level of service and travel speeds.

Areas able to perform traffic assignment are advised to use an emissions factor model, such as MOBILE or EMFAC (PART5 for particulate emissions), to furnish emissions estimates, using the results from the traffic assignment process (note that MOBILE produces emission *factor* estimates rather than estimates of emissions *amounts*).

Areas without emissions models may apply emissions factor estimating methods to the net changes in travel projected from traffic assignment.

Areas without traffic assignment capability are not expected to be able to perform this assessment, except in limited circumstances as earlier described.

■ 3.3 Review of Methods and Procedures

Clearly, the most reliable basis for projecting the impacts of changes in pricing levels—especially major changes—would be to statistically track and measure consumer response to such actions under (and in relation to) actual conditions. Before-and-after studies, possibly involving consumer panels, can provide great insight into the expected and unexpected nature of response. Unfortunately, there are relatively few studies (in the United States) in which such measurements have been made. It will be important to institute such monitoring systems in coming years and as new policies are tested to obtain a fuller understanding of consumer response.

In the interim, we must rely on existing planning and emissions analytic procedures and develop new ones. As indicated in Chapter 2, current capabilities vary widely across the U.S. Virtually all major urbanized areas and many smaller areas use some variation of the four-step planning process for all transportation-related analyses. This process portrays transportation decision-making as a series of sequential steps. The four core steps are trip generation, trip distribution, modal choice, and traffic assignment. These systems work from *trip tables* that describe travel movements between origins and destinations defined by traffic analysis zones. These trips are assigned to a coded transportation network to simulate actual traffic flows and conditions on actual facilities. Emissions analysis is then performed as a separate step, utilizing basic travel outputs (vehicle trips, VMT) from the four-step process.

In practice, there are many variations within each analytical stratum with respect to:

- Level of detail used to characterize travel by purpose, time of day, income and other socioeconomic differences;
- Detail in the travel networks; and
- Sophistication of individual models.

Smaller urbanized areas, where transit service is minimal or non-existent, may not have a formal mode choice capability (these systems are characterized as three-step models). In some areas, capabilities are even more limited. With this wide range of capabilities among areas that might consider market-based measures, it is difficult to prescribe use of particular methods or standard techniques. Rather, the objective of this guidance is to encourage areas to perform the best possible analysis using their existing tools and data, and to recommend special procedures that may help them to improve their analysis. Those with more sophisticated analytical capabilities will be rewarded with greater opportunity to receive emission credits.

It is commonly acknowledged that current-generation travel forecasting tools are not sensitive to pricing; rather, price sensitivity has had to be back-fit into their structure. These forecasting tools were developed primarily to guide the location and design of highway facilities; cost was not included in their structure because of an underlying assumption that the price of transportation would change at the same rate as inflation, thus would not be an important future criterion.[7] The gasoline crises of the 1970s and 1980s, together with federal requirements related to transit system funding, caused many areas to initiate upgrades to their models to formally include pricing.

Pricing sensitivity, however, is limited to mode choice in most models. It is reasonable to believe that the effects of many pricing measures will extend beyond mode choice to include destination choice, route choice, and even time of day; some of these may have even more significant impacts than mode choice. It also is reasonable to expect that longer-term effects on household or business locational decisions can affect land use, vehicle ownership, and trip generation.

Current models may be unable to deal with these broader impacts. In many areas, model capabilities are in a state of flux as they (1) undergo change and enhancement in response to the requirements of the CAAA and ISTEA and (2) respond to new data available from the 1990 Census and numerous urban area regional travel surveys.

Until agencies have greater experience with actual implementation of major pricing applications, there will be limited empirical evidence upon which to base or validate projected impacts from these measures. Hence, it is necessary to extract the best possible analysis from existing travel forecasting tools. There are numerous ways that these tools can be adapted to improve their sensitivity and accuracy in the evaluation of pricing measures. Adaptive procedures include:

- Accounting for cost throughout the travel demand choice hierarchy through a generalized cost measure such as *composite impedance* or *accessibility;*
- Sharpening estimates of *price coefficients* through special surveys or transferring coefficients or models from other sites;
- Improving sensitivity to differences in response by income level through i*ncome stratification* or similar techniques;
- Gaining initial insight into relationships between special pricing instruments and travel behavior response through *stated preference surveys*;
- Using *sample enumeration* methods to achieve greater specificity for particular measures as they are experienced by households and possibly greater accuracy in estimating response; and
- Use of *sketch planning* or *off-line methods* to support formal methods where tools or capabilities do not currently exist.

This section provides a brief review of the steps in travel forecasting that may be involved in assessing pricing actions and evaluating their impacts on travel and emissions. The intent is not to provide a full review of the transportation planning process, but rather to

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[7] Transportation cost also was a difficult element to include in model structures because of the models heavy reliance on travel time and the close correlation between [per-mile] cost and travel time for most trips in most U.S. urban areas.

draw attention to those aspects of the process that are important in relation to pricing. This section describes modeling concepts that offer improved accuracy for analyzing pricing and presents references for additional information on their development and use.

This section is designed to address the range of needs and capabilities that may exist among areas desiring to perform pricing analysis. Larger urbanized areas may include many of these concepts in their modeling systems, while other areas seek to develop such capabilities as part of a longer-term model enhancement process. Other areas with more limited capabilities may need help identifying more basic techniques, as well as help prioritizing future model development activities.

The reader is directed to two primary resources that serve as important guides for agencies involved in performing transportation air quality analysis:

1. ***Manual of Regional Transportation Modeling Practice for Air Quality Analysis***[8] (hereafter referred to as the NARC Manual), developed in 1993 for the National Association of Regional Councils, is a major resource on current model capabilities and deficiencies in relation to air quality applications. It provides a thorough review of the requirements of the Clean Air Act and their impact on travel forecasting tools, the nature and capability of current tools, and suggestions toward most effective methods. Numerous references to example sites and literature sources are provided.
2. ***Travel Model Improvement Program (TMIP)***[9], which is being jointly sponsored by the U.S. Department of Transportation, the U.S. Department of Energy, and the U.S. Environmental Protection Agency to foster both near and long-term improvements in travel forecasting tools. An October 1994 report on *Short Term Model Improvements*[10] provides a valuable update on model enhancements that are underway or in place for addressing air quality and other closely related modeling issues.

Both of these sources were used extensively in preparing the synthesis of analytic procedures in this section.

In addition to these two primary references, the reader should be aware of several key research projects now underway or recently completed which are charged with developing major enhancements and new approaches to the analysis of transportation-related emissions. These include:

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[8] Greig Harvey et al., A Manual of Regional Transportation Modeling Practice for Air Quality Analysis, National Association of Regional Councils, 1993.

[9] Cambridge Systematics, Inc., Travel Model Improvement Program: Short Term Model Improvements, prepared for the Federal Highway Administration, U.S. Department of Transportation, 1994.

[10] B. Spear, New Approaches to Travel Forecasting Models: A Synthesis of Four Research Proposals, Travel Model Improvement Program, Volpe National Research Center for the U.S. Department of Transportation and the U.S. Environmental Protection Agency, January 1994.

- **National Cooperative Highway Research Program (NCHRP) Project No. 8-33: Quantifying Air Quality and Other Benefits and Costs of Transportation Control Measures:** This study is undertaking a comprehensive review of the analytic techniques used for evaluating TCMs. It is also charged with designing a new framework that addresses the overall linkages between transportation, emissions, and atmospheric models. Computational limitations in each of the steps are to be addressed individually, as are those features that affect accuracy in the step-to-step linkages.

  Phase 1 of NCHRP Project Number 8-33 is complete, and copies of Phase 1 reports are available on loan from the NCHRP. Research papers based on Phase 1 work are expected to be available for review in Fall 1997. Working titles for these papers are Relationships between Implemented Transportation Control Measures and Measured Pollutant Levels, and Development of an Improved Framework for the Analysis of Air Quality and Other Benefits and Costs of Transportation Control Measures.

- **NCHRP Project No. 25-11: Modal Emissions Factor Development:** Undertaken by researchers at the University of California at Riverside, this study is charged with developing a new emissions-factor model that addresses the deficiencies of the current-generation MOBILE and EMFAC models with regard to sensitivity to vehicle and transportation inputs. Specifically, current models are insensitive to variations that occur in vehicle emissions under normal driving conditions where acceleration, idling, steady state, etc., produce very different emissions rates. Current models smooth over these variations by using emissions factors based on an average speed. This project is obtaining substantial new vehicle activity and emissions data. This data will be used to develop a modal emissions model that (1) is compatible with the types of traffic simulation models used to design and evaluate transportation operational improvements, and (2) accurately reflects the impacts of speed, engine load and start conditions on emission.

  Research has been completed for Phase 1 of NCHRP Project Number 25-11. This phase called for 1) review of the existing literature on factors in the vehicle operating environment; 2) definition of the domain and distribution of the modal parameters of each vehicle operating mode; 3) evaluation of extent to which existing models meet analytical needs; 4) design of testing protocol to measure vehicle modal emissions; 5) preliminary testing of a sample of vehicles currently in use; and 6) development of a working model for analysis.

- **NCHRP Project No. 25-7: Improving Transportation Data for Mobile Source Emissions Estimate:** This study by the University of Tennessee and SAIC, et al., is specifically directed at appraising the data requirements needed for transportation/air quality modeling. Key elements of the research include: 1) identifying transportation variables that are available or needed for preparing air quality forecasts; 2) identifying techniques for quantifying these variables; and 3) describing the inter-relationships between transportation and emissions rates.

Project number 25-7 has been completed, and the final report will be available on a loan basis pending a publication decision by the NCHRP.

- **Air Quality Issues in Intercity Freight:** Sponsored by the U. S. DOT and EPA, this project has developed methods for evaluating the emissions impacts of intercity freight operations, especially truck and intermodal rail. Extensive work has been done to develop practical planning procedures to (1) realistically assess intercity freight travel characteristics and reactions to policy actions (TCMs), and (2) refine emissions factor estimates for these modes.

Finally, it also should be noted that this guidance document is followed by two technical appendices that may be of great relevance to reviewers:

- ***Appendix A: A Case Study Adaptation of a Regional Model to Increased Price Sensitivity***. Appendix A provides an illustrative, step-by-step example of how a typical four-step modeling process was strategically upgraded and enhanced to improve its ability to analyze pricing measures, and then applied to test a range of market-based measures. The base model that was transformed is the Greater Metropolitan Washington Council of Governments (MWCOG) model. The improvements are hypothetical; because the adaptation was done as a demonstration, typical steps to thoroughly validate the revised model were not performed, and the revised model is not in use by MWCOG. However, the case study model is useful in demonstrating how enhancements such as those suggested in this chapter could be made.
- ***Appendix B: An Example of the Application of the STEP Process to the Analysis of Pricing Strategies***. Appendix B illustrates how sample enumeration techniques can be used to link travel survey data and conventional modeling methods, which would provide additional flexibility and even accuracy to analysis of pricing measures impacts on air quality. These methods have been used to analyze pricing TCMs in Seattle, Washington and several California cities.

Neither of the approaches set forth in these appendices represent an analytic procedure prescribed by EPA. They are provided for illustration only, to show analysts how specific adjustments and innovative applications are being made to address the complex range of impacts that may derive from market-based measures. The procedures described also are useful in demonstrating two very different ways of approaching analysis of market-based measures through concerted direct modifications to the existing four-step process, and through a parallel approach that moves outside the conventional process for key analytic assessments. Both approaches have distinct advantages and disadvantages, which must be evaluated by the performing agency.

3.3.1 Land Use/Activity Allocation Methods

Most regional planning processes start with a procedure that allocates household and employment activity to specific geographic locations across the region. The pattern and level of these allocations then becomes the basis for all subsequent estimates of trip levels and flow patterns.

A key question for analysis of pricing measures is whether these locational decisions might be or should be sensitive to levels and variations of transportation pricing effects. This question has two levels: (1) real world sensitivity of household and business locational decisions to pricing measures and (2) analytical sensitivity of the transportation planning process to pricing measures.

This is perhaps one of the least precise steps in the current transportation analysis process, though it represents what can be a very significant factor in long-term travel trends and effectiveness of air quality and other management strategies. Currently, most land use allocation decisions are made through a process of negotiation, with considerable political involvement and concern. Market realism may or may not be prominent in this process.

There are two basic ways in which areas attempt to account more explicitly for the effects of market forces or transportation policy on growth allocations: scenario approaches and land use allocation models.

3.3.1.1 Scenario Approaches

Generally, population and employment allocations based upon hard data (including population and employment trends, land availability and price, land use occupancy and rent, zoning and land use decisions, economic development plans and market assessments, measures of current and anticipated transportation accessibility, etc.) are more realistic and sensitive to market forces than those based purely on fair share allocations or political aspirations. Some areas address their uncertainty in both level and distribution of growth by formulating one or more scenarios that are then carried forward into the analysis. These scenarios can be used to reflect major differences in expectations linked to pricing, urban design and zoning/growth management changes, or other policies. Analysts should take care that eventual emissions results that stem from these scenarios reflect realistic and implementable land use assumptions.[11]

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[11] Greig Harvey et al., A Manual of Regional Transportation Modeling Practice for Air Quality Analysis, 1993, Sec. 3.3.2, pp. 3-13 to 3-18.

3.3.1.2 Land Use Allocation Models

Formal mathematical models for land use allocation exist and are in use in a small number of regions. Options include DRAM/EMPAL[12] (most commonly used land use model in U.S.), POLIS[13] (currently used in the San Francisco Bay Area), the Herbert-Stevens Model[14] (used in the Penn-Jersey Study), MEPLAN[15], METROSIM[16], TRANUS[17], and TOPAZ[18]. A recent draft report prepared for EPA s Office of Mobile Sources provides a comprehensive review of the various land use modeling tools currently available.[19]

The models mentioned above generally use zone-level time series data on population, employment, land availability and accessibility to allocate population and employment forecasts to subareas. Use of these models has been limited, however, both by the effort required to run them and by questions about their predictive accuracy.

Factors that appear to limit the accuracy of current generation land use models include: a tendency to extrapolate past trends, rather than incorporate behavioral decision-making; a tendency to base household location decisions substantially on the work trip; limited accounting for market responses (real estate, speculative investments, ethnicity) and time-lags; and weak representation of transportation accessibility and cost.

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[12] S.H. Putman, DRAM/EMPAL - ITLUP: Integrated Transportation Land-Use Activity Allocation Models: General Description, S.H. Putman Associates, Philadelphia, Pennsylvania, 1991.

[13] P. Prastacos, Urban Development Models for the San Francisco Region: From PLUM to POLIS, Transportation Research Record 1046, 1985.

[14] J.P. Herbert and B.H. Stevens, A Model for the Distribution of Residential Activity in Urban Areas, *Journal of Regional Science* 2(2), 1960, pp. 21-36.

[15] MEPLAN was developed by staff at the Center for Land Use and Built Form Studies at Cambridge University, at the firm of Applied Research of Cambridge, and at the firm of Marcial Echenique and Partners. MEPLAN allocates exogenous forecasts of basic employment to analysis zones and then allocates non-basic employment and population to zones based on costs of travel, floor space, and the availability of other goods and services. Demand for accessibility generates rent levels, and land uses are segregated from one another based on capacity to pay rent.

[16] METROSIM models regional impacts on land use patterns and transportation systems that may result from project development, and was developed by Alex Anas of the University of Buffalo. The model can analyze impacts for up to 3,500 analysis zones. For each zone, METROSIM models employment, real estate demand, household demographic characteristics, and travel patterns.

[17] TRANUS shares many characteristics with MEPLAN. Development of the TRANUS model is outlined in T. de la Berra, Integrated Land Use and Transport Modeling, Cambridge University Press, 1989.

[18] J.F. Brotchie et al., Alternative Approaches to Land Use Modeling, Commonwealth Scientific and Industrial Research, United Kingdom, 1981.

[19] Systems Applications International, Inc., Evaluation of Modeling Tools for Assessing Land Use Policies and Strategies, draft report prepared for Office of Mobile Sources, April 1997.

These models can aid land use impact evaluations, provided they are applied with careful judgment. Similar to typical trip distribution models, land use models generally employ travel time in their allocation process. One way to enhance their utility for pricing analysis is to introduce pricing directly as a variable through a measure such as *composite impedance* (see Section 3.3.5.1). The Bay Area model system utilizes such a formulation, and would be worth further study by areas considering such enhancements and/or where the rate or pattern of growth is a major issue.

Readers are encouraged to consult the NARC Manual (Section 3.3.2) and the TMIP's review of Short-term Travel Model Improvements (Section 3.0) for more information on land use models and potential enhancements.[20]

3.3.2 Vehicle Ownership

Vehicle ownership is often used as an input for U.S. urban area model systems. Agencies in some areas use vehicle ownership rates (or a measure of vehicle availability) as a measure of households propensity to travel in trip generation and other modeling steps. Very few areas explicitly estimate a policy-sensitive model of vehicle ownership rates as part of their overall transportation modeling system. Most planning professionals believe that explicit representation of vehicle ownership results in more accurate and realistic transportation analysis. Evidence suggests that vehicle ownership influences person trip generation in ways that extend beyond the effect of income. Vehicle availability may have a key effect on discretionary trips and on the level of errand chaining. Households with fewer vehicles per licensed driver are more pressed to work out vehicle use priorities, which affects vehicle sharing decisions and use of non-motorized modes. Where residential densities and levels of transit service are high enough to affect vehicle ownership levels, explicit prediction of vehicle ownership would clearly be expected to increase forecasting accuracy.

Model systems that rely exclusively on household income and not vehicle ownership can still offer good accuracy, depending on how well income is specified as an explanatory variable. Generally, this means that other modeling steps must exhibit strong relationships between travel and income.

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[20] Throughout the remainder of this section, the Greig Harvey et al., publication entitled A Manual of Regional Transportation Modeling Practice for Air Quality Analysis, National Association of Regional Councils, December 1993, will be referred to as the NARC Manual.

The report by Cambridge Systematics, Inc., entitled Travel Model Improvement Program: Short Term Model Improvements, (prepared for the Federal Highway Administration, U.S. Department of Transportation, 1994), will be referred to throughout the remainder of this report as the Short-term Model Improvements Report.

There are several types of vehicle ownership predictive models. These include:

- **Cross-Classification Models:** tables of factors derived from Census or travel survey data (generally have no explicit linkage to transportation conditions).
- **Nomographs or Curves:** empirical curves that reflect the fraction of households owning a particular number of vehicles, based on household size and income level.
- **Mathematical Models:** actual equations that calculate the number of vehicles owned, based on the value of specific equation variables.

Generally, the form of model is less important than the sensitivity with which it reflects and responds to key socio-demographic and policy variables, especially pricing. Aggregation of key variables may affect accuracy levels. For example, some models produce an estimate of average vehicles per household rather than preserve the distribution of number of households by number of vehicles. The reader is encouraged to consult the NARC Manual[21] for a more detailed discussion of the attributes of vehicle ownership models.

In order to analyze the effect of pricing measures such as registration fees, these models must be somewhat sensitive to the price of purchasing a vehicle and the annual cost of owning one. In the context of travel modeling, increases in ownership cost should be reflected in decreased numbers of multiple-vehicle households and increased numbers of one-vehicle households (possibly even an increase in zero-vehicle households). The inclusion of ownership cost is not a common feature in current vehicle ownership models, presenting an area for research, along with composition and use of vehicles (discussed below under vehicle mix). At least one vehicle ownership model has been documented that is sensitive to user cost.[22]

3.3.3 Vehicle Mix

Vehicle mix, which is a special area of concern in modeling pricing impacts on vehicle ownership, is not accounted for in conventional vehicle ownership analyses. Vehicle ownership models account exclusively for the *number* of vehicles owned by a household, and do not deal in any way with the *characteristics* or use patterns of those vehicles. Yet, vehicle mix is an important factor for policies such as emissions-based registration fees or even fuel prices, where the respective economic forces may be more likely to influence the *type* of vehicle owned or its *relative use*, rather than the *number* of vehicles owned.

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[21] Greig Harvey et al., A Manual of Regional Transportation Modeling Practice for Air Quality Analysis, National Association of Regional Councils, December 1993

[22] K. Train, *Qualitative Choice Analysis, Theory, Econometrics, and an Application to Automobile Demand*, The MIT Press, Cambridge, Massachusetts, 1986.

The accuracy of emissions analyses based on an emissions factor model depends on the distribution of the regional vehicle fleet and its average emissions rates, which derive from vehicle distribution. Shifts in the age or type of vehicles owned would obviously affect this relationship, as would different patterns of use, since the distribution is weighted by VMT for analysis.

Typically, vehicle distribution is not directly considered by conventional travel analysis tools. Hedonic models, scrappage studies, empirical studies, special studies, and sample enumeration offer approaches to considering fleet vehicle mixes. It should be noted that there may be overlap between these categories of approaches. For example, empirical studies may include some examples of special studies. The bullets below provide brief descriptions of these analytical tools and some illustrative examples

- *Hedonic Models* These models analyze the relationship between consumer demand for *characteristics* of goods rather than for goods themselves. These models can be used, for example, to project price-induced shifts in ownership of vehicles with different characteristics. Hedonic models are complex and may only be an option where staff have a strong economics background. Works by Train and by Golub and Kitamura offer two examples of hedonic vehicle choice models.[23, 24]
- *Sample Enumeration* Sample enumeration involves, in the vehicle mix context, taking a sample of households within a region and extrapolating to the regional population base from the sample s vehicle ownership and/or usage responses to pricing measures. Survey samples have the advantage that they can be re-surveyed in follow-up analyses to study actual responses to changes in price signals (see Section 3.3.6.7 below for more information).
- *Scrappage Studies* Scrappage studies have been performed in conjunction with programs to buy back or otherwise accelerate the retirement of older, high-emitting vehicles from the regional fleet. These studies offer estimating methods that may be of value to many areas.[25][26]
- *Empirical Studies* Periods of major change in fuel prices relative to income during the 1970s and early 1980s, and major changes in the price of vehicles and their characteristics relative to real incomes, have produced trends in ownership that are reflected in various research studies. These studies could

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[23] K. Train, *Qualitative Choice Analysis, Theory, Econometrics, and an Application to Automobile Demand*, The MIT Press, Cambridge, Massachusetts, 1986.

[24] T. Golob and R. Kitamura, for the California Energy Commission. It should be noted that the analysis conducted by Golob and Kitamura is not publicly available as of this writing.

[25] U.S. Environmental Protection Agency, Accelerated Retirement of Vehicles, in *Transportation Control Measure Information Documents*, March 1992.

[26] Beth Deysher and Don Pickrell, *Emissions Reductions from Vehicle Retirement Programs*, U.S. Department of Transportation, John A. Volpe National Transportation Systems Center, 1996.

be used to develop estimates or assumptions regarding shifts in ownership or use patterns that might occur in response to price signals.[27, 28]

- *Special Studies* Locally-performed studies involving stated preference techniques could produce estimates of consumer response to particular types of vehicle-based pricing policies (see Section 3.3.6.8 below for more information). Recent work sponsored by the California Energy Commission has used such methods to ascertain the demand for electric vehicles. The study used travel data from panels of households to establish current travel and vehicle use patterns, and investigated how these patterns might change under different pricing and vehicle attribute conditions.[29]

3.3.4 Trip Generation

This step of the planning process estimates the *number of daily trips* that are produced by households [*productions*] or that originate in a zone [*attractions*]. These trips usually are estimated separately by trip purpose. The simplest classification is home-based work, home-based other, and non-home based trips; more complex systems split home-based non-work trips into shop, school, and other and disaggregate non-home-based trips into work-related and other.[30]

Trip productions and attractions are estimated through separate procedures. These may be either *cross-classification* relationships, matching a particular trip rate with a particular combination of determining characteristics, or *regression models*, which use a functional relationship expressed as an equation. The cross-classification models are the most common approach, and can be reasonably accurate depending on the variables used for stratification, the degree of stratification, and the reliability of the trip rates themselves. Regression models are generally regarded as less accurate (unless they are of a fairly sophisticated non-linear form).

Significant references exist on trip generation practices. The reader is advised to consult Section 3.3.5 of the NARC Manual or the TMIP Short-term Travel Model Improvement report for more information and references on the general subject.[31]

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[27] David L. Greene, Vehicle Use and Fuel Economy: How Big is the Rebound Effect?, *The Energy Journal* 13, No. 1, 1992, pp. 117-143.

[28] Don Pickrell, Automobile and Gasoline Demand Revisited, Volpe National Transportation Systems Center, U. S. Department of Transportation, 1992.

[29] C. Kavalec, CALCARS: The California Conventional and Alternative Fuel Response Simulator, California Energy Commission, April 1996.

[30] Some models, such as those of the Maryland National Capital Parks & Planning Commission, have evaluated trips generated by time of day and purpose, (Montgomery County, Maryland) and applied distribution, mode choice and parking factors.

[31] Cambridge Systematics, Inc., Travel Model Improvement Program: Short Term Model Improvements, prepared for the Federal Highway Administration, U.S. Department of Transportation, 1994.

Greig Harvey et al., A Manual of Regional Transportation Modeling Practice for Air Quality Analysis, National Association of Regional Councils, December 1993

There are a number of issues related to trip generation methods that are important when considering the suitability of models to evaluate pricing actions; these include:

- Person trips versus vehicle trips;
- Inclusion of transportation and cost variables;
- Disaggregating household by vehicles (income) and size and workers; and
- Trip chaining and other trip adjustments.

Procedures exist within current practice or are being looked at in research efforts that offer to enhance trip generation capabilities in dealing with pricing.

3.3.4.1 Person Trips versus Vehicle Trips

Most trip generation models furnish estimates of daily person trips; however, these trips are commonly limited to *vehicle* trips and exclude non-vehicle trips such as walking and bicycle trips.[32] Smaller planning agencies may even restrict trip production estimates to person trips made in private vehicles (eliminating transit entirely).

Exclusion of non-motorized or non-automobile trips from trip generation analysis generally stems from capabilities elsewhere in the model system, especially mode choice and trip distribution analyses. Including non-automobile trips in *vehicle trip-only* systems implies a separate need for a mode choice model, which greatly increases the system s complexity. Yet, agencies that use vehicle trip-only approaches seldom deal with non-automobile travel. Consideration of non-motorized modes requires an approach that:

- Looks at a finer-grained pattern and mix of land uses, street space allocation and design; and
- Considers proximity, as well as mobility.

The availability and consideration of these modes as travel options in response to pricing (or land use) actions is clearly important; their inclusion in the analytic process may represent a future standard for progressive model systems and planning agencies. Areas that have developed true *person trip* generation capabilities include Portland, Oregon and Montgomery County, Maryland. The EPA and the FHWA are currently developing a manual for MPOs to use to upgrade their micro-scale design features modeling practice. This manual should be available in 1998 through the Travel Model Improvement Program.

As a near-term goal, agencies that limit trip generation to vehicle trips should endeavor to expand their systems to full person trips.

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[32] A vehicle-trip is the one-way movement of a vehicle between two points. A passenger- or person-trip is defined as one passenger making a one-way trip from origin to destination. Person-trips are measured as the sum of the number of passengers added across all vehicle-trips. Thus, person-trips are equal to vehicle-trips only if the average vehicle occupancy is one passenger per vehicle.

3.3.4.2 Inclusion of Transportation and Cost Variables

Few trip generation models relate the effect of transportation level of service or cost to household trip productions. More research is needed to determine whether a major change in transportation cost or level of service would affect the overall number of *person* trips made by a household, particularly in light of non-motorized travel options and growing opportunities for telecommunications or delivery as substitutes for travel.

Transportation characteristics and costs might be incorporated through the development of a measure of *composite impedance* (see Sec. 3.3.5.1 below). Composite impedance is a measure which combines the time and cost of highway and transit (and perhaps other) modes into one statistic. In the trip generation context, composite impedance is the unit of measure used to determine how far travelers are willing to go from a defined origin. More specifically, the question is phrased as How many jobs (or other activity variable) in each zone can be reached within X units of composite impedance from that zone? The value of X, the tolerance limit for composite impedance, would be determined in the calibration phase.

Analytically, an increased road price (or reduced level of service) would increase the composite impedance associated with trips along that road, thus reducing the destinations that could be reached within a fixed impedance limit from zones in the area. As composite impedance increases and accessibility decreases, trip frequency should also decrease because in general it becomes more difficult to go *anywhere,* particularly by *vehicle.*

The Bay Area model system includes composite impedance (termed *accessibility*) in its trip generation model for home-based shopping, and is one example of an attempt to include such a relationship in trip generation (see the NARC Manual, Sec. 3.3.5, pp. 3-36-37 for more information).

Trip generation also can respond indirectly to pricing. If pricing applications are evaluated with models or procedures that affect an earlier-step change in land-use/activity location, or in vehicle ownership levels through some type of composite impedance relationship, then trip generation estimates would be subsequently affected. The Portland, Oregon vehicle ownership model, for example, is sensitive to transit service accessibility (and pedestrian environmental quality) and, in turn, trip generation is sensitive to vehicle ownership.

3.3.4.3 Disaggregating Households by Vehicles (Income) and Size

Most trip generation and distribution models are handicapped because they must use zonal-average data. One of the more important recent modeling improvements is *disaggregation* of certain zonal data by characteristics that influence travel. A common practice is to split households jointly by:

- Household size and vehicles available, used by Washington, DC, Detroit, Philadelphia, San Francisco, and Portland, Oregon; or

- Household size and household income, used by New Orleans, Atlanta, Northern New Jersey, Dallas, Denver, Phoenix and Minneapolis-St. Paul.

Such disaggregation of household data produces cells that are more homogeneous in nature, reducing the variance in trip rates. Using income or vehicles as one of the dimensions also allows the explicit identification of trips by some measure of wealth, which can be useful for modeling the differential effect of pricing on various groups.

Typically in these submodels, analysts use Census data to establish the relationship between zonal averages and the distribution of households by number of persons (1, 2, 3, 4 and 5+) and number of vehicles (0, 1, 2+). From these individual distributions, the region's joint distribution of households by size and vehicles is used to estimate the equivalent joint distribution for each zone. The reader is encouraged to consult Appendix A for a discussion of this procedure, demonstrated by the case study model.

3.3.4.4 Trip Chaining and Other Trip Adjustments

Trip chaining is one likely response to an increase in the cost of travel (or reductions in the number of vehicles available to a household); that is, individuals group trips to make more efficient use of vehicles or reduce the cost associated with a given trip. This could have an effect on total VMT and potentially an impact on cold starts.

No conventional models deal explicitly with trip chaining[33], although research is ongoing under the Travel Model Improvement Program, and improved operational models that deal with this activity should be available in the next few years.[34, 35, 36, 37] Data from the 1974 and 1980 gasoline shortages might be investigated to gauge the impact of chaining responses to travel constraints.

Current efforts to develop activity-based models represents one important approach to addressing methodological difficulties posed by trip chaining and other trip adjustments. In this approach, the number of trips generated by a household is not considered to be a function of household characteristics directly, but of activities that generate travel. This approach is expected to be useful because respondents typically can provide better

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[33] Montgomery County, Maryland: TRAVEL2 Model deals with chaining in a form that is sensitive to land use (Maryland National Capital Parks and Planning Commission, 1991).

[34] Ernio Cascetta (University of Naples - Italy), Agostino Nuzzolo (University of Tor Vergata - Rome - Italy), Vito Velardi (ELASIS - Salerno - Italy), A System of Mathematical Models for the Evaluation of Integrated Traffic Planning and Control Policies. Unpublished research paper, Laboratorio Richerche Gestione e Controllo Traffico, Salerno, Italy, 1993.

[35] Moshe Ben-Akiva, John L. Bowman, and Dinesh Gopinath, Travel Demand Model System for the Information Era *Transportation*, vol. 23, pp. 241-266, 1996.

[36] Yoram Shiftan, A Practical Approach to Incorporate Trip Chaining in Urban Travel Models, Fifth National Conference on Transportation Planning Methods Application, a Compendium of Papers, 1995.

[37] Konstadinos Goulias, Ram Pendyala, and Ryuichi Kitamura, Practical Method for the Estimation of Trip Generation and Trip Chaining, University of California Transportation Center, University of California, Berkeley, 1991.

information about the number of travel-generating activities they are involved in, and can provide better information about the number of trips associated with each activity.

Households can affect overall trip rates through other trip generation adjustments, such as telecommuting and other telecommunications applications and alternative schedules (compressed work weeks), which reduce the physical number of home-based work trips. The TDM Evaluation Model allows for some estimation of the change in person trips due to these strategies (see Section 3.3.6.9. below). However, there is some question as to whether households that engage in telecommuting or alternate schedules actually reduce overall household trip rates or simply substitute other travel. Research is still necessary on this issue before these pattern shifts can be assumed to lower household trip rates.[38]

3.3.5 Trip Distribution

The trip distribution analytic step links together the trip ends (i.e., *productions* and *attractions)* that are estimated in trip generation, into specific origin-destination trip movements, or trip tables.

In most instances, the distribution of trips from an origin zone to a potential destination zone is performed using a *gravity model.* This model distributes trips as a function of the number of trip attractions relative to the degree of separation among the zones. Almost all areas measure separation by highway travel time.

Researchers have long known, however, that factors other than highway time play a role in the allocation of trips among destinations. For example, there is considerable evidence that the presence of good transit service between two zones will increase the number of *person* trips between those zones. A logical extension of this concept is that other dimensions of separation, such as prices that users pay for transportation, also influence destination choice. The significance of these factors, which is supported by intuitive logic and empirical observation, should be taken into account.

This section discusses several topics that affect analytic accuracy of the trip distribution step: composite impedance, income stratification, travel time equivalency, over-allocation of attractions, trip distribution as destination choice, and importance of short trips.

3.3.5.1 Composite Impedance

Gravity modeling that uses *composite impedance* as its measure of separation is one approach that is being tested and used as a way of accounting for pricing effects in trip distribution. Composite impedance, a measure that combines the time and cost of travel modes into one statistic, is generally computed as the natural logarithm of the sum of the exponentiated disutilities for all available modes (including non-motorized), i.e., the natural log of the denominator of a logit mode choice model, also called the log sum.

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[38] P. Mokhatarian et al., Effectiveness of Telecommuting as a Transportation Control Measure, University of California, Davis, 1994.

This approach has been used in the model systems of New Orleans, San Francisco, Boston, Atlanta and Denver.[39] Most areas that use this formulation use it only for work trips, but theoretically it is applicable to all trip purposes. The Case Study Model in Appendix A also illustrates such an application.

3.3.5.2 Income Stratification

The New Orleans model adds another dimension to trip distribution that merits consideration: income stratification. The composite impedance calculation accounts for income level of the traveler, as well as time and cost of all modes. This is practical because all elements of the New Orleans model (from trip generation to mode choice) are income-stratified.

The benefit of income stratification in this context is that the effect of price on destination choice is differentiated according to traveler [household] income level. Since pricing changes will generally influence low income travelers more strongly than high income, stratifying by income allows the trip destination choice to vary realistically in discontinuous fashion relative to income. Other models provide similar sensitivity by dividing price variables by average household income for travelers expressed as cents per minute.

3.3.5.3 Travel Time Equivalency

Many agencies include travel time only in their measure of separation for trip distribution and mode choice analyses. These agencies may approximate the effect of an increase in cost for certain measures by translating cost into an equivalent value of travel time. Such agencies incorporate a cost increase from market-based measures as an increase in travel time impedance for a given origin-destination pair. The increment in time is computed by using traveler value of time to convert cost to minutes of equal value, which can be interpreted from the coefficients in the mode choice model.[40]

Time equivalents can vary by situation and type of market measure to reflect variations in traveler price sensitivity. For example, a pricing action that affects automobile operating cost would probably translate as a lower value of time than an out-of-pocket cost such as a parking charge. Also, non-work travel would be expected to exhibit a lower value of time/higher value of cost ratio than work travel.

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[39] Greig Harvey et al., A Manual of Regional Transportation Modeling Practice for Air Quality Analysis, National Association of Regional Councils, December 1993, Sec. 3.3.6, pp. 3-47,48.

[40] In the Washington, D.C. Council of Governments model, for example, the ratio of the home-based work auto running time coefficient to the auto operating cost coefficient = 0.0173/0.0035, or about $0.05 per minute.

3.3.5.4 Over-Allocation of Attractions

With a doubly-constrained trip distribution procedure, such as the standard gravity model, it may prove necessary for trip *attraction* estimates to be sensitive to user costs. Otherwise, trip pattern distortions could occur under certain pricing scenarios as the gravity model tries to reallocate attractions in response to cost changes, but the attraction model would maintain the same attractions in a zone. This could result in over-allocation of attractions.

This problem can be minimized by including some type of price sensitive variable, such as composite impedance, in the attraction model. Another option is to switch to a logit destination choice model to allocate attractions, as discussed below.

3.3.5.5 Trip Distribution as Destination Choice

Trip distribution analysis attempts to represent the process of travelers choosing destinations. Ultimately, it approximates behavior by matching origin and destination potentials, offset by the degree of difficulty in traveling between zone pairs.

Some areas have implemented a more advanced procedure that explicitly models destination choice as a behavioral process, much like mode choice. These models estimate the probability that a traveler will choose a particular destination based on the utility or attractiveness of that place relative to other places; attractiveness is defined by characteristics of the destination, the traveler, and travel conditions, *including cost*.

The behavioral approach offers a more realistic evaluation of destination choice behavior, particularly with regard to cost factors, than conventional gravity models, which require considerable manipulation with adjustment factors to match behavior with observed origin-destination trip volumes. Portland, Oregon uses such a model, with separate formulations for home-based work, school, college, and other; non-home based work-related; and non-work.[41]

Some areas also have found it advantageous to model destination choice and mode choice simultaneously, particularly for non-work travel where these decisions are so interrelated. The Bay Area exemplifies this approach with its logit probability model for shopping trips.[42]

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[41] Greig Harvey et al., A Manual of Regional Transportation Modeling Practice for Air Quality Analysis, National Association of Regional Councils, December 1993, Sec. 3.3.6, pp. 3-45,47.

[42] Greig Harvey et al., A Manual of Regional Transportation Modeling Practice for Air Quality Analysis, National Association of Regional Councils, December 1993, Sec. 3.6, pp. 3-47,48.

3.3.5.6 Importance of Short Trips

Pricing measures place a great premium on being able to effectively model short-distance trips, since short vehicle trips contribute substantial emissions from cold starts. These are the trips that are perhaps most amenable to diversion to transit or non-motorized modes. The importance of short trips in emissions policies raises concerns about the existing level of detail in analytical representation of transportation highway and zonal networks.

In fact, the importance of short trips could justify an increased level of network detail, down to the level of minor collectors and perhaps local streets in applicable areas, accompanied by smaller traffic analysis zones to overcome problems with non-representation of internal trips. Moreover, this same concern might argue for better data on walk and bicycle trips and infrastructure, transit accessibility, and information on the mix of land uses.

3.3.6 Mode Choice

The mode choice step estimates the share of trips made using each mode of travel. Within the four-step process, mode choice models generally stand out as being the most rigorously developed and directly price-sensitive analytic procedure. Many larger urban areas have developed sophisticated discrete-choice *logit models* that estimate the share of person trips by mode, based on the socioeconomic level of the traveler, and the time and user cost attributes of the various modes. Models typically address the major vehicular modes—autos and transit—with shared-ride often treated as a separate mode. More advanced models also include non-motorized modes (walk and bike), which is an important consideration for pricing.

There are a number of characteristics or application procedures that can maximize the sensitivity and accuracy of mode choice models with regard to pricing. Topics in this section include:

- Satisfactory model coefficients;
- Effects of inflation;
- Income stratification;
- Differentiation by purpose;
- Integrating mode and destination choices;
- Nested versus multinomial models;
- Special modes;
- Sample enumeration methods;
- Stated preference surveys; and
- Off-line methods.

3.3.6.1 Satisfactory Model Coefficients

The ultimate product from a mode choice analysis depends most directly on the value and validity of the coefficients that are used to indicate traveler sensitivity to pricing. An area can take one of several approaches if it is not comfortable with its coefficients, wishes to confirm its coefficients, or does not have particular coefficients:

- **Develop new coefficients/models**: Development of a new mode choice model is a data- and time-intensive task. Yet, in conjunction with the 1990 Census, many areas commissioned new regional travel surveys that, taken together with Census data, serve as an excellent opportunity for model update or upgrade. A number of references can provide guidance to areas interested in developing new coefficients and/or models (see NARC Manual Section 3.3.7 for information on models, or Section 3.6.2 for information on data sources and requirements[43]). Areas interested in developing new models or greatly modifying current models should consider incorporating such features as: nesting, income stratification, non-motorized modes, and special pricing variables; these topics are discussed elsewhere in this section.

- **Conduct surveys:** Coefficients can be estimated from formal (cross-sectional or longitudinal) travel surveys of *revealed preference*. Assuming these surveys correctly capture the appropriate travel conditions, they may be fairly accurate in describing travel behavior response.[44] However, revealed preference surveys must be conducted in response to actual pricing changes or signals.

  Stated preference surveys, which derive estimates of response sensitivity from reactions to carefully staged hypothetical pricing situations (or from a combination of real and stated preference data), may be an acceptable alternative or complementary approach. Stated preference surveys are discussed in more detail in section 3.3.6.8.

- **Transfer coefficients:** An area that is not comfortable with its cost coefficients for pricing analyses may consider transferring model coefficients from another urban area. The disaggregate nature of logit models generally supports transferability. Analysis of coefficients from different areas indicates that the variation among these coefficients is not as great as might be expected, suggesting that careful transference is possible.

  The most critical issue is ensuring that independent variables are consistent within the same model, and that the donor model itself is the result of a well-documented development and application process. Inflation adjustment of price coefficients (to reflect the year in which the original model was developed) is another major consideration in transferring pricing coefficients (inflation

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[43] Greig Harvey et al., A Manual of Regional Transportation Modeling Practice for Air Quality Analysis, National Association of Regional Councils, December 1993.

[44] Cambridge Systematics, Inc., Travel Model Improvement Program: Short Term Model Improvements, prepared for the Federal Highway Administration, U.S. Department of Transportation, 1994.

adjustment is discussed below). For example, if the original model was calibrated using 1980 prices, the new model must either: (1) have its prices converted to 1980 dollars; or (2) have its original cost coefficients adjusted to reflect the effect of inflation since 1980.

- **Synthesize coefficients:** If it is not possible to derive a particular cost sensitivity from direct sources, it may be acceptable to *synthesize* a coefficient value and then perform a series of sensitivity tests on it. The model would be run for a series of parameter values above and below the hypothesized value; the results of these simulations (mode choice, trip length, VMT, etc.) would be charted for each run.

  Comparing the variation in results with theoretical values, coupled with judgment from experienced practitioners, can often help identify an acceptable value for a parameter. Although such an analysis cannot conclusively identify the proper value for an unknown parameter (even though carefully reasoned and conducted), it may provide a suitable interim result until better information can be found.

- **Develop specialized coefficients:** Some models have different coefficients for parking cost than for regular automobile operating cost; these may be higher by a factor of 1.5 to 2.0. This difference may reflect a higher sensitivity to parking as an out-of-pocket cost, or it may be a function of higher density/more restricted parking supply in areas that are priced. Parking cost coefficients may be synthesized from other models. Separate coefficients for roadway tolls are not in widespread use. Both parking and toll coefficients might be approximated initially by such methods as stated preference surveys.

3.3.6.2 Effects of Inflation

Traveler sensitivity to a given dollar price, reflected in model coefficients, will change over time with the general rate of inflation. As a general rule, the monetary value of a pricing policy should be deflated to reflect the change in prices between the forecast year and the year in which the model is calibrated. Extreme care should be taken in *forecasting* what the value of a price will be in a *future year*. It is commonly assumed that all travel prices will increase in the future at the same rate as inflation, and, thus, that there is no change in the relative price among travel choices. This may be an acceptable assumption, though it should be noted that automobile operating costs have generally been dropping in real terms since WW II.[45]

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[45] It should be noted, however, that the environment for non-auto modes like walking, biking and transit, has steadily eroded, further decreasing the utility of these modes relative to the auto which has been increasing in terms of vehicular and environmental design features. This suggests that the generalized cost for auto may continue to decrease in its rate over time, leading to greater demand than would occur under the assumption of constant pricing.

3.3.6.3 Income Stratification

One of the biggest issues raised in evaluating pricing strategies is how impacts vary with the income level of the traveler. Two concerns are raised: assuring an accurate estimate of traveler response in light of real income differences and accounting for the distribution of winners and losers. Since mode choice is such a significant step in travel demand analysis of pricing policies (in terms of impact and cost specificity), it is important to account directly for income differences when applying mode choice models.

Generally, income differences can be accommodated by applying purpose-specific models independently to each income stratum (usually quartiles or quintiles). It is essential that the trip tables brought into mode choice from trip distribution already have this segmentation. Readers are encouraged to consult both appendices for examples of how this procedure is performed. Another way income differences can be accommodated is by developing mode choice models with coefficients that are directly sensitive to traveler income.[46]

3.3.6.4 Differentiation by Purpose

Traveler response is likely to vary by trip purpose and mode choice. Coefficients valid for one purpose may be invalid for another type of trip. Some model systems include a true mode choice model only for home-based work (HBW) trips. Non-work trips, usually home-based other (HBO) and non-home based (NHB) are calculated as a distance-based factor multiplied by the HBW shares. This implies that the non-work mode shares move up or down in the same proportion as the HBW mode shares, which is unlikely.

Evidence suggests that mode choice in non-work trips is more sensitive to price and less sensitive to time than for work trips. Therefore, it is preferable to develop separate mode choice coefficients for work and non-work trips. This is particularly important if a composite impedance measure is developed from the mode choice model to be used in trip distribution and possibly elsewhere.

While the Census of Transportation (CTPP) has been a robust source of calibration data for work trips, more extensive home interview surveys (perhaps as large as 1.0 to 1.5%) may be needed to furnish enough observations of *non-work* trips to permit calibration of mode choice coefficients. The NPTS micro-sample provides one source for non-work model estimation. Montgomery County, MD has such a model system, developed from about a 0.5% to 1.0% sample.[47]

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[46] See M. Ben-Akiva and S. Lerman, *Discrete Choice Analysis: Theory and Application to Travel Demand,* MIT Press, Cambridge, MA, 1985.

[47] Montgomery County, Maryland: Travel2 model deals with chaining in a form that is sensitive to land use, Maryland National Capital Parks and Planning Commission, 1991.

3.3.6.5 Nested versus Multinomial Models

Most first-generation mode choice models have been multinomial models, where all modes in the alternative set are assumed to represent independent options in the model. However, when alternatives are closely related, straight multinomial logit models can pose problems because they assume that the alternatives represent realistic independent choices (e.g., a red bus versus a blue bus on the same service schedule).

Probit model formulations are one way of addressing this issue, but they are highly complex and have difficulty incorporating more than two modes. The preferred approach has become the *nested logit*, which is easier and more practical to develop and apply. The nested model splits the choice process into tiers, where the choices at any given level are relatively independent. This ensures that two similar modes, for example, do not capture an independent share of the total, but rather split the subtotal after the generic share for that type of mode is determined.

There are many resources on logit and probit models for the interested reader (consult the NARC Manual, Section 3.3.7, or Ben-Akiva and Lerman for references[48]); examples of nested logit mode choice models are used in Portland, Oregon and San Francisco. The reader also is advised to consult the illustration in the Case Study Model in Appendix A, in which a nested logit model was adapted and applied for mode choice.

3.3.6.6 Special Modes

Some modes are not well accommodated by conventional mode choice procedures; this is a function of the models as well as the data available. This is a second-order, but important, issue for pricing because these modes are often key options. Examples include special transit services or improvements that depart from the coded network, including auto-access/park-and-ride, and non-motorized modes. Bike and walk modes are considered in only a small number of metropolitan area models, with Portland being an example.

Modeling bike and walk is made even more challenging because many of the trips are intra-zonal (and hence not well represented), may not be well represented in the base data on trip rates (field and subsequent trip generation), and require special descriptors in the models. Portland, Oregon includes non-motorized modes in their mode choice model,[49] as do Montgomery County, Maryland and Sacramento, California.

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[48] Greig Harvey et al., A Manual of Regional Transportation Modeling Practice for Air Quality Analysis, National Association of Regional Councils, December 1993.

M. Ben-Akiva and S. Lerman, *Discrete Choice Analysis: Theory and Application to Travel Demand,* MIT Press, Cambridge, MA, 1985

[49] Cambridge Systematics, Inc., Calthorpe Associates, and Parsons Brinckerhoff Quade & Douglas, Inc., *Making the Land Use Transportation Air Quality Connection: The Pedestrian Environment*, Volume 4A, for 1,000 Friends of Oregon, December 1993.

Most areas will have to analyze these modes off-model, usually relying on evidence from other implementations and adjusting regional trip tables accordingly. [50] Another possible way of representing these modes might be through *sample enumeration* methods, discussed below.

Another example of a special mode is any mode used to access transit. Access modes can include walking, bicycling, auto travel, and transit itself. Many of the difficulties associated with modeling transit-access modes are described above, with the additional complication that transit access points may need to be treated as trip attractors themselves. Mode of access to transit has been modeled in some cases as part of the nested logit mode choice model. In the mode choice model, walk and drive access are modeled at the same level or nest. The Washington Council of Governments (WashCOG) mode choice model is an example of transit access modeled in this way.[51]

3.3.6.7 Sample Enumeration Methods

Some analysts have suggested that they can realize a higher level of flexibility and realism, and possibly accuracy, if they evaluate pricing actions through a sample of households, rather than work with the zonal averages of the conventional 4-step model. In this approach, called *sample enumeration,* a sample of households (generally derived from a regional home interview survey, although Census data may be a source) is used to represent the regional travel base, and becomes the level at which the models are applied.

While this method is being introduced in connection with mode choice, in fact it may be applied to various other steps in the travel demand hierarchy. The household sample is drawn to represent the range of geographic, socioeconomic and travel situations that would occur in the regional population. Generally, the sample is related (by zonal location) to the 4-step modeling process through the regional trip tables and the corresponding travel times and costs of the transportation alternatives.

Policies are then applied directly to the households; evaluation takes advantage of important information on household composition, vehicle ownership, income, and proximity to activities and alternatives to generate fairly robust estimates of response to the given policy. These results are then weighted back to reflect the behavior of the population.

The process may or may not involve actual modification of regional trip tables and performance of traffic assignment in estimating emissions. In the view of practitioners, this approach implies a tradeoff between the accuracy and flexibility that can be derived from a household-level analysis and the intricacies of a network-based traffic assignment, though traffic assignment can be performed.

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[50] Delaware Valley Regional Planning Commission, An Analysis of Potential Transportation Control Measures for Implementation in the DVRPC Region, May 1994.

[51] *FY 94 Development Program for MWCOG Travel Forecasting Models; Volume A: Current Applications*, June 1994

This technique has been applied in a number of locations, including California and Washington state, and has shown good potential.[52, 53, 54] It offers the additional advantage of flexibility in analyzing certain alternatives or behaviors that can be traced at a household level, but not at a zonal aggregation level. For example, analysis at the household level is particularly useful for tracing short bike/walk trips, access to special alternatives, automobile ownership/fleet composition/usage issues, and greater specificity of particular pricing issues (such as parking cash out, etc.). The reader is encouraged to consult Appendix B, which reports on an application of this approach.

3.3.6.8 Stated Preference Surveys

Stated preference surveys represent an interesting option for gaining insight into mode choice response to policies, alternatives, and situations when solid empirical information does not exist.[55] Stated preference surveys might be used, for example, because no data has yet been generated on a new type of travel mode or a special type of pricing instrument with unique characteristics.

In a stated preference approach, it is possible to derive statistical estimates of tradeoff rates between various alternatives or their attributes by making respondents choose from among them in measured ways that indicate the relative importance of key attributes. These rates can then be evaluated in relation to the type of traveler and his/her circumstance.

The validity of the derived statistical relationships relies on how well the alternatives are portrayed to (and understood by) the respondent, and their comparison to known standards. While stated preference surveys rely on hypothetical situations, comparison of elasticity relationships derived from stated preference with more conventional *revealed preference* surveys or models have shown surprising corroboration. The results from these surveys should be used with caution, but they offer an important interim tool for agencies to estimate relationships between pricing instruments and travel behavior response, not just in mode choice but in relation to destination, time of day, route choice, etc.

Stated preference methods were developed by the private market research industry, and have been used successfully for many years to aid companies in identifying the critical attributes of their product, and maximizing those attributes to gain market share over competitors. Use of the techniques in transportation is a fairly recent development, but

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[52] Greig Harvey, *Curbing Gridlock: Peak Period Fees to Relieve Congestion*, Transportation Research Board Special Report 242, Vol. 2, National Academy Press, Washington, D.C., 1994.

[53] Greig Harvey, Transportation Pricing and Travel Behavior, presented at 69th Annual Western Economic Association International Conference, June 1994.

[54] Greig Harvey et al., Transportation Pricing for California: An Assessment of the Air Quality, Congestion, Energy, and Equity Impacts, Vol. 1: Summary Report, Draft, California Air Resources Board, June 1995.

[55] Cambridge Systematics, Inc. and Barton-Aschman Associates, *Travel Model Improvement Program: Short Term Travel Model Improvements*, U.S. Department of Transportation, U.S. Environmental Protection Agency, U.S. Department of Energy, October 1994, pp. 1-7,1-8.

there are numerous examples of its successful application.[56, 57, 58, 59, 60] Portland and Denver have both utilized stated preference methods in relation to pricing. Portland has used stated preference methods to explore time of day choice, conducting its survey in conjunction with its recent home interview survey, while Denver used such a survey to assist in development of a route choice model (described under traffic assignment, below).

3.3.6.9 Off-Line Methods

A number of planning agencies may have limited ability to perform mode choice analysis, either because they do not have mode choice models or the models they have are insufficient for evaluation of the particular measure. The NARC Manual cites a number of off-line methods that may be valuable as substitute or complementary approaches. Examples include:

- **TDM Evaluation Model**: The Federal Highway Administration is distributing a special software product that can substitute for or enhance a conventional mode choice model. The TDM Model is a spreadsheet approach that incorporates a pivot-point procedure to estimate mode choice changes. The model forecasts the change from an initial mode share based on information regarding changes in decision variables associated with the policy action. A wide variety of pricing and other strategies can be considered, individually or grouped into programs, with great flexibility to vary the levels of the strategies and target their application.

  The starting base may be trip tables from an existing planning process, special trip tables formed from survey data, or simply aggregate estimates of person, vehicle and/or transit trips. The coefficients in this model have been synthesized from national experience and can be altered by the user to use local or other coefficient estimates. Results are both aggregate and in trip table format. The trip table results can be returned to the four-step process (if applicable) for traffic assignment and emissions.[61]

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[56] M. Ben-Akiva and S. Lerman, *Discrete Choice Analysis: Theory and Application to Travel Demand*, MIT Press, Cambridge, Massachusetts, 1985.

[57] M. Ben-Akiva et al., Combining Revealed and Stated-Preference Data, prepared for publication in *Marketing Better*.

[58] Cambridge Systematics, Inc. and Hague Consulting Group, *VFT Feasibility Study: Market Analysis*, Final Report, July 1988.

[59] David A. Hensher, P. Truong, and P.O. Barnard, The Role of Stated Preference Methods in Studies of Travel Choice, *Journal of Transport Economics and Policy*, January 1988, pp. 45-57.

[60] J. Bates, Econometric Issues in Stated Preference Analysis, *Journal of Transport Economics and Policy*, January 1988.

[61] COMSIS Corporation, *Users Guide: Travel Demand Evaluation Model*, for the Federal Highway Administration, 1993 (For information contact McTRANS, distributing agent for FHWA at 904-392-0378).

The TDM Model has special capabilities for trip table manipulation or creation. The model interfaces directly with the common planning software packages (TRANPLAN, MinUTP and EMME/2), enabling easy interactions with the core model system. The TDM Model allows analysts to alter starting trip tables, or create a trip table from scratch (e.g., for transit or vanpool trips). Trip tables may be created entirely from scratch using survey data, if desired, or more simplistic estimates of total tripmaking and starting mode shares may be used to fuel the model. *For areas with vehicle-only trip tables, it may be feasible to use the model in reverse, knowing average occupancy rate, to create a person trip table suitable for performing mode choice analysis.* (Unfortunately, the TDM model does not incorporate non-motorized modes, and this should be adjusted for in its application.)

- **Quick Response System:** The quick response system procedure (QRS) consists of a collection of short-cut, parametric methods that may be used for transportation analysis in the absence of a local model system. Procedures exist to cover the steps of trip generation through traffic assignment, and include mode choice. It exists in either microcomputer or manual form, and allows users with minimum data and computer capability to form reasonable estimates of travel response.[62, 63]

- **Elasticity Factoring Methods:** Agencies without access to computerized planning methods or to either of the above techniques may consider using factoring methods to derive estimates of mode choice responses to pricing strategies. Such an analysis requires the following travel estimates:

  - Person trips
  - Vehicle trips (or average occupancy rate)
  - Transit trips (if applicable)
  - Vehicle miles of travel

  Ideally, these estimates would be in the form of trip tables, separated by trip purpose (work, non-work). Given information on trip length for each origin-destination trip combination and starting modal shares, analysts should be able to estimate the change in mode shares triggered by the respective pricing action.

  The report Transportation Air Quality Analysis Sketch Planning Methods [64] provides a convenient spreadsheet method for performing this analysis. The

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[62] COMSIS Corporation, NCHRP Report 187: Quick Response Urban Travel Estimation Techniques and Transferable Parameters, 1978.

[63] COMSIS Corporation, *QRS User's Manual*, for the Federal Highway Administration, January 1984.

[64] Cambridge Systematics, *Transportation Air Quality Analysis Sketch Planning Methods, Volume I: Analysis Methods*, prepared for the U.S. Environmental Protection Agency, 1979.

reader may also consult various sources for estimates of elasticities, but should be careful to choose a value or values appropriate to local conditions.[65, 66, 67]

In the event that the agency does not have trip tables, it may be acceptable to estimate policy responses from a more aggregate estimate of regional trip making. Baseline estimates can come from:

- Local travel survey data;
- Census CTPP estimates;
- Population or activity estimates factored by measured or ITE vehicle trip rates; and
- HPMS estimates.

Obviously, the more coarse the background estimate, the less accurate the estimated response and the more simplistic must be the strategy definition. The above references are recommended as sources for elasticities and application methods.

3.3.7 Time of Day

The ability of a model system to simulate differences in travel volumes and conditions at different times of the day is critical to realistic estimates of speeds, congestion levels, and emissions, particularly in larger urban areas with pronounced travel peaks. Yet, time of day allocation of travel is done in a very approximate way, using peaking factors derived from local surveys to apportion a certain percentage of daily trips into one or more peak hours or periods.

Time of day is an important dimension for many TCMs, since changes in the level of congestion and time distribution of travel affect important calculations regarding speeds and travel volumes, which fuel the emissions model. Time of day takes on special importance in relation to pricing measures that vary by time of day, for example, roadway congestion pricing. With major price differentials between peak and off-peak, it is likely that travelers who are sensitive to cost and/or who have flexibility in trip timing will consider shifting their departure to another time period; alternatively, persons without flexibility and/or with a high value of time might pay a higher price to travel in the peak (and possibly even enjoy a higher level of service).

This is a fairly complex choice that is not well handled by conventional peaking factor approaches. Research is underway in this area; sites interested in time of day forecasting

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[65] COMSIS Corporation, *Users Guide: Travel Demand Evaluation Model*, for the Federal Highway Administration, 1993 (For information contact McTRANS, distributing agent for FHWA at 904-392-0378).

[66] R.H. Pratt Associates, *Traveler Response to Transportation System Changes*, prepared for the Federal Highway Administration, Second Edition, 1981.

[67] Apogee Research, Inc., *Costs and Effectiveness of Transportation Control Measures: A Review and Analysis of the Literature,* prepared for the National Association of Regional Councils, January 1994.

(because of their interest in congestion pricing types of measures) might investigate the following activities or options:

- Approximating methods;
- Time of day choice models;
- Time of day factors; and
- Stated preference surveys

3.3.7.1 Approximating Methods

Current travel models do not attempt to accommodate potential traveler response to pricing measures that vary by time of day. Such analysis requires procedures that are sensitive to travel by time period, which in turn would require input data on price by period. This type of information would be cumbersome to create, but would not be outside the reach of current software.

For example, consider a model to estimate the percent of daily trips that begin in the morning peak three hours, which could be applied in two phases. The first phase would calculate one percentage split for all O/D pairs, separately by trip purpose. The second phase would consider the cost of making each trip during the morning peak and during the off-peak, and then adjust the initial percentage split based on the peak/off-peak cost differential for that O/D pair.

Non-work trips would be expected to exhibit greater sensitivity to time of day price differentials than work trips because of greater traveler flexibility. The exact sensitivity of trip start times to price differentials is speculative in light of current knowledge, but it should be possible to make a reasoned estimate using stated preference methods (see discussion below), which can be refined later using observed data.

3.3.7.2 Time of Day Choice Models

Domestic modeling practices have not featured formal modeling of time of day as a travel choice. Several researchers have devoted particular attention to this element and performed work that may serve as a basis for agencies that wish to advance their capability.[68, 69]

3.3.7.3 Time of Day Factors

If trip generation models can be made to include a measure of accessibility (composite impedance) that incorporates cost and travel conditions at different times of day, it may

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[68] Kenneth A. Small, Fundamentals of Pure and Applied Economics, *Urban Transportation Economics*, Vol. 51, Harwood Academic Publishers, 1993.

[69] P.R. Stopher and A.H. Meyburg, *Urban Transportation Modeling and Planning*, Lexington Books, 1975.

be possible to reflect time of day preferences through the trip rates themselves, prior to trip distribution and mode choice.[70] If overly simple measures of accessibility are used, however, the value of such an approach would be minimal. It is also possible to develop separate trip generation models by trip purpose by time of day, followed by separate trip distribution and mode choice analysis; this has been done by Montgomery County, Maryland.

3.3.7.4 Stated Preference Surveys

Traveler response to time of day pricing/service differences may be approximated through *stated preference* surveys. Sites also might consider synthesizing time of day relationships from other travel contexts that employed differential time of day pricing, such as bridge tolls or peak/off-peak transit fare differentials.

3.3.8 Traffic Assignment/Route Choice

The traffic assignment step estimates the traffic volumes for each link in the transportation network, for each time period that is considered. Traffic assignment is critical to the transportation analysis and emissions process; it produces the estimates of link volumes, speeds/travel times, and vehicle miles of travel (VMT) that are key inputs to earlier planning steps, particularly trip distribution and mode choice, and are the primary determinants of emissions when input to the emissions factor model.

Traffic assignment consists of assigning trips from a trip table to a transportation network according to specified criteria, almost exclusively the *minimum travel time* path. Travel cost is generally not included as a criterion, although some models account for tolls.[71] It is feasible to include cost in assignment, and therefore extend its effect more broadly through the other steps of the modeling process (see discussion below).

The details of the traffic assignment process are not of central concern in this manual. It is clear, however, that the accuracy of travel speeds generated by traffic assignment are of key importance. First, travel speeds are critical to effective analysis of all transportation alternatives, including those affected by pricing mechanisms. Second, travel speeds are a direct input to emissions analysis.

Additionally, there is concern about how well conventional assignment models deal with the issue of *route choice* when a roadway pricing system creates competing opportunities.

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[70] Greig Harvey et al., A Manual of Regional Transportation Modeling Practice for Air Quality Analysis, National Association of Regional Councils, December 1993, p. 3-58.

[71] Cambridge Systematics, Inc. and Barton-Aschman Associates, Travel Model Improvement Program: Short Term Travel Model Improvements, prepared for U.S. Department of Transportation, U.S. Environmental Protection Agency, U.S. Department of Energy, October 1994, Sec. 4.0, p 4.1.

Techniques in use or under development that may be of interest in addressing these issues include:

- Incremental loading and equilibrium assignment methods;
- Dynamic assignment;
- Traffic microsimulation;
- Speed feedback and recursion; and
- Path choice.

3.3.8.1 Incremental Loading and Equilibrium Assignment Methods[72]

Incremental loading and equilibrium assignment methods are largely replacing the all-or-nothing methods and provide much more realism in allocation of trips to paths. Among other things, these new methods greatly increase the realism with which level of service variations are represented and, in principle, provide a means for *incorporating the **cost** of highway travel as well as travel time,* which can then be used in the earlier steps of the modeling process.

3.3.8.2 Dynamic Assignment[73]

Dynamic assignment, which is an improvement on conventional static assignment procedures, addresses problems with demand variations within an analysis time period and begins to account for queuing impacts on speed.

3.3.8.3 Traffic Microsimulation[74, 75, 76]

The outputs of a typical traffic assignment analysis reflect average link speeds, and do not document variations in those speeds that would result from queuing at intersections, entrance ramps, or under congested stop/go conditions. Such variations in speed can significantly affect vehicular emissions; valid estimation can be critical to proper

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[72] Greig Harvey et al., A Manual of Regional Transportation Modeling Practice for Air Quality Analysis, National Association of Regional Councils, December 1993, Section 3.3.9, p. 3-66.

[73] Cambridge Systematics, Inc. and Barton-Aschman Associates, Travel Model Improvement Program: Short Term Travel Model Improvements, prepared for the U.S. Department of Transportation, U.S. Environmental Protection Agency, U.S. Department of Energy, October 1994, Section 4.0, pp. 4-1 to 4-7.

[74] Cambridge Systematics, Inc. and Barton-Aschman Associates, Travel Model Improvement Program: Short Term Travel Model Improvements, prepared for the U.S. Department of Transportation, U.S. Environmental Protection Agency, U.S. Department of Energy, October 1994, Sec. 5.3, pp. 5-4 to 5-7.

[75] Patrick DeCorla-Souza et al., A Trip-Based Approach to Estimate Emissions with EPA's MOBILE Model, Paper No. 940376, Transportation Research Board, 1994.

[76] E. Ruiter, Highway Vehicle Speed Estimation Procedures, prepared for the U.S. Environmental Protection Agency, 1991.

computation of emissions. Research is ongoing in this area to improve the linkage between the assignment models and emissions analysis through use of traffic microsimulation techniques. The current NCHRP Project No. 25-7: Improving Transportation Data for Mobile Source Emissions Estimates, is developing emission profiles that can be linked to a microsimulation to account for these effects.

3.3.8.4 Speed Feedback and Recursion[77]

Modeling accuracy would benefit from a formal recursive procedure that cycles information from assignment back to the earlier steps, thus ensuring compatible values among the steps when equilibrium is reached. If this is not done the inconsistency between the assumptions that are inputs to different modeling steps raises serious questions about the reliability of the final outputs. If pricing is introduced as a factor in more of the modeling steps through a measure like *composite impedance*, then it becomes even more important to ensure passage of this information through the relevant steps. Methods are currently under development by the Federal Highway Administration in conjunction with the Travel Model Improvement Program, and are in use in various places.[78]

3.3.8.5 Path Choice

Few conventional models are able to adequately model the effect of the cost of driving on route choice, which becomes a particular issue in evaluating roadway pricing. A common procedure is to convert the toll value to an equivalent number of extra minutes by dividing it by some value of travel time. Thus, when a route is considered as a potential path, the effect of the toll would be reflected in an increased travel time. This may be acceptable as a default analysis, but it greatly clouds the issue of choice discrimination among classes of travelers, some of whom would recognize the toll as a signal to avoid the facility and some of whom might be expected to pay the toll in exchange for a higher level of service (shorter travel time).

Toll diversion models are a more realistic way to account for route choice responses to pricing measures. Toll diversion models split vehicle trips for each O/D pair into toll and free trips. This split is based on a comparison of toll and free path characteristics—mainly travel time and cost (at least one model also includes number of toll stops as a variable). The toll path is the one that would be taken if the trip were forced to use the toll facility and the free path is the one that would be taken if the trip were prohibited from using the toll facility. Popular planning software packages such as TRANPLAN, MinUTP, and EMME2 are able to create and skim these paths.

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[77] Greig Harvey et al. A Manual of Regional Transportation Modeling Practice for Air Quality Analysis, National Association of Regional Councils, December 1993, Sec. 3.3.9, pp. 3-70, 71.

[78] Montgomery County, Maryland has documented the effects of incorporating full feedback in a composite equilibrium trip distribution/mode choice/network assignment model (Levinson & Kuman, 1992)

Incorporating Feedback in Travel Forecasting: Methods, Pitfalls, and Common Concerns, Travel Model Improvement Program, March 1996.

Simplified versions of these models have been used for years by toll road planners, most often by applying manual adjustments (based on rough estimates of travel time savings) to estimated toll road traffic volumes. The process has been implemented within a computerized traffic forecasting model for use in planning a toll road in the Denver region.[79]

This same procedure can be adapted to analysis of priced roadways. Unfortunately, this method is subject to the same limitation as methods to deal with the mode choice and time of day effects of congestion pricing: lack of observed data with which to calibrate a model. The Denver model is based on a small-sample *stated preference survey* of Denver area residents, most of whom had never used a toll road. The model has undergone extensive reasonableness checks and its results have been accepted as plausible.

The reader is referred to the case study model application detailed in Appendix A for an example of this procedure.

3.3.9 Emissions Modeling

The final step in the analysis process is the translation of the transportation effects estimated in the other analytic steps into quantities of the respective mobile source pollutants: VOC, NO_x and CO, and PM. Areas with comprehensive regional model systems generally perform this step by applying EPA's MOBILE5a model or, in California, the EMFAC7F model, and PART5 for reentrained dust emissions. These models accept input from the traffic assignment process on vehicle trip ends, VMT and speeds, sorted by facility type, geography and time of day. These inputs are then translated into emissions through the application of emissions factors, which are based on the regional vehicle fleet mix, average annual distance traveled by class, average travel speeds, ambient temperatures, inspection and maintenance programs, fuel policies and other factors.

This manual does not detail the development and specific operating features of the MOBILE or EMFAC models or the PART 5 model. Readers who desire more information can consult existing reference documents on these models.[80,81,82] What is of particular concern here is the effect that particular pricing actions may have on the vehicle mix that is included in the models. Pricing measures such as fuel taxes and emissions fees would

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[79] J. Heisler et al., Estimating Toll Diversion Using Existing Transportation Planning Software, presented at the Second Conference on the Application of Transportation Planning Methods, April 1989.

[80] Sierra Research, Inc. and Jack Faucett Associates, Evaluation of MOBILE Vehicle Emission Model, prepared for Volpe National Transportation Systems Center, U.S. Department of Transportation, December 1994.

[81] California Air Resources Board, Methodology for Estimating Emissions from On-Road Motor Vehicles, Volume I: EMFAC7F, Draft Report, June 1993.

[82] U.S. Environmental Protection Agency, Office of Mobile Sources, Draft User s Guide to PART5: A Program for Calculating Particle Emissions from Motor Vehicles, February 1995 (EPA-AA-AQAB-94-2).

have their principal effect on changes in the composition of the regional fleet. It is this change in vehicle mix, separate from (or in addition to) any change in travel level, that would alter emissions levels. Section 3.2.2.3 addressed issues associated with changes in vehicle mix and suggested methodologies and sources for estimating these changes.

Areas that analyze fuel price or registration fee measures should use their analysis of the probable changes in regional vehicle fleet mix to alter the base distribution in MOBILE (or EMFAC). The Case Study Model application in Appendix A presents an example of how this can be done.

Users should recognize that changes in vehicle mix may be the compounded result of two shifts:

- Vehicles may shift in proportion by model year; and
- Vehicles may also shift by relative use (VMT).

Historical trends, such as reflected in the Nationwide Personal Transportation Survey and the Motor Vehicle Manufacturers Association statistics, indicate a tendency to use new cars more than older ones; this is reflected in the annual VMT assigned to each vehicle age-category in the analysis. Thus, an analytic process that re-apportions fleet mix by age (to favor newer vehicles), yet maintains mileage rates (VMT) in each age-stratum at their prior levels implicitly assumes that a shift to newer vehicles means more VMT each year an unlikely result. Analytically, if not corrected, this would result in newer, cleaner models in the MOBILE distribution being given an unrealistically high VMT weighting.

Unless some type of analysis or survey research is performed to support adjustments by year and mileage, users should normalize the distribution of mileages to account for this effect. In the example below, the ratio of pre-shift [VMT*share] to post-shift [unadjusted VMT* share] is 0.97 (i.e., 6.69/6.89). Adjusted VMT is obtained by applying this ratio to the original VMT figures for each age stratum.

Table 3.6 Example of VMT Adjustment

Age (yrs)	**Pct. of Vehicles**	**Annual VMT 000**	**Revised Veh. Pct.**	**Effect. VMT 000**	**Adjusted VMT (*) 000**
1	15	15	20	15	14.6
2	12	14	13	14	13.6
3	10	13	9	13	12.6
4	8	12	5	12	11.6
5	5	10	3	10	9.7
	50%		50%		

Sum Original Veh. Dist. x Ann VMT = 6.69k;
Sum Revised Veh. Dist. x Ann VMT = 6.89k
Adjustment = 6.69/6.89 = 0.97

4.0 Implementation Issues

■ 4.1 Introduction

The ability of market-based measures to achieve their intended objectives depends on: (1) measures that are technically effective; and (2) an implementation program that is administratively and politically practicable. Applying sound analysis to the estimation of travel and emission impacts of market-based measures is the necessary first step in receiving emissions reduction credit for a proposed program. Submitting agencies should also provide complementary documentation to assure reviewing agencies that reasonable progress can be expected in program implementation.

In short, agencies proposing to incorporate and receive credit for market-based measures should address the implementation issues outlined in this section to receive EPA approval. The significance of specific implementation issues will vary from one area to another, and from one measure to another; this chapter presents generic guidelines that may not apply in some instances. For example, this section notes that any needed technology must be shown to be available, yet some measures require no technology deployment at all.

Implementation covers a broad array of concerns. It includes substantive issues such as legal authority and administrative capacity. It also includes more politically-oriented issues; clearly, the method and form in which market-based measures are packaged and introduced influences public acceptance and ultimate program success. A sampling of implementation questions might include:

- What organization will bear responsibility for implementation, administration and enforcement?
- What other measures will be combined with the subject measure? Would these other measures offer attractive and meaningful choices?
- How significant are technical and financial uncertainties? How would public acceptance and program goals be affected if a partial program were implemented?
- How are the resulting revenues allocated back to complementary transportation services, or used for other societal purposes? Should fees be set so revenues equal the cost of these complementary uses/services, that is, a revenue-neutral policy?
- How will equity issues be handled?

The way in which issues such as these are addressed will determine: (1) how the measure itself is defined and its impact quantified; and (2) the likelihood that the measure will actually be implemented as proposed. In turn, these factors will influence the emissions credit determination.

The Clean Air Act requires EPA to recognize and approve SIP credit for any quantifiable, permanent, and enforceable emissions reduction; it does not give EPA authority to advise on implementation issues that do not (directly) affect air quality. Thus, although all implementation issues contribute to ultimate program success, this section discusses only those implementation issues that affect an implementing body s ability to produce predicted air quality benefits. Several research institutions are available to advise cities and states on the non-air quality aspects of implementing market-based measures. EPA and the Department of Transportation also are able to provide research and related assistance.[1]

Experience with implementation of market-based measures is growing but is still limited. EPA is committed to working with states and their agencies to resolve any implementation uncertainty and to respond to reasonable assumptions where experience has not yet provided a sure guide. This chapter of the Guidance summarizes EPA s position on supporting documentation to address the following types of implementation issues:

- Public policy context;
- Legal authority;
- Administrative capacity;
- Technology availability; and
- Revenue generation and reinvestment.

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[1] Much of the information in this chapter has been summarized from Special Report 242, Volume 2, *Curbing Gridlock: Peak-Period Fees to Relieve Traffic Congestion*, Transportation Research Board, Washington, D.C., 1994.

■ 4.2 EPA Position on Documentation

States and their subsidiary agencies and implementing authorities requesting emissions credit for market-based measures should provide a narrative summary of critical implementation issues along with their technical analysis of travel and emissions impacts.

While there are no standard analytical approaches for examining implementation issues, EPA needs enough information to (1) be assured that the intended market-based measures can be implemented over the timetable proposed and (2) understand uncertainties that may affect the implementation timetable and total emissions reductions.

The discussion of implementation issues identified below should, at a minimum, describe:

- Current circumstances likely to affect implementation in each issue area;
- Actions currently underway to advance implementation of proposed measures;
- Planned or proposed future actions, with projected timetables; and
- Implementation issues as yet unresolved, remaining uncertainties, and their potential implications for the implementation of proposed measures.

In each case, the submitting agency should include relevant empirical or quantitative information or reference the appropriate sources. In short, if pricing measures are to be credible and creditable, sponsors should provide reasonable evidence that the actions underway will lead to implementation within the specified timetable.

4.2.1 Public Policy Context

Like any transportation or emissions policy, successful implementation of proposed market-based measures will depend, in part, on how well they can be introduced and integrated into the city s or state s general priorities. It is important to acknowledge that public relations and public participation may be as influential as any technical analysis in the implementation of pricing mechanisms. For instance, the current consumer costs of travel may be widely perceived as the actual market costs. An increase in consumer costs would consequently be regarded in a negative light, rather than as a movement toward a more equitable cost structure. Therefore, educating and involving the public is a very important element of any pricing strategy.

Sponsors should briefly describe the public policy setting in their region, priorities among competing objectives, and the extent to which implementation of market-based measures has been integrated with major public policy objectives. Sponsors also should address issues related to public involvement and education regarding planned implementation of market-based mechanisms.[2]

4.2.2 Legal Authority

Because this class of measures is new to many areas, and may involve multiple agencies, questions of legal authority may be raised that were not raised for other kinds of emissions-control strategies. Local units of government sponsoring, endorsing, or implementing market-based measures should document that they have the full legal power to do so, based on statutory or delegated authority. The credibility of a measure depends on the availability of such authority. Sponsors should review and confirm legal authority to ensure that they are able to enact and enforce the proposed market-based measures.

Sponsoring agencies should answer the following questions:[3]

- What is the nature and source of the legal authority?
- Are the proposed measures a reasonable exercise of this authority?
- Are the revenue-raising provisions and pricing structures consistent with existing taxing authority?

If any measures affect multiple jurisdictions, sponsors should detail the mechanisms to be used and the basis for crafting agreements among multiple units of government.

If implementation requires legislative action, sponsors must detail the process, prospects and timetable for any required legislative action to establish or clarify legal authority.

4.2.3 Administrative Capacity

In addition to legal authority, sponsoring agencies should demonstrate that capacity exists to effectively administer all aspects of the proposed measure.

Sponsors of market-based measures should describe the administration that will support each measure, noting areas in which increased competence or capability may be needed and outlining the approach and timetable for making necessary improvements. Depending on the measure, implementation will require adequacy in some or all of the following areas:

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[2] For additional discussion of issues related to public involvement, public acceptance, and equity, see: USEPA, *Opportunities to Improve Air Quality through Transportation Pricing Programs(EPA 420-R-97-004)*, September 1997. This document is also available at the following world wide web address: http://www.epa.gov/OMSWWW/gopher/Market/pricing.pdf

[3] See articles by Olson and by Pietrzyk in Transportation Research Board Special Report 242, Vol. 2, 1994.

- Staffing levels and skills;
- Computer resources;
- Budget support;
- Audit capability;
- Accounting capability;
- Ability to process revenues;
- Contracting capability; and
- Leasing and procurement capability.[4]

4.2.4 Technology Availability

Some measures, such as congestion pricing, require technology deployment. In these cases, sponsors should do the following in their submission:

- Document access to the required technology, either available currently off-the-shelf or available in the future in time for scheduled implementation;
- Evaluate the technologies to be deployed to ensure that they (1) are capable of achieving the objectives established for each measure, and (2) operate effectively and efficiently;
- Summarize the results of technical analyses and assessments that have been carried out for the proposed measures; and
- Note constraints, areas of uncertainty, and areas needing further development in the deployment of new technologies.

Assessments for congestion pricing, for example, would cover the following technology areas: in-vehicle units, vehicle to roadside communication systems, vehicle detection and classification systems, and payment and accounting systems.

4.2.5 Revenue Generation and Reinvestment

In a number of cases, pricing measures generate new revenue. This revenue could be used in two basic ways: (1) to reduce other fees or taxes; or (2) to invest in public programs, particularly in transportation. In the case of fee or tax offset, sponsors do not need to detail revenue use.

In general, sponsors should describe:

- Anticipated programs for which new revenues will be used;

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[4] See Olson in Transportation Research Board Special Report 242 Vol. 2, 1994.

- Anticipated impacts of those investments on travel behavior and emissions;
- Analysis used to estimate travel and emissions impacts, including consideration of synergism and overlaps;
- Actions and timetables anticipated in implementing the reinvestment strategy and programs; and
- Anticipated difficulties or uncertainties in executing the reinvestment strategy and how they will be overcome.

If revenues are to be reinvested in any way that affects transportation demand or emissions, sponsors should detail demand and the final emissions impacts. Reinvestments with such impacts include:

- Investment in *transit facilities*: generates shifts in mode share and reductions in vehicle trips and VMT;
- Investment in *traffic flow improvements* or *preferential facilities for high-occupancy vehicles*: generate increases in travel speed and shifts in mode share;
- Revenue used to support *transit fares*: produce shifts in mode share, reductions in vehicle trips and VMT;
- Investment in *vehicle buy-back programs*: induce changes in fleet mix and emission characteristics;
- Financial support of local government and business *trip reduction programs*: support reductions in vehicle trips and VMT; and
- Enhancement of *pedestrian and bicycle environment*, or *non-motorized access to public transportation*: support reductions in vehicle trips and VMT.

Many market-based measures gain effectiveness when supported by non-market measures, for example, expanding the diversity of transportation choices through increased transit options or enhanced pedestrian environment. Land use strategies may likewise be supportive. These are mentioned here because some may be potential recipients of program-generated revenue.

Emissions effects can be established by iterating through the modeling process described in earlier sections, adjusting the processes and values for effects of the reinvestment, where they can be determined or estimated. Alternatively, effects can be estimated independently.

If planned reinvestment whether in fixed capital, or operations and maintenance is expected to generate these types of impacts at a significant level, additional iterations in the modeling analysis may be required to capture the full effects and claim full emissions credit.

Appendix A

Modeling Pricing Measures in a Traditional Modeling Environment -- A Case Study Approach

A.1 Introduction

Almost all existing travel models were developed not for policy analysis, but for planning major transportation facility improvements. One of the unintended consequences of this is that most models are not well suited for analyzing the full range of travel impacts of different transport pricing strategies. Although these models are generally not structured for assessing the impacts of such public and private policy actions, they still represent the best available data base for travel forecasting within most urban areas. Thus, there is a strong need either to modify existing models or develop new models that can meet a wider range of analysis requirements.

It was not the goal of this research effort to develop and calibrate a new model set, because that would have required time and data resources that were not available. Instead, this project took the approach that many good models exist in different urban areas and that it should be possible to create a model set that could serve the study s purposes by borrowing appropriate parts from various models and assembling them into one model set that would exhibit reasonable sensitivities towards pricing measures. A side benefit of this approach is that the resulting model would not be biased towards any one urban area, but would represent a composite picture of a variety of areas.

The model would, however, be applied and tested using actual data from one metropolitan area, in order to produce more realistic results than an analysis using a hypothetical urban area. The resulting model set is referred to as the *Case Study Model*, because it was used to analyze the different market-based case studies for this project. This model is described further in the next section.

It should be noted that the Case Study Model is not intended to be one that can be picked up and applied as is to any particular area for use in analyzing market-based TCMs. It was only intended for use in this national-level overview analysis of the potential emission reductions of market mechanisms. However, the model documentation is presented here as part of the technical guidance for urban transportation planning staffs who may seek to adapt their local models to better analyze pricing strategies. As such, the following is intended to assist such staffs to develop and use similar modeling advances so as to conduct more credible forecasts of the effects of market mechanisms in their areas.

A.1.1 Case Study Model Specification

As noted above, the Case Study Model set is adapted from various four-step travel forecasting models from urban areas across the U.S. Despite some of the problems associated with the four-step process, it is still the most widely used and readily understood modeling approach. It was an explicit premise of this project that most of the problems with the four-step process are related to the way in which the steps are applied and other deficiencies in the input data, rather than flaws that are inherent in the process itself. The project s researchers hypothesized that an enhanced model set could be developed that would satisfy the need for specific sensitivity to pricing measures within the context of the four-step process.

Figure A-1 is a flowchart depicting the overall structure of the Case Study Model set. The following sections describe how each component of the model was crafted, with emphasis on the nature of the sensitivity to pricing. It bears emphasis that although each component of the Case Study Model set might not be considered the most advanced state of the art technique, the way they are combined, as shown in Figure A-1, is unique and is the most important feature of the model set.

The Case Study Model is applied to data representing 1996 conditions in the Washington, D.C. metropolitan area. This city and scenario were selected because the data were readily available, courtesy of the Metropolitan Washington Council of Governments (MWCOG). However, neither the Case Study Model nor any results of this analysis are endorsed or supported by MWCOG. It also bears emphasis that this model has not been fully calibrated to any set of data and cannot be said to represent the specific sensitivity of Washington area travelers (or any other travelers) to pricing. Its purpose is to demonstrate the structure of a pricing-sensitive model and to produce results that are reasonably illustrative of the range of emission reductions that might be associated with the assumed levels of transport pricing changes. Neither EPA nor the authors warrant that the results estimated by this model would be achieved in actual practice.

A.1.2 Submodels

The Case Study Model set includes two important submodels: households by vehicles and size, and parking cost.

Households by Vehicles and Size Submodel: Most existing trip generation and distribution models are handicapped in many cases by working with zonal average data. One of the most substantial modeling improvements in recent years has been the increasingly popular practice of subdividing certain items of zonal data by those characteristics which influence travel. A common practice is to split households jointly by size and vehicles available (or household income). Washington, D.C., Detroit, Philadelphia, San Francisco, and Portland (Ore.) are examples of urban areas which use *vehicles*, while New Orleans, Atlanta, Northern New Jersey, Dallas, Denver, Phoenix, and Minneapolis-St. Paul use *income*. This produces cells of households which are more homogeneous in nature, reducing the variance in trip rates. Using income or vehicles as one of the dimensions also allows the explicit identification of trips by some measure of wealth, which can be useful for modeling the differential effect of pricing on the different groups.

The submodel operates by using Census data to establish the relationship between zonal averages and the distribution of households by integer values. The size submodel splits households by number of persons: 1, 2, 3, 4, and 5+, and the vehicle submodel splits households by number of vehicles: 0, 1, 2+. For the Case Study Model, data on households by vehicles available were provided by MWCOG, and so only a size submodel was needed. Figure A-2 presents the size submodel.

Once the individual distributions of households by size and by vehicles are known for a zone, the region s joint distribution of households by size and vehicles is used to estimate the joint distribution for each zone. The size and vehicle submodels and the joint distribution submodel used in the Case Study Model were developed from a 1987-88 home interview survey in the Washington, D.C. metropolitan region. The regional joint distribution is shown in Table A-1. This distribution is used as a seed for each zone and then modified to match the desired distributions of households by size and by vehicles for that zone.

Parking Cost Submodel: The Case Study Model s parking costs were estimated using the MWCOG parking cost model. This model estimates average daily parking cost in a zone as a function of the number of home-based work person trip attractions per square mile in that zone. A threshold value is included, so that no parking cost is estimated for most zones. The parking cost submodel is implemented as a look-up table, shown graphically in Figure A-3. The values in this chart represent the average cost of parking between those who pay something and those who pay nothing and are expressed in cents per day, in 1980 year dollars. (Throughout the Case Study Model set, *all* costs are expressed in 1980 dollars.) The average parking cost value estimated by this submodel can be overridden by the user for any zone.

**Figure A-1
Case Study Travel Forecasting Model Flowchart**

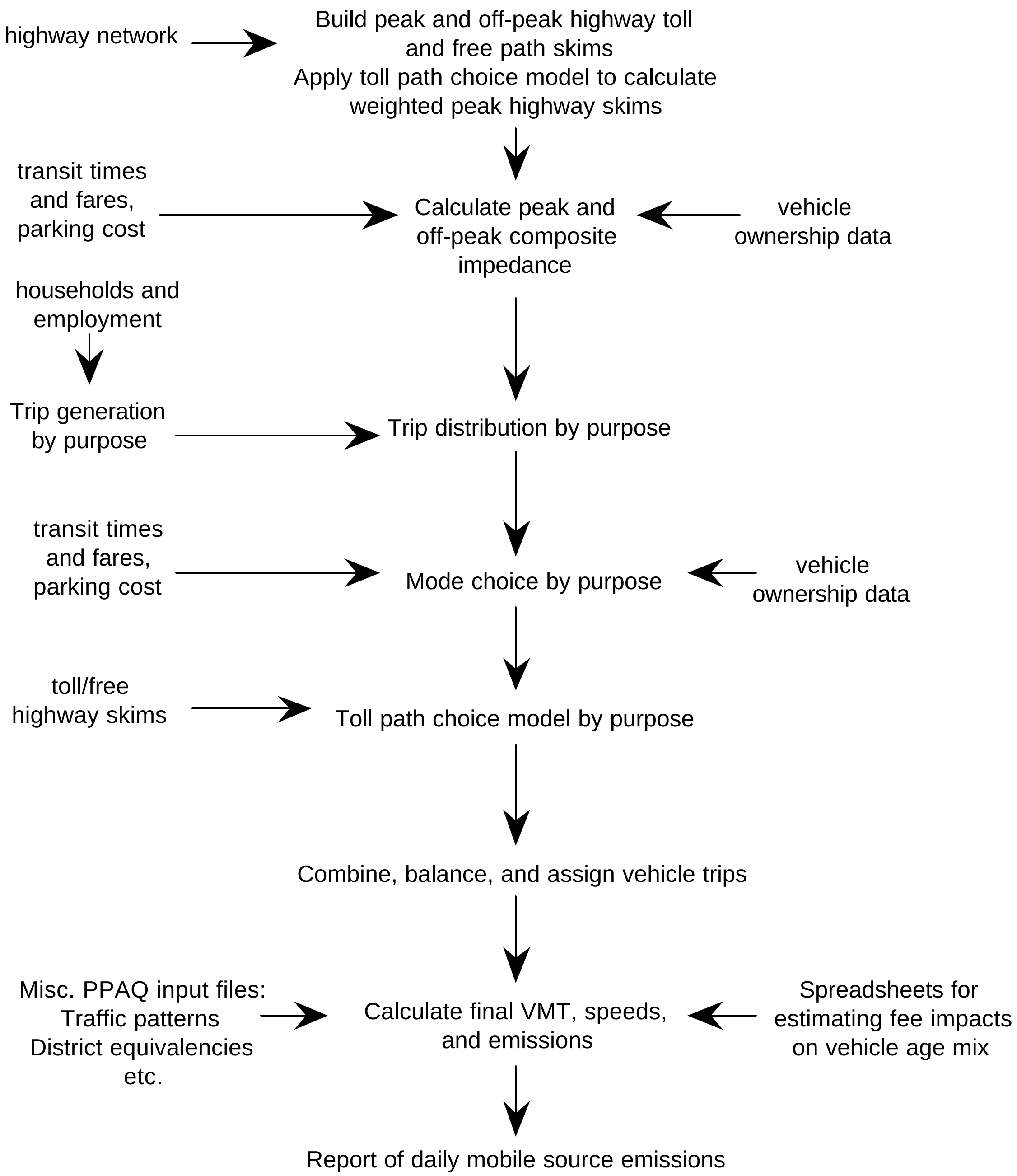


Figure A-2
Household Size Submodel

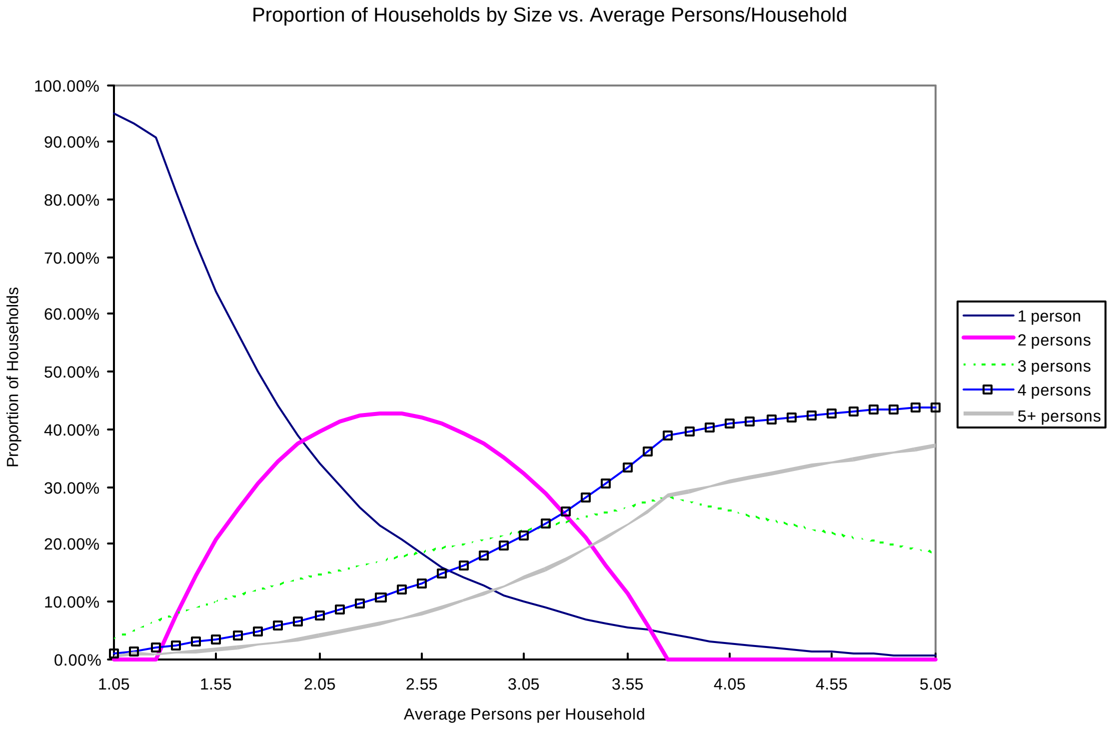


Table A-1
Regional Joint Percentage Distribution of Households by Size and Vehicles

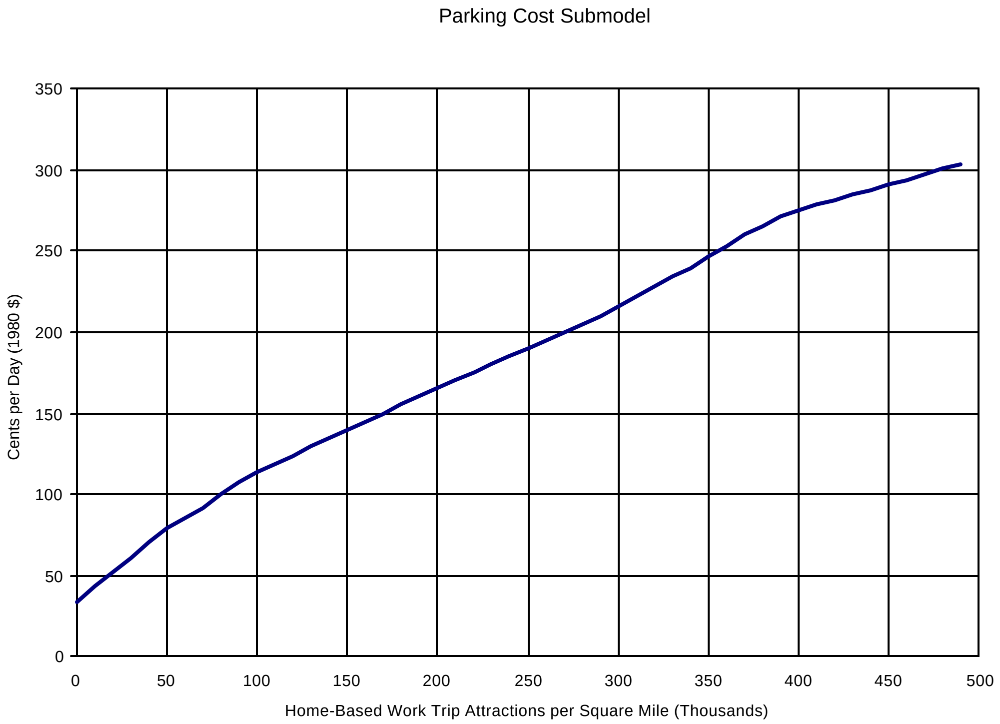
	Vehicles			
Size	0	1	2+	Total
1	4.2%	18.6%	2.1%	24.9%
2	1.1%	9.7%	24.7%	35.5%
3	0.3%	2.6%	14.9%	17.8%
4	0.1%	1.5%	13.4%	15.0%
5+	0.0%	0.6%	6.2%	6.8%
Total	5.7%	33.0%	61.3%	100.0%

Source: 1987/88 MWCOG Home Interview Survey.

A.1.3 Trip Generation Specifications

This component is the most traditional part of the model set. Daily home-based person trips produced by households are estimated as a function of the joint number of households by size and vehicles ownership. Daily person trips attracted to a zone are estimated as a linear function of households and employment by type. Four trip purposes are used: home-based work (HBW), home-based other (HBO), non-home-based (NHB), and truck. NHB and Truck vehicle trips are calculated as trip ends only; i.e., origins = destinations = trip ends. The trip rates include all trips and the split of trips that begin or end outside the region (external) are estimated as a percentage of total trip ends. External trips are then split off as a separate trip purpose. Internal/external productions are distributed to external stations in proportion to the 1990 traffic count at the external station.

Figure A-3
Parking Cost Submodel



Source: MWCOG.

Work trip ends are balanced to the attraction total and trip ends for the other purposes are balanced to production totals. The trip rates and attraction equations were derived from the models of Washington, D.C., Dallas, and Minneapolis-St. Paul. The trip generation model is presented in Tables A-2 to A-4. This is a very simplistic model, not so much calibrated as synthesized, whose main focus was on matching the Washington, D.C. region s total number of trips by purpose. This trip generation model is not sensitive to pricing.

Table A-2
Trip Production Model

HBW trips/HH	Vehicles		
Size	0	1	2+
1	0.372	1.147	1.583
2	1.105	1.540	2.581
3	1.912	2.347	3.367
4	1.912	2.347	3.367
5+	3.038	3.187	3.951
HBO trips/HH			
1	3.074	3.190	3.335
2	4.437	5.220	5.452
3	4.930	8.120	8.497
4	6.293	12.180	12.644
5+	8.207	15.950	19.372

Table A-3
Trip Attraction Model

HBW Attractions = 1.484 * total employment

HBO Attractions = 0.45 * office employment + 13.50 * retail employment + 3.00 * other employment + 0.75 * households

NHB Trip Ends = 0.555 * office employment + 2.59 * retail employment + 1.11 * other employment + 0.37 * households

Truck Trip Ends = 0.011 * office employment + 0.212 * retail employment + 0.212 * other employment + 0.042 * households

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Table A-4
External Trip Percentages

HBW	5.9%
HBO	1.5%
NHB	2.0%
Truck	5.9%

A.1.4 Trip Distribution Specifications

In most areas, the distribution of trips from an origin zone to potential destination zones is performed using a *gravity model.* This model distributes trips as a function of the number of trip attractions and a measure of the separation of the zones. Almost all areas use highway time as this measure of separation. However, researchers have long known that factors other than highway time play a role in the allocation of trips to destination zones. For example, there is considerable evidence that the presence of good transit service between two zones will increase the number of *person* trips between those zones. A logical extension of this concept is that other components of this separation, such as prices that users pay for transportation, should also influence destination choice and thus be accounted for. This effect appears to have an intuitive and empirical basis that cannot be ignored.

So far, very few urban areas have developed distribution models that are sensitive to the prices travelers pay and service levels of all travel modes (also referred to as *composite impedance*). Some examples include San Francisco, Boston, New Orleans, Atlanta, and Denver. Most areas that use this formulation use it only for work trips, but in theory it should be applicable to all trip purposes. This has become a well documented process and was adopted for the Case Study Model.

The Case Study Model distributes trips for all purposes with a gravity model that uses composite impedance (CI) as its measure of zonal separation. This impedance is defined as the *log sum* from the mode choice model, i.e., the natural logarithm of the inverse of the sum of the exponentiated disutilities of all available travel modes (the denominator of the mode choice equation). This method was adopted from the New Orleans regional model. This version of composite impedance includes the following travel costs: auto operating cost, tolls, transit fares, and parking fees.

The use of this function makes the allocation of trips to destination zones sensitive to differences in those user costs. For example, if transit fares were to decrease in a certain corridor, not only would the transit share increase for those trips (from the mode choice model), but the number of person trips in that corridor would increase slightly, because the decrease in fare causes a decrease in the separation between zones in that corridor. Further, using information from the mode choice model addresses the need for model connectivity, even though the models are still applied sequentially. Equation A-1 presents the log sum equation as used in this model.

$$CI_{ij} = 25 * \left[2 + \ln \left(\frac{1.0}{e^{-U(tr)} + e^{-U(da)} + e^{-U(cp)}} \right) \right] \qquad \text{(A-1)}$$

where:
CI_{ij} = composite impedance from zone i to zone j
U(tr) = disutility of Transit mode
U(da) = disutility of Drive Alone mode
U(cp) = disutility of Carpool mode

The disutility equations are presented in the discussion of the mode choice model, below. Peak (congested) travel times and user costs were used for HBW trips; off-peak times and user costs were used for the other purposes. A separate CI value was calculated for each of three vehicle ownership groups and three transit access areas (walk to transit, drive to transit, no transit access). A weighted average of these nine values was then calculated. The value of 2 in equation A-1 is to ensure that the resulting value is greater than zero and the value of 25 is to spread the CI values over the range of 1 to 254.

In the New Orleans model, composite impedance is used to distribute work trips, but not non-work trips. In the calibration of that model, it was found that travel prices and transit service were uncertain influences on non-work destination choice. However, it seems intuitive that travel cost to users should affect non-work trip patterns in some way and so the Case Study Model uses composite impedance to distribute home-based other, non-home-based, truck, and external trips as well.

Special friction factors (F-factors) were developed for use with the composite impedance values. These were estimated such that the resulting trip tables would have the same average trip length and average CI as the known trip tables from the Washington, D.C. area. The F-factor curves are shown in Figure A-4. In order to adhere to MINUTP requirements, the F-factors are scaled to be integers between the values of 1 and 999,999.

Various trip distribution calibration statistics are shown in Table A-5. The observed data are based on 1996 trip tables previously estimated by MWCOG. These results suggest that the CI-based gravity models reproduce known trip patterns fairly well.

Figure A-4
F-Factor Curves

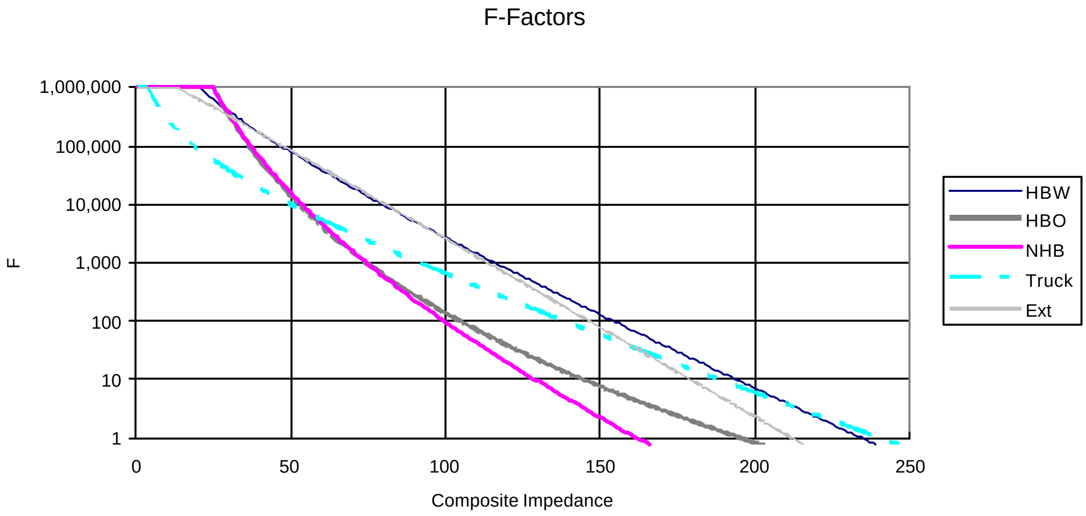

Table A-5
Trip Distribution Statistics

Purpose	Avg. Composite Imped. Observed	Avg. Composite Imped. Estimated	Intrazonal Trips Observed	Intrazonal Trips Estimated
HBW	68.10	67.90	116,300	133,300
HBO	45.58	47.52	538,500	581,500
NHB	45.81	47.04	314,100	269,800
Truck	61.88	61.84	10,000	11,200
I/X75.24	75.29	---	---	

The resulting trip tables were found to sharply overestimate travel across the Potomac River and so K factors were developed to force a better correspondence with the traffic counts on the bridge crossings. HBW trips across the river were factored by 0.20, while all other purposes were factored by 0.25. The need for such factors is supported by the existing MWCOG model, which uses extra time penalties on the Potomac River bridges to accomplish essentially the same function.

A.1.5 Mode Choice Specifications

Within the four-step process, current mode choice models stand out as being the most rigorously developed and properly price-sensitive component. Many larger urban areas have developed sophisticated *logit models* which estimate the share of person trips by mode, based on the socioeconomic level of the traveler and the time and user cost attributes of the various modes. The Case Study Model mode choice model is based on the approach used in the Washington, D.C. area, which is considered fairly representative of good practice.

The HBW mode choice model incorporates a Carpool model which estimates the split among 2-person carpools, 3-person carpools, and 4+-person carpools. Those percentages are used to estimate the average attributes of the Carpool mode, allowing the model to then split total person trips into Drive Alone, Carpool, and Transit modes. Separate walk-access and drive-access markets are used to calculate the Transit split. This split is sensitive to various auto mode attributes, including terminal time, driving time, auto operating cost, tolls, and parking cost, as well as transit attributes, including walk time, initial wait time, transfer time, in-vehicle time, and transit fare. A special high-occupancy vehicle (HOV) feature allows the modeler to define HOVs as having either 2, 3, or 4+ persons per vehicle and uses special travel times and costs for such trips. The Washington model s sensitivity coefficients were replaced with those representing an average of experience from logit models in numerous urban areas around the country (which turned out to be quite similar to the Washington area s coefficients).

Equation A-2 presents the logit mode choice model structure.

$$P_{ijma} = \frac{e^{-U(m_a)}}{e^{-U(tr_a)} + e^{-U(da_a)} + e^{-U(cp_a)}} \qquad \text{(A-2)}$$

where:

P_{ijma} = probability of choosing mode m for a trip from zone i to zone j by travelers with auto availability a

$U(tr_a)$ = disutility of Transit mode for travelers with auto availability a

$U(da_a)$ = disutility of Drive Alone mode for travelers with auto availability a

$U(cp_a)$ = disutility of Carpool mode for travelers with auto availability a

$U(m_a)$ = disutility of mode m (Transit, Drive Alone, or Carpool) for travelers with auto availability a

The disutility of the Carpool mode is a weighted average of the disutility of each integer Carpool occupancy mode:

$$U(cp) = P_2 * U(2) + P_3 * U(3) + P_4 * U(4) \qquad \text{(A-3)}$$

where:

U(2), U(3), U(4) = disutility of 2-person, 3-person, and 4+-person carpools

P_2, P_3, P_4 = probability of the trip being made in a 2-person, 3-person, or 4+-person carpool, given that the traveler is in a carpool, calculated as:

$$P_{ijoa} = \frac{e^{-U(o_a)}}{e^{-U(2_a)} + e^{-U(3_a)} + e^{-U(4_a)}} \qquad \text{(A-4)}$$

where:

P_{ijoa} = probability of the trip being made in a vehicle with occupancy o for a trip from zone i to zone j by carpoolers with auto availability a

$U(o_a)$ = disutility of carpool occupancy o for travelers with auto availability a

This is considered a quasi-nested logit structure in that the carpool model (equation A-4) is not used to directly calculate the carpool share, but rather to calculate the average carpool disutility (equation A-3), which is then used in the primary model (equation A-2). Table A-6 presents the disutility equations for the HBW primary model and the carpool model.

For home-based other and non-home-based trips, the MWCOG model does not use the logit equation to calculate a mode share. Instead, it multiplies the estimated HBW mode shares by a factor that varies with distance (and, for HBO trips, by vehicle ownership). A similar approach was used in the Case Study Model, except that the non-work mode shares are based on off-peak highway and transit times. The factors are shown in Table A-7.

A very important point to note about the cost coefficients is that they were originally calibrated using prices expressed in 1980 year dollars. Thus, when this model is applied, all prices must be adjusted to represent the equivalent price in 1980 dollars. For example, prices in 1993 dollars must be deflated to 1980. This is done by multiplying them by a deflation factor of 0.57, which is the ratio of the U.S. Urban Consumer Price Indices of 1993 to 1980 (= 82.4/144.4). Neglecting to account for this effect will result in the model being improperly sensitive to price.

This model was not calibrated, *per se*, but the bias coefficients were adjusted so as to achieve approximately the same transit trips and auto occupancy that had been forecasted for the Washington, D.C. region for 1996. Those statistics are shown in Table A-8.

Prices were carefully specified in this model. All prices were expressed in cents per one-way trip, in 1980 year dollars, because that is the year for which the original coefficients were developed. Auto operating cost was calculated as 11.0 cents/mile, multiplied by the minimum path distance for each O/D pair. This is the *incremental* cost of using a vehicle for each trip and does not include any of the fixed costs of vehicle ownership. Parking cost to users was calculated using the density-based model shown above in Figure A-3 and divided by two to represent half the daily price. For non-work trips, the average parking cost to users is assumed to be 20% of the daily parking price. The toll (roadway price) input represents the weighted average toll for each O/D.

Table A-6
Home-Based Work Mode Choice Disutility Equations

Prime Mode Choice

U(tr) = 0.05 * (WLK + WT1 + WT2) + 0.02 * RUN + 0.004 * FARE + 0.02 * AAC + ACBIAS
U(da) = 0.1001 * TERM + 0.02 * RUN + 0.004 * OPCST + 0.0095 * (PKCST + TOLL) + DABIAS
U(cp) = 0.0519 * TERM + 0.02 * (RUN + 1.1*(CPOCC-1)) + 0.004 * OPCST/CPOCC + 0.0095 * (PKCST + TOLL)/CPOCC + CPBIAS

$$\text{CPOCC} = \frac{1.0}{\frac{P(2)}{2.0} + \frac{P(3)}{3.0} + \frac{P(4)}{4.394}}$$

Carpool Share

U(2) = 0.1823 * TERM + 0.07 * (RUN + 1.1) + 0.014 * OPCST/2 + 0.0333 * (PKCST + TOLL)/2
U(3) = 0.1823 * TERM + 0.07 * (RUN + 2.2) + 0.014 * OPCST/3 + 0.0333 * (PKCST + TOLL)/3 + 3PBIAS
U(4) = 0.1823 * TERM + 0.07 * (RUN + 3.733) + 0.014 * OPCST/4.394 + 0.0333 * (PKCST + TOLL)/4.394 + 4PBIAS

Bias Constants by Vehicles Owned

Vehicles	0	1	2+
ACBIAS	2.1333	0.9360	0.9501 (if auto used to access transit system)
DABIAS	3.3077	-0.0439	-1.0552
CPBIAS	2.9882	1.0989	0.4200
3PBIAS	1.2951	1.7186	1.6952
4PBIAS	2.1106	2.5532	2.1909

Abbreviations:

WLK = transit walk time
WT1 = transit initial wait time
WT2 = transit transfer time
RUN = transit in-vehicle time
FARE = transit fare
AAC = auto access time to transit

TERM = highway terminal time
OPCST = auto operating cost to the user
PKCST = daily parking cost to the user (divided by 2)
TOLL = average toll paid
CPOCC = average occupancy of Carpool mode

All times are in minutes and costs are in cents, expressed in 1980 year dollars.

Table A-7
Non-Work Mode Share Factors

Distance (mi.)	Vehicles Owned	HBO Transit Factor	HBO Auto Pass. Factor	NHB Transit Factor	NHB Auto Pass. Factor
0-1	0	0.5261	2.1790	0.1334	2.0081
	1	0.2374	1.5515	0.1334	2.0081
	2+	0.2374	2.7676	0.1334	2.0081
1-2	0	0.6428	2.1790	0.1334	2.0081
	1	0.1807	1.5515	0.1334	2.0081
	2+	0.1807	2.7676	0.1334	2.0081
2-3	0	0.6428	3.7090	0.1334	2.0081
	1	0.1807	2.0419	0.1334	2.0081
	2+	0.1807	3.3290	0.1334	2.0081
3-4	0	0.6428	2.9104	0.1334	2.0081
	1	0.1807	2.0419	0.1334	2.0081
	2+	0.1807	3.3290	0.1334	2.0081
4-5	0	0.6428	2.1036	0.1334	2.0081
	1	0.1807	2.0419	0.1334	2.0081
	2+	0.1807	3.3290	0.1334	2.0081
5-6	0	0.6236	2.0978	0.1334	2.0081
	1	0.1607	1.9051	0.1334	2.0081
	2+	0.1607	3.3290	0.1334	2.0081
6-7	0	0.6236	1.8674	0.1334	2.0081
	1	0.1607	1.9051	0.1334	2.0081
	2+	0.1607	3.3290	0.1334	2.0081
7-10	0	0.6236	1.7769	0.1334	2.0081
	1	0.1607	1.9051	0.1334	2.0081
	2+	0.1607	3.3290	0.1334	2.0081
10-30	0	0.5156	1.5292	0.1274	2.0081
	1	0.1514	1.8150	0.1274	2.0081
	2+	0.1514	3.3290	0.1274	2.0081
30-50	0	0.0	1.5057	0.0	2.0081
	1	0.0	1.7791	0.0	2.0081
	2+	0.0	3.3290	0.0	2.0081

Table A-8 Summary of Mode Choice Results

	HBW	HBO	NHB	Total
Transit Trips*	675,900	460,300	110,300	1,246,500
Percent Transit	15.4%	4.5%	2.8%	6.7%
Vehicle Trips	3,309,700	7,513,700	3,052,600	13,876,000

Auto Occupancy	1.125	1.314	1.239	1.252

* Linked trips.

pair, which is the skimmed toll value multiplied by the percent of drivers which are estimated to use the toll path for that trip.

The mode choice model outputs vehicle trips by LOV and HOV occupancy categories. The HOV occupancy criterion can be 2, 3, or 4 persons/vehicle; in this project it was set to 3. The Washington area does have HOV highway facilities and their impact was included in the analysis.

A.1.6 Path Choice and Traffic Assignment Specifications

Studies of toll roads focus on drivers trade-off between paying a toll and saving time. Traditionally, relatively less attention has been paid to drivers path choices, as planners have relied mainly on traffic assignment software to handle that task. However, recent toll road studies have discovered that such software is inadequate for modeling complex toll vs. time trade-offs and have developed more sophisticated models of path choice. These models determine the best free path for each zone-to-zone pair, i.e., the best path that does not use the toll facility. They then determine the best toll path, which is the best path that includes the toll facility. Those paths are analyzed to determine their time and toll difference, which is then used in a logit model to estimate the split of trips between the two paths. This is done for every zone-zone pair in the network. Separate toll and time sensitivities are used for work and non-work trips. Recent advances in assignment software permit the two resulting trip tables to be assigned simultaneously, but each to its own set of paths. Within the multiple iterations of assignment, trips are allowed to migrate between paths to a limited degree in response to congestion. The result is a more realistic assignment of trips to toll facilities, in a manner that is sensitive to the level of toll as well as to the capacity of the alternative non-toll routes.

This kind of process has been recently used in toll road studies in Denver and New Jersey, and was adapted for use in the Case Study Model, under the assumption that it is suitable for analyzing roadway pricing measures. The resulting toll values affect not only the path choice, but also the choice of mode, which uses toll as an input, as noted above. Because toll is part of the composite impedance calculation, toll values affect the distribution of trips as well.

The toll diversion model is a logit formulation that splits all vehicle trips for each O/D pair into toll and free trips. The equation is as follows:

$$P(\text{toll})_{ij} = \frac{1.0}{e^{\Delta U(\text{toll}-\text{free})}} \qquad \text{(A-5)}$$

where:
$P(toll)_{ij}$ = probability of choosing the toll path for a trip from zone i to zone j
$\Delta U(toll\text{-}free)$ = difference in disutility between toll and free path
= 0.301 * (toll time - free time) + 0.0127 * toll path toll + 1.5 (HBW trips)
= 0.191 * (toll time - free time) + 0.0272 * toll path toll + 0.3 (all other trips)
toll is in cents and time is in minutes

The toll time is computed based on paths that are built by temporarily reducing the time on all tolled links by 10%. This encourages any trip which is near the toll link to use it. The free path time is computed by prohibiting the use of all tolled links. Throughout the Case Study Model, highway paths for skimming and for assignment are built on the basis of minimizing impedance, where impedance is calculated in equivalent cents as:

impedance (in cents) = 10.0 * time (in minutes) + 11.0 * distance (in miles)

The 10.0 factor on time is derived from an assumed effective value of travel time of $6.00 per hour (roughly 22% of the Washington, D.C. area s mean 1990 household income). The 11.0 factor on distance represents the user cost of operating an automobile, as noted above. This formulation ensures that user cost influences highway paths.

The traffic assignment procedure uses four iterations of incremental, capacity-restrained assignment, with 25% of the trips assigned on each iteration, following current MWCOG practice. Thus, the assignment of trips is sensitive to roadway capacity in an incremental fashion: some trips see an open roadway, while others see a congested one. The input daily vehicle trips are split by four categories: low-occupancy vehicle (LOV) free path, LOV toll path, HOV free path, and HOV toll path, with each category of trips being assigned to its specific set of paths, respecting the presence of priced roadways and HOV roadways. The output of this process is a loaded network with daily traffic volumes on each link.

A.1.7 Emissions Calculation Specifications

The estimation of mobile source emissions requires two basic data items from the traffic assignment: VMT and speed. U.S. EPA s MOBILE5a emission factor program is applied to calculate emission rates in grams/mile for the criteria pollutants (the EMFAC7F program is used in California). These rates are a function of the mix of vehicles by eight types, the average distance they travel per year, average travel speeds, ambient temperatures, inspection and maintenance (I/M) programs, fuel policies, and other factors. The PPAQ (Post-Processor for Air Quality) program developed by Garmen Associates is used to read the loaded network, revise the speed calculations by facility type and time period, summarize VMT by facility type and time period, and apply the MOBILE5a emission factors. PPAQ requires a series of input tables that reflect the mix of vehicle types by roadway type, the percentage of traffic by hour, and other parameters that describe traffic patterns in more detail. These parameters have been adopted from work recently performed in the Philadelphia region. The result of a PPAQ run is an estimate of total daily tons of HC, CO, and NO_X from on-road mobile sources.

Changes in most of the pricing measures under study, such as roadway pricing, transit fares, and parking costs, will be reflected in the assigned link volumes. The exceptions are the measures involving registration fees that are based on age or emission level. It is assumed that such strategies have no measurable impact on the amount of VMT, but will affect the mix of vehicles by age. Strategies that make it more expensive to own an older vehicle should result in fewer older vehicles on the road. Since older vehicles were generally built to less stringent emission standards and are usually less well maintained, a reduction in such vehicles can be expected to reduce the emission rates calculated by MOBILE5a.

Spreadsheets have been developed in this study to analyze age-based fees and emission-based fees. These spreadsheets estimate the impact of different fee structures on the default MOBILE5a vehicle mix by year. The spreadsheets use a very simplistic relationship between the annual user cost of owning a vehicle and the percentage of vehicles in each age category. For each age category, a value is computed representing the annual fee divided by the estimated market value of the vehicle. This value is the change in fee as a percent of the vehicle s value. An elasticity of -1.0, derived from literature on the price elasticity of new car sales, is applied to that change in fee. The resulting value is the estimated percentage change in fleet share for that age category. This is done separately for each of the eight MOBILE5a vehicle types and MOBILE5a defaults are used for the initial age mix. It is assumed that none of the registration fee policies would affect the total number of vehicles; only the age mix. Thus, all of the vehicles removed from older age categories are shifted to newer age categories, in their existing proportions.

The output of these spreadsheets is a revised set of vehicle age mixes by vehicle type that can be input directly into MOBILE5a. Table A-9 shows an example spreadsheet, analyzing a fee schedule for light-duty gasoline vehicles (passenger cars) that varies from $100 for 4 year old vehicles to $900 for vehicles of 20 years or more.

The revised age mix is entered into PPAQ, along with the loaded highway network from the assignment step. PPAQ splits the link volumes by time period, adjusts the speeds on each link, summarizes VMT and average speed by time period, facility type, and jurisdiction, applies MOBILE5a to each scenario , multiplies the resulting emission rates by the VMT, and produces a concise summary of the regional mobile source emissions of interest. Table A-10 is a sample of the summary page of PPAQ output.

Table A-9
Sample Vehicle Age Mix Adjustment Spreadsheet (Age Fee)

LDGV		elasticity:	-1.00					
	estimated		fee change	MOBILE5a registration mix by year (starting 1 July 90)				new/base
year	value	change in fee	as % of value	base % by yr	new % by yr	% left	cum % left	ratio
25	$400	$900	225.0%	1.10%	0.00%	1.10%	1.10%	0.0%
24	$500	$900	180.0%	0.30%	0.00%	0.30%	1.40%	0.0%
23	$600	$900	150.0%	0.40%	0.00%	0.40%	1.80%	0.0%
22	$700	$900	128.6%	0.50%	0.00%	0.50%	2.30%	0.0%
21	$900	$900	100.0%	0.60%	0.01%	0.59%	2.89%	2.4%
20	$1,000	$900	90.0%	0.80%	0.10%	0.70%	3.58%	13.0%
19	$1,200	$800	66.7%	1.10%	0.41%	0.69%	4.27%	37.1%
18	$1,500	$800	53.3%	1.50%	0.77%	0.73%	5.01%	51.2%
17	$1,800	$700	38.9%	1.40%	0.93%	0.47%	5.48%	66.5%
16	$2,100	$700	33.3%	1.90%	1.38%	0.52%	6.00%	72.6%
15	$2,500	$600	24.0%	2.40%	1.98%	0.42%	6.41%	82.6%
14	$3,000	$600	20.0%	3.70%	3.23%	0.47%	6.88%	87.3%
13	$3,500	$500	14.3%	4.70%	4.41%	0.29%	7.17%	93.9%
12	$4,100	$500	12.2%	5.40%	5.23%	0.17%	7.34%	96.8%
11	$4,900	$400	8.2%	5.00%	5.09%	-0.09%	7.26%	101.7%
10	$5,700	$400	7.0%	5.10%	5.28%	-0.18%	7.08%	103.5%
9	$6,700	$300	4.5%	5.00%	5.33%	-0.33%	6.75%	106.6%
8	$7,900	$300	3.8%	5.60%	6.03%	-0.43%	6.32%	107.6%
7	$9,100	$200	2.2%	7.70%	8.44%	-0.74%	5.58%	109.6%
6	$10,500	$200	1.9%	8.10%	8.93%	-0.83%	4.75%	110.3%
5	$12,000	$100	0.8%	8.40%	9.39%	-0.99%	3.76%	111.8%
4	$13,500	$100	0.7%	8.20%	9.19%	-0.99%	2.77%	112.1%
3	$14,700	$0	0.0%	8.30%	9.39%	-1.09%	1.68%	113.1%
2	$14,800	$0	0.0%	7.90%	8.94%	-1.04%	0.64%	113.1%
1	$17,922	$0	0.0%	4.90%	5.54%	-0.64%	0.00%	113.1%
				100.0%	100.0%	0.0%		
			avg age:	8.2	7.1		avg fee:	$235

Note: LDGV = light-duty gasoline vehicle

Table A-10
Sample PPAQ Output

```
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_______________________________________________________________________________________________
____
       Total Emissions by Scenario:
       ----------------------------

                          VMT         VHT       Avg Spd      VOC HC         CO          NOx
          Scenario     (veh-mi)    (veh-hr)      (mph)        (kg)         (kg)        (kg)
       -------------  ----------  ----------  ----------  ----------  ----------  ----------

        A  67F 1T 1     6959230      141448        49.2        7289       49933       13690
        A  67F 1T 2     9368194      324159        28.9       16466      107271       16541
        A  67F 1T 3    17085802      411706        41.5       22108      142505       31823
        A  67F 1T 4    11197222      189783        59.0       12909      131713       32602
        A  67F 2T 1      819904       20345        40.3         942        6434        1404
        A  67F 2T 2     1285529       76520        16.8        3435       22543        2085
        A  67F 2T 3     2004210       49856        40.2        2563       16282        3452
        A  67F 2T 4      951494       17818        53.4         926        6571        2052
        A  67F 3T 1     6361328      340178        18.7       12872       99395       10507
        A  67F 3T 2     9973934     1049888         9.5       42272      273395       17313
        A  67F 3T 3    15549907      822746        18.9       35269      249739       25847
        A  67F 3T 4     7382279      232147        31.8        9719       70717       12602
        A  67F 4T 1     4687831      393935        11.9       13371      102474        8178
        A  67F 4T 2     7350054     1080890         6.8       40505      267663       13550
        A  67F 4T 3    11459147      962954        11.9       38330      260217       19982
        A  67F 4T 4     5440198      256613        21.2        9549       74506        8818
        A  67F 5T 1     1564851      115915        13.5        4071       31003        2687
        A  67F 5T 2     2745873      450143         6.1       17039      110003        5153
        A  67F 5T 3     3572584      244698        14.6       10154       69201        6048
        A  67F 5T 4     1958525       99925        19.6        3616       28669        3129
        A  67F 6T 1     2094284       66910        31.3        2903       20651        3575
        A  67F 6T 2     3674875      117784        31.2        5964       37679        6094
        A  67F 6T 3     4781289      152757        31.3        7395       48753        8159
        A  67F 6T 4     2621150       83743        31.3        3457       25087        4355
                      ----------  ----------  ----------  ----------  ----------  ----------
       TOTAL - kg     140889696     7702861        18.3      323124     2252406      259645
             - tons                                         356.179    2482.827     286.207

                             HC Emissions Breakdown:
                                          Exhaust     186606 kg  205.696 tons    57.8%
                                      Evaporative      33070 kg   36.453 tons    10.2%
                                        Refueling          0 kg    0.000 tons     0.0%
                                          Running      91180 kg  100.507 tons    28.2%
                                          Resting      12268 kg   13.523 tons     3.8%

____________________________________________________________________________________
PPAQ/MOBILE5
04-21-1994 / 00:57:18
```

Note: A 67 refers to the summary jurisdiction, of which there is only one.
F x refers to the facility type.
T y refers to the time period: 1=AM peak, 2=PM peak, 3=midday, 4=night.

Post-processor programs such as PPAQ are commonly used in air quality modeling. This is mainly because historically, the constrained speeds that result from most traffic assignments are not sufficiently accurate. These speeds represent just one particular value and they tend to include other elements of impedance, as needed to obtain accurate assigned volumes. Many planning agencies have developed their own speed processor programs to adjust these constrained speeds to be more realistic and to summarize VMT by various stratifications, in preparation for running MOBILE5a.

A.1.8 Model Application

The case study model set is applied in a series of 15 program steps. The MINUTP planning software system is used for most of these. Custom FORTRAN programs were written to prepare the land use data and to apply the mode choice model. PPAQ and MOBILE5a are stand alone programs and the age mix spreadsheets are in Microsoft Excel. The full model set requires about 9 hours to apply using an 80486-based computer running at 66 MHz.

The case study model set was applied using basic land use and network data from the Washington, D.C. area (1,478 zones), representing approximate 1996 forecast conditions. However, since the model incorporates components from various cities, the results do not reflect actual (or forecasted) conditions in Washington and cannot be compared to the results from the Washington area s own model set.

The Washington area is projected to comprise about 1.8 million households, 4.0 million persons, and 3.0 million jobs. The area has an extensive Interstate system, including a Beltway around the District of Columbia and the close-in Maryland and Virginia suburbs (I-95/I-495) . In addition to an extensive bus network, the area is served by the Metrorail system and four commuter rail lines. Major HOV facilities exist in Virginia on the Shirley Highway (I-395 and I-95 to the south) and I-66 to the west. There is one existing toll road, connecting the Beltway to Dulles International Airport to the west.

As Figure A-1 shows, the model set is applied backwards :

- The path choice model is applied first, to derive weighted average highway time, distance, and toll values. Peak period values are used for work trips and off-peak values are used for all other purposes.
- The mode choice program is then applied to calculate the composite impedance value by zone-zone pair.
- Trip generation and distribution are applied to estimate person trips by purpose.
- The mode choice program is applied again, this time to split person trips by mode.
- The path choice model is applied again to split vehicle trips by toll vs. free path.
- The vehicle trips are assigned to the highway network.
- The age mix spreadsheets are applied to determine changes in the age mix.

- PPAQ and MOBILE5a are applied to compute emissions from the loaded network.

The case study model has not been calibrated in the true sense, since it was developed from data representing several urban areas. However, the results of the various components were checked for internal consistency and to ensure an approximate level of correspondence with 1996 total VMT estimates for the Washington, D.C. area.

A.1.9 Summary of Advanced Features of the Case Study Model

As noted above, the Case Study Model set is not based on new research and does not represent any breakthrough in the state of the practice in travel demand modeling. Its advancement is that it was created from the best pricing-related features from several other well-documented model sets that have been extensively tested throughout the years. It is very likely the first time that these various components have been assembled in this exact manner and demonstrates one way in which the four-step process can be enhanced to be sensitive to policy issues such as pricing.

The most noteworthy features of this model set are:

Use of composite impedance for trip distribution for all trip purposes

Integration of a toll/free path choice model within a four-step process

Mode choice model, including a nested carpool occupancy model

Parking price sub-model within the mode choice model that permits separate specification of parking prices for LOVs and HOVs

Assignment procedure that simultaneously handles LOV/HOV and toll/free path trips

Ability to easily calculate effects of vehicle age mix changes

Integration of mobile source emission calculations within a four-step travel model

A.2 Enhancements to the Case Study Model

The resource constraints of this project limited the development of the Case Study Model. As this work progressed, several shortcomings became apparent. These are described here as guidance for enhancing this particular model set, and other models in general.

Income Stratification: It would be preferable to stratify the entire model set by income level. This would permit the identification of differential price sensitivities by income level and would facilitate the examination of the differential effect of pricing policies by income level. Unfortunately, time did not permit the development of such a model, nor was the 1990 Census Transportation Planning Package (CTPP) available at the time this work was conducted. Now that CTPP files have become more widely available, income stratification should be pursued more vigorously. This is important because there is considerable evidence which suggests that people of different income levels respond to pricing measures differently, and public policy considerations suggest the need to analyze how the implementation of such measures affects each income group. More investigation into the combined effects of income and vehicle ownership on traveler behavior should also be conducted. Traveler surveys need to collect information on household income (or income category, such as quartile). Progress is being made in the difficult area of estimating the stratification of trip attractions by income.

Vehicle Ownership: There is growing evidence that the effect of vehicle ownership on person trip generation cannot be discounted, even after considering the effect of income. Vehicle availability may well have a measurable effect on discretionary trips and on the level of trip chaining. Considerable attention is now being paid to developing vehicle ownership models that are sensitive to income, locational, density, accessibility, and/or transit service variables.

In order to analyze the effect of registration fees or one-time purchase surcharges/rebates, these models must also be at least marginally sensitive to the price of buying a vehicle and the annual user cost of owning one. In the context of travel modeling, increases in ownership cost should be reflected in decreased numbers of multiple-vehicle households and increased numbers of one-vehicle households. There might even be an increase in zero-vehicle households, but that is much less clear. At least one vehicle ownership model sensitive to user cost has been well documented [5].

Speed Feedback: The Case Study Model now begins with peak and off-peak speed values, the peak speeds having been derived from previous MWCOG model runs. It would be preferable to run the entire model set at least one more time in each application, using the speeds from the first run (modified as necessary to more closely match observed data) as peak speeds in the second run. This is particularly important for estimating congestion pricing scenarios. However, in this model, two iterations would require a total of 18 hours (this is one of the disadvantages of an interconnected model set -- changing one thing changes everything and so the entire model set must be iterated to ensure equilibrium). Doing this would have severely limited the ability to meet this project s schedule and so was not done.

In addition, numerous studies have documented the sensitivity of emission rates to average speeds. Thus, it is vital to have reasonably consistent and accurate speeds for emission modeling. In this study, the PPAQ program was used to adjust assignment speeds by facility type and time period.

Auto-Access to Transit Trips: Very few models include such trips in their vehicle trip table. To do so requires access to transit network data (such as park-and-ride [PnR] lot locations) that was unavailable for this project, as well as additional processing steps and time. Still, this phenomenon should not be overlooked, because some improvements to transit service can *increase* emissions by enticing some who carpool or who walk to transit to switch to driving to transit. Although most drive-access trips are short, they almost always involve a cold engine, and therefore cold start emissions. Increasing the number of such trips might not compensate for the passenger car VMT that is removed from the network.

Parking Price Measurement: The cost of parking to the user is one of the most important variables in determining mode choice. Thus, it would be preferable to measure it more carefully, such as specifically modeling the proportion of travelers who have free parking (instead of accounting for that effect in the average value, as the Case Study Model does). This would require some additional data, which is difficult to obtain, but it would improve the model s ability to respond directly to policies which change the percent of travelers who park for free. It would also be preferable to include variables other than density in the parking cost submodel, to increase its accuracy.

In addition, if strategies to change non-work parking pricing are to be properly modeled, an improved method of estimating non-work parking prices is needed. This submodel would probably be based on employment density and locational variables. The cost of all-day parking to commuters is relatively stable and closely related to work trip end density, as suggested above in Figure A-3. Of course, non-work travelers have a shorter parking duration time and are even more likely to park for free than commuters, but otherwise little is known about their average parking costs.

Effect of Price on Trip Generation: In this model set, the *number* of person trips per household is completely insensitive to the incremental user cost of travel by any or all modes. As was noted above, that might be remedied by including some kind of composite accessibility measure at the zonal or household level, which would require additional research. This would make travel estimates sensitive to area-wide pricing measures such as a gasoline tax increase. It would also address the phenomenon of induced travel that is a concern to some planners by making trip rates sensitive to the general level of development in a region and the general quality of highway and transit service.

With a doubly-constrained trip distribution procedure such as the standard gravity model, it would probably prove necessary for the trip *attraction* estimate to be sensitive to user cost (if the gravity model uses composite impedance). Otherwise, trip pattern distortions could occur under certain pricing scenarios as the gravity model tries to reallocate attractions in response to cost changes, but the attraction model would maintain the same attractions in a zone.

Time of Day: This model set estimates total daily travel only. Although separate peak and off-peak impedances are used to represent those periods, the model does not account for the possible migration of trips from one period to the other. Such migration might occur due to congestion, pricing, or employer policy. A basic model that splits daily travel into three or four periods is not conceptually difficult; such models are currently used in several cities. Further refinements to make that model sensitive to peak/off-peak time savings should be readily feasible. However, to analyze peak-only pricing or congestion pricing measures, the model also needs to be sensitive to the peak/off-peak travel cost differential and it is uncertain whether the data to define such sensitivity exists. However, it may be necessary to synthesize such a sensitivity (or perhaps estimate it from stated preference surveys or the experience of transit systems with peak/off-peak fares) and re-examine it in the context of an actual congestion pricing experiment. This is important, because a likely major response to peak-only pricing measures is to shift the time of travel.

Trip Chaining: As in most other travel forecasting models, this model does not directly estimate any effects on trip chaining . Many researchers believe that a logical and likely response to increases in the price of travel (or reductions in the number of vehicles available to a household) is for people to use their vehicles more efficiently. This could have some effect on VMT and potentially a greater impact on cold starts. It would be helpful if the model set could reflect this phenomenon.

Nested Logit Model: Although the multinomial logit model is the most widely used formula for mode choice modeling, it is starting to be replaced by the *nested logit* model. This is because the true nested model is more adept at handling sub-mode splits (e.g., bus vs. rail, within the transit mode). There is some evidence that the nested logit structure more closely represents travelers trade-offs of attributes when selecting a travel mode. The nested logit also eliminates the independence of irrelevant alternatives property, which can cause mode share estimation errors for travel modes with similar characteristics.

Separate Mode Choice Models by Purpose: The Case Study Model includes a true mode choice model only for HBW trips. HBO and NHB mode shares are calculated as a distance-based factor multiplied by the HBW shares. This implies that the non-work mode shares move up or down in the same proportion as the HBW mode shares, which is unlikely. There is evidence from around the country that the mode share of non-work trips is more sensitive to price and less sensitive to time than for work trips, which is logical. It would be preferable to develop separate mode choice coefficients for work and non-work trips. This is particularly important, given that the mode choice coefficients influence trip distribution in this model as well.

One of the reasons why there is so much attention to work trips is because the CTPP provides a potentially robust source of calibration data for commuting. More extensive home interview surveys, perhaps as large as 1.0 - 1.5%, may be needed to capture enough observations of HBO and NHB trips (especially using transit) to permit the calibration of usable coefficients.

Improved Vehicle Age Mix Submodel: The Case Study Model s vehicle age mix submodel is overly simplistic and based on rough approximations. For example, its assumption that the age mix is sensitive to the ratio of the *annual* fee divided by the *value* of the vehicle is open to question. The submodel that estimates the average value of the vehicle by age and type was not rigorously calibrated due to time constraints but should be redeveloped based on known data. Further, for the emission-based fee, some provision in the submodel should be made to allow motorists the option of repairing the vehicle to improve its emissions, thus avoiding some or all of the fee. Additional research is necessary to determine if an annual or quarterly fee would truly affect vehicle ownership decisions or day-to-day travel choices (or both).

Finally, some research should be conducted into the effect of leasing vs. buying on vehicle replacement decisions.

Long-Term Land Use Allocation Effects: The Case Study Model, as with most travel demand models, simulates travel choices that are made in the short-term; i.e., hours, days, weeks. However, those pricing strategies *which travelers perceive to be permanent* can also have long-term influences; i.e., months or years. It would be very desirable for the travel model to be supplemented by a land use model that could adjust the allocation of households and jobs in response to such pricing changes. For example, a significant change in the toll on a bridge might be expected ultimately to persuade some existing travelers, over time, to change their location of residence, work, shopping, etc. Such tolls might also influence the locational decisions of residents and/or employers who are new to the region. Modifying future land use in response to pricing changes is one way to respond to the issue of induced demand . The few land use allocation models now in use employ travel time in their allocation process, just as typical trip distribution models do. Introducing pricing variables, such as composite impedance, might be one way for land use allocation models to be sensitive to the travel cost of users.

It should also be noted that the sensitivity of long-term locational decisions to pricing is probably quite different than short-term decisions on where to travel or by what mode. This long-term sensitivity is probably lower, but additional research is needed to quantify this difference.

Emissions Estimate Sensitive to Trips: The Post-Processor for Air Quality (PPAQ) program used in this project greatly facilitates the calculation of the emissions burden from each scenario s loaded network. However, PPAQ uses only VMT in its calculations. Although the additional emissions from cold starts, and hot soak and diurnal VOCs are included in the MOBILE5a emission rates, these should more properly be modeled as a function of the number of trips rather than VMT. This would more accurately differentiate the emissions impact of those strategies that reduce vehicle trips from those that reduce VMT.

This can also be partially addressed through an alternative technique for estimating cold start emissions [8]. That method uses purpose-based factors to split the vehicle trips into cold- and hot-start trips. The two trip tables are then assigned and the assignment software keeps track of where the cold start VMT occurs on the network. This provides an estimate of cold start VMT on each link, which improves the estimation of cold start emissions without having to calculate the change in vehicle trips.

A.3 Application of the Case Study Model

In this project, market-based measures to reduce mobile source emissions were classified into several groups. Within each group, specific variations of the measures were identified for detailed analysis. The following sections discuss how the Case Study Model was used to evaluate each measure. This information is presented primarily to provide guidance to travel demand forecasters in the development and use of similar techniques for evaluating market-based measures in their own areas.

A.3.1 Parking Pricing Measures

Analysis of parking pricing measures involves adjusting parking costs for a specific part of the region (e.g., the CBD), and/or a specific time period (peak vs. off-peak), and/or a specific segment of the travel market (e.g., work trips). Parking pricing measures are represented by a fixed incremental change or a percentage adjustment to existing parking costs. Parking costs are represented in the model by specifying the average daily cost for parking in each traffic analysis zone. A separate cost can be supplied for each zone for both LOV parking and HOV parking. This allows the specification of strategies with differential pricing based on vehicle occupancy.

Parking costs are used to compute combined impedances and to estimate modal shares. This affects the estimation of traveler choice of destination and mode of travel (with the potential to affect travel by time of day). Five parking scenarios were examined in two broad categories:

- Increase in average cost of parking (all spaces)

    (a) $4 per day increase in the core area and $2 increase elsewhere
    (b) $10 per day increase in the core area and $5 increase elsewhere
    (c) $5 per day increase in the core area and no change elsewhere

- Increase in average cost of parking (employee parking only)

    (a) same as (a) above but only applied to home based work trips
    (b) same as (b) above but only applied to home based work trips

Each of the scenarios are represented by adjusting the zonal data file used in the combined impedance step and the mode choice step. All incremental cost adjustments are converted to 1980 dollars by using the 0.57 factor prior to adjusting the parking costs in the zonal data file. Table A-11 summarizes the impacts of this scenario.

Table A-11
Parking Cost Impacts

Model Step	Impact
Trip Distribution	The composite impedance changes for paths destined to zones that have modified parking costs. This does not change the total number of trips that are attracted to these zones since that value is fixed from the trip generation step. It does change the distribution of trips to zones with modified parking costs.
Mode Choice	Changes in parking cost affect both the split between auto and transit and the split between LOV auto trips and HOV trips.
Assignment	VMT decreases due to fewer vehicle trips.
Emissions	HC, CO and NO_X emissions decrease due to the decrease in VMT.

A.3.2 Roadway Pricing Measures

Roadway pricing involves charging a fee (or toll) for vehicles to use certain roadways or to cross a border into a designated area. The toll can vary by time of day, by vehicle occupancy, and/or by the level of congestion on the roadway. Most such proposals would have the toll collected through automatic vehicle identification so that no delay would be imposed in collecting the toll.

It was assumed that this toll would influence travelers choice of 1) destination zone, 2) travel mode, and 3) highway path. The Case Study Model does not include a time of day submodel, so influences on the time of travel could not be estimated. In effect, the toll is assumed to be assessed to all vehicle trips (LOV and HOV) on the selected roadways at all times of the day. In this scenario, the selected roadways were those specific freeway and expressway links in the Washington, D.C. region that had been shown, through previous trip assignments, to have an estimated peak hour volume/capacity (V/C) ratio of 0.9 or higher. These were almost all of the Interstate and major through Primary roads in the region (727 one-way links out of a total of 18,400 links). Although these priced roadways represent 4% of the total coded network, they carry about 31% of the total daily VMT.

One level of toll was analyzed: $0.10/mile. This is a typical high-side value of the toll being charged in newly proposed toll roads in various areas. The first step was to convert this into 1980 year dollars by multiplying by 0.57, as noted above. The equivalent 1980 toll level is then $0.057/mile. The increased cost of using certain roads was first reflected in the path skimming step, in which path-building impedance is defined as the sum of auto operating cost (cost/mile multiplied by distance), and the money value of travel time. Priced roadway paths and non-priced (free) roadway paths were then built and input to the toll diversion model, which estimated the priced route/free route share for all O/D pairs. The average toll paid is then the toll on the shortest path, multiplied by the proportion of drivers who are estimated to use that path. A weighted average of the priced and free travel time and the priced and free distance were also computed.

The average time, distance, and toll for each O/D pair was then input to the mode choice program in order to calculate composite impedance. That impedance value was used in the gravity model to distribute trips from origins to destinations. The average time, distance, and toll were again input to the mode choice program, this time to compute the split among travel modes. The toll diversion model was applied a second time to split the vehicle trips by priced/free path. The assignment program assigned priced trips to the priced paths and free trips to the free paths. Within the four assignment iterations, priced trips were allowed to migrate to the free paths (and back) in response to changing relative congestion levels between priced and free roadways; however, free trips were required to stay on a free path. Table A-12 summarizes the impacts of this scenario on the travel choices.

Table A-12
Roadway Pricing Impacts

Model Step	Impact
Highway Skims	Highway paths are modified to select paths that minimize the total cost. Average time, distance, and toll values are estimated that reflect the impact of the priced roadways.
Trip Generation	No impact.
Trip Distribution	Composite impedance increases for paths using the priced roads due to the toll. It also increases slightly for paths using free roads because they are longer (drivers are accepting increased distance, and operating cost, in order to avoid the toll).
Mode Choice	Cost of driving increases; driving alone decreases, and carpooling and transit increase slightly.
Toll Diversion	Presence of tolls causes a share of the remaining vehicle trips in affected O/D pairs to switch to the free paths.
Assignment	VMT decreases due to fewer vehicle trips. However, congestion increases on the free roads, resulting in much slower overall average speed.
Emissions	HC and CO emissions increase, and NO_X emissions decrease due to the lower average speed.

These results fit with the initial expectations and the results of other research, up through the toll diversion model. The assignment results, however, bear further explanation. Although some switching to carpools and transit occurs, this does not occur in significant numbers.

Some travelers switch destinations to one which can be reached via a free route. The majority of travelers are those who do not change their destination or mode and the primary method for them to escape tolls in this model is by switching to a free route. In this scenario, the free routes are generally the arterials, which already had slower average speeds to begin with, and those speeds are made even slower with the additional traffic from the priced freeways. Reducing average network speeds generally has a negative effect on HC and CO (although this depends on the existing average speed values, as noted above).

Part of the problem may lie in the definition of congestion . In this scenario, the priced roads were those freeways and expressways with a V/C of 0.9 or more. Although V/C is a good indicator of a roadway s congested speed compared to its free-flow speed, that is a false indicator of emissions. That is, MOBILE5a s emission rates are not based on congestion, *per se*, but absolute average speed. Consider the case of a freeway section with a free-flow speed of 60 mph. With congestion, the speed might drop to 40 mph, a difference of 33%. But according to MOBILE5a, vehicles on that roadway will still have lower emission rates than vehicles on a nearby arterial, whose congested speed might typically be 35 mph. This is true even through the arterial s free-flow speed might be 40 mph, in which case the arterial is experiencing less *congestion* than the freeway (i.e., a speed drop of 13%).

Still, this example highlights some of the complexity of roadway pricing analysis. Even with the enhancements made to the Case Study Model, the following shortcomings are still seen:

- No price-sensitive time of day model.
- Toll diversion model not specifically calibrated to Washington, D.C. area.
- No speed feedback in the model set.

The above problems notwithstanding, a key observation of this analysis is that a network-based procedure is essential to the complete analysis of roadway pricing measures. The interactions among traveler choices of destination, mode, and path are too complex to model without performing a specific assignment of vehicle trips to a roadway system.

A.3.3 Vehicle-Based Measures

A.3.3.1 VMT Fee

A fee would be assessed for each vehicle-mile driven. It was assumed that this fee would be collected in such a manner that travelers would be aware of it on a daily basis and therefore the fee would influence their short-term travel decisions. Thus, the VMT fee was modeled in terms of an increment to the automobile operating cost parameter. No impact on vehicle ownership levels, land use, or long-term locational choices was assumed.

Three levels of VMT fee were analyzed: $0.04/mile, $0.10/mile, and $0.40/mile. The first step was to convert these into 1980 year dollars by multiplying by 0.57, as noted above. The equivalent 1980 fee levels are then \$0.023/mile, \$0.057/mile, and \$0.228/mile. These values were then added to the base automobile operating cost of \$0.11/mile to yield new automobile operating costs of \$0.133/mile, \$0.167/mile, and \$0.338/mile. The mode choice/composite impedance application program includes a specific user-coded parameter for auto operating cost per mile and this parameter was adjusted for each run.

In addition, the increased cost of driving was reflected in the highway network path building and skimming steps, performed using the MINUTP PTHBLD program. Since paths are built based on an impedance that includes time and operating cost, changes in the operating cost will affect paths. In PTHBLD, this change is achieved by coding DCOST as 133, 167, or 338, for the three pricing levels. Table A-13 presents a summary of the travel choices affected by this change, as reflected in the Case Study Model.

It should be noted that the Table A-13 shows no impacts of VMT fees on trip generation. This is because the Case Study Model s trip generation module is not sensitive to pricing changes.

Table A-13
VMT Fee Impacts

Model Step	Impact
Highway Skims	Highway paths are modified to select paths that are shorter in distance, to minimize the cost of travel.
Trip Generation	No impact.
Trip Distribution	Composite impedance increases with distance (operating cost) and goes up relatively faster for longer-distance trips; thus, travelers tend to choose destinations that are slightly closer. Average trip distances decrease slightly.
Mode Choice	Cost of driving increases; driving alone decreases, carpooling decreases slightly, and transit use increases.
Toll Diversion	No impact.
Assignment	VMT decreases due to fewer vehicle trips and shorter trip lengths; reduced VMT means less congestion, resulting in faster average speed.
Emissions	Emissions of all pollutants decrease due to less VMT and higher average speed.

A.3.3.2 Fuel Tax

The tax on all motor fuels would increase. It was assumed that this increase would be perceived as simply more expensive gasoline and that this would influence the short-term decisions of travelers. Thus, the fuel tax was modeled in terms of an increment to the automobile operating cost parameter.

Three levels of fuel tax were analyzed: $0.20/gallon, $1.00/gallon, and $1.50/gallon. These were converted into 1980 year dollars: $0.114/gallon, $0.570/gallon, and $0.855/gallon. These were then converted into cents/mile by dividing by an average value for on-road fuel economy. A value of 19 mpg was calculated from the 1990 Nationwide Personal Transportation Study (passenger cars only), but this was increased to 20 mpg for all scenarios by assuming that a short- to medium-term (3-12 months) impact of higher fuel prices would be to encourage the purchase of more fuel-efficient vehicles. The resulting additional cost per mile is then: $0.0057/mile, $0.0285/mile, and $0.0428/mile, making the new automobile operating cost parameter: $0.1157/mile, $0.1385/mile, and $0.1528/mile, respectively.

This new cost of driving was then input to the model in exactly the same manner as for the VMT fee, as described above. The impacts were the same as noted in Table A-13, although at a lower level due to the lower level of operating cost increase.

A.3.3.3 Age-Based Registration Surcharge

A surcharge would be placed on the annual registration cost of all vehicles and would vary with the age of the vehicle. It was assumed that this fee would be collected annually and that travelers would not be aware of it on a daily basis and therefore the surcharge would not influence their short-term travel decisions. This surcharge was assumed to affect only the age mix of the vehicle fleet by encouraging drivers to trade-in their older vehicles for newer ones. Such older vehicles were presumed to be removed from the fleet (i.e., scrapped) and replaced with newer vehicles, in roughly the same proportion as newer vehicles currently exist in the fleet. The MOBILE5a default age mix by vehicle type was used as the initial age mix.

The analysis methodology presented estimates only the impacts due to changes in vehicle mix by age and assumes that no changes in VMT occur due to the shift from older vehicles to newer vehicles. Since the fee is levied solely based on vehicle age, no changes in travel characteristics are assumed except for changes in vehicle mix by model year. The fee can be structured in various combinations of fee variation by each separate model years, or can be charged by certain ranges of vehicle ages, or it can be varied among different vehicle types.

The changes in registration distribution by model year are estimated through a process in which certain assumptions about the value of the vehicles in each age group and changes in car ownership behavior are made to quantify the change in number of vehicles under each model year. The basic principle in the analysis methodology is that the vehicles are dispensed or scrapped at a rate which is proportional to the ratio of the registration fee to the market value for that particular model year of vehicle.

General Assumptions:

It is assumed that market value for a particular model year of vehicle is the same for all the vehicles under that year.

No drop in the latest model year vehicle registration is assumed because the market value for these vehicles is much higher than the estimated registration fee.

LDGT2, HDGV, LDDT and HDDV are assumed to have lower price elasticity than other lighter duty vehicles because they are mostly used for business purposes and are less likely to be scrapped or replaced (see Table A-14).

Motorcycles are assumed to have lower price elasticity because of their unique nature.

Model Specific Assumptions:
(these are assumptions that could be replaced by more accurate data if available to the user)

The same estimated market value is assumed for both LDGVs and LDGT1s.

The estimated market value for a late model year HDDV and Motorcycle are assumed to be $60,000 and $7,500 respectively.

Table A-14
Price Elasticities by Vehicle Type

Type	LDGV	LDGT1	LDGT2	HDGV	LDDV	LDDT	HDDV	MC
Elasticity	-1.0	-1.0	-0.9	-0.5	-1.0	-0.9	-0.5	-0.75

The two major inputs to the analysis are the existing vehicle mix by model year and the average market value for each model year of vehicle. In the Case Study Model, the MOBILE5a default vehicle mix is assumed for the base conditions, but these can be replaced by more accurate local data if available or from any other updated versions of MOBILE.

The other key input to the analysis is the average market value for each model year of vehicle, which could also be replaced with more accurate local data. For the Case Study Model, the average market value for the latest model year (1993) light duty gasoline vehicle is assumed to be $17,922 (source: *Automotive News, 26 May 1993, p. 61*) and the value for older models is estimated from this number assuming a price deterioration rate which is proportional to the age of the vehicle. The following summarizes the specific steps of the analysis:

Step 1 Percent Registration Fee Cost of the Total Market Value:

The percentage of the registration fee cost of the total market value for that model year of car is calculated. This percentage of registration fee cost of the total value is assumed to be equal to the percentage of vehicles scrapped or replaced.

Percent Registration Fee = Registration Fee $_{my}$* 100 / Total Market Value $_{my}$

Step 2 Estimation of Vehicle Scrappage or Replacement:

It is assumed that the vehicle scrappage or replacement percentage due to the registration fee is same as the percentage of registration fee of the total market value. If the registration fee exceeds the market value of the vehicle (as in the case of older cars) then all the vehicles under that model year are replaced by newer model years. For example, if the registration fee is 1% of the market value, then 1% of those model year vehicles are assumed to be replaced by newer cars. This approach is applied to all the vehicle model years except for the latest model year which is assumed to be independent and no scrappage or replacement for this year is calculated.

To account for the variation among different vehicle types, especially the differences between lighter and heavy duty vehicles, different price elasticities as given in Table A-14. are assumed for different vehicle types. Lower elasticities are assumed for heavy duty vehicles since most of these vehicle types are generally used for business purposes. The estimated scrappage percentages as calculated above are corrected for these price elasticities for each vehicle type.

Example: Assume a market mechanism with a $900 registration fee for cars between ages 15 to 25, $600 for ages 5 to 15, and $300 for ages 0 to 5 years, the estimated market value of a 24 year old car is $400, the registration fee for this model year vehicle from the above description is $900, the percentage of registration fee is more than 100% of the total market value, hence all of these model year cars are assumed to be replaced by newer cars. Similarly, for a 7 year old model year car with a market value of $9,100, the registration fee for this vehicle is 600, which is about 6.6% of the market value. Hence 6.6% of these model year cars are assumed to be replaced with newer cars.

Step 3 Estimation of Replacement Vehicles

In the analysis all the scrapped vehicles are replaced with newer model year vehicles in the same proportion as their existing vehicle distribution and weighted by appropriate values to make the total of the distributed percentages to 100.

Step 4 Results from the Analysis

All the above described steps have been included in a spreadsheet which performs the calculations and estimates the resulting vehicle registration distribution. The resulting revised age mix was used in the PPAQ/MOBILE5a run instead of the default age mix.

Three levels of maximum surcharge were assumed: $100/year, $500/year, and $900/year. The maximum surcharge was assessed on vehicles 20 years old or older, no surcharge was assessed on vehicles 3 years old or newer, and an intermediate surcharge was assessed on vehicles between 3 and 20 years old, varying with age (see Table A-9 for an example, showing the $900/year surcharge). Table A-15 summarizes the impacts.

Table A-15
Age-Based Surcharge Impacts

Model Step	Impact
Emissions	Emissions decrease due to shift in age mix of fleet from older to newer vehicles.

A.3.3.4 Emission-Based Registration Surcharge

A surcharge would be based on the estimated total annual emissions of all vehicles. An estimate would be made of the annual emissions of each vehicle (by the 8 MOBILE5a vehicle types), using the default MOBILE5a emission rates by age and the default MOBILE5a annual mileage by age. 1993 was assumed as the base year, so a 25-year-old vehicle is of model year 1969, for example. It was assumed that this fee would be collected annually and that travelers would not be aware of it on a daily basis and therefore the surcharge would not influence their short-term travel decisions. This surcharge was assumed to affect only the age mix of the vehicle fleet by encouraging drivers to trade in their older vehicles for newer ones. Such older vehicles were presumed to be removed from the fleet (i.e., scrapped) and replaced with newer vehicles, in roughly the same proportion as newer vehicles currently exist in the fleet. In the definition of this measure, it was assumed that the surcharge would be based on the estimated emissions for all vehicles of a certain age, not measured emissions. Vehicle owners would not have the option of repairing and retesting the vehicle. The MOBILE5a default age mix by vehicle type was used as the initial age mix.

The emissions fee is similar to the age-based registration surcharge, the only difference being that the fee is levied on the total emissions emitted by the vehicle. The emissions fee has certain advantages over the registration surcharge in terms of equity, since this measure changes the price based on total emissions rather than on age. Empirical evidence shows that newer cars travel much more than the older cars, although this is more than compensated for by the net emissions per mile (emission factors) being much lower for newer cars. This type of measure takes these characteristics into consideration and distributes the price uniformly over all vehicle age groups based on their total emissions. Equity is also maintained across different vehicle types, since the heavy-duty vehicles which have higher emission rates and VMT accumulation are assumed to pay a higher fee compared to the lighter duty vehicles.

The changes in registration distribution are based on essentially the same technique as described in the previous section on age-based registration surcharges. The differences in assumptions are as follows:

General Assumptions:

> An average emission factor and VMT accumulation is used for all the vehicles under a particular model year.

Model Specific Assumptions:
(these are assumptions that could be replaced by more accurate data if available to the user)

> MOBILE5a estimated average emission levels by each model year and default registration distribution by age are used in the analysis.

The three major inputs to the analysis are the vehicle emission levels by model year, the annual mileage accumulation by model year, and the average market value for each model year of vehicle. In the Case Study Model, MOBILE5a default annual mileage accumulation rates and emission rates were used for the base conditions, but these can be replaced by more accurate local data if available or from any other updated versions of MOBILE.

The following two steps are used to estimate the change in annual user cost for this measure. From that point, the analysis proceeds exactly as in Steps 1 - 4 of the age-based registration surcharge, described above.

Step 1 Estimation of Pollutant Tonnage:

The initial step in the analysis is the estimation of pollutant levels for each model year of vehicle. The emission rates (g/mile) for each model, accounting for the appropriate control measures such as inspection and maintenance, reformulated gasoline, etc., as well as local conditions such as temperature and altitude, are estimated using MOBILE5a. A single index of pollutant tonnage is calculated by combining the estimated levels of HC, CO and NO_X, using equivalency factors for each pollutant based on previous EPA studies. The factors used in this project are shown in Table A-16. The level of each pollutant multiplied by its equivalency factor is summed to get to the combined emission rate for each model year.

$$\text{Combined Emission Rate}_{my}(\text{gms/mi}) = E_{HC} * \text{HC level} + E_{CO} * \text{CO level} + E_{NOx} * \text{NOx level}$$

Table A-16
Pollutant Equivalency Table

Type	E_{HC}	E_{CO}	E_{NO_x}
Equivalency	1.0	0.1	0.9

The combined emission rate by model year multiplied by the annual mileage accumulation for that model year vehicle gives the annual total tonnage of pollutants:

$$\text{Combined Annual Tonnage of Pollutants}_{my}$$
$$= \text{Combined Emission Rate}_{my} * \text{Annual Mileage Accumulation}_{my}$$

Step 2 Estimation of Emissions Fee by Model Year:

The combined annual tonnage of pollutant as calculated from the previous step for each model year is multiplied by the emissions fee set for the market mechanism. This gives the additional price paid by each model year s vehicles due to the emissions fee.

$$\text{Price due to Emissions Fee}_{my}$$
$$= \text{Combined Tonnage of Pollutant}_{my}(\text{tons}) * \text{Emissions fee } (\$/\text{ton})$$

(From this point, continue with Step 1, from Section A.3.3.3, described above.)

Application of the Methodology:

The calculations involved in the estimation of the changes in vehicle registration distribution due to emissions fee are performed in a spreadsheet, an example of which is shown in Table A-17. These revised distributions go into the MOBILE input section of the PPAQ set up file.

This methodology is a sketch planning technique involving numerous assumptions and factors in the process which are based solely on engineering judgment and are not substantiated by empirical results. The methodology itself is in a rudimentary stage and requires further enhancement with respect to the factors and values assumed in the process. The key assumption regarding changes in vehicle ownership in response to external costs such as emissions fees and registration surcharges should be verified. The assumed independence between changes in vehicle ownership and changes in the annual vehicle mileage also bears further examination.

Table A-17
Sample Vehicle Age Mix Adjustment Spreadsheet (Emission Fee)

year	model year	MOBILE ann. miles	MOBILE cum. miles	MOBILE5 exh HC lvl	MOBILE5 CO level	MOBILE5 NOx level	combined level	combined tons/yr	estimated value	change in fee	fee chg as % of value	base % by year	new % by year	% left	cum. % left	new/base ratio
LDGV	combining factor:			1.0	0.1	0.9	elasticity:	-1.00	fee/ton:	$10,000		MOBILE5a registration mix by year (starting 1 July 1990)				
25	1969	4,305	178,369	8.89	101.82	4.35	22.99	0.11	$400	$1,089	272.1%	1.10%	0.00%	1.10%	1.10%	0.0%
24	1970	4,305	174,064	9.44	96.65	4.35	23.02	0.11	$500	$1,090	218.0%	0.30%	0.00%	0.30%	1.40%	0.0%
23	1971	4,305	169,759	9.28	95.30	4.35	22.73	0.11	$600	$1,076	179.4%	0.40%	0.00%	0.40%	1.80%	0.0%
22	1972	4,305	165,454	6.17	81.15	4.35	18.20	0.09	$700	$862	123.1%	0.50%	0.00%	0.50%	2.30%	0.0%
21	1973	4,305	161,149	6.10	80.10	3.51	17.27	0.08	$900	$818	90.9%	0.60%	0.07%	0.53%	2.83%	11.5%
20	1974	4,305	156,844	6.03	79.05	2.91	16.55	0.08	$1,000	$784	78.4%	0.80%	0.20%	0.60%	3.43%	24.5%
19	1975	4,559	152,539	5.19	57.74	2.90	13.57	0.07	$1,200	$681	56.7%	1.10%	0.52%	0.58%	4.02%	46.9%
18	1976	4,829	147,980	5.07	56.56	2.88	13.32	0.07	$1,500	$707	47.2%	1.50%	0.86%	0.64%	4.66%	57.1%
17	1977	5,114	143,151	4.94	55.31	2.99	13.16	0.07	$1,800	$740	41.1%	1.40%	0.89%	0.51%	5.17%	63.9%
16	1978	5,416	138,037	4.80	53.98	2.94	12.84	0.08	$2,100	$765	36.4%	1.90%	1.31%	0.59%	5.76%	69.2%
15	1979	5,737	132,621	4.65	52.58	2.89	12.51	0.08	$2,500	$790	31.6%	2.40%	1.79%	0.61%	6.36%	74.8%
14	1980	6,076	126,884	1.63	15.35	2.39	5.31	0.04	$3,000	$355	11.8%	3.70%	3.53%	0.17%	6.53%	95.4%
13	1981	6,435	120,808	1.70	25.08	1.56	5.61	0.04	$3,500	$397	11.3%	4.70%	4.53%	0.17%	6.70%	96.4%
12	1982	6,815	114,373	1.59	22.94	1.54	5.28	0.04	$4,100	$396	9.6%	5.40%	5.33%	0.07%	6.77%	98.8%
11	1983	7,218	107,558	1.50	21.53	1.42	4.93	0.04	$4,900	$392	8.0%	5.00%	5.06%	-0.06%	6.71%	101.1%
10	1984	7,645	100,340	1.50	21.76	1.43	4.97	0.04	$5,700	$418	7.3%	5.10%	5.22%	-0.12%	6.59%	102.4%
9	1985	8,096	92,695	1.31	19.21	1.36	4.46	0.04	$6,700	$397	5.9%	5.00%	5.22%	-0.22%	6.37%	104.4%
8	1986	8,575	84,599	1.22	17.62	1.29	4.14	0.04	$7,900	$390	4.9%	5.60%	5.93%	-0.33%	6.05%	105.8%
7	1987	9,082	76,024	1.11	15.33	1.29	3.81	0.04	$9,100	$380	4.2%	7.70%	8.25%	-0.55%	5.50%	107.1%
6	1988	9,619	66,942	1.00	13.63	1.20	3.45	0.04	$10,500	$365	3.5%	8.10%	8.79%	-0.69%	4.81%	108.5%
5	1989	10,187	57,323	0.89	11.83	1.10	3.06	0.03	$12,000	$343	2.9%	8.40%	9.23%	-0.83%	3.98%	109.9%
4	1990	10,789	47,136	0.72	9.72	1.00	2.59	0.03	$13,500	$308	2.3%	8.20%	9.13%	-0.93%	3.05%	111.3%
3	1991	11,427	36,347	0.60	7.76	0.89	2.18	0.03	$14,700	$274	1.9%	8.30%	9.34%	-1.04%	2.00%	112.6%
2	1992	12,102	24,920	0.47	5.68	0.78	1.74	0.02	$14,800	$232	1.6%	7.90%	9.01%	-1.11%	0.89%	114.1%
1	1993	12,818	12,818	0.34	3.47	0.66	1.28	0.02	$17,922	$181	1.0%	4.90%	5.79%	-0.89%	0.00%	118.2%
												100.0%	100.0%	0.0%		
											avg age:	8.2	7.1		avg fee:	$360

Note: LDGV = light-duty gasoline vehicle

A.3.4 Modal Subsidies

Analysis of modal subsidy measures involves reducing cost to travelers who use a mode that is promoted by subsidy. Typical subsidies involve incentives for transit (fare reduction, on-site transit stops), cost incentives for ridesharing (cost reimbursement, reduced parking costs, preferential parking locations, toll reductions) and transportation allowances (parking cash out). Two levels of transit fare reduction were studied:

- 50% reduction in transit fares
- 100% reduction in transit fares (i.e. free transit service)

A reduction in transit fares influences a traveler s choice of destination zone, travel mode and (indirectly) highway path. Destination zone choice is affected by changing the computation of combined impedance which is an input to the trip distribution model. Travel mode choice is affected in the mode choice model by making transit more attractive and thereby increasing transit share. Highway paths are affected by assigning fewer vehicle trips to the highway network which reduces congestion effects and causes path changes to occur in the traffic assignment model.

There are two matrix files that reflect zone to zone transit fares in 1980 dollars. These files (walk to transit fare matrix and drive to transit fare matrix) are modified with the MINUTP program MATRIX. For the 50% reduction, all cells are factored by 0.50. For the 100% reduction, all cells are replaced with zero. These revised fare matrix files are specified in the model setup and used during both the combined impedance calculation and the mode choice estimation steps. Table A-18 summarizes the impacts of this scenario on the travel choices:

Table A-18
Modal Subsidy Impacts

Model Step	Impact
Trip Distribution	The composite impedance decreases for those paths that show a reduction in transit fare under this scenario. This modifies the distribution of trips in favor of transit accessible zone pairs.
Mode Choice	Transit costs decrease causing transit shares to increase and vehicle trips to decrease.
Assignment	VMT decreases due to fewer vehicle trips. This can also result in some increases in speed for certain highway facilities.
Emissions	HC, CO and NO_X emissions all decrease due to the decrease in VMT.

A.4 Other Model Enhancement Issues

A.4.1 Addressing the Unknown Sensitivity to Pricing

The sensitivity of urban travel demand to pricing has not received much attention in the past. The best known analysis has been the Curtin Rule , which states that a 10% increase in transit fare leads to a 3% drop in transit ridership. In almost all other applications, the price of transportation to the traveler has often been assumed to change at the same rate as inflation and thus be of no more or less importance in the future than today.

The rapid rise in gasoline prices in the mid-1970 s and early 1980 s, combined with a flurry of activity in rail transit planning created a need for mode choice models which were sensitive to auto operating cost to the user. There is now over a decade of experience with such models, and transportation planners have some confidence that adjusting this parameter to account for increases in the price of driving, as described in sections A.3.3.1 and A.3.3.2, produces reasonable results that are not too great an extrapolation beyond present experience. A similar comment can be made for the price of parking, which has been identified in the past ten years as a significant influence on mode choice.

However, when it comes to more innovative pricing strategies, such as congestion pricing, planners in the U.S. have little or no experience on which to draw. Moreover, there is an intuitive and logical belief that in some way, strategies such as congestion pricing will have a travel impact far beyond the choice of travel mode. But the problem remains: without actual experience from which to observe and compare, how can demand modelers estimate the impacts of such measures without falling back on theory?

A powerful argument can be made that before-and-after studies offer the best evidence of travelers response to pricing measures. The problem, of course, is that this assumes that a strategy has actually been implemented, in a relatively controlled manner, and without other confounding factors that could also influence the outcome. Careful analysis of the last gasoline crisis might yield some insight into motorists response to steep and rapid increases in the user cost of driving, assuming one could filter out the impact of the apparent shortage of supply and the psychological (and real) effects of long lines at the pump. Analyses of the ridership effects of existing differential peak/off-peak transit fares, before and after implementation, might produce some insight into the cost sensitivity of trip start time.

Another criticism of the pricing parameters currently used in models is that they are based on *cross-sectional surveys*. Such parameters are not based on what a fixed group of people did over time, but on what many people did at one time. Current model calibration theory says that if you can take a snapshot survey of enough people with different enough travel conditions and choices, you can generalize enough to draw conclusions as to how one traveler would respond to changes over time. Although this is how almost all mode choice models are presently calibrated, there is some sentiment among planners that it is an insufficient basis for identifying true traveler sensitivity to pricing.

One alternative which is gaining popularity is the *panel survey*, which follows a fixed group of households and individuals over time and attempts to measure changes in their travel behavior in response to actual changes in their travel conditions. In theory, this should produce more accurate cost sensitivities, but in practice such surveys are very expensive and difficult to conduct. Worse, they generally require 18-24 months or more, to allow for three or more survey waves . Still, such surveys have been conducted in Seattle, Washington and Montgomery County, Maryland and hold considerable promise for the future.

Another technique that may be useful is the *stated preference survey*, in which people are asked how they would respond to a series of hypothetical situations. Such surveys are not as reliable as surveys of observed behavior, because of the large gap between what people say they will do (especially under hypothesized conditions which may be far outside their normal experience) and what they actually do. Still, if performed under carefully controlled conditions, stated preference surveys can produce estimates of pricing sensitivity for travel decisions, when no other option is available.

Some mode choice models have been developed by transferring model coefficients from another urban area. The disaggregate nature (i.e., modeling individual choices) of logit mode choice models generally supports this. Analyses of coefficients from different areas indicates that the variation in these coefficients is not terribly great, suggesting that careful transference is possible. Perhaps the most critical issue here is to be aware of how the independent variables were developed for the original model and to maintain consistency in the new model.

Another major trap to avoid: in transferring pricing coefficients, one must be aware of the year for which the original model was developed and adjust such coefficients for inflation as needed. For example, if the original model was calibrated using 1980 prices, then the new model must either also convert its prices to 1980 year dollars, or adjust the original cost coefficients to reflect the effect of inflation over the years. For example, the Case Study Model uses prices expressed in 1980 dollars. To convert its operating cost coefficient (0.004) to 1993 dollars, it must be multiplied by 0.57, which is the ratio of Urban Consumer Price Index values for 1980 and 1993, resulting in a 1993 equivalent value of 0.0023.

In some cases it might not be possible to derive a particular cost sensitivity from any of the above sources. In the last resort, it will generally be acceptable to synthesize a coefficient value and then perform a series of sensitivity tests on it. The value of the parameter would be varied above and below the hypothesized value, the model would be re-applied, and the results (mode choice, trip length, VMT, etc.) would be charted for each variation. Comparing this variation with theoretical values and a great deal of common sense from a variety of external reviewers can often help identify an acceptable value for a parameter. Although such an analysis, even though carefully reasoned and conducted, cannot conclusively identify the proper value for an unknown parameter, it may provide a suitable interim result until better information can be found.

A.4.2 Model Development/Application

In revising travel models to be more sensitive to pricing, several development and application issues must be considered, including the following:

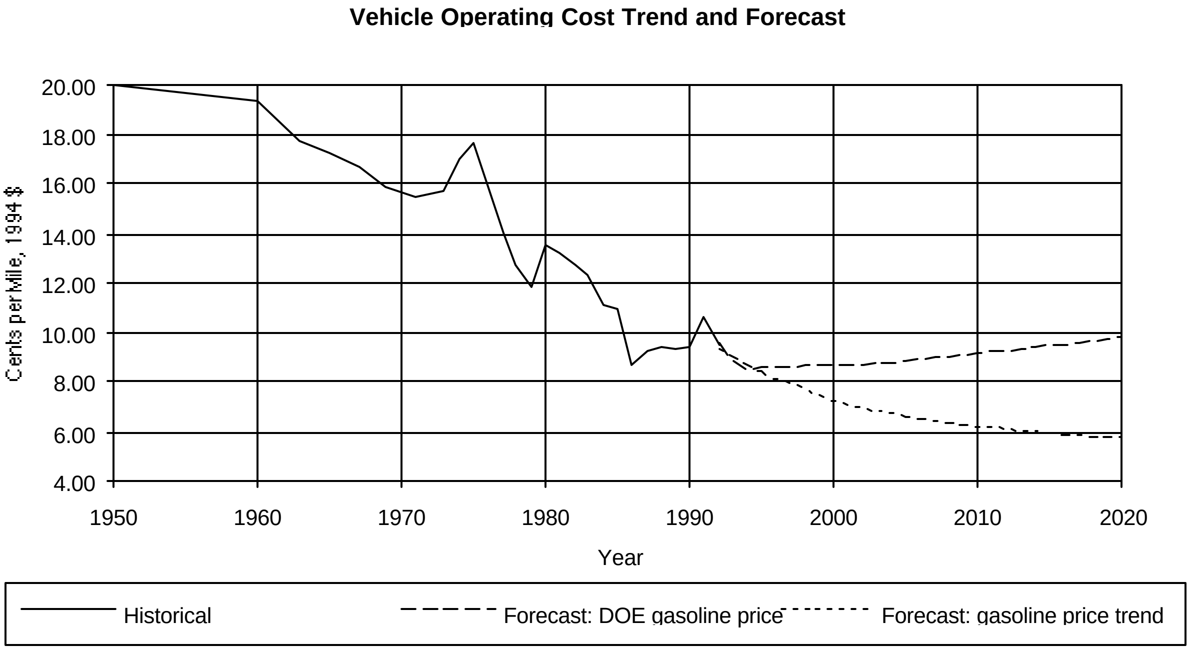
Connectivity and Feedback: As the Case Study Model demonstrates, in order for pricing to affect each simulated travel choice, the model set must be connected ; i.e., all travel prices must influence each model step. In a four-step model, one implication of this is that the model must be applied backwards and forwards , as in the Case Study Model. This increases model application time and resource requirements (e.g., hard disk space) but is probably unavoidable within the current sequential model structures. Advanced programming, such as combining the mode choice and distribution steps, can minimize this, but only at the cost of increased overall complexity.

A related issue is the question of achieving model equilibrium, usually defined as the consistency of travel speeds throughout the entire model. It is unclear if or how these improvements to handle pricing would affect the potential and the need to iterate the model set until speed equilibrium is achieved. It may be that price-sensitive models need to use a different definition of equilibrium, possibly one that involves achieving consistency of equivalent prices throughout the model (equivalent price being defined as actual price plus the traveler s cost of time).

Effects of Inflation: As noted above, the sensitivity of travelers to price, as reflected in the model s coefficients, is expected to change over time with the general rate of inflation. Price coefficients that are borrowed from other areas (or from different years) must be adjusted to account for the effects of inflation. This means that cost coefficients can be expected to decrease numerically over time, as the purchasing power of money erodes, more or less steadily, over time.

Extreme care must be taken in forecasting price information. It is commonly assumed that all travel prices will rise in the future at the same rate as inflation, meaning that there is no change in the relative price between travel choices. This is not always true. For example, transit fares in many cities have not kept pace with inflation. If a forecast assumes that that trend will continue into the future, then that must be reflected in reduced fare values for a future model run. Similarly, as Figure A-5 shows, the trend in automobile operating cost has been dropping since after World War II, when expressed in 1994 dollars, and the trend is for continued declines in real dollar terms.

Figure A-5
Trends in Passenger Car Operating Cost



Different Strategy Specifications: Some market-based strategies have many different variations which affect how the strategy is implemented and may affect how it is perceived by the public. However, it is unlikely that any travel model will be sophisticated enough to be sensitive to such nuances. It is enough of a challenge to create models which are properly sensitive to a change in actual travel price, much less be influenced by the context in which the change is implemented.

For example, two ways of increasing the user cost of driving are: 1) increase the gasoline tax, and 2) convert the cost of motor vehicle insurance from a semi-annual payment to a pay-at-the-pump fee, as has been proposed in California. Although these two measures are quite different from an implementation perspective, it is questionable if motorists would perceive them as different (as long as the increased price per gallon was the same). It would seem reasonable to estimate their quantitative effects on travel in the same manner.

Model Refinement/Development: Some of the enhancements described above can be made fairly easily, while others require considerable effort. An example of the former would be the Case Study Model feature which permits the separate consideration of LOV and HOV parking price, thus allowing the testing of differential parking price by zone by vehicle occupancy. It would be very easy to incorporate this into a mode choice model which already uses parking price and splits trips by occupancy level, which quite a few mode choice models already do. This would require only a few hours of programming to revise the mode choice application procedure; no new calibration would be required.

At the other end of the spectrum, modifying the distribution model to use composite impedance is a much more significant task, requiring the development of a new program (or modification of an existing one) to calculate composite impedance and the complete re-calibration of the distribution models to use the new impedance value. This could take from a few weeks to a few months.

It is important to recognize that the improvement of the pricing sensitivity of most existing travel models is a difficult undertaking which requires time, data, computing resources, and staff expertise which are not universally available in local planning agencies. Such a task is made all the more difficult since agencies are usually expected to pursue this work in addition to their usual on-going planning and forecasting duties. One way to organize the workload is to establish formal parallel tracks , one for on-going work and another for new model development, to ensure that neither effort is neglected.

Of course, agencies which are in the process of updating their models or developing new models anyway should take all reasonable steps to improve the sensitivity of their models to pricing. The features of the Case Study Model and the enhancements described in Section A.5 should be strongly considered. Once a commitment is made to develop new models, the incremental effort to make such models reasonably price-sensitive is not very large.

A.5 Summary

A.5.1 Summary of Desirable Model Features

The analyses of this appendix lead to the following major conclusions:

- Improve the Four-Step Process: Although many current four-step models are now largely inadequate for modeling most pricing measures, this process can be modified to improve its sensitivity to pricing strategies, as illustrated in this appendix. Such modifications will address most of the criticisms of this process and enable it to perform adequately until the next decade, at which time a new model structure may be sufficiently developed and tested to serve as a replacement.

- Improvements are Not Easy: A few of the model enhancements described above are fairly simple, quick, and inexpensive but most of them are not. Most of these changes will require a recalibration of a region s entire travel model chain, which is usually a multi-year effort with a budget in the high six figures. If a region is planning to pursue such an effort *anyway*, then incorporating these improvements does not entail a significant incremental investment of resources.

- Improvements are Necessary Anyway: Most of the model enhancements discussed here would help improve the sensitivity and credibility of travel forecasts in contexts other than pricing strategies. For example, analyses of TCMs such as changes in transit supply, land use, ridesharing policy, and HOV lanes would benefit from these enhancements. Thus, there are several reasons to enhance existing models.

- Recognize the Unknown Sensitivities: The fact that the sensitivity of certain travel choices to some pricing measures is still largely unknown cannot be used as an excuse to eschew their analysis. Additional research, transferable parameters, and sensitivity analyses can be used to make a reasoned estimate, leaving room for future revisions to model results when better information is forthcoming.

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Appendix B

The STEP Analysis Package: Description and Application Examples

B.1 Overview

This appendix discusses STEP, a travel demand modeling package designed for planning applications and policy analysis, and shows how the model was used to analyze a wide range of transportation pricing measures for four California metropolitan areas: the San Francisco Bay Area, Los Angeles, San Diego, and Sacramento. We begin with a description of STEP, then discuss how we used the STEP models to examine the potential impacts of pricing strategies on travel behavior, traffic volumes, energy consumption, and emissions for two analysis years, 1991 and 2010. We also briefly describe other methods used to supplement the STEP analyses, including estimates of the elasticity of vehicle fuel economy with respect to fuel price, and detailed regional highway network models. A series of tables present the analysis results.

B.2 Introduction to the STEP Package

STEP is a travel demand analysis package composed of an integrated set of travel demand and activity analysis models, supplemented by a variety of impact analysis capabilities and a simple model of transportation supply. STEP is based on microsimulation - a modeling technique which uses the individual or household as the basic unit of analysis rather than dealing with population averages. (cf. Orcutt, 1976). STEP results are aggregated only after the individual or household analyses are completed, allowing the user great flexibility in specifying output categories. This is more commonly referred to as sample enumeration in the literature, or as discrete choice analysis.

STEP has been applied in a number of Bay Area studies over the years, and has been adapted for use in studies in Los Angeles, Sacramento, Chicago, and the Puget Sound region (Seattle). Applications can proceed with model re-estimation specifically for the region - essentially, by creating a completely new set of models for STEP - but to date nearly all applications outside the Bay Area have relied on extensive re-calibration of the default (Bay Area) models plus a limited amount of re-estimation as needed to match local conditions.

Several features of STEP supported its choice as the basic modeling tool for the case studies presented here. STEP's regional, subarea, and corridor-level analysis capabilities fit well with the scope and scale of the policies under consideration. Its model formulations can represent a comprehensive set of possible price effects, and its models display linkages consistent with travel behavior and pricing theory. Its use of microsimulation makes it possible to address many of the questions about equity and the distribution of impacts that frequently arise in debates about pricing. Finally, it is far faster to calibrate STEP for a region than to upgrade the regional models to include pricing variables, and far faster and less expensive to run STEP than to apply regional models.

STEP's data analysis capability is another important asset in pricing studies. STEP's microsimulation formulation permits the package to be used as a survey tabulation technique employing sophisticated data transforms and linkages. For example, many travel surveys contain detailed information about the vehicles each household owns and indicate which vehicle was used for each trip made on the survey day(s). Using STEP, these vehicle data can be tabulated so that exact usage patterns by model year or vehicle type can be determined. They also can be related to personal and household characteristics to yield useful information about low-income households' dependence on old vehicles and their contributions to vehicular emissions.

STEP itself was originally developed for sketch planning analyses in the San Francisco Bay Area (Harvey, 1978). Since that time, all of the models in STEP have been completely re-estimated and additional models addressing location choice, time-of-day of travel choice, and congestion effects have been added. The most recent formulations are nested logit. A number of versions of STEP are currently available, including options that permit the analysis of activity data as well as travel data, and versions that use either MOBILE or California EMFAC emissions data.

STEP's models are applied using actual or forecast data on household socioeconomic characteristics, the spatial distribution of population and employment (land use), and transportation system characteristics for the selected analysis year(s). The socioeconomic characteristics of a sample of households and its members are usually taken from a regional travel survey or from the U.S. Census Public Use Microdata Sample (PUMS). Population, number of households, and employment by category (type) are taken from the regional land use data base. Transportation level-of-service data (times and costs) are derived from the region's travel model system. The land use data are provided to STEP for subareas (which could be zones, districts, or corridors) and for the region as a whole; the level-of-service data are provided in the form of large matrices of interzonal times and costs. STEP then reads through the household sample, attaching level-of-service and land use data to each household record as necessary. For each household, STEP uses its models to predict a daily travel and activity pattern for each individual in the household. Finally, household travel is summed up and household totals are expanded to represent the population as a whole.

STEP can analyze any change in the population or in the transportation system that 1) can be represented in terms of the variables in its models and 2) can be associated with a specific geographic area or grouping of households. Testing the effect of a change in conditions or policies is a simple matter of re-analyzing the household sample using the new data values, and comparing the results with previous outputs. For example, a new highway or new transit service can be represented by changed travel times and costs for the areas served; a parking price increase can be represented by an increase in out-of-pocket costs; an increase in income in a particular area or for a particular population subgroup can be represented by editing the household file to incorporate the revised incomes. Along similar lines, future years can be represented through proportional factoring and re-weighting of survey observations to reflect expected regional trends, or can be based upon a more sophisticated microsimulation of household changes based on cohort survival and other methods of demographic forecasting.

The sampling framework preserves the richness of the underlying distribution of population characteristics and permits tabulation by any subgroup with sufficient observations to be statistically significant. For example, the results can be disaggregated by income level and age, which would allow an assessment of effects for, say, various income quintiles among the retired population. This is a significant advantage over an aggregate model, which uses zonal averages for most socioeconomic-economic data.

STEP maintains its quick response capability while achieving great detail in representing behavior in part by reducing its detail in representing transportation networks. STEP does not have an internal transportation network representation and traffic assignment model, so changes in level of service resulting from changes in demand must be calculated in another way. Both an approximate method and a more detailed and conventional network modeling approach have been developed for this purpose.

To approximate the effects of changes in demand on network performance and vice versa, a simple routine for estimating level-of-service was incorporated into STEP in the early 1980s (Harvey, 1993). The simplified level of service model uses peak and off-peak travel times and base case demand estimates to calibrate a supply function for appropriate spatial groupings of trips (i.e., trips in broadly-defined corridors). The basic form of this equation is: t=a*(1+[V/C]^b), where t is the travel time in minutes per mile; V is the volume in vehicles per hour; C is the capacity in vehicles per hour; and a and b are coefficients fit to each corridor. For each change in demand, the calibrated function can be used to compute a new equilibrium in the corridor (This is generally known as the Bureau of Public Roads function for determining travel time on congested links).

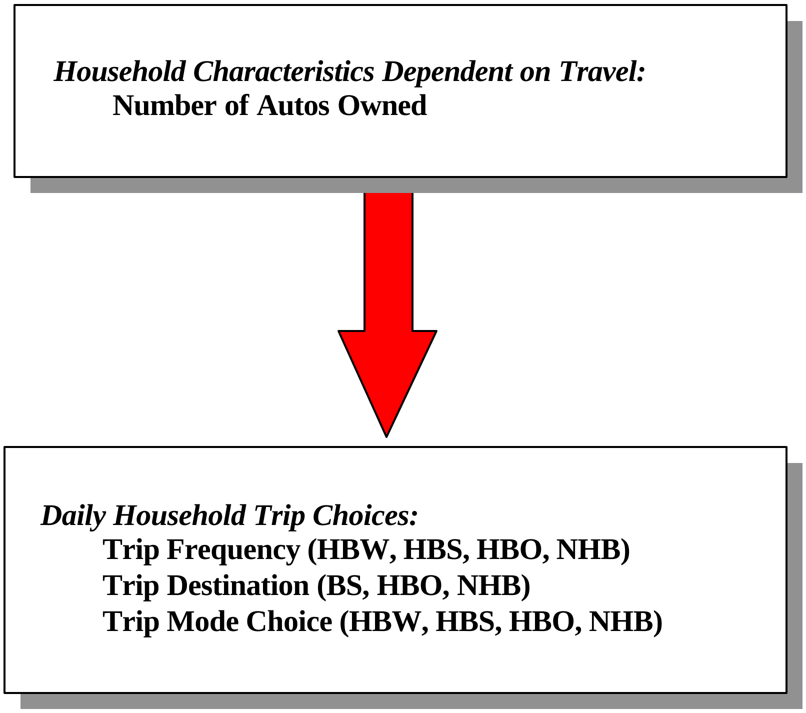
While the simplified level of service model is useful for many analyses, it is intended only as an approximation of changes in network performance and is likely to be inadequate in cases where large network perturbations could occur or where specific route choice changes are at issue. When network questions are critical, STEP must be used in conjunction with a more detailed network model.

In the typical application, STEP is interfaced with the region's detailed highway network. STEP's modal trip outputs are summarized on a district-to-district basis (a district is defined as an aggregate of the zones for which land use data are reported; for example, in the Los Angeles region there are 1555 zones and 55 districts defined by the regional agency). If the policy under analysis results in any significant differences from the base-case district-to-district trip tables, the differences are used to factor the zone-to-zone trip tables in the aggregate model system. The network models are then run using these new trip tables, and the results are fed back into STEP as a revised set of level of service inputs. Iterations continue much as is done in a conventional travel model system until an acceptable level of convergence is achieved. Transit networks also may need to be run in conjunction with STEP in cases producing significant differences in highway travel times of a sort likely to affect bus operations.

For certain transportation pricing measures, such as proposals to toll specific links or facilities in a network, use of the detailed network models together with STEP is of particular importance. For the case studies presented here, we used the network models for Los Angeles and the Bay Area to test the route choice effects of congestion pricing, interfacing in the manner described above with the versions of STEP developed for each region.

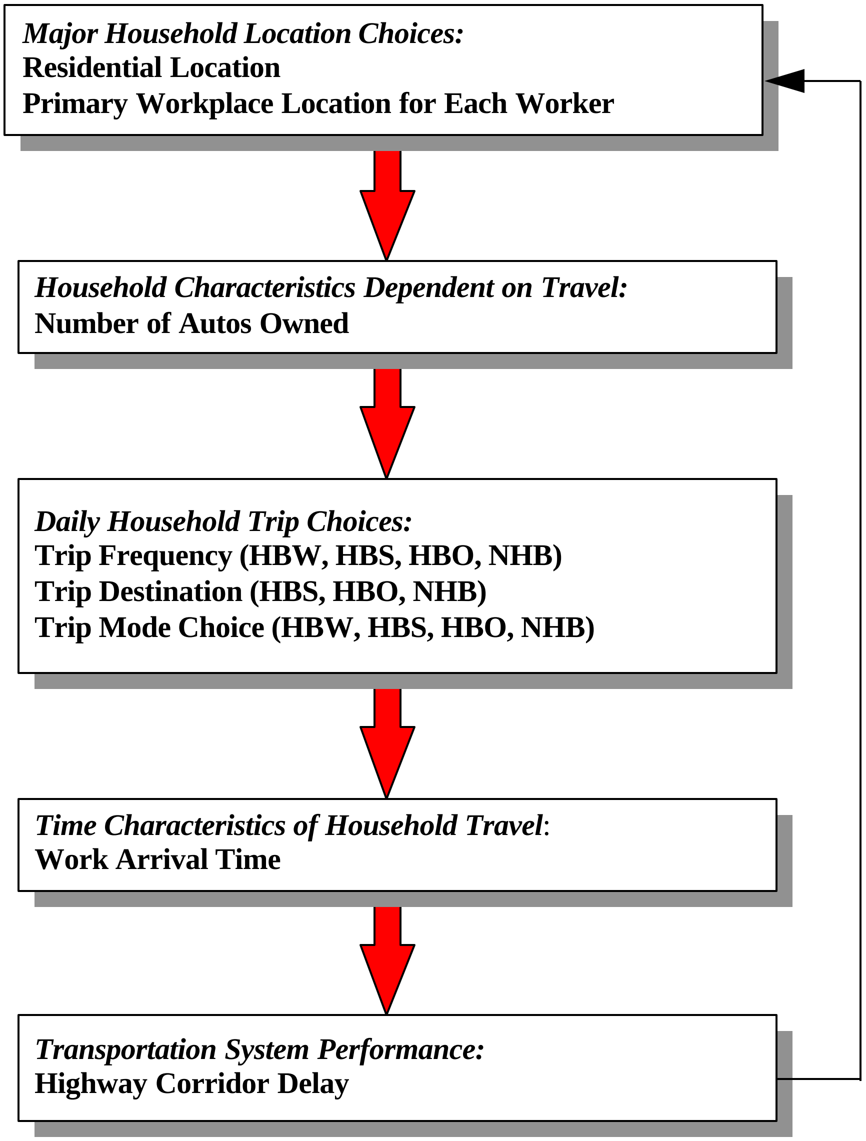
Three major variants of the STEP model system are shown in Figures B-1a, b, and c; Figure B-1b shows the version used in our pricing studies. The basic data requirements of the STEP model are summarized in Figure B-2. A typical sequence of activities for a STEP application is shown in Figure B-3.

Figure B.1a:
STEP Model Structure with Basic MTC Models



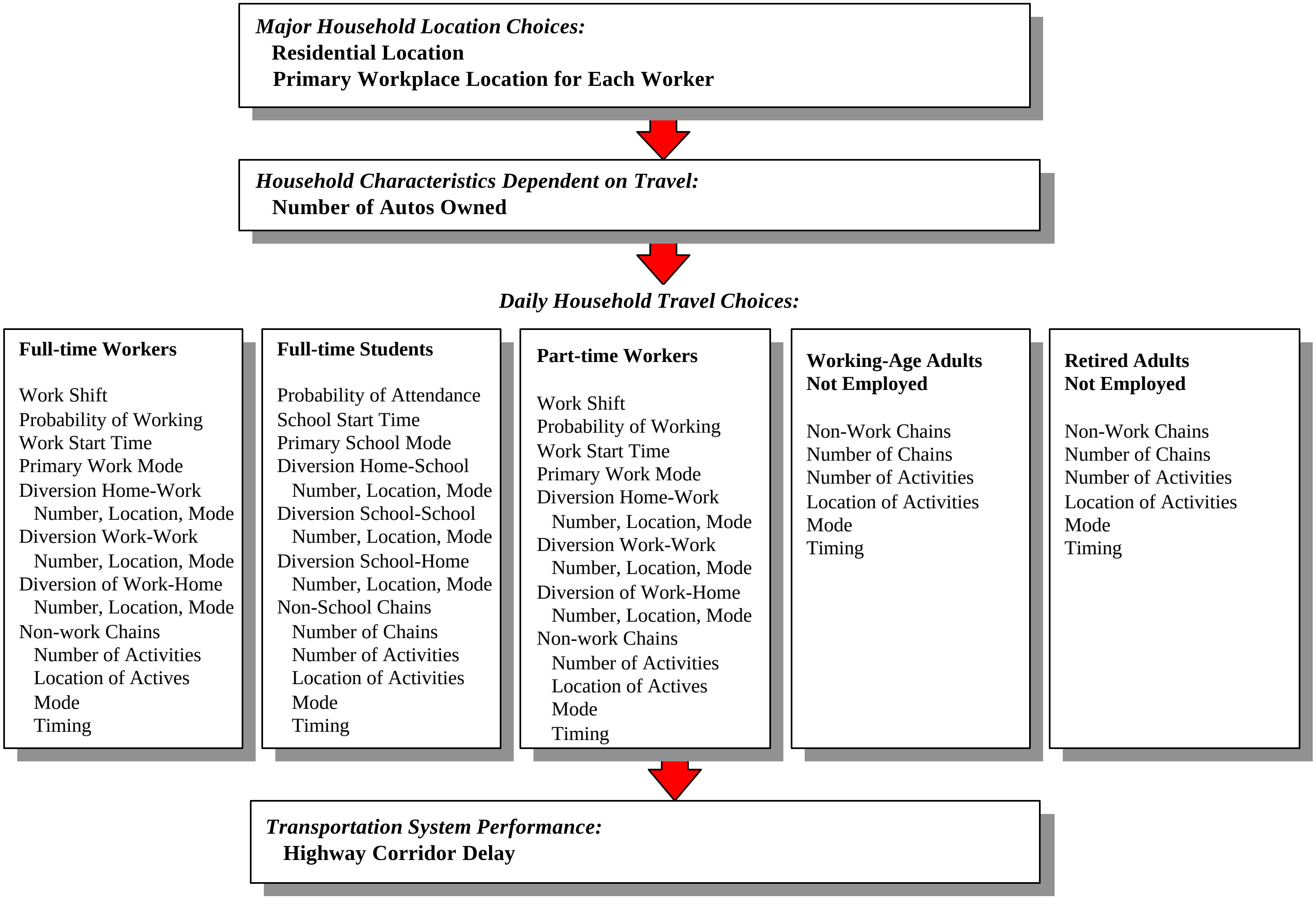
Note:
HBW - Home-Based Work Trips
HBS - Home-Based Shopping Trips
HBO - Home-Based Other Trips
NHB - Non-Home Based Trips

Figure B.1b:
STEP Model Structure with Enhanced MTC Models



Note:
HBW - Home-Based Work Trips
HBS - Home-Based Shopping Trips
HBO - Home-Based Other Trips
NHB - Non-Home Based Trips

Figure B.1c: STEP Model Structure with Activity-Oriented Models



Major Household Location Choices:
Residential Location
Primary Workplace Location for Each Worker

Household Characteristics Dependent on Travel:
Number of Autos Owned

Daily Household Travel Choices:

Full-time Workers

Work Shift
Probability of Working
Work Start Time
Primary Work Mode
Diversion Home-Work
  Number, Location, Mode
Diversion Work-Work
  Number, Location, Mode
Diversion of Work-Home
  Number, Location, Mode
Non-work Chains
  Number of Activities
  Location of Actives
  Mode
  Timing

Full-time Students

Probability of Attendance
School Start Time
Primary School Mode
Diversion Home-School
  Number, Location, Mode
Diversion School-School
  Number, Location, Mode
Diversion School-Home
  Number, Location, Mode
Non-School Chains
  Number of Chains
  Number of Activities
  Location of Activities
  Mode
  Timing

Part-time Workers

Work Shift
Probability of Working
Work Start Time
Primary Work Mode
Diversion Home-Work
  Number, Location, Mode
Diversion Work-Work
  Number, Location, Mode
Diversion of Work-Home
  Number, Location, Mode
Non-work Chains
  Number of Activities
  Location of Actives
  Mode
  Timing

Working-Age Adults
Not Employed

Non-Work Chains
Number of Chains
Number of Activities
Location of Activities
Mode
Timing

Retired Adults
Not Employed

Non-Work Chains
Number of Chains
Number of Activities
Location of Activities
Mode
Timing

Transportation System Performance:
Highway Corridor Delay

Figure B.2:
Primary STEP Data Requirements

Basic Data:
- **Regional Household Travel Survey**
- **1990 US Census Public Use Microdata Sample**

For the Survey Year:
- **Geography**
  - **land area, population, housing stock**
  - **for tracts, zones, and/or districts**
- **Network Level-of-Service**
  - **highway, transit**
  - **a.m. peak, p.m. peak, off-peak**
  - **times, costs**

For Each Forecast Scenario:
- **Geography**
  - **land area, population, housing stock**
  - **for tracts, zones, and/or districts**
- **Network Level-of-Service**
  - **highway, transit**
  - **a.m. peak, p.m. peak, off-peak**
  - **times, costs**
- **Economics**
  - **expected real income growth**
  - **expected real fuel price growth**

Figure B.3:
Sequence of Activities for a STEP Application

Prepare Survey Data for Initial Analysis:

- **Screen Survey for Unusable Observations**
- **Reweight Survey to Match Key Census Demographic Characteristics**
- **Reformat Network and Geographic Data to Match Database Requirements**
- **Assemble and Test Database**

Calibrate the STEP Models:

- **Run STEP for Base Conditions**
- **Compare STEP Calculations with Actual Household Travel Patterns**
- **Adjust Constants, Beginning with Upper-Level Models, and Rerun STEP**
- **Iterate the Adjustment Process Until the Overall Fit is Acceptable**

Prepare STEP for the Forecast Scenario:

- **Adjust Household Data to Reflect Changed Conditions**
  - **Income**
  - **Subarea Population**
  - **Household Type Cohorts**
- **Reformat Network and Geographic Data to Match Database Requirements**
- **Assemble and Test Database**
- **Run STEP to Create a Base Case**

Test the Policy Alternative(s) with STEP:

- **Alter the Database as Necessary to Represent the Policy Option**
- **Run STEP to Estimate the Effects of the Policy Option**
- **Post-Process the STEP Outputs**
- **Repeat the Analysis Sequence for Variants of the Policy Option**

B.2.1 Transferring STEP Models to Other Regions

Although each application of STEP could utilize models estimated specifically for the region being studied, a less costly approach is to transfer models estimated in one region to another. In the case studies presented here, STEP models originally estimated for the Bay Area were transferred to Los Angeles, Sacramento, and San Diego, with detailed calibrations and a moderate amount of model re-estimation in each case.

Procedures for transferring models and evaluating their performance are well established - in fact, many regions routinely use one or more transferred models in their regional model systems. The procedure for transferring STEP to a new region follows much the same general sequence of actions and so will be discussed only briefly here.

To transfer STEP to a new region, the required data first must be set up. The region's most recent household travel survey is obtained and checked (incomplete observations are excluded), and network data and land use data for the year of the survey are extracted from the regional modeling data bases. The data are then linked and a trial simulation is carried out to determine how closely the models to be transferred match the actual travel patterns in the survey data. Invariably, a sequence of adjustments to model constants (and sometimes to a small number of coefficients) is necessary to achieve an acceptable replication of the base travel pattern. These adjustments serve both to capture actual differences in behavior and to compensate for variation in the way regional planning agencies define certain variables such as transit wait times, income ranges, and specific categories of land use.

Once an acceptable simulation of the survey year (the base case) has been obtained in this fashion, STEP should closely reflect travel conditions and behaviors in the region to which it is being transferred, and consequently can be used with local data and forecasts for the full range of modeling applications.

B.3 Applying STEP to Pricing Measures

B.3.1 Overview

The application of travel forecasting models to specific pricing policies is rarely a straightforward matter. In nearly every case, both the models themselves and the available data bases impose some limits on the policies that can be tested. For example, the regional transportation data bases (and models based on the data bases) typically lack information about the variation of parking price in each zone, and may have only approximate information about the vehicle used for a specific trip. In cases where such details would play a large role in determining the impact of a policy being studied, only an approximate estimate of the policy's effects can be formally estimated through modeling: the analyst must devise a means of representing the policy as well as possible given the models and data, and must be prepared to make off-line calculations and adjustments to improve the realism of the analysis, or to do further analyses after gathering additional information.

Some discussion of implementation scenarios is necessary simply to determine how a proposed pricing concept should be analyzed; clearly, however, much more attention to specifics would be needed in an actual implementation. In our analyses, for example, we implicitly assume that evasion or outright fraud would be insignificant, hence the measures would be fully effective as proposed. For most transportation pricing measures, monitoring, enforcement, and audits would be needed to assure that.

In our case studies we found that it generally was possible to define transportation pricing strategies in ways that were tractable from an analysis perspective and also yielded information which is helpful in thinking about policies as they might actually be implemented. The use of advanced modeling capabilities, along with the availability of good data, made it possible to explore behaviors that often would be omitted from a more conventional analysis. Nevertheless, the analyses did require a number of assumptions, and they have certain limitations that must be acknowledged and taken into consideration in policy evaluations.

The following sections detail how the pricing concepts analyzed in our case studies were specified and analyzed. In each case, the underlying rationale for the pricing concept is stated, a specific pricing measure is defined, modeling assumptions to represent the pricing measure are outlined, and key implications of the assumptions are noted.

B.3.2 Congestion Pricing

Congestion occurs in the highway system when more vehicles attempt to traverse a segment of road per unit of time than that segment can accommodate. Such a location is called a bottleneck. Congestion pricing builds on the simple realization that travelers are sensitive to the cost of travel; a fee levied at a bottleneck will divert some vehicles from the traffic stream, reducing congestion. The diversion of a specific vehicle might be to a different route, time-of-travel, mode, or destination; it could reflect a trip foregone; or, over the long run, it might follow from a change in residence or workplace location.

Two major design issues arise in thinking about how to use pricing to manage congestion at a bottleneck:

- **Price level** - Price can be varied over a wide range to achieve different levels of traffic improvement. Economic theory tells us that price should be set to reflect the social cost caused by the marginal user at a bottleneck, less the average variable cost already paid by users. While this should be the clear goal of any congestion pricing application, considerations of implementation and management ease may point toward a simpler price criterion based, for example, on achieving and maintaining a conventional level of service measure from the literature of traffic engineering. We know that the optimal level of congestion reduction will be unique at each bottleneck, but it is much easier to explain a generally applicable congestion reduction goal in the policy-making process, and easier to implement and manage facilities based on observed performance. Hence, the actual criterion for setting the congestion price may well be framed in terms of standard traffic level-of-service metrics (e.g., B, C, D, E). For similar reasons of simplicity and clarity, specific prices might be chosen to reduce the amount of change-making required (rounded to the nearest 25 cents or to the nearest dollar, for instance), although with modern road pricing technologies this would not be strictly necessary. Periodic adjustments in price are likely to be needed to maintain effectiveness, and they too would likely be done in simple, rounded increments of 25 cents or a dollar, unless electronic toll collection were in place.

- **Period of application** - Some economists have argued forcefully that congestion prices should change dynamically in response to traffic conditions, perhaps varying from minute to minute to achieve the optimal reduction in congestion. However, few seriously believe that such a dynamic scheme would be implemented any time soon, for several reasons: 1) the practical difficulties of creating, testing, and maintaining the hardware and software required for such a system; 2) the unresolved theoretical question of whether a truly dynamic system would produce a stable set of prices; 3) the strong revealed preference of travelers for predictable conditions, even if the price of predictability is a somewhat higher average time or cost; and 4) the question of how to treat incident-related delay in a dynamic pricing environment. An initial congestion pricing scheme more likely would involve prices that can be explained through relatively simple signage and do not vary from day-to-day (though weekend-weekday and seasonal variations might be both desirable and feasible). Hour-to-hour variation might, however, be used to avoid large price increases and decreases at the peak / off-peak boundaries, and might be designed as a pyramid of prices centered on each peak hour in order to be relatively easy for the driver to remember.

In addition to these basic design issues for pricing at a bottleneck, there is a question about how widely congestion pricing would be applied in the highway network. While pricing would be easiest to implement on limited access facilities, spillover from priced freeways to unpriced arterials and collectors could be a problem in some locations.[1] Local communities seem unlikely to tolerate significant traffic diversion to the facilities under their jurisdiction,

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[1] The first US congestion pricing project opened in December 1995 on State Route 91 in Orange County, California; the San Francisco-Oakland Bay Bridge is currently being studied as a second possible application. Because of the special characteristics of these two applications, spillover to arterials is not likely to be a major issue. SR 91 pricing will apply only to the new lanes added in each direction, with the original lanes left unpriced; in the Bay Bridge case there are essentially no realistic alternative highway routes. The extension of pricing to other facilities such as I-10 in the Los Angeles area or I-80 in the Bay Area would, however, have to confront the possibility of spillovers to parallel routes.

and could be expected to oppose freeway pricing schemes if they created or worsened congestion on local roads. The localities might, however, accept a broader-based pricing plan which manages traffic on a systemwide basis, especially if part of the revenues were returned to affected jurisdictions. Widespread implementation of congestion pricing hence could mean pricing both freeways and parallel routes where significant delay appears.

The congestion pricing measures tested in our case studies were designed to reflect these observations about the policy environment. We assumed that some form of electronic payment system would be used rather than toll booths, so that there would be no stopping to pay tolls. Prices were applied everywhere delay appeared in the highway network (as represented in each region's model system - freeways and arterials plus some major collectors). Price levels were set to reduce congestion to meet specific levels of service; we investigated a range of level-of-service targets and eventually chose LOS D/E for use in all four metropolitan areas.[2] Our analyses allowed prices to vary by corridor, determined peak definitions by the extent of congestion in each corridor, and permitted different prices to be charged in each corridor for each hour of the AM and PM peak periods, but we stopped short of dynamic pricing. Rather, we assumed that travelers would face a fairly simple schedule of prices by time of day, readily comprehensible to travelers and influencing their travel behavior and location choices.[3]

It is important to note that under this pricing approach, users of the facilities in greatest demand still would perceive traffic as heavy and somewhat constrained, with speeds below posted limits (at least for the cases considered here, higher speeds would not be as efficient from an economic point of view). Note also that we assume that prices would be maintained in constant dollars, meaning that from time to time price adjustments might be necessary.

The STEP analyses were carried out by focusing on highway performance at the corridor level, as follows. In the STEP calibration phase each of the metropolitan areas was divided into major corridors based on topography and highway function. Each district-to-district trip interchange was assigned to a corridor, and approximate volume-delay relationships (i.e., expressing travel time per mile as a function of volume and capacity) were developed for the corridors.[4] This was carried out for both the AM and the PM peak in each region.

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[2] The choice of LOS D/E was based on analyses of benefit measures from the STEP model which indicated that stable, near-capacity flows (about 10 percent below actual capacities) were the most economically efficient traffic regime. Specifically, we used delay reduction per marginal unit of price as the measure of benefit.

[3] We assumed congestion prices would be in effect on non-holiday weekdays only - 250 days a year.

[4] The shape of the volume/delay curve is a critical determinant of the outcome of the analysis, because it indicates how much traffic would have to be removed from the peak in order to achieve a given LOS. To represent volume/delay relationships for corridor-level changes, STEP uses an equation roughly analogous to the Bureau of Public Roads (BPR) equation relating link-level volumes and travel times. The STEP equation was initially developed in a study for the California Energy Commission and later re-estimated in studies for the Metropolitan Transportation Commission, the Southern California

The level of service target was defined in terms of the volume delay function. For the generic functional form used in this version of STEP, level-of-service D/E corresponds to a travel time that is about 85 percent longer than the time under free-flow conditions. In other words, the target level-of-service was represented by a 1.85 ratio of peak to uncongested travel time in a corridor.

In the Los Angeles region, about 300 aggregate corridors were defined in this manner, and about 220 of them - 73 percent - were sufficiently congested in the AM peak to justify congestion pricing. For the San Francisco Bay Area 150 corridors were defined, with 90 (60 percent) meeting the criteria for pricing in the AM peak. San Diego and Sacramento were both considerably less congested; only 15 percent of the 80 corridors analyzed in San Diego and 8 percent of the corridors analyzed in Sacramento were candidates for pricing.

To estimate the price needed to achieve the target level of service, STEP was applied to each sample of households and the average price per mile was adjusted on a corridor-by-corridor basis until all corridors were at or below the 1.85 peak/off-peak travel time ratio, and no corridor had a higher congestion price than necessary. This took approximately five iterations (model runs) for each region and each analysis year.

For each region, a specific congestion price was estimated for each corridor and time period.[5] For 1991 conditions, the congestion prices would vary from zero (for the

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Association of Governments, and the Puget Sound Council of Governments (Seattle region). The equation expresses the relationship between the ratio of average peak to average off-peak travel times in each "corridor" - basically a trip exchange - and the aggregate capacity serving that corridor. Separate estimations were done using data from the detailed highway networks of the three regions; because the coefficients of all three models were nearly identical, a single equation was implemented in STEP. The specific functional form is $t/t_o = 1 + (V/C)^2$.

This corridor function, derived from regional network models, shows travel time climbing rather gradually as congestion builds. We know from highway operations research that the buildup of congestion for specific facilities is more abrupt and steeper in the region of capacity flows than this equation indicates. However, because the corridor function represents an aggregation of facilities of different types, it reflects the "family" of volume-delay relationships for the freeways, arterials, and major collectors embedded in the network models and producing their travel time estimates.

The steepness of the buildup of congestion is important in determining what the congestion price would have to be. If the slope is steeper than our equation indicates, as it would be in a corridor with a single facility, congestion prices could be lower for a given level-of-service improvement than we report here. This is because a steeper slope implies that fewer vehicles would have to be priced off each corridor's facilities to achieve a given LOS. We tested a number of functional forms in STEP, and the different forms did indeed produce some variation in optimal prices. For example, letting the slope parameter rise to 4, the value used in the standard Bureau of Public Roads (BPR) equation, would lower the "optimal" congestion price by about 40 percent (regional average). Since the BPR curve is for a single freeway facility, it is much steeper than any corridor curve could be (unless the corridor consisted of a single freeway). Therefore the BPR value should be viewed as an outer limit.

[5] In the four case study regions, PM peak conditions are less sharply congested but last longer than AM

uncongested exchanges) to as much as $1.00 per mile for a very few corridors, such as the I-80 corridor and the Bay Bridge corridor in the San Francisco Bay Area and the I-405 and I-10 corridors in the West Los Angeles - Santa Monica area. In San Diego, the highest corridor level prices would reach about 40 cents per mile, whereas in Sacramento the highest corridor prices would be about 20 cents per mile. By the year 2010, congestion is expected to worsen considerably in all four regions; many more corridors would be candidates for pricing, and prices would have to be higher to maintain the LOS D/E target.[6]

Estimated reductions in travel time, VMT, trips, emissions, and fuel use resulting from the calculated congestion prices, as well as estimates of the total revenues generated, were calculated by summing up the analysis results for each corridor. To simplify the presentation of price levels and provide an indicator of overall price impact, a corridor-weighted average price per mile is shown in the tables, and can be thought of as the average price peak period drivers would face overall. It is not necessarily the price any individual traveler would experience. For example, the price necessary to obtain LOS D/E on the San Francisco Bay Bridge in 1991 would have been about $6, or 75 cents a mile for that corridor, in contrast to the average Bay Area AM peak price of about 9 cents a mile.[7]

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peak conditions. Hence evening congestion prices, at least initially, could be somewhat lower but would be in effect for a somewhat longer period of time than those in the morning peak. However, congestion pricing would flatten and spread out the AM peak somewhat, diminishing AM-PM differences in prices and hours of application.

[6] One might ask whether the prices arrived at in this manner are the optimal prices. The issue is not simple to resolve; in the first place it is well understood that user-optimal may not be identical to system-optimal (Wardrop,1952). User optimality is examined here, although we note in passing that pricing also could be used to achieve system rather than user optimality. The analysis of user-optimal prices is particularly complex, because travelers can respond to pricing in a number of ways, shifting trips among corridors and altering their frequency and times of travel. It is necessary to account for the possibility that travelers could switch to another route, travel at a different time of day, change modes, choose different destinations for some trips, increase or reduce the number of trips made, move to a different residence, or change their place of work. STEP accounts for these phenomena, but because STEP is a hybrid mix of non-linear demand functions of various types, it is not possible to mathematically prove the existence of a unique set of congestion prices for a given level-of-service criterion. Simulation offers an alternative approach for assessing whether model results represent a stable and unique equilibrium, and we used it to investigate the optimality of our corridor prices. We applied a number of procedures designed to determine whether STEP would produce different sets of "optimal" congestion prices. These included adopting different search algorithms in the program code, and starting the searches from different initial corridor prices. All search strategies that produced stable outcomes were in agreement with the initial "optimal" prices, which lends some support to the notion of a unique equilibrium.

[7] The Bay Bridge congestion pricing studies underway at the time of this writing are discussing considerably smaller prices, e.g., a $3.00 peak period toll. A $3.00 toll in 1996-1997 dollars would be the equivalent of a $2.50 toll in 1991 dollars. Such a price increase would be sufficient to cut the queue at the toll plaza by about a third, but would not achieve LOS D/E.

Corridor-level results are useful for preliminary planning purposes, but for implementation planning it is important to translate the results into specific facility charges. Within the resources of this study, we were not able to test congestion pricing in a full network context for each of the four case study areas. Instead, we ran STEP for the four areas, then selected two corridors for more detailed analysis: I-80 from the Carquinez Bridge to the Oakland-San Francisco Bay Bridge, and I-10 from Santa Monica to Downtown Los Angeles - two of the most congested locations of all those we studied. We ran regional network models for the Bay Area and Los Angeles to see how prices would need to vary among facilities in the selected corridors, given the corridor prices and demand levels produced by STEP. The Tranplan network analysis program was used, with an equilibrium traffic assignment for the AM peak hour and price incorporated into the route choice criterion.[8]

Tranplan corridor analyses produce results comparable to STEP if the per-mile price is applied equally across all facilities in the corridor. With the same price per mile on all alternate routes, the main effect will be a reduction of overall corridor demand rather than a rearrangement of traffic among corridor facilities (absent differential prices, traffic in a congested corridor will distribute itself such that all routes will have about the same travel times). However, Tranplan analysis made it possible to test link-by-link pricing to more precisely target bottlenecks in the system. We went through five iterations in which we manually adjusted link prices in the two test corridors, each time increasing the price on links that remained congested and decreasing the price on links with better than D/E level-of-service and then running Tranplan to evaluate link-level impacts. Overall corridor delay reduction tended to improve from iteration to iteration, while overall price levies tended to fall. After the five iterations, we judged that the effectiveness of congestion pricing, in terms of reduced delay per dollar, might be 10-15 percent higher in these corridors than the approximate results of the STEP analyses would suggest. This should be considered when reviewing the average prices and/or time savings presented in the tables.

What if prices varied by location, but were set at modest prices initially and were increased only gradually to the levels necessary to avoid stop-and-go driving? This approach would give people a chance to adjust their travel and location behavior under prices that accurately signal the ultimate spatial distribution of impacts. Dynamic models would be necessary to fully explore the changes that such a pricing approach would produce over time; STEP does not currently include such dynamic models. However, STEP is able to evaluate lower-than- optimal congestion prices as would occur in a pricing phase-in (and perhaps in many cases where prices are set on political as well as technical grounds). We tested the impacts of lower prices by taking the final corridor congestion prices for the Bay Area and Los Angeles and applying them in 10 percent increments (i.e., prices at 10 percent of optimal corridor prices, 20 percent of optimal prices, etc.). The STEP results indicate that the shape of the aggregate demand curve is moderately convex, with slightly

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[8] It was possible to use the network provided by the Southern California Association of Governments for this part of the analysis, but for the Bay Area a new Tranplan network was created as part of the study (MTC uses UTPS networks and the study team did not have access to this software).

decreasing effects for each price increment. For each of the two case analyses, the first price increment of 10 percent produced almost twice the impact of the final increment of 10 percent. This suggests that implementing a constrained price can still be reasonably effective.

The STEP analyses are for scenarios in which pricing is used to manage congestion wherever it occurs on the network of highways and arterials; how congestion pricing would work if implemented on a few facilities is a different question. Even if the ultimate objective is system-wide implementation, it is likely that initial applications would be spot pricing - pricing applied to just a few facilities or corridors. As we discussed earlier, however, closely-parallel routes could receive significant amounts of diverted traffic if a single congested facility is priced; such traffic diversion could lead to significant congestion on the parallel routes; and opposition from affected jurisdictions might well be enough to halt implementation, unless the parallel routes can be priced as well.

Even where diversion to parallel routes is infeasible for most travelers, as is the case for the San Francisco-Oakland Bay Bridge, or where each facility in a corridor can be differentially priced, as our analyses of the I-80, I-405, and I-10 corridors considered, a number of concerns about spot pricing remain. For example, our analyses indicate that implementation at a single highly-congested location or in a single corridor will alter regional patterns of trip distribution, residential location, and workplace location, with specific effects varying with household income level. The result of spot pricing could lead to a distortion of the spatial structure of the region, because the spot pricing leads to exaggerated locational impacts. Thus single facility pricing may produce a misleading view of the eventual areawide effects of congestion pricing.

B.3.3 Employee Parking Charges

In most metropolitan areas, parking is commonly provided to its users free of charge, although providing such parking can be quite expensive and presumably is recouped in other ways (e.g., through the prices charged for goods and services, for private parking, or through public tax subsidies, for public parking). Charging for parking, whether done through private initiative or in response to government incentives or mandates, would make the costs of parking more apparent to travelers and would likely reduce auto use somewhat.

Parking could be priced for all users, and sometimes is (at many commercial garages, e.g., or by local governments who install on-street meters). However, proposals for the implementation of parking pricing often focus on daytime employee parking, since the associated employee travel typically occurs during the costly peak periods. If employees had to pay for parking, it is reasoned, they would be more likely to use alternative commute modes such as transit, carpooling, or walking. In the case studies we present here we analyze only employee parking charges.

In comparison with congestion pricing, parking pricing is a relatively simple measure to analyze using STEP. The average zonal parking price (daily, for work trips, and hourly, for non-work trips) is a variable in each of the STEP mode choice models, and zone-level parking price data are available for each of the four metropolitan areas studied here. Thus, any parking scenario that can be expressed as a change in an average zonal price can be analyzed using STEP.

Proposed parking price changes do not always target the average zonal parking price, however. Consider a city in which a substantial amount (varying by zone) of the all-day parking is provided by a private operator, who charges a daily fee for use. The operator, perhaps given an incentive by local or state tax policy, decides to raise the fee by $1.00 per day. To analyze the impact of this increase, it is necessary to have an estimate of the percent of all-day parking in each zone that is provided by this operator and hence will be affected by the increase. A number of cities maintain a parking inventory which could provide this information, although many other cities would have to conduct a special survey to produce this estimate.

Other parking pricing proposals can be far more complicated to analyze. Consider a $3.00/day parking surcharge which applies only at employment sites with 100 or more employees. In order to translate this surcharge into zonal average price estimates, we would need information about the fraction of workers in each zone who work at sites with 100 or more employees. We would need to account for the possibility that some of those employees do not provide any parking now, in order to figure out what share of each zone's employees would be subject to the fee. The possibility that some employees could avoid a fee at their workplace by parking elsewhere should already be reflected in the calculation of zonal average parking cost, but we also must consider the possibility that employers will simply pay the fee themselves rather than passing it on to the employee, again reducing the number of affected workers (note that certain implementation strategies, such as treating parking as a taxable benefit or requiring the surcharge to be collected from the employee as a payroll deduction, would reduce the likelihood and the impact of this latter concern). Very few cities have an employer and parking data base organized to support such an analysis, and we have found none that has information on likely alternative parking sites or on employer responses to such policies. Hence, calculating the actual increase in zonal average parking charges that our surcharge would produce could require either a great deal of data collection. Nevertheless, for preliminary planning purposes it usually will suffice to make some simple assumptions in developing the data inputs or in interpreting the results. For example, we could analyze the parking surcharge as if it applied to all employees and then factor the results downward to account for its more restricted reach: if regional employment data indicate that only 40 percent of the region s jobs are provided by employers with 100 or more workers, then our impact estimates should be reduced by about 60 percent.

For our four case studies, we utilized parking cost data files developed by the regional transportation agencies. These files present only the estimated average employee parking price (nominal price) by zone. Given the data we had available, we chose to model two general policy options: a flat daily charge on all employees who drive alone and do not currently pay for parking, as well as a daily surcharge on all employee parking, paid or not. The first option could be thought of as a rough approximation of what prices might be like if free parking were no longer provided to employees; or it might be thought of as the result of a policy that imposes an impact fee or tax on free employee parking but waives the fee on parking that is already priced at or above some threshold level. The second option would be a flat impact fee (or tax, depending on how it is structured and applied).

Using STEP, a range of daily employee parking charges from $1.00 to $10.00 was examined for each of the four metropolitan areas. To model the minimum price threshold option, drive-alone parking fees for all workers in each sample were set to the specified minimum or to current levels, whichever was higher - fees in zones where existing zonal average parking fees exceeded the threshold charge were held constant. The second option we evaluated, a flat fee or surcharge on all employee parking, was even easier to represent than the minimum price option; the fee was simply added to the employee parking price in effect in each zone. In both analyses, we assumed that the employees would personally pay the parking charges (hence we treated the charges as out-of-pocket expenses). We also assumed that carpool and vanpools would be permitted to park for free at their destinations, and that no charges would be imposed for park-and-ride parking. These latter assumptions are generally consistent with the current treatment of HOVs and park-and-ride in the four case study regions.

STEP accounts for the full set of travel effects we would expect parking pricing to have, including impacts on highway performance, but to verify that STEP's simplified level-of-service functions provide an adequate representation of the latter, the peak period trip tables from STEP were assigned using Tranplan to the relevant networks for Los Angeles and the Bay Area, and the resulting travel times were cycled back through the STEP model. No significant changes from STEP aggregate performance measures were identified.

Results for $1.00 and $3.00 parking price increases are reported here. Given the ubiquitousness of free parking in each of the four regions, the differences between the two policy options were minimal: the estimated impacts of the parking fees varied by 10 percent or less (i.e., a reduction of 1 percent in VMT for the minimum price option, a 1.1 percent VMT reduction for the surcharge).

Our assumptions that prices would apply to all drive-alone vehicles[9] and that HOV parking would be exempt from charges maximize the impact of the employee parking fees. In actual implementation, a number of factors could reduce these impacts. For example, as our earlier discussion pointed out, exemptions of certain employers would reduce the number of employees in each zone who actually would pay a parking fee, with the impact varying widely among zones.

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[9] To calculate impacts on an annual basis, we assumed employee parking charges would apply 250 days a year.

In addition, in situations where parking is differentially available to or subsidized for different income or occupation groups, the impacts of price changes may vary from those we have shown. Our results assume that a parking fee would be paid by all who drive alone. But under some conditions the fee might actually be absorbed by the employer; for example, some blue collar workers have negotiated for free parking as part of their labor agreements, and a parking surcharge would have to be paid for by the employer or compensated through offsetting salary increases. In cases such as these, the fee on parking could vary systematically with income group, and hence be disproportionate to the number of workers affected.

Finally, the impact of free parking for high-occupancy vehicles deserves special attention. Free HOV parking is a common measure in our case study regions and might well be permitted under a policy to charge for parking; but it is not a necessary feature of the analysis. If the parking fees apply equally to HOVs, HOV users still experience an advantage over solo drivers because they can split the cost among all passengers, but the price differential between drive-alone and HOV decreases - by about 40 percent on average. Based on STEP runs for all four metropolitan regions, this diminished advantage would cut the impact of the parking fee by about 15 percent, because fewer current drivers would switch to HOV and some of those who currently are HOV users would decide to drive to work.

B.3.4 Fuel Tax Increases

A fuel tax increase would be a direct approach for reducing fuel consumption and also for reducing greenhouse gas emissions (because CO_2 emissions are proportional to fuel consumed). Its effects on other emissions and travel are muted, though still significant, because auto purchase decisions and usage patterns can lead to a more efficient vehicle fleet and reduced per-mile operating costs.

The fuel tax increases analyzed here are expressed as straightforward additions to the at-the-pump price of gasoline and diesel fuel. For our base case, vehicle fleet fuel economy is about 22 miles per gallon (.0364 gallons per mile). Base-case fuel cost is about $1.20 per gallon, or 5.45 cents per mile at average fuel economy. With no increase in fleet fuel economy, a 50 cent per gallon fuel tax increase would add about 2.3 cents and a $2.00 per gallon tax (or other form of price increase) would add about 9.1 cents to the average per-mile cost of driving. However, empirical evidence and common sense suggest that the in-use vehicle fleet would become more efficient under a significant fuel price increase. In the many households with more than one car, household members could quickly arrange to make more use of their fuel-efficient vehicles and less use of their gas guzzlers, cutting fuel consumption considerably. Over time, both single-vehicle households and multi-vehicle households could be expected to increase vehicle fuel efficiency as they replace some vehicles and retire others.

How fast and to what degree such vehicle substitutions, replacements, and retirements might occur in response to fuel price increases has been a matter of considerable dispute. The issue is important to our analysis because it could significantly affect the impact of a fuel tax. Travel and location choices are undoubtedly affected by the costs of vehicle ownership and operation, i.e., by both the number of vehicles a household chooses to own and the type and age of its vehicle(s). Faced with higher fuel costs, a household which for whatever reason does not reduce its per-mile fuel consumption (by changing its vehicle holdings or changing which vehicles it uses most) will have to devote more of its income to fuel purchases, or take steps to reduce its vehicular travel (or some combination of the two). If on the other hand the household finds it possible to reduce the price effect through vehicle substitution and replacement, fuel efficiency improvements will have a smaller effect on travel.[10]

STEP includes a model of the number of vehicles a household chooses to own, so we were able to capture the effects of fuel price increases on auto ownership in our analyses. However, STEP currently does not address the type or age of the vehicles owned, information which is needed to estimate the cost per mile under different fuel price scenarios. We did not have direct access to a model of household vehicle purchase decisions for this study, so to account for the broader range of impacts, we turned to outside sources for evidence on the elasticity of fleet fuel economy with respect to fuel price.

The literature from the U.S. and abroad suggests that fleet fuel economy (miles per gallon) is quite sensitive to the price of fuel. Pickrell s recent research (Pickrell, 1993) and his syntheses for the Presidential Commission on Greenhouse Gas Reduction (a group known popularly as Car Talk)(Pickrell, 1995) examine the impact of fuel prices and report findings from a wide range of reputable U.S. and international studies in advanced economies. He cites numerous estimates of long-run average elasticity of fleet fuel economy with respect to fuel price in the .5 - .6 range, with estimates as low as .2 to .3 and some higher than 1.0. An elasticity of 0.5 means that a 25 percent increase in real fuel price (e.g., from $1.20 to $1.50) would increase long run average fleet fuel economy from 22 miles per gallon (mpg) to almost 25 mpg; a 167 percent increase in real fuel price (e.g., from $1.20 to $3.20) would increase long run average fleet fuel economy from 22 mpg to about 40 mpg (82 percent). A 40 mpg fleet average sounds high for U.S. conditions, but it cannot be dismissed out-of-hand, especially for a longer-term scenario (2010 or later) and/or one in which the price increase was implemented nationwide or in a majority of urban states (so that manufacturers would have sufficient time and incentive to offer more fuel-efficient vehicles).

Substantial fuel economy improvements could, in fact, be obtained through shifts in consumer choices among the vehicles currently available for purchase: for example, by

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[10] A household's ability to change vehicle holdings is related to its current and expected income, its current vehicle holdings, ownership and operating costs of the alternatives, etc. The household's willingness to change its vehicle holdings depends on many additional factors, such as vehicle seating capacity, comfort, handling, and safety; fuel economy, an element of operating cost, is but one influence.

purchasing the four cylinder rather than the six cylinder version of a midsize sedan, a consumer could obtain a 10-15 percent improvement in mpg. This percent increase in fuel economy is about what a 25-50 cents per gallon price increase would require, at a .5 elasticity. However, for large fuel price increases, an elasticity of .5 would imply that at least some consumers also would have to change the type of vehicles they own and use, i.e., greater numbers would have to purchase and use highly efficient vehicles and restrain their purchase and use of the least efficient ones. Currently over a dozen vehicles are sold in the U.S. which obtain over 40 mpg, so this seems technically feasible, and may become more so if gradual improvements in technical efficiency, averaging perhaps 1-2 percent a year, are forthcoming over the next decade or so, as many analysts expect (Pickrell, 1995). Whether buying habits in fact would change in the necessary fashion could be debated.

For further evidence of how fuel prices might affect fleet composition and use, we turned to models of the vehicle fleet. Since our case study regions were all in California, we were particularly interested in an analysis tool known as the Personal Vehicle Model (PVM), which the California Energy Commission has used to estimate the composition of the state's vehicle fleet by size and age, as a function of the price of fuel and other factors.[11] We asked the CEC to provide some indication of the PVM elasticity of fuel economy with respect to fuel price, as evidence for California fleet conditions. A run of the PVM made for this study by the CEC in January 1995 indicated that a $2.00 fuel surcharge would lead to a 2 mpg increase in fuel consumption (from 22 to 24 mpg), for an average elasticity of .05.

The PVM-estimated elasticity is much lower than the elasticities reported by Pickrell. A partial reason for the difference is that most national and international long-term elasticity estimates allow for changes in the products manufacturers offer in response to fuel price increases. In contrast, the PVM analysis assumed that the price increase would only apply in California, and that manufacturers would not increase the fuel economies of the cars they offer in response to a change in only one state, even a state as large as California. The PVM analysis does allow consumers to purchase more efficient vehicles from those otherwise available. It does not consider increased relative use of the more fuel efficient vehicles within each household s existing vehicle holdings.

We discussed the fuel economy - fuel price elasticity issue with a number of researchers and ultimately settled on testing a range of assumptions about the fleet response to fuel price, expressed in terms of the elasticity of fuel economy (miles per gallon) with respect to price. Results for three elasticity levels are reported here: 0.5, 0.16, and 0.05. The researchers we contacted felt (and we agreed) that the .05 PVM elasticity should be used as a lower boundary, and that a 0.5 elasticity, i.e., the lower end of the .5-.6 estimates from the national studies, was a reasonable upper boundary for a California-only policy.[12]

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[11] The PVM was developed more than a decade ago, and at the time of our study the CEC was engaged in a multi-million dollar project to replace it with an updated package based on new data and state-of-the-art modeling concepts. Hence we chose to treat the PVM as one source of evidence rather than to rely solely on it.

[12] A California-only gas tax increase seems more plausible for small to moderate tax increases (25 cents

The fuel economy elasticities can be used to compute average mpg and out-of-pocket vehicle operating costs per mile resulting from a fuel price increase. For example, consider a two dollar per gallon increase, i.e., a fuel price of $3.20 per gallon. In comparison to the current $1.20 per gallon, for which average out-of-pocket expenditure is about 5.5 cents per mile, the estimated mpg and cents-per-mile costs would be:

Elasticity	MPG	Cents per Mile
0.00	22	14.6
0.05	24	13.3
0.16	28	11.4
0.50	40	8.0

It is clear from this table why fleet response to fuel price is such an important issue. At a .05 fuel economy elasticity, the average fuel cost per mile increases by more than 140 percent; this would result in large reductions in travel. By comparison, at an elasticity of .5, the average fuel cost per mile increases by about 45 percent. In the first case, trip and VMT reductions account for most of the drop in fuel use, while in the second case, improved fleet fuel economy accounts for most of the drop in fuel use. Since both the incidence and the economic implications of the fuel price increase differ markedly between these two cases, forming a more precise understanding of fleet fuel economy sensitivity to fuel price is of some importance.

Using our three elasticities, we studied a range of fuel price increases from $0.10 to $3.00 in 10 cent increments. The results for the $2.00 fuel price increase under different elasticity assumptions are presented here, along with some results for a $0.50 price increase. Results for these two price levels are sufficient to support generalization about price effects over the full range.[13]

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or less) than for higher ones, especially those of a dollar or more. Of course, it is not necessary to assume that a fuel tax or other fuel price increase would be implemented in California only: the analyses could equally well represent the impacts of scenarios involving federal fuel tax increases or state tax increases implemented in many states. Also, for the analyses presented here, at-the-pump price increases implemented by sellers would have the same effects as a fuel tax increase. A California-only interpretation of our analyses does not necessarily require new, highly efficient vehicles to be produced for the state market (though it might make California an attractive test bed for such vehicles, including ones currently sold overseas but not now marketed in the U.S.). It does however presume that, of the vehicles produced for the U.S. market, manufacturers would sell a higher share of the most efficient vehicles in California. Also, the used car market would be affected; demand for low mpg cars would decline in the state, and such cars would likely be retired earlier or perhaps shipped to other states or countries for sale there.

[13] We calculated impacts on the basis of 250 times the average weekday rate plus 115 weekend and holiday days at 95 percent of the weekday rate.

It is worth noting that for some policy objectives, the fuel price (fuel tax) might be adjusted periodically to maintain the per-mile cost, i.e., to reduce the impact of improved fuel economy. Such tax adjustments would make sense in terms of paying for road maintenance, since maintenance costs do not decline proportional to fuel use. Similarly, if pay-at-the-pump insurance policies were implemented, it would be necessary for the component of the fuel tax designated for insurance to be de-coupled from fleet efficiency. If for either reason the fuel tax were adjusted to compensate for revenue losses due to fleet efficiency improvements, its effects on VMT, trip rates, delay, and emissions would be greater than we have estimated here. Essentially, such adjustments would make the fuel tax very much like the VMT fee discussed below.

B.3.5 VMT Fees

A fee on vehicle-miles of travel (VMT) would directly charge users for the amount of vehicular travel consumed. A VMT fee therefore could be used to reduce VMT-related impacts.[14] Such a fee also would be a better targeted road user payment mechanism than the fuel taxes we now use, because drivers could not reduce their exposure to the fee by purchasing more fuel efficient vehicles.[15]

Currently, the easiest way of collecting a VMT fee would be through a charge determined at the time of vehicle registration or vehicle inspection, based on owner-reported or inspector-recorded odometer readings. However, if one goal of a VMT fee is to reduce vehicular travel and its negative externalities, the fee should be linked as closely as possible to day-to-day use of the vehicle. Collecting the VMT fee as part of an annual payment for vehicle registration would probably be less effective in reducing VMT than more frequent charges: an annual fee is remote from individual drivers' thinking about their day-to-day driving behavior, and may be less effective in influencing it. Also, drivers would discount annual payments compared to more frequent levies.

There is no reason, of course, that a VMT fee tied to registration or I/M programs would have to be paid annually. One can imagine a variety of alternative arrangements, including ones in which the registration or I/M fee itself is paid in monthly or quarterly installments. One approach might mimic the billing method used by public utilities, in which monthly

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[14] VMT is roughly related to congestion, though a VMT fee would have a bigger effect on non-work travel than on work trips, which make up the majority of VMT during the congested peak periods. VMT is also roughly related to fuel use and to hydrocarbon, NOx, and carbon monoxide emissions. In contrast, PM_{10} emissions from on-road transportation are closely related to VMT.

[15] Used as a road user payment mechanism, the VMT fee would have to be adjusted periodically or indexed to reflect costs of road construction, operations, and maintenance, or if such road costs increase, the fee's percent cost coverage would decline. Nevertheless, costs to each user would remain proportional to use. Per-gallon fuel taxes also suffer from declining cost coverage unless adjusted or indexed, but are far less directly related to use of the roads because of divergent vehicle fuel efficiencies.

or quarterly bills are based on estimated usage, and a periodic reading (or report) is used to calculate the additional increment due or credit earned.[16]

Recent technological developments offer other ways to frequently measure and collect a VMT fee. It is currently feasible to put in place a VMT monitoring system using automatic vehicle identification (AVI) technologies and covering all major facilities including freeways and major arterials. Systems such as these are currently being deployed on tollways in many parts of the U.S. as well as abroad, and offer timely and accurate fee collection. In one design motorists purchase debit cards which are displayed on their vehicles; fees are deducted from the cards electronically as the vehicles pass AVI readers. In another design the readers record each passing vehicle's identification code and transmit the data to a computerized system which accumulates the charges and periodically bills the vehicle owner.

An alternative concept currently in prototype stage would base the VMT fee on an at-the-pump reading of an electronic odometer or a special VMT-accumulating smart card; the corresponding fee would be calculated electronically and could be collected as part of the payment for fuel, or perhaps recorded and billed separately. In one approach, scanner or microwave technologies would automatically read the odometer or another on-board electronic device designed to monitor VMT. In another approach, the motorist would insert the vehicle's smart card into a special reader, following a sequence of actions much like those used with the automatic credit card debiting devices now present in many fuel pumps.

The availability of approaches, high tech or low, for collecting a VMT fee at or close to the time of road use is important, because such immediate and visible prices are likely to be treated by travelers essentially as out-of-pocket costs similar to current fuel costs. Here we treat the VMT fee as a pure increase in the per-mile cost of driving, with no possibility of avoidance and no discounting by drivers for delayed payment. In essence, the fee defined in this way would be the equivalent of a fuel tax increase that is indexed to vehicle fleet efficiency.

VMT fees ranging from 1 to 10 cents per mile were analyzed for each metropolitan area (at the base case fleet fuel economy, this is equivalent to fuel price increases ranging from $0.22 to $2.20 per gallon). Results for the 2 cents per mile fee are reported here.[17] In keeping with the methodology described earlier, all elements of the STEP model were employed, from residential location through supply response. For Los Angeles and the Bay Area, we further checked the results by assigning STEP-based peak trip patterns to the highway networks. No differences were found that would significantly alter the findings from STEP.

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[16] Income and payroll tax collection methods are another possible model: frequent payments are made based on estimated amounts due and reconciliation of the amounts due is done via an annual report, subject to audit.

[17] We calculated impacts on the basis of 250 times the average weekday rate plus 115 weekend and holiday days at 95 percent of the weekday rate.

Note that because the results were produced at a regional level, they are for within-region VMT only. They do not include VMT generated outside each region being analyzed. A VMT fee designed for revenue generation might, of course, be implemented on a statewide basis and could be analyzed in that fashion.

A regional VMT fee based on AVI monitoring of road use would be simple enough to implement. A regional fee based on odometer readings, on the other hand, would charge the motorist for inter-regional, interstate, and international travel (Mexico, Canada) unless some mechanism for excluding such travel were devised. One can easily imagine ways to credit motorists for interstate and international travel; for example, motorists who want a credit for out-of-state travel could have their odometers read at stations along major entry and exit routes to the state, or a procedure might be established allowing a tax credit for documented out-of-state travel, much like the one now used for fuel tax credits for exempt off-road vehicle use. It would be much more difficult to devise a low-tech way to credit within state inter-regional travel without creating a major paperwork burden for all involved. Since Caltrans periodically does statewide travel surveys which include both within-region and inter-regional travel, one approach might be to use the survey data to create a system of adjustments for each region to account for the average out-of-region component of VMT, perhaps by vehicle age.

If the VMT fee were collected infrequently, e.g., once a year based on an odometer reading or report, its impacts might be somewhat less than we estimate here due to discounting of future lump-sum payments in comparison to equivalent out-of-pocket payments. Hence the results reported here should be viewed as the high end of likely effectiveness.

B.3.6 Emissions Fees

Emissions fees represent a means of reducing tailpipe emissions that could give the consumer somewhat more flexibility than the current system of mandated performance backed by vehicle inspection and maintenance. The basic concept is that the total pool of annual vehicular emissions in a region would be assigned a cost (presumably pollutant-by-pollutant), and each vehicle would be charged a fee set to reflect its contribution to the total emissions burden. Levying such a fee on vehicular emissions arguably would be the most direct way to instill a sense of personal responsibility for mobile source air pollution.

While the concept may be simple to state, emissions-based vehicle fees are the most difficult of the pricing policies to define and analyze. Reasons for this are:

- the literature offers widely varying perspectives on the social costs of air pollution, so an agreement on a monetary basis for the emissions fee is not easy to reach;

- estimates of cumulative emissions from individual vehicles are imprecise and are likely to remain so unless and until vehicles are equipped with accurate, tamper-proof on-board emissions monitoring devices;
- because knowledge about how consumers would trade off emissions fees, repair costs, insurance, and other auto-related expenditures is not well developed, the change in fleet composition resulting from a targeted emissions fee is difficult to estimate.

We carried out analyses of two prototypical emissions fee strategies, each using a different type of information about emissions. Following the same line of argument as for the VMT fee, we assume that emissions fees can be collected on a pay as you go basis, so that they are perceived by drivers as an out-of-pocket expense. This could be done with a technologically advanced system such as an on-board monitor, read and billed, e.g., at the time of fuel purchase; or by combining some other method of fee calculation with a monthly billing system. If the emissions fee is determined as part of vehicle registration or inspection/maintenance and is billed annually or biennially as part of those programs, the fee may well have less influence on day-to-day travel behavior than we show (on the other hand, a large, infrequent fee might have a big influence on vehicle ownership levels, vehicle age and type, and vehicle maintenance).

All non-arbitrary emissions fee concepts rely on some assumption about the social costs of air pollution. Accordingly, we searched through the literature for evidence that would support a specific emissions fee in each region, and sought the advice of experts in university research groups and air pollution control agencies. We found that the costs of air pollution had not been researched consistently for all the case study regions, and that the sources that do exist show a wide disparity in their damage estimates. Credible cost estimates for mobile source pollutants range from about .25 cents per vehicle mile to about 8 cents per vehicle mile (using regional damage estimates, reduced by the portion of emissions not attributable to mobile sources, divided by annual regional VMT). The range reflects differences in the severity of the pollution problems of the various regions and in the types of damage considered, as well as disagreements over specific costs in a given region (controversy is especially acute concerning the interpretation of epidemiological studies).

Lacking more specific estimates of the social costs of emissions in each of the California regions, we chose to set our emissions fee to average one cent per vehicle mile. This represents a plausible, perhaps somewhat conservative estimate of current social costs of mobile source air pollution in these urban areas. Evidence suggests a much higher pollution cost in the Los Angeles region and perhaps a lower pollution cost in the Bay Area. The one cent per vehicle mile average fee would total about $1.15 million per day in the Bay Area and about $2.9 million per day in the Los Angeles Region, under base year

(1991) VMT conditions. While the amounts sound high, annual receipts from such a fee would amount to about 0.3 percent of the gross domestic product of each region.[18]

Clearly, it would be inaccurate to simply charge each vehicle the regional average per-mile emissions fee, since vehicles' emissions characteristics vary widely. We therefore analyzed two possible methods for assigning a per-mile emissions fee to different vehicles. Under the first method, the per-mile emissions fee would vary by model year and would be based on data on each model year's average emissions characteristics (i.e., using EMFAC in California). Under the second method, the per-mile emissions fee would vary with the actual emissions performance of each vehicle, which might be determined through emissions testing, remote sensing, or on-board emissions monitoring. The latter approach would account for the differences in emissions among vehicles of the same model year.

For each household in the four regional travel survey samples,[19] we knew the make, model, and age (year) of the vehicle holdings for the base year, and we knew how each vehicle actually was used on a representative weekday. Thus, we were able to provide a well-grounded assessment of how vehicles of different ages and types are used and who would be impacted by emissions fees.[20] However, we did not have access to a model of how household vehicle holdings or vehicle usage patterns would change as a result of differential changes in the per-mile cost of vehicle operations, so we had to address these issues in terms of plausible scenarios rather than modeled estimates.

Fees Based on Average Emissions by Model Year:

For the average emissions by model year approach, we began by determining, for each region, the average daily within-region VMT and emissions for every vehicle in the regional travel survey. We extracted from the survey data the vehicle trip sequences and their characteristics, and inferred whether the trip was a cold start, etc., based on the time between trips in the trip sequence. We also determined the average trip speed and distance, deriving these data from the applicable highway networks. We then used EMFAC7F data specific to each vehicle model year to compute the emissions for each vehicle trip.

From the resulting samples of vehicle trips and their associated emissions, average weekday emissions and VMT were calculated for each model year on a region-by-region basis. Annual emissions and VMT for each region were then estimated. The annual VMT

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[18] We used the same one cent per vehicle mile average fee for the year 2010 analyses, lacking more specific cost data.

[19] The most recent regional survey for Los Angeles did not record vehicle make and model data. However, the Caltrans statewide survey of the same vintage included these data and had enough observations in the Los Angeles region to support the analyses described here. For this policy only, then, we extracted the Los Angeles data from the Caltrans survey and used it for our analyses.

[20] We calculated impacts on the basis of 250 times the average weekday rate plus 115 weekend and holiday days at 95 percent of the weekday rate.

estimates were used to calculate total emissions costs for each region at the postulated one cent per mile average.

For the year 2010 forecasts, it was necessary to describe the likely vehicle age distribution and patterns of use for that future year. We made the simple assumption that the 2010 fleet would have the same general characteristics (age distribution, usage profiles) as the current fleet does. We then applied EMFAC7F 2010 emissions factors to this hypothesized future fleet's trips to determine the future base case (total VMT and emissions, emissions by model year, etc.).

For both 1991 and 2010, we used our calculations of emissions by vehicle model year to apportion the regional emissions cost estimates among model years. The annual VMT calculations by model year then were used to determine an average emissions cost per mile for each model year. For example, from the 1991 data for Los Angeles, the average emissions fee per mile for a 1 year old vehicle would be about 0.4 cents, while the average emissions fee for a 17 year old vehicle (from the pre-catalyst era) would be about 7.0 cents.

Note that the method we describe here should apply only to miles driven within each urban area, since emissions costs are calculated and apportioned on a regional basis. If the collection scheme used odometer readings as the basis for the VMT portion of the fee, some vehicle owners would be charged for miles driven in other regions or in other states. To avoid this potential inequity, methods could be developed to estimate in-region and out-of-region vehicle use and apportion the fee(s) accordingly, and credits could be given for documented out-of-state travel.

We analyzed the effects of our per-mile emissions fees varying by vehicle age, assuming that households would not alter their vehicle holdings or pattern of use in response to the fees. This assumption is not entirely realistic, since households could lower their fees by replacing their older cars with newer ones, and if AVI measurements or odometer readings are the basis for the VMT component of the fee, by using their newer cars in place of their older ones for some trips.[21] Nevertheless, the analysis results provide an indication of the maximum travel impact and the minimum emissions impact that such an emissions fee could be expected to have; without fleet changes the full impact of the fee would be passed through as an out-of-pocket cost to the driver, and the emissions reductions would come from reductions in travel rather than from the use of newer, presumably cleaner, cars.

A more robust analysis would consider how vehicle holdings and usage patterns might change in response to an emissions fee. The analysis would account for the determinants of household vehicle ownership and use and would estimate the effects of an emissions fee on the number of vehicles owned, the vehicle makes and model years, and VMT per

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[21] Alternatively, VMT could be estimated based on averages by model year taken from survey data. This might be simpler to implement than an approach requiring odometer readings, but would remove much of the incentive for multi-car households to reduce "older car" use by substituting their newer, presumably cleaner vehicles for certain trips.

vehicle. Such a comprehensive model was not available to us, but we did have STEP's internal auto ownership model, which estimates whether a household will have 0, 1, or 2+ vehicles as a function of household characteristics, travel conditions, and vehicle ownership and operating costs.

We used the STEP auto ownership model to partially account for the effects on the vehicle fleet as follows. For each region and analysis year, the base case household fleet was used to estimate the average annual cost of auto ownership for each household. Then, revised annual ownership costs were computed to reflect the addition of emissions fees for each vehicle (based on model year and the actual daily VMT revealed in the survey). New auto ownership probabilities then were calculated using STEP.[22]

While this method is an improvement over simply representing the emissions fee as an increase in out-of-pocket costs, we feel that on balance it still is likely to overstate travel effects and understate emissions effects: For implementation scenarios involving AVI or odometer readings, households with more than one vehicle could shift use among household vehicles to reduce their emissions fees without cutting back on travel. Both the revenues from emissions fees and their impact on households are therefore likely to be lower than what we have estimated here.

Fees Based on Measured Emissions:

To analyze an emissions fee based on measured emissions, we first needed an estimate of how emissions vary within each vehicle model year. One possible source of such information would be the data from vehicle inspection and maintenance tests, but we did not have access to these data. Therefore we used an alternative source, a database from Professor Donald Stedman of the University of Denver, containing in-use measurements obtained passively with his remote sensing device at a location on Rosemead Blvd. in Southern California.[23] Stedman expressed these data as frequency distributions of emissions by model year.

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[22] Since STEP does not predict which autos might be disposed of or what model years added when auto ownership levels change, we imposed a series of assumptions. We assumed that, since the per-mile emissions fee is higher for older vehicles, households that reduce their auto ownership levels would get rid of their oldest car(s). We assumed that households maintaining their current auto ownership levels would also maintain the age distribution of the vehicles they own. Households that added vehicles were assumed to add car(s) of the average age and fuel efficiency for that ownership level. These assumptions allowed us to estimate the effects on emissions, fuel use, etc.

[23] There is some reason for concern that emissions distributions recorded for a single location and operating environment may not reflect the full spectrum of operating conditions, and thus cannot be assumed to represent the "high-emitter" distribution for all regimes of urban travel. A similar criticism would apply, however, to vehicle inspection/maintenance test measurements, which are based on a single measurement and a specified operations sequence, or to any other data set based on single measurements and conditions.

We used the Stedman data to develop a frequency distribution of emissions fees per mile for each model year in each region. Taking the fleet age distribution and the VMT by model year estimated from the regional survey data, we used the Stedman emissions distributions both to estimate the aggregate emissions by model year and to apportion emissions responsibility within model years. This approach allowed us to assess a higher fee for high-emitting vehicles, and a lower fee for relatively clean vehicles, within each model year.[24]

To estimate the effects of a measurement-based emissions fee, we first made a special STEP run to create a base case with emissions derived from the high-emitter distributions rather than from the pure EMFAC data. Since we did not have actual emissions measurements for the vehicles in our samples, during this run we simulated the presence of high emitters in the fleet. Each vehicle in the sample was randomly assigned an emissions level from the distribution for its model year (and tagged with that emissions level for use in the after analysis). Then, the fee policy was tested using the same method as for the fee based on model year averages, except that in this case the proposed fees were based on the emissions level assigned during the before run.

A fee based on measured emissions would probably require new technology of one sort or another. Tamper-resistant on-board monitoring and recording equipment would be the preferred approach; fees based on multiple measurements using remote sensing equipment would be a second option. A third approach would be to use the emissions measurements from I/M testing, though this would raise a number of issues including whether the fee should be prospective or retrospective and whether it should be based on before-repair or after-repair measurements.

With an emissions fee targeting super-emitters, households could be expected to adroitly manipulate their vehicle holdings and use to minimize the impact of the fee. This would tend to produce lower travel impacts and higher emissions reductions than shown here.

B.4 Impacts of Transportation Pricing Strategies

B.4.1 Basic Analysis Results

This section presents analysis results for the set of transportation pricing measures we analyzed for our four case study regions. We present a series of 18 tables summarizing the basic findings of our analyses, both by measure and by region. For each pricing measure, we present the predicted percentage changes in VMT, trips made, and travel time; fuel

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[24] An alternative approach would be to use the EMFAC data as the estimate of the average emissions by model year, and to use the Stedman data (or another source) to represent the underlying distribution of emissions for that model year. Note that the overall approach does not produce different results if a higher or lower total emissions burden is assumed.

consumed and CO_2 emitted; ROG, CO and NOx emissions; and annual gross revenues[25], for the years 1991 (the base year) and 2010.

The results for each analysis year represent the long-term effects of pricing measures, i.e., the impacts resulting from the pricing measures as if they had been implemented several years earlier.

The results show that carefully crafted and targeted transportation pricing strategies could do much to reduce travel times (hence congestion), cut energy use, and reduce emissions, at the same time increasing gross revenues substantially. At the same time, it is clear that auto use and its impacts are quite inelastic with respect to most aspects of price. This has two important implications: first, sizable increases in revenue can be obtained with relatively little effect on travel; conversely, large price increases are necessary to obtain sizable reductions in travel and its externalities.

The results also provide an empirical dimension to the notion that the most efficient way to use price as a mechanism for reducing transportation externalities is to price each externality in a direct way. Thus, as the tables detail, the most effective pricing strategy for emissions control (in the sense of emissions reductions per dollar charged) is to target high-emitting vehicles as precisely as possible; the most effective strategy for reducing fuel consumption (and CO_2 production) is to raise the price of fuel; the most effective way to reduce congestion is to impose a toll at congested locations; and so on. Note that we refer to efficiency and effectiveness here in a purely technical sense. Other factors - ethical, institutional, political, and social - contribute to a broader assessment that may lead to different conclusions about policy effectiveness.

Tables B1-B5 present the results organized by pricing measure for the year 1991. Tables B6-B10 present a subset of the year 1991 results, reorganized by region. Each regional table includes analyses of the synergistic effects of groups of pricing measures, under two scenarios:

1. **Modest Pricing** - A relatively low set of prices from each category (e.g., $1.00 per day parking; $0.50 per gallon fuel tax), coupled with enough investment in transit only to maintain existing levels of service.

2. **Full Pricing** - A relatively high set of prices from each category (e.g., $3.00 per day parking; $2.00 per gallon fuel tax), coupled with investment in transit corresponding to build-out of each region's long-range transit plan (as expressed in future network files made available by each MPO). Note that such a transit expansion would absorb a significant fraction of the pricing revenues.

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[25] Net revenues depend on the specific implementation strategy selected (public vs. private sector implementation and administration, technologies used, scope of implementation, timing of implementation, etc.). In general, implementation designs costing a small fraction (5-15%) of gross revenues are feasible.

Tables B11-B18 present the same ensemble of results for the year 2010. The percent changes presented are changes from a year 2010 base case, created by using STEP as a forecasting tool. The regions' forecasts of households, household income, and household size (or population) were used to factor the 1991 household file to create a year 2010 household file for each region. The STEP models then were run to create a year 2010 base case, using the 2010 household file plus the MPO network data for the year 2010.[26] Finally, policy analyses were carried out to predict changes from the future base case.

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[26] In the Los Angeles region, some adjustments were made to SCAG's highway travel times after analyses indicated that the SCAG models then in use showed far more trips and VMT than STEP's more complex models would predict. Otherwise, MPO level-of-service projections were broadly consistent with STEP internal calculations and were used as provided to form the basis of the 2010 base case.

Table B.1
Analysis Results for Congestion Pricing - 1991

		Average	Change From 1991 Base								Annual
Description	Region	Price	VMT/VKT/PM	Trips	Time	Delay	Fuel/CO2	ROG	CO	NOx	Revenue
The congestion pricing strategy analyzed here assumes that prices would be assessed on a per mile basis everywhere that congestion appears in the highway network, including on arterials and collector streets as necessary. A technology for electronic toll collection would be required. Roadway message signs or in-vehicle readouts would provide information about tolls on upcoming segments, likely as part of a broader highway information system. Prices would not vary minute-by-minute, but would be set to reflect average conditions on each highway link during each period of the day, perhaps with seasonal adjustments. The results shown here are based on a reduction of congestion to level-of-service D/E, defined as a volume-to-capacity ratio of .9. Note that travelers would continue to experience some delay under this criterion, but that greater reductions in volume might not be justifiable in economic terms.	Bay Area	$0.09	-1.8%	-1.7%	-5.7%	-19.5%	-5.8%	-4.5%	-4.7%	-2.1%	1143
	Sacramento	$0.04	-0.6%	-0.5%	-1.8%	-6.0%	-1.8%	-1.5%	-1.6%	-0.7%	143
	San Diego	$0.06	-1.0%	-0.9%	-3.1%	-10.5%	-2.9%	-2.6%	-2.7%	-1.1%	401
	South Coast	$0.10	-2.3%	-2.2%	-6.8%	-22.5%	-6.7%	-5.5%	-5.5%	-2.5%	3187

Notes: Revenue expressed in millions of dollars per year; VMT denotes weekday vehicle-miles traveled; VKT is weekday vehicle-kilometers traveled; PM10 is particulate emissions of 10 microns or less; trips are weekday vehicle-trips; time is weekday vehicle-hours of travel; delay is weekday vehicle-hours of delay; fuel is daily gallons of gasoline/diesel; CO2 is daily tons of carbon dioxide; ROG is daily tons of reactive organic hydrocarbons; CO is daily tons of carbon monoxide; and NOx is daily tons of oxides of nitrogen.

Table B.2
Analysis Results for Employee Parking Pricing - 1991

		Minimum	Change From 1991 Base								Annual
Description	Region	Price	VMT/VKT/PM	Trips	Time	Delay	Fuel/CO2	ROG	CO	NOx	Revenue
The parking pricing strategy analyzed here applies only to spaces used by workers in each region. The intent is to make parking cost explicit by requiring each worker to pay at least some threshold cost to park all day at or near the workplace. Only drive-alone vehicles would be charged under this scheme. The analysis was carried out through adjustments in the average zonal parking price. Basically, if an average zonal price in the base data was less than the minimum price to be tested, it was raised to match the minimum. This is tantamount to saying that no worker would face an average area price less than the stated minimum. However, basing an analysis on such an average implies that some individual workers still might experience prices lower than the minimum.	Bay Area	$1.00	-0.8%	-1.0%	-1.3%	-2.3%	-1.1%	-0.9%	-0.9%	-0.8%	405
		$3.00	-2.3%	-2.6%	-3.7%	-7.0%	-2.6%	-2.5%	-2.6%	-2.4%	1196
	Sacramento	$1.00	-1.1%	-1.2%	-1.6%	-2.5%	-1.2%	-1.2%	-1.2%	-1.0%	99
		$3.00	-2.9%	-3.1%	-4.1%	-6.0%	-3.0%	-3.1%	-3.1%	-2.8%	290
	San Diego	$1.00	-1.0%	-1.1%	-1.5%	-2.5%	-1.1%	-1.0%	-1.0%	-0.9%	190
		$3.00	-2.6%	-2.9%	-3.8%	-6.0%	-2.7%	-2.7%	-2.8%	-2.5%	558
	South Coast	$1.00	-1.0%	-1.1%	-1.5%	-2.5%	-1.2%	-1.1%	-1.1%	-1.0%	948
		$3.00	-2.7%	-3.0%	-4.2%	-7.5%	-2.9%	-2.8%	-2.9%	-2.7%	2788

Notes: Revenue expressed in millions of dollars per year; VMT denotes weekday vehicle-miles traveled; VKT is weekday vehicle-kilometers traveled; PM10 is particulate emissions of 10 microns or less; trips are weekday vehicle-trips; time is weekday vehicle-hours of travel; delay is weekday vehicle-hours of delay; fuel is daily gallons of gasoline/diesel; CO2 is daily tons of carbon dioxide; ROG is daily tons of reactive organic hydrocarbons; CO is daily tons of carbon monoxide; and NOx is daily tons of oxides of nitrogen.

Table B.3
Analysis Results for Fuel Tax Increases - 1991

Description	Region	Tax Increment	Fuel Elasticity	Change From 1991 Base								Annual Revenue
				VMT/VKT/PM	Trips	Time	Delay	Fuel/CO2	ROG	CO	NOx	
The fuel tax analyzed here is a straightforward addition to the pump price of gasoline and diesel fuel. Base fleet fuel efficiency is about 22 miles per gallon (.0364 gallons per mile). Base fuel cost is about $1.20 per gallon, or 5.45 cents per mile. With no increase in fleet fuel economy, a $2.00 per gallon fee would add about 9.1 cents to the per mile cost of driving. However, both empirical evidence and common sense suggest that the vehicle fleet would become more efficient under a significant price increase, both from substitution of more efficient vehicles within each household and from replacement through vehicle purchase. We tested a range of assumptions about increased fuel efficiency, expressed in terms of the elasticity of fuel consumption (gallons per mile) with respect to fuel price. Three versions are reported here: -0.22, which implies an increase in fuel efficiency from 22 tp 35 mpg for a $2.00 fuel tax; -0.13, which implies an increase from 22 to 28 mpg for a $2.00 fuel tax; and -0.05, which implies an increase from 22 to 24 mpg. The latter figure is consistent with estimates from the California Energy Commission Personal Vehicle Model, which shows a 2 mpg increase from a $2.00 fuel surcharge. Studies of international experience with fuel price changes tend to point toward higher elasticity values.	Bay Area	$0.50	-0.13	-3.9%	-3.6%	-5.4%	-7.5%	-9.1%	-3.7%	-3.6%	-3.4%	954
		$2.00	-0.13	-12.6%	-12.1%	-17.0%	-22.0%	-31.3%	-12.5%	-12.2%	-11.8%	2884
		$2.00	-0.05	-16.6%	-15.8%	-21.8%	-26.0%	-23.6%	-16.3%	-16.0%	-15.5%	3207
		$2.00	-0.22	-7.7%	-7.1%	-10.1%	-12.0%	-42.3%	-7.5%	-7.3%	-7.0%	2422
	Sacramento	$0.50	-0.13	-4.3%	-4.0%	-5.6%	-6.5%	-9.5%	-4.1%	-4.0%	-3.7%	264
		$2.00	-0.13	-13.9%	-13.3%	-17.6%	-18.5%	-32.4%	-13.7%	-13.5%	-12.6%	790
		$2.00	-0.05	-18.4%	-17.6%	-23.0%	-23.0%	-25.2%	-18.2%	-17.8%	-17.3%	874
		$2.00	-0.22	-8.5%	-7.8%	-10.9%	-12.0%	-42.8%	-8.3%	-8.1%	-7.7%	668
	San Diego	$0.50	-0.13	-4.1%	-3.8%	-5.5%	-7.0%	-9.2%	-3.9%	-3.8%	-3.6%	497
		$2.00	-0.13	-13.2%	-12.7%	-17.3%	-20.5%	-31.8%	-13.0%	-12.8%	-12.5%	1494
		$2.00	-0.05	-17.4%	-16.5%	-22.4%	-25.0%	-24.3%	-17.2%	-16.9%	-16.3%	1658
		$2.00	-0.22	-8.0%	-7.4%	-10.8%	-14.0%	-42.5%	-7.7%	-7.5%	-7.2%	1259
	South Coast	$0.50	-0.13	-4.1%	-4.0%	-5.4%	-6.5%	-9.1%	-3.8%	-3.7%	-3.5%	2405
		$2.00	-0.13	-13.3%	-12.8%	-17.5%	-21.0%	-31.8%	-13.2%	-13.0%	-12.2%	7219
		$2.00	-0.05	-17.6%	-16.7%	-23.4%	-29.0%	-24.5%	-17.4%	-17.1%	-16.4%	7992
		$2.00	-0.22	-8.1%	-7.5%	-10.6%	-12.5%	-42.5%	-7.9%	-7.8%	-7.4%	6086

Notes: Revenue expressed in millions of dollars per year; VMT denotes weekday vehicle-miles traveled; VKT is weekday vehicle-kilometers traveled; PM10 is particulate emissions of 10 microns or less; trips are weekday vehicle-trips; time is weekday vehicle-hours of travel; delay is weekday vehicle-hours of delay; fuel is daily gallons of gasoline/diesel; CO2 is daily tons of carbon dioxide; ROG is daily tons of reactive organic hydrocarbons; CO is daily tons of carbon monoxide; and NOx is daily tons of oxides of nitrogen.

Table B.4
Analysis Results for a VMT Fee - 1991

Description	Region	Change From 1991 Base								Annual
		VMT/VKT/PM	Trips	Time	Delay	Fuel/CO2	ROG	CO	NOx	Revenue
The VMT fee was analyzed as a simple increment of two cents per mile in the out-of-pocket cost of driving. No specific assumption was made about the method of collection. However, the analysis approach treats the price increment as if it were charged in the same manner as a fuel tax, i.e., as if the driver were aware of the expenditure from moment to moment. This implies a potentially complex collection scheme involving real-time reading of the odometer, perhaps each time a vehicle is fueled. The simpler alternative of billing once a year based on the odometer reading at the time of registration possibly would have less effect on travel and emissions, perhaps substantially less, although revenues would be about the same as shown here.	Bay Area	-4.2%	-4.0%	-5.8%	-8.0%	-4.2%	-4.1%	-4.0%	-3.9%	804
	Sacramento	-4.7%	-4.4%	-6.1%	-7.0%	-4.7%	-4.6%	-4.5%	-4.3%	223
	San Diego	-4.4%	-4.2%	-5.9%	-7.5%	-4.4%	-4.3%	-4.3%	-4.1%	419
	South Coast	-4.4%	-4.2%	-6.2%	-9.0%	-4.5%	-4.3%	-4.2%	-3.8%	2024

Notes: Revenue expressed in millions of dollars per year; VMT denotes weekday vehicle-miles traveled; VKT is weekday vehicle-kilometers traveled; PM10 is particulate emissions of 10 microns or less; trips are weekday vehicle-trips; time is weekday vehicle-hours of travel; delay is weekday vehicle-hours of delay; fuel is daily gallons of gasoline/diesel; CO2 is daily tons of carbon dioxide; ROG is daily tons of reactive organic hydrocarbons; CO is daily tons of carbon monoxide; and NOx is daily tons of oxides of nitrogen.

Table B.5
Analysis Results for Emissions Fees - 1991

Description	Region	Fee Basis	Change From 1991 Base								Annual Revenue
			VMT/VKT/PM	Trips	Time	Delay	Fuel/CO2	ROG	CO	NOx	
Emissions fees are the most difficult of the pricing policies to analyze, because knowledge about how consumers would trade off emissions fees, repair costs, insurance, and other auto-related expenditures is not well developed. We looked at two broad strategies: 1) the emissions fee would be calculated based on EMFAC data for average model year emissions per mile and actual VMT (so that the per mile fee would vary only by model year); and 2) the emissions fee would be based on data about actual performance of each vehicle, obtained perhaps from some type of in-use testing device. Unlike the EMFAC-based approach, strategy two would focus high prices on super-emitting vehicles. In both cases, prices were set so that the fee would average about one cent per mile over the entire personal vehicle fleet. The analysis was based on assumptions about how the distribution of vehicles by age and household income would change in the face of higher registration fees (under each strategy). These assumptions then were used to adjust auto ownership and out-of-pocket costs and applied to households in the STEP sample (see text for a full discussion).	Bay Area	EMFAC In-Use	-2.0% -1.6%	-1.7% -1.4%	-2.7% -1.9%	-3.5% -1.5%	-4.1% -6.9%	-6.5% -18.2%	-6.5% -17.9%	-5.7% -15.7%	320 284
	Sacramento	EMFAC In-Use	-2.7% -2.2%	-2.3% -1.8%	-3.1% -2.5%	-2.0% -1.5%	-5.2% -7.9%	-8.1% -20.7%	-8.0% -20.4%	-7.4% -18.8%	77 68
	San Diego	EMFAC In-Use	-2.4% -2.0%	-2.1% -1.7%	-2.9% -2.3%	-2.5% -1.5%	-4.9% -7.6%	-7.5% -20.1%	-7.4% -19.7%	-6.8% -17.5%	148 131
	South Coast	EMFAC In-Use	-2.2% -1.8%	-1.9% -1.6%	-2.8% -2.1%	-3.0% -1.5%	-4.4% -7.2%	-7.0% -19.4%	-6.9% -19.0%	-6.2% -17.1%	743 658

Notes: Revenue expressed in millions of dollars per year; VMT denotes weekday vehicle-miles traveled; VKT is weekday vehicle-kilometers traveled; PM10 is particulate emissions of 10 microns or less; trips are weekday vehicle-trips; time is weekday vehicle-hours of travel; delay is weekday vehicle-hours of delay; fuel is daily gallons of gasoline/diesel; CO2 is daily tons of carbon dioxide; ROG is daily tons of reactive organic hydrocarbons; CO is daily tons of carbon monoxide; and NOx is daily tons of oxides of nitrogen.

Table B.6
Analysis Results for Congestion Pricing - 2010

Description	Region	Average Price	Change From 2010 Baseline								Annual Revenue
			VMT/VKT/PM	Trips	Time	Delay	Fuel/CO2	ROG	CO	NOx	
The congestion pricing strategy analyzed here assumes that prices would be assessed on a per mile basis everywhere that congestion appears in the highway network, including on arterials and collector streets as necessary. A technology for electronic toll collection would be required. Roadway message signs or in-vehicle readouts would provide information about tolls on upcoming segments, likely as part of a broader highway information system. Prices would not vary minute-by-minute, but would be set to reflect average conditions on each highway link during each period of the day, perhaps with seasonal adjustments. The results shown here are based on a reduction of congestion to level-of-service D/E, defined as a volume-to-capacity ratio of .9. Note that travelers would continue to experience some delay under this criterion, but that greater reductions in volume might not be justifiable in economic terms.	Bay Area	$0.13	-2.8%	-2.7%	-8.2%	-27.0%	-8.3%	-6.9%	-6.9%	-3.2%	2274
	Sacramento	$0.08	-1.5%	-1.4%	-4.8%	-16.5%	-4.8%	-3.7%	-3.9%	-1.7%	443
	San Diego	$0.09	-1.7%	-1.6%	-5.4%	-18.5%	-5.4%	-4.2%	-4.3%	-2.0%	896
	South Coast	$0.19	-3.3%	-3.1%	-9.7%	-32.0%	-9.6%	-8.1%	-7.9%	-3.6%	7343

Notes: Revenue expressed in millions of dollars per year; VMT denotes weekday vehicle-miles traveled; VKT is weekday vehicle-kilometers traveled; PM10 is particulate emissions of 10 microns or less; trips are weekday vehicle-trips; time is weekday vehicle-hours of travel; delay is weekday vehicle-hours of delay; fuel is daily gallons of gasoline/diesel; CO2 is daily tons of carbon dioxide; ROG is daily tons of reactive organic hydrocarbons; CO is daily tons of carbon monoxide; and NOx is daily tons of oxides of nitrogen.

Table B.7
Analysis Results for Employee Parking Pricing - 2010

Description	Region	Minimum Price	Change From 2010 Base								Annual Revenue
			VMT/VKT/PM	Trips	Time	Delay	Fuel/CO2	ROG	CO	NOx	
The parking pricing strategy analyzed here applies only to spaces used by workers in each region. The intent is to remove a hidden subsidy by requiring each worker to pay at least some threshold cost to park all day at or near the workplace. Only drive-alone vehicles would be charged under this scheme. The analysis was carried out through adjustments in the average zonal parking price. Basically, if an average zonal price in the base data was less than the minimum price to be tested, it was raised to match the minimum. This is tantamount to saying that no worker would face an average area price less than the stated minimum. However, basing an analysis on such an average implies that some individual workers still might experience prices lower than the minimum.	Bay Area	$1.00	-0.8%	-0.9%	-1.3%	-2.7%	-1.0%	-0.8%	-0.8%	-0.7%	473
		$3.00	-2.1%	-2.4%	-3.5%	-7.0%	-2.4%	-2.3%	-2.4%	-2.2%	1399
	Sacramento	$1.00	-1.0%	-1.1%	-1.5%	-2.5%	-1.1%	-1.1%	-1.1%	-0.9%	142
		$3.00	-2.6%	-2.8%	-3.9%	-6.5%	-2.7%	-2.8%	-2.8%	-2.5%	419
	San Diego	$1.00	-0.9%	-1.0%	-1.4%	-2.5%	-1.0%	-0.9%	-0.9%	-0.8%	271
		$3.00	-2.4%	-2.6%	-3.8%	-7.0%	-2.5%	-2.5%	-2.5%	-2.4%	800
	South Coast	$1.00	-0.9%	-1.1%	-1.5%	-2.9%	-1.1%	-1.0%	-1.0%	-0.9%	1408
		$3.00	-2.5%	-2.8%	-4.2%	-8.5%	-2.7%	-2.6%	-2.7%	-2.5%	4151

Notes: Revenue expressed in millions of dollars per year; VMT denotes weekday vehicle-miles traveled; VKT is weekday vehicle-kilometers traveled; PM10 is particulate emissions of 10 microns or less; trips are weekday vehicle-trips; time is weekday vehicle-hours of travel; delay is weekday vehicle-hours of delay; fuel is daily gallons of gasoline/diesel; CO2 is daily tons of carbon dioxide; ROG is daily tons of reactive organic hydrocarbons; CO is daily tons of carbon monoxide; and NOx is daily tons of oxides of nitrogen.

Table B.8
Analysis Results for Fuel Tax Increases - 2010

Description	Region	Tax Increment	Fuel Elasticity	Change From 2010 Base								Annual Revenue
				VMT/VKT/PM	Trips	Time	Delay	Fuel/CO2	ROG	CO	NOx	
The fuel tax analyzed here is a straightforward addition to the pump price of gasoline and diesel fuel. Base fleet fuel efficiency is about 22 miles per gallon (.0364 gallons per mile). Base fuel cost is about $1.20 per gallon, or 5.45 cents per mile. With no increase in fleet fuel economy, a $2.00 per gallon fee would add about 9.1 cents to the per mile cost of driving. However, both empirical evidence and common sense suggest that the vehicle fleet would become more efficient under a significant price increase, both from substitution of more efficient vehicles within each household and from replacement through vehicle purchase. We tested a range of assumptions about increased fuel efficiency, expressed in terms of the elasticity of fuel consumption (gallons per mile) with respect to fuel price. Three versions are reported here: -0.22, which implies an increase in fuel efficiency from 22 tp 35 mpg for a $2.00 fuel tax; -0.13, which implies an increase from 22 to 28 mpg for a $2.00 fuel tax; and -0.05, which implies an increase from 22 to 24 mpg. The latter figure is consistent with estimates from the California Energy Commission Personal Vehicle Model, which shows a 2 mpg increase from a $2.00 fuel surcharge. Studies of international experience with fuel price changes tend to point toward higher elasticity values.	Bay Area	$0.50	-0.13	-3.6%	-3.4%	-5.3%	-8.5%	-8.8%	-3.5%	-3.5%	-3.3%	1332
		$2.00	-0.13	-11.7%	-11.3%	-16.8%	-25.5%	-30.6%	-11.6%	-11.5%	-11.1%	4053
		$2.00	-0.05	-15.5%	-14.8%	-22.8%	-36.5%	-22.5%	-15.3%	-15.2%	-14.5%	4526
		$2.00	-0.22	-7.1%	-6.8%	-10.1%	-15.0%	-42.0%	-7.0%	-6.9%	-6.4%	3387
	Sacramento	$0.50	-0.13	-4.1%	-3.9%	-5.5%	-7.0%	-9.3%	-4.0%	-3.9%	-3.7%	414
		$2.00	-0.13	-13.2%	-12.7%	-17.6%	-22.0%	-31.8%	-13.0%	-12.9%	-12.5%	1245
		$2.00	-0.05	-17.4%	-16.7%	-23.1%	-28.5%	-24.3%	-17.2%	-17.0%	-16.3%	1382
		$2.00	-0.22	-8.0%	-7.7%	-11.4%	-17.0%	-42.5%	-8.0%	-7.9%	-7.5%	1049
	San Diego	$0.50	-0.13	-3.9%	-3.5%	-5.5%	-8.0%	-9.1%	-3.8%	-3.6%	-3.3%	747
		$2.00	-0.13	-12.5%	-12.0%	-17.1%	-23.0%	-31.3%	-12.3%	-12.2%	-11.8%	2257
		$2.00	-0.05	-16.5%	-15.7%	-22.6%	-30.5%	-23.5%	-16.3%	-16.2%	-15.4%	2513
		$2.00	-0.22	-7.6%	-7.3%	-10.6%	-15.0%	-42.3%	-7.5%	-7.3%	-6.8%	1895
	South Coast	$0.50	-0.13	-4.2%	-3.9%	-6.1%	-9.5%	-9.3%	-4.1%	-4.0%	-3.8%	3724
		$2.00	-0.13	-13.0%	-12.5%	-18.7%	-28.5%	-31.6%	-12.8%	-12.7%	-12.4%	11235
		$2.00	-0.05	-17.1%	-16.4%	-24.8%	-38.5%	-24.0%	-16.9%	-16.8%	-16.0%	12483
		$2.00	-0.22	-8.2%	-7.8%	-11.7%	-17.5%	-42.6%	-8.0%	-8.0%	-7.1%	9428

Notes: Revenue expressed in millions of dollars per year; VMT denotes weekday vehicle-miles traveled; VKT is weekday vehicle-kilometers traveled; PM10 is particulate emissions of 10 microns or less; trips are weekday vehicle-trips; time is weekday vehicle-hours of travel; delay is weekday vehicle-hours of delay; fuel is daily gallons of gasoline/diesel; CO2 is daily tons of carbon dioxide; ROG is daily tons of reactive organic hydrocarbons; CO is daily tons of carbon monoxide; and NOx is daily tons of oxides of nitrogen.

Table B.9
Analysis Results for a VMT Fee - 2010

Description	Region	Change From 2010 Base								Annual
		VMT/VKT/PM	Trips	Time	Delay	Fuel/CO2	ROG	CO	NOx	Revenue
The VMT fee was analyzed as a simple increment of two cents per mile in the out-of-pocket cost of driving. No specific assumption was made about the method of collection. However, the analysis approach treats the price increment as if it were charged in the same manner as a fuel tax, i.e., as if the driver were aware of the expenditure from moment to moment. This implies a potentially complex collection scheme involving real-time reading of the odometer, perhaps each time a vehicle is fueled. The simpler alternative of billing once a year based on the odometer reading at the time of registration possibly would have less effect on travel and emissions, perhaps substantially less, although revenues would be about the same as shown here.	Bay Area	-3.9%	-3.7%	-5.7%	-9.0%	-4.1%	-3.8%	-3.7%	-3.6%	1122
	Sacramento	-4.4%	-4.1%	-5.9%	-7.5%	-4.4%	-4.3%	-4.2%	-3.9%	349
	San Diego	-4.2%	-4.0%	-5.9%	-8.5%	-4.2%	-4.1%	-4.0%	-3.8%	629
	South Coas	-4.3%	-4.1%	-6.4%	-10.5%	-5.2%	-4.2%	-4.2%	-3.9%	3144

Notes: Revenue expressed in millions of dollars per year; VMT denotes weekday vehicle-miles traveled; VKT is weekday vehicle-kilometers traveled; PM10 is particulate emissions of 10 microns or less; trips are weekday vehicle-trips; time is weekday vehicle-hours of travel; delay is weekday vehicle-hours of delay; fuel is daily gallons of gasoline/diesel; CO2 is daily tons of carbon dioxide; ROG is daily tons of reactive organic hydrocarbons; CO is daily tons of carbon monoxide; and NOx is daily tons of oxides of nitrogen.

Table B.10
Analysis Results for Emissions Fees - 2010

Description	Region	Fee Basis	Change From 2010 Base								Annual Revenue
			VMT/VKT/PM	Trips	Time	Delay	Fuel/CO2	ROG	CO	NOx	
Emissions fees are the most difficult of the pricing policies to analyze, because knowledge about how consumers would trade off emissions fees, repair costs, insurance, and other auto-related expenditures is not well developed. We looked at two broad strategies: 1) the emissions fee would be calculated based on EMFAC data for average model year emissions per mile and average model year VMT (so that the fee would vary only by model year); and 2) the emissions fee would be based on data about actual performance of each vehicle, obtained perhaps from some type of in-use testing device. Unlike the EMFAC-based approach, strategy two would focus high prices on super-emitting vehicles. In both cases, prices were set so that the fee would average about one cent per mile over the entire personal vehicle fleet. The analysis focused on assumptions about how the distribution of vehicles by age and household income would change in the face of higher registration fees (under each strategy). These assumptions then were used to adjust auto ownership and out-of-pocket costs and applied to households in the STEP sample (see text for a full discussion).	Bay Area	EMFAC In-Use	-2.2% -1.6%	-1.9% -1.4%	-2.9% -2.1%	-3.5% -2.5%	-3.9% -6.6%	-5.4% -17.7%	-5.3% -17.5%	-4.5% -14.9%	384 341
	Sacramento	EMFAC In-Use	-2.6% -2.3%	-2.3% -2.1%	-3.5% -3.3%	-4.5% -5.0%	-4.0% -7.4%	-5.7% -20.2%	-5.6% -19.7%	-4.2% -17.3%	116 102
	San Diego	EMFAC In-Use	-2.5% -1.9%	-2.2% -1.7%	-3.2% -2.6%	-3.5% -3.5%	-4.1% -7.1%	-5.5% -19.5%	-5.4% -19.2%	-4.6% -16.2%	211 186
	South Coast	EMFAC In-Use	-2.5% -2.1%	-2.3% -1.9%	-3.6% -3.3%	-5.5% -6.0%	-3.9% -7.2%	-5.5% -18.9%	-5.4% -18.6%	-4.5% -15.8%	1106 980

Notes: Revenue expressed in millions of dollars per year; VMT denotes weekday vehicle-miles traveled; VKT is weekday vehicle-kilometers traveled; PM10 is particulate emissions of 10 microns or less; trips are weekday vehicle-trips; time is weekday vehicle-hours of travel; delay is weekday vehicle-hours of delay; fuel is daily gallons of gasoline/diesel; CO2 is daily tons of carbon dioxide; ROG is daily tons of reactive organic hydrocarbons; CO is daily tons of carbon monoxide; and NOx is daily tons of oxides of nitrogen.

Table B.11
Analysis Results for the San Francisco Bay Area - 1991

			Change From 1991 Base								Annual
	Strategy	Description	VMT/VKT/PM	Trips	Time	Delay	Fuel/CO2	ROG	CO	NOx	Revenue
1	Regionwide Congestion Pricing (level-of-service D/E) - Average $0.09 per Mile in Peak	An Automatic Vehicle Identification (AVI) scheme would be used to price the regional freeway and arterial system to maintain level-of-service (LOS) D/E	-1.8%	-1.7%	-5.7%	-19.5%	-5.8%	-4.5%	-4.7%	-2.1%	1143
2a	Regionwide Employee Parking Charge of $1.00 Per Day	All workers driving alone in the region would experience a minimum $1.00 (1991) per day charge for parking at the workplace	-0.8%	-1.0%	-1.3%	-2.3%	-1.1%	-0.9%	-0.9%	-0.8%	405
2b	Regionwide Employee Parking Charge of $3.00 Per Day	All workers driving alone in the region would experience a minimum $3.00 (1991) per day charge for parking at the workplace.	-2.3%	-2.6%	-3.7%	-7.0%	-2.6%	-2.5%	-2.6%	-2.4%	1196
3a	Fuel Tax Increase by $0.50 (1991)	Fees would be paid at the pump.	-3.9%	-3.6%	-5.4%	-7.5%	-9.1%	-3.7%	-3.6%	-3.4%	954
3b	Fuel Tax Increase by $2.00 (1991)		-12.6%	-12.1%	-17.0%	-22.0%	-31.3%	-12.5%	-12.2%	-11.8%	2884
4a	Mileage- and Emissions-Based Fee (Range Approx. 40-400/yr)	Fees would average 1 cent per mile, and would be collected frequently, as for the VMT fee. In alternative 4a, the fee would be based on annual mileage and average model year emissions as reflected in EMFAC7F. In alternative 4b, the fee would be based on actual odometer readings and in-use tailpipe measurements.	-2.0%	-1.7%	-2.7%	-3.5%	-4.1%	-6.5%	-6.5%	-5.7%	320
4b	Mileage- and Emissions-Based Fee (Range Approx. 10-1000/yr)		-1.6%	-1.4%	-1.9%	-1.5%	-6.9%	-18.2%	-17.9%	-15.7%	284
5	VMT Fee of $0.02 per mile	Fees would be paid often, e.g., in the same manner as fuel taxes. This implies a potentially complex collection scheme involving real-time reading of the odometer, perhaps each time a vehicle is fueled. The simpler option of billing once a year based on the odometer reading likely would have less effect on travel and emissions.	-4.2%	-4.0%	-5.8%	-8.0%	-4.2%	-4.1%	-4.0%	-3.9%	804
	Example of Combined Effects: Moderate Impact	1, 2a, 3a, and 4a with maintenance of current transit service	-8.1%	-7.5%	-13.9%	-28.9%	-18.3%	-14.4%	-14.6%	-11.3%	2589
	Example of Combined Effects: High Impact	1, 2b, 3b, and 4b with extensive transit investment. (Revenue not reduced to reflect cost of new transit.)	-19.7%	-19.0%	-29.1%	-46.8%	-46.3%	-37.4%	-37.3%	-32.6%	4817

Notes: Revenue expressed in millions of dollars per year; VMT denotes weekday vehicle-miles traveled; VKT is weekday vehicle-kilometers traveled; PM10 is particulate emissions of 10 microns or less; trips are weekday vehicle-trips; time is weekday vehicle-hours of travel; delay is weekday vehicle-hours of delay; fuel is daily gallons of gasoline/diesel; CO2 is daily tons of carbon dioxide; ROG is daily tons of reactive organic hydrocarbons; CO is daily tons of carbon monoxide; and NOx is daily tons of oxides of nitrogen.

Table B.12
Analysis Results for the Sacramento Region - 1991

			Change From 1991 Base								Annual
	Strategy	Description	VMT/VKT/PM	Trips	Time	Delay	Fuel/CO2	ROG	CO	NOx	Revenue
1	Regionwide Congestion Pricing (level-of-service D/E) - Average $0.04 per Mile in Peak	An Automatic Vehicle Identification (AVI) scheme would be used to price the regional freeway and arterial system to maintain level-of-service (LOS) D/E.	-0.6%	-0.5%	-1.8%	-6.0%	-1.8%	-1.5%	-1.6%	-0.7%	143
2a	Regionwide Employee Parking Charge of $1.00 Per Day	All workers driving alone in the region would experience a minimum $1.00 (1991) per day charge for parking at the workplace.	-1.1%	-1.2%	-1.6%	-2.5%	-1.2%	-1.2%	-1.2%	-1.0%	99
2b	Regionwide Employee Parking Charge of $3.00 Per Day	All workers driving alone in the region would experience a minimum $3.00 (1991) per day charge for parking at the workplace.	-2.9%	-3.1%	-4.1%	-6.0%	-3.0%	-3.1%	-3.1%	-2.8%	290
3a	Fuel Tax Increase by $0.50 (1991)	Fees would be paid at the pump.	-4.3%	-4.0%	-5.6%	-6.5%	-9.5%	-4.1%	-4.0%	-3.7%	264
3b	Fuel Tax Increase by $2.00 (1991)		-13.9%	-13.3%	-17.6%	-18.5%	-32.4%	-13.7%	-13.5%	-12.6%	790
4a	Mileage- and Emissions-Based Fee (Range Approx. 40-400/yr)	Fees would average 1 cent per mile, and would be collected frequently, as for the VMT fee. In alternative 4a, the fee would be based on annual mileage and average model year emissions as reflected in EMFAC7F. In alternative 4b, the fee would be based on actual odometer readings and in-use tailpipe measurements.	-2.7%	-2.3%	-3.1%	-2.0%	-5.2%	-8.1%	-8.0%	-7.4%	77
4b	Mileage- and Emissions-Based Fee (Range Approx. 10-1000/yr)		-2.2%	-1.8%	-2.5%	-1.5%	-7.9%	-20.7%	-20.4%	-18.8%	68
5	VMT Fee of $0.02 per mile	Fees would be paid often, e.g., in the same manner as fuel taxes. This implies a potentially complex collection scheme involving real-time reading of the odometer, perhaps each time a vehicle is fueled. The simpler option of billing once a year based on the odometer reading likely would have less effect on travel and emissions.	-4.7%	-4.4%	-6.1%	-7.0%	-4.7%	-4.6%	-4.5%	-4.3%	223
	Example of Combined Effects: Moderate Impact	1, 2a, 3a, and 4a with maintenance of current transit service.	-8.3%	-7.6%	-11.3%	-14.9%	-16.3%	-13.9%	-13.9%	-12.1%	535
	Example of Combined Effects: High Impact	1, 2b, 3b, and 4b with extensive transit investment. (Revenue not reduced to reflect cost of new transit.)	-21.1%	-20.0%	-27.2%	-30.2%	-45.6%	-38.9%	-38.7%	-35.5%	1136

Notes: Revenue expressed in millions of dollars per year; VMT denotes weekday vehicle-miles traveled; VKT is weekday vehicle-kilometers traveled; PM10 is particulate emissions of 10 microns or less; trips are weekday vehicle-trips; time is weekday vehicle-hours of travel; delay is weekday vehicle-hours of delay; fuel is daily gallons of gasoline/diesel; CO2 is daily tons of carbon dioxide; ROG is daily tons of reactive organic hydrocarbons; CO is daily tons of carbon monoxide; and NOx is daily tons of oxides of nitrogen.

Table B.13
Analysis Results for the San Diego Region - 1991

			Change From 1991 Base								Annual
	Strategy	Description	VMT/VKT/PM	Trips	Time	Delay	Fuel/CO2	ROG	CO	NOx	Revenue
1	Regionwide Congestion Pricing (level-of-service D/E) - Average $0.06 per Mile in Peak	An Automatic Vehicle Identification (AVI) scheme would be used to price the regional freeway and arterial system to maintain level-of-service (LOS) D/E	-1.0%	-0.9%	-3.1%	-10.5%	-2.9%	-2.6%	-2.7%	-1.1%	401
2a	Regionwide Employee Parking Charge of $1.00 Per Day	All workers driving alone in the region would experience a minimum $1.00 (1991) per day charge for parking at the workplace.	-1.0%	-1.1%	-1.5%	-2.5%	-1.1%	-1.0%	-1.0%	-0.9%	190
2b	Regionwide Employee Parking Charge of $3.00 Per Day	All workers driving alone in the region would experience a minimum $3.00 (1991) per day charge for parking at the workplace.	-2.6%	-2.9%	-3.8%	-6.0%	-2.7%	-2.7%	-2.8%	-2.5%	558
3a	Fuel Tax Increase by $0.50 (1991)	Fees would be paid at the pump.	-4.1%	-3.8%	-5.5%	-7.0%	-9.2%	-3.9%	-3.8%	-3.6%	497
3b	Fuel Tax Increase by $2.00 (1991)		-13.2%	-12.7%	-17.3%	-20.5%	-31.8%	-13.0%	-12.8%	-12.5%	1494
4a	Mileage- and Emissions-Based Fee (Range Approx. 40-400/yr)	Fees would average 1 cent per mile, and would be collected frequently, as for the VMT fee. In alternative 4a, the fee would be based on annual mileage and average model year emissions as reflected in EMFAC7F. In alternative 4b, the fee would be based on actual odometer readings and in-use tailpipe measurements.	-2.4%	-2.1%	-2.9%	-2.5%	-4.9%	-7.5%	-7.4%	-6.8%	148
4b	Mileage- and Emissions-Based Fee (Range Approx. 10-1000/yr)		-2.0%	-1.7%	-2.3%	-1.5%	-7.6%	-20.1%	-19.7%	-17.5%	131
5	VMT Fee of $0.02 per mile	Fees would be paid often, e.g., in the same manner as fuel taxes. This implies a potentially complex collection scheme involving real-time reading of the odometer, perhaps each time a vehicle is fueled. The simpler option of billing once a year based on the odometer reading likely would have less effect on travel and emissions.	-4.4%	-4.2%	-5.9%	-7.5%	-4.4%	-4.3%	-4.3%	-4.1%	419
	Example of Combined Effects: Moderate Impact	1, 2a, 3a, and 4a with maintenance of current transit service.	-8.1%	-7.5%	-12.0%	-19.7%	-16.6%	-13.9%	-13.9%	-11.7%	1134
	Example of Combined Effects: High Impact	1, 2b, 3b, and 4b with extensive transit investment. (Revenue not reduced to reflect cost of new transit.)	-20.3%	-19.4%	-27.5%	-36.4%	-45.4%	-38.3%	-38.1%	-34.3%	2270

Notes: Revenue expressed in millions of dollars per year; VMT denotes weekday vehicle-miles traveled; VKT is weekday vehicle-kilometers traveled; PM10 is particulate emissions of 10 microns or less; trips are weekday vehicle-trips; time is weekday vehicle-hours of travel; delay is weekday vehicle-hours of delay; fuel is daily gallons of gasoline/diesel; CO2 is daily tons of carbon dioxide; ROG is daily tons of reactive organic hydrocarbons; CO is daily tons of carbon monoxide; and NOx is daily tons of oxides of nitrogen.

Table B.14
Analysis Results for the Los Angeles Metropolitan Region -

			Change From 1991 Base								Annual
	Strategy	Description	VMT/VKT/PM	Trips	Time	Delay	Fuel/CO2	ROG	CO	NOx	Revenue
1	Regionwide Congestion Pricing (level-of-service D/E) - Average $0.10 per Mile in Peak	An Automatic Vehicle Identification (AVI) scheme would be used to price the regional freeway and arterial system to maintain level-of-service (LOS) D/E	-2.3%	-2.2%	-6.8%	-22.5%	-6.7%	-5.5%	-5.5%	-2.5%	3187
2a	Regionwide Employee Parking Charge of $1.00 Per Day	All workers driving alone in the region would experience a minimum $1.00 (1991) per day charge for parking at the workplace.	-1.0%	-1.1%	-1.5%	-2.5%	-1.2%	-1.1%	-1.1%	-1.0%	948
2b	Regionwide Employee Parking Charge of $3.00 Per Day	All workers driving alone in the region would experience a minimum $3.00 (1991) per day charge for parking at the workplace.	-2.7%	-3.0%	-4.2%	-7.5%	-2.9%	-2.8%	-2.9%	-2.7%	2788
3a	Fuel Tax Increase by $0.50 (1991)	Fees would be paid at the pump.	-4.1%	-4.0%	-5.4%	-6.5%	-9.1%	-3.8%	-3.7%	-3.5%	2405
3b	Fuel Tax Increase by $2.00 (1991)		-13.3%	-12.8%	-17.5%	-21.0%	-31.8%	-13.2%	-13.0%	-12.2%	7219
4a	Mileage- and Emissions-Based Fee (Range Approx. 40-400/yr)	Fees would average 1 cent per mile, and would be collected frequently, as for the VMT fee. In alternative 4a, the fee would be based on annual mileage and average model year emissions as reflected in EMFAC7F. In alternative 4b, the fee would be based on actual odometer readings and in-use tailpipe measurements.	-2.2%	-1.9%	-2.8%	-3.0%	-4.4%	-7.0%	-6.9%	-6.2%	743
4b	Mileage- and Emissions-Based Fee (Range Approx. 10-1000/yr)		-1.8%	-1.6%	-2.1%	-1.5%	-7.2%	-19.4%	-19.0%	-17.1%	658
5	VMT Fee of $0.02 per mile	Fees would be paid often, e.g., in the same manner as fuel taxes. This implies a potentially complex collection scheme involving real-time reading of the odometer, perhaps each time a vehicle is fueled. The simpler option of billing once a year based on the odometer reading likely would have less effect on travel and emissions.	-4.4%	-4.2%	-6.2%	-9.0%	-4.5%	-4.3%	-4.2%	-3.8%	2024
	Example of Combined Effects: Moderate Impact	1, 2a, 3a, and 4a with maintenance of current transit service.	-9.1%	-8.6%	-15.1%	-30.1%	-19.4%	-16.0%	-15.9%	-12.4%	6627
	Example of Combined Effects: High Impact	1, 2b, 3b, and 4b with extensive transit investment. (Revenue not reduced to reflect cost of new transit.)	-21.5%	-20.7%	-31.1%	-48.1%	-47.8%	-40.1%	-39.8%	-34.9%	11955

Notes: Revenue expressed in millions of dollars per year; VMT denotes weekday vehicle-miles traveled; VKT is weekday vehicle-kilometers traveled; PM10 is particulate emissions of 10 microns or less; trips are weekday vehicle-trips; time is weekday vehicle-hours of travel; delay is weekday vehicle-hours of delay; fuel is daily gallons of gasoline/diesel; CO2 is daily tons of carbon dioxide; ROG is daily tons of reactive organic hydrocarbons; CO is daily tons of carbon monoxide; and NOx is daily tons of oxides of nitrogen.

Table B.15

Analysis Results for the San Francisco Bay Area - 2010

Notes: Revenue expressed in millions of dollars per year; VMT denotes weekday vehicle-miles traveled; VKT is weekday vehicle-kilometers traveled; PM10 is particulate emissions of 10 microns or less; trips are weekday vehicle-trips; time is weekday vehicle-hours of travel; delay is weekday vehicle-hours of delay; fuel is daily gallons of gasoline/diesel; CO2 is daily tons of carbon dioxide; ROG is daily tons of reactive organic hydrocarbons; CO is daily tons of carbon monoxide; and NOx is daily tons of oxides of nitrogen.

	Strategy	Description	Change From 2010 Base								Annual Revenue
			VMT/VKT/PM	Trips	Time	Delay	Fuel/CO2	ROG	CO	NOx	
1	Regionwide Congestion Pricing (level-of-service D/E) - Average $0.13 per Mile in Peak	An Automatic Vehicle Identification (AVI) scheme would be used to price the regional freeway and arterial system to maintain level-of-service (LOS) D/E	-2.8%	-2.7%	-8.2%	-27.0%	-8.3%	-6.9%	-6.9%	-3.2%	2274
2a	Regionwide Employee Parking Charge of $1.00 Per Day	All workers driving alone in the region would experience a minimum $1.00 (1991) per day charge for parking at the workplace.	-0.8%	-0.9%	-1.3%	-2.7%	-1.0%	-0.8%	-0.8%	-0.7%	473
2b	Regionwide Employee Parking Charge of $3.00 Per Day	All workers driving alone in the region would experience a minimum $3.00 (1991) per day charge for parking at the workplace.	-2.1%	-2.4%	-3.5%	-7.0%	-2.4%	-2.3%	-2.4%	-2.2%	1399
3a	Fuel Tax Increase by $0.50 (1991)	Fees would be paid at the pump.	-3.6%	-3.4%	-5.3%	-8.5%	-8.8%	-3.5%	-3.5%	-3.3%	1332
3b	Fuel Tax Increase by $2.00 (1991)		-11.7%	-11.3%	-16.8%	-25.5%	-30.6%	-11.6%	-11.5%	-11.1%	4053
4a	Mileage- and Emissions-Based Fee (Range Approx. 40-400/yr)	Fees would average 1 cent per mile, and would be collected frequently, as for the VMT fee. In alternative 4a, the fee would be based on annual mileage and average model year emissions as reflected in EMFAC7F. In alternative 4b, the fee would be based on actual odometer readings and in-use tailpipe measurements.	-2.2%	-1.9%	-2.9%	-3.5%	-3.9%	-5.4%	-5.3%	-4.5%	384
4b	Mileage- and Emissions-Based Fee (Range Approx. 10-1000/yr)		-1.6%	-1.4%	-2.1%	-2.5%	-6.6%	-17.7%	-17.5%	-14.9%	341
5	VMT Fee of $0.02 per mile	Fees would be paid often, e.g., in the same manner as fuel taxes. This implies a potentially complex collection scheme involving real-time reading of the odometer, perhaps each time a vehicle is fueled. The simpler option of billing once a year based on the odometer reading likely would have less effect on travel and emissions.	-3.9%	-3.7%	-5.7%	-9.0%	-4.1%	-3.8%	-3.7%	-3.6%	1122
	Example of Combined Effects: Moderate Impact	1, 2a, 3a, and 4a with maintenance of current transit service.	-8.9%	-8.4%	-16.2%	-36.5%	-19.9%	-15.3%	-15.3%	-11.0%	4073
	Example of Combined Effects: High Impact	1, 2b, 3b, and 4b with extensive transit investment. (Revenue not reduced to reflect cost of new transit.)	-19.5%	-18.9%	-31.1%	-57.7%	-47.1%	-37.9%	-37.9%	-32.0%	7026

Table B.16
Analysis Results for the Sacramento Region - 2010

			Change From 2010 Base								Annual
	Strategy	Description	VMT/VKT/PM	Trips	Time	Delay	Fuel/CO2	ROG	CO	NOx	Revenue
1	Regionwide Congestion Pricing (level-of-service D/E) - Average $0.08 per Mile in Peak	An Automatic Vehicle Identification (AVI) scheme would be used to price the regional freeway and arterial system to maintain level-of-service (LOS) D/E	-1.5%	-1.4%	-4.8%	-16.5%	-4.8%	-3.7%	-3.9%	-1.7%	443
2a	Regionwide Employee Parking Charge of $1.00 Per Day	All workers driving alone in the region would experience a minimum $1.00 (1991) per day charge for parking at the workplace.	-1.0%	-1.1%	-1.5%	-2.5%	-1.1%	-1.1%	-1.1%	-0.9%	142
2b	Regionwide Employee Parking Charge of $3.00 Per Day	All workers driving alone in the region would experience a minimum $3.00 (1991) per day charge for parking at the workplace.	-2.6%	-2.8%	-3.9%	-6.5%	-2.7%	-2.8%	-2.8%	-2.5%	419
3a	Fuel Tax Increase by $0.50 (1991)	Fees would be paid at the pump.	-4.1%	-3.9%	-5.5%	-7.0%	-9.3%	-4.0%	-3.9%	-3.7%	414
3b	Fuel Tax Increase by $2.00 (1991)		-13.2%	-12.7%	-17.6%	-22.0%	-31.8%	-13.0%	-12.9%	-12.5%	1245
4a	Mileage- and Emissions-Based Fee (Range Approx. 40-400/yr)	Fees would average 1 cent per mile, and would be collected frequently, as for the VMT fee. In alternative 4a, the fee would be based on annual mileage and average model year emissions as reflected in EMFAC7F. In alternative 4b, the fee would be based on actual odometer readings and in-use tailpipe measurements.	-2.6%	-2.3%	-3.5%	-4.5%	-4.0%	-5.7%	-5.6%	-4.2%	116
4b	Mileage- and Emissions-Based Fee (Range Approx. 10-1000/yr)		-2.3%	-2.1%	-3.3%	-5.0%	-7.4%	-20.2%	-19.7%	-17.3%	102
5	VMT Fee of $0.02 per mile	Fees would be paid often, e.g., in the same manner as fuel taxes. This implies a potentially complex collection scheme involving real-time reading of the odometer, perhaps each time a vehicle is fueled. The simpler option of billing once a year based on the odometer reading likely would have less effect on travel and emissions.	-4.4%	-4.1%	-5.9%	-7.5%	-4.4%	-4.3%	-4.2%	-3.9%	349
	Example of Combined Effects: Moderate Impact	1, 2a, 3a, and 4a with maintenance of current transit service.	-8.7%	-8.2%	-14.1%	-26.6%	-17.6%	-13.4%	-13.5%	-9.9%	1016
	Example of Combined Effects: High Impact	1, 2b, 3b, and 4b with extensive transit investment. (Revenue not reduced to reflect cost of new transit.)	-21.0%	-20.2%	-30.2%	-46.1%	-46.5%	-39.3%	-39.1%	-34.5%	1922

Notes: Revenue expressed in millions of dollars per year; VMT denotes weekday vehicle-miles traveled; VKT is weekday vehicle-kilometers traveled; PM10 is particulate emissions of 10 microns or less; trips are weekday vehicle-trips; time is weekday vehicle-hours of travel; delay is weekday vehicle-hours of delay; fuel is daily gallons of gasoline/diesel; CO2 is daily tons of carbon dioxide; ROG is daily tons of reactive organic hydrocarbons; CO is daily tons of carbon monoxide; and NOx is daily tons of oxides of nitrogen.

Table B.17
Analysis Results for the San Diego Region - 2010

	Strategy	Description	Change From 2010 Base								Annual
			VMT/VKT/PM	Trips	Time	Delay	Fuel/CO2	ROG	CO	NOx	Revenue
1	Regionwide Congestion Pricing (level-of-service D/E) - Average $0.09 per Mile in Peak	An Automatic Vehicle Identification (AVI) scheme would be used to price the regional freeway and arterial system to maintain level-of-service (LOS) D/E	-1.7%	-1.6%	-5.4%	-18.5%	-5.4%	-4.2%	-4.3%	-2.0%	896
2a	Regionwide Employee Parking Charge of $1.00 Per Day	All workers driving alone in the region would experience a minimum $1.00 (1991) per day charge for parking at the workplace.	-0.9%	-1.0%	-1.4%	-2.5%	-1.0%	-0.9%	-0.9%	-0.8%	271
2b	Regionwide Employee Parking Charge of $3.00 Per Day	All workers driving alone in the region would experience a minimum $3.00 (1991) per day charge for parking at the workplace.	-2.4%	-2.6%	-3.8%	-7.0%	-2.5%	-2.5%	-2.5%	-2.4%	800
3a	Fuel Tax Increase by $0.50 (1991)	Fees would be paid at the pump.	-3.9%	-3.5%	-5.5%	-8.0%	-9.1%	-3.8%	-3.6%	-3.3%	747
3b	Fuel Tax Increase by $2.00 (1991)		-12.5%	-12.0%	-17.1%	-23.0%	-31.3%	-12.3%	-12.2%	-11.8%	2257
4a	Mileage- and Emissions-Based Fee (Range Approx. 40-400/yr)	Fees would average 1 cent per mile, and would be collected frequently, as for the VMT fee. In alternative 4a, the fee would be based on annual mileage and average model year emissions as reflected in EMFAC7F. In alternative 4b, the fee would be based on actual odometer readings and in-use tailpipe measurements.	-2.5%	-2.2%	-3.2%	-3.5%	-4.1%	-5.5%	-5.4%	-4.6%	211
4b	Mileage- and Emissions-Based Fee (Range Approx. 10-1000/yr)		-1.9%	-1.7%	-2.6%	-3.5%	-7.1%	-19.5%	-19.2%	-16.2%	186
5	VMT Fee of $0.02 per mile	Fees would be paid often, e.g., in the same manner as fuel taxes. This implies a potentially complex collection scheme involving real-time reading of the odometer, perhaps each time a vehicle is fueled. The simpler option of billing once a year based on the odometer reading likely would have less effect on travel and emissions.	-4.2%	-4.0%	-5.9%	-8.5%	-4.2%	-4.1%	-4.0%	-3.8%	629
	Example of Combined Effects: Moderate Impact	1, 2a, 3a, and 4a with maintenance of current transit service.	-8.5%	-7.8%	-14.2%	-28.4%	-17.9%	-13.4%	-13.2%	-10.1%	1940
	Example of Combined Effects: High Impact	1, 2b, 3b, and 4b with extensive transit investment. (Revenue not reduced to reflect cost of new transit.)	-19.9%	-19.1%	-29.6%	-48.5%	-46.1%	-38.2%	-38.1%	-33.0%	3619

Notes: Revenue expressed in millions of dollars per year; VMT denotes weekday vehicle-miles traveled; VKT is weekday vehicle-kilometers traveled; PM10 is particulate emissions of 10 microns or less; trips are weekday vehicle-trips; time is weekday vehicle-hours of travel; delay is weekday vehicle-hours of delay; fuel is daily gallons of gasoline/diesel; CO2 is daily tons of carbon dioxide; ROG is daily tons of reactive organic hydrocarbons; CO is daily tons of carbon monoxide; and NOx is daily tons of oxides of nitrogen.

Table B.18
Analysis Results for the Los Angeles Metropolitan Region - 2010

	Strategy	Description	VMT/VKT/PM	Change From 2010 Base							Annual Revenue
				Trips	Time	Delay	Fuel/CO2	ROG	CO	NOx	
1	Regionwide Congestion Pricing (level-of-service D/E) - Average $0.15 per Mile in Peak	An Automatic Vehicle Identification (AVI) scheme would be used to price the regional freeway and arterial system to maintain level-of-service (LOS) D/E.	-3.3%	-3.1%	-9.7%	-32.0%	-9.6%	-8.1%	-7.9%	-3.6%	7343
2a	Regionwide Employee Parking Charge of $1.00 Per Day	All workers driving alone in the region would experience a minimum $1.00 (1991) per day charge for parking at the workplace.	-0.9%	-1.1%	-1.5%	-2.9%	-1.1%	-1.0%	-1.0%	-0.9%	1408
2b	Regionwide Employee Parking Charge of $3.00 Per Day	All workers driving alone in the region would experience a minimum $3.00 (1991) per day charge for parking at the workplace.	-2.5%	-2.8%	-4.2%	-8.5%	-2.7%	-2.6%	-2.7%	-2.5%	4151
3a	Fuel Tax Increase by $0.50 (1991)	Fees would be paid at the pump.	-4.2%	-3.9%	-6.1%	-9.5%	-9.3%	-4.1%	-4.0%	-3.8%	3724
3b	Fuel Tax Increase by $2.00 (1991)		-13.0%	-12.5%	-18.7%	-28.5%	-31.6%	-12.8%	-12.7%	-12.4%	11235
4a	Mileage- and Emissions-Based Fee (Range Approx. 40-400/yr)	Fees would average 1 cent per mile, and would be collected frequently, as for the VMT fee. In alternative 4a, the fee would be based on annual mileage and average model year emissions as reflected in EMFAC7F. In alternative 4b, the fee would be based on actual odometer readings and in-use tailpipe measurements.	-2.5%	-2.3%	-3.6%	-5.5%	-3.9%	-5.5%	-5.4%	-4.5%	1106
4b	Mileage- and Emissions-Based Fee (Range Approx. 10-1000/yr)		-2.1%	-1.9%	-3.3%	-6.0%	-7.2%	-18.9%	-18.6%	-15.8%	980
5	VMT Fee of $0.02 per mile	Fees would be paid often, e.g., in the same manner as fuel taxes. This implies a potentially complex collection scheme involving real-time reading of the odometer, perhaps each time a vehicle is fueled. The simpler option of billing once a year based on the odometer reading likely would have less effect on travel and emissions.	-4.3%	-4.1%	-6.4%	-10.5%	-5.2%	-4.2%	-4.2%	-3.9%	3144
	Example of Combined Effects: Moderate Impact	1, 2a, 3a, and 4a with maintenance of current transit service.	-10.3%	-9.7%	-18.9%	-43.0%	-21.5%	-17.1%	-16.9%	-12.0%	12256
	Example of Combined Effects: High Impact	1, 2b, 3b, and 4b with extensive transit investment. (Revenue not reduced to reflect cost of new transit.)	-22.2%	-21.4%	-35.7%	-67.4%	-49.5%	-41.1%	-40.9%	-34.6%	20206

Notes: Revenue expressed in millions of dollars per year; VMT denotes weekday vehicle-miles traveled; VKT is weekday vehicle-kilometers traveled; PM10 is particulate emissions of 10 microns or less; trips are weekday vehicle-trips; time is weekday vehicle-hours of travel; delay is weekday vehicle-hours of delay; fuel is daily gallons of gasoline/diesel; CO2 is daily tons of carbon dioxide; ROG is daily tons of reactive organic hydrocarbons; CO is daily tons of carbon monoxide; and NOx is daily tons of oxides of nitrogen.

B.4.2 Equity

One of the biggest contentions raised about strategies that increase the price of transportation is that, while some people would benefit, others would be unduly hurt. Whether from an ethical or a pragmatic political perspective, these equity concerns, which stem from the possibility of unevenly distributed benefits and costs, are a central implementation issue for transportation pricing. Price increases are especially a worry for low income individuals who may not be able to afford the higher costs and hence might be priced out of certain travel options. Higher transportation prices also are a concern for moderate income people who have little flexibility about when or where they travel and hence might have to devote a larger share of their income to transportation.

One would not want to overstate equity issues. First, one might argue that there is nothing inherently unfair about expecting people to pay for the services they consume, to cover the costs of damage they do to the environment, and so on, regardless of their socioeconomic status. In fact, this could be seen as a more equitable result, since it removes undeserved burdens from others. Second, it is important to note that for many pricing applications, and especially for congestion pricing, the dollar cost is higher for those who pay it, but time and other costs decline; many people should be better off despite the higher prices. Finally, for any of the measures, use of the revenues to improve transportation services could result in net benefits for most. In short, simply noting that prices are higher does not mean that the result is necessarily less equitable.

Nevertheless, it is important to have good information on the distribution of costs and benefits of various transportation pricing strategies, including the status quo, so that the social and political ramifications can be anticipated and dealt with and so that program designs can be structured to achieve a satisfactory level of fairness. While full treatment of the equity issues of transportation pricing would require a separate study, a portion of our effort was devoted to exploring the impacts of the various pricing strategies on different groups and interests. Indeed, the analysis procedures described here were designed to produce as much information about the distributional consequences of pricing as possible.

The distribution of impact and equity can be thought of along many dimensions - income, class, race. ethnicity, age, sex, and geography are among those commonly considered. For the illustrative purposes of this section, however, we have chosen to focus our attention primarily on differences by income level. We split the households of California into five equal household income groups, and used the resulting quintile boundaries to categorize our findings throughout the analysis of pricing policies. The five quintiles are:

Quintile	Income Range (1994$)
1	<= $18,700
2	$18,701-$36,500
3	$36,501-$52,100
4	$52,101-$71,300
5	>=$71,301

Tables B19 and B20 present a distillation of quintile data based on the 1990 U.S. Census Public Use Microdata Sample for California. It may be helpful to begin a discussion of equity by first looking at some basic facts about the distribution of income in California, as shown in these tables.

Table B.19: 1990 US Census California Statewide Summary Public Use Microdata Sample

Share of Households in Each State Income Quintile

Region	Share by State Income Quintile 1	2	3	4	5	Total Households
Sacramento Region	0.22	0.22	0.21	0.20	0.15	598405
San Diego Region	0.19	0.21	0.21	0.20	0.18	885574
San Francisco Bay Area	0.16	0.17	0.19	0.22	0.26	2242554
South Coast	0.19	0.19	0.20	0.20	0.22	4560620
Balance of State	0.27	0.24	0.20	0.17	0.12	1744923
California Combined Total	0.20	0.20	0.20	0.20	0.20	10032076

Share of Population in Each State Income Quintile

Region	Share by State Income Quintile 1	2	3	4	5	Total Population
Sacramento Region	0.17	0.21	0.22	0.23	0.17	1560521
San Diego Region	0.15	0.20	0.22	0.23	0.21	2386031
San Francisco Bay Area	0.11	0.15	0.19	0.25	0.31	5852335
South Coast	0.15	0.18	0.20	0.22	0.25	13233643
Balance of State	0.21	0.24	0.22	0.19	0.14	4930037
California Combined Total	0.15	0.19	0.20	0.22	0.23	279962567

Share of Autos in Each State Income Quintile

Region	Share by State Income Quintile 1	2	3	4	5	Total Autos
Sacramento Region	0.13	0.19	0.22	0.25	0.21	1080383
San Diego Region	0.10	0.17	0.22	0.25	0.26	1577796
San Francisco Bay Area	0.08	0.13	0.18	0.26	0.36	3941140
South Coast	0.10	0.15	0.19	0.24	0.31	8077199
Balance of State	0.17	0.22	0.23	0.22	0.18	3163821
California Combined Total	0.11	0.16	0.20	0.24	0.29	17840339

Share of Resident Workers in Each State Income Quintile

Region	Share by State Income Quintile 1	2	3	4	5	Total Workers
Sacramento Region	0.09	0.18	0.23	0.27	0.23	715029
San Diego Region	0.08	0.17	0.22	0.26	0.26	1145517
San Francisco Bay Area	0.05	0.12	0.18	0.27	0.37	2993791
South Coast	0.08	0.15	0.20	0.26	0.32	6237629
Balance of State	0.11	0.21	0.24	0.25	0.19	2010851
California Combined Total	0.08	0.16	0.21	0.26	0.30	13102817

Table B.20: 1990 US Census California Statewide Summary Public Use Microdata Sample

Autos per Worker in Each State Income Quintile

	Autos per Worker by Income Quintile					Regional
Region	1	2	3	4	5	Average
Sacramento Region	2.16	1.62	1.48	1.38	1.36	1.51
San Diego Region	1.75	1.37	1.33	1.33	1.36	1.38
San Francisco Bay Area	1.89	1.38	1.30	1.25	1.27	1.32
South Coast	1.75	1.28	1.24	1.23	1.28	1.29
Balance of State	2.37	1.66	1.47	1.37	1.42	1.57
California Combined Total	1.93	1.40	1.32	1.27	1.30	1.36

Work-at-Home Share in Each State Income Quintile

	Share by State Income Quintile					Regional
Region	1	2	3	4	5	Average
Sacramento Region	0.041	0.029	0.030	0.026	0.037	0.031
San Diego Region	0.042	0.033	0.026	0.032	0.039	0.034
San Francisco Bay Area	0.052	0.034	0.030	0.027	0.034	0.032
South Coast	0.035	0.023	0.022	0.022	0.032	0.027
Balance of State	0.044	0.038	0.032	0.031	0.047	0.037
California Combined Total	0.041	0.030	0.026	0.026	0.035	0.03

Commute Time per Worker in Each State Income Quintile

	Minutes per Worker by Income Quintile					Regional
Region	1	2	3	4	5	Average
Sacramento Region	19.17	20.28	21.55	22.89	22.53	21.71
San Diego Region	21.72	21.84	22.28	23.23	23.20	22.65
San Francisco Bay Area	23.24	23.64	25.35	26.20	26.37	25.65
South Coast	25.65	25.30	25.90	26.81	27.28	26.46
Balance of State	18.00	18.70	19.45	20.47	20.26	19.55
California Combined Total	22.84	23.04	24.03	25.20	25.83	24.63

Drive Alone Share for Workers in Each State Income Quintile

	Drive Alone Share by Income Quintile					Regional
Region	1	2	3	4	5	Average
Sacramento Region	0.65	0.71	0.76	0.79	0.77	0.75
San Diego Region	0.62	0.67	0.73	0.77	0.80	0.74
San Francisco Bay Area	0.54	0.61	0.67	0.71	0.73	0.69
South Coast	0.58	0.64	0.70	0.75	0.80	0.72
Balance of State	0.64	0.70	0.75	0.77	0.79	0.74
California Combined Total	0.59	0.65	0.71	0.75	0.78	0.72

By definition, each income quintile contains one fifth of the total number of households in the state. But the distribution of household income within the state is uneven; there are notable differences among regions. For example, the San Francisco Bay Area is relatively well off, with 48 percent of its households in the top two quintiles and only 33 percent of its households in the bottom two quintiles. In contrast, the small urban and non-metropolitan areas of the state have just 29 percent of their households in the top two quintiles and 51 percent in the bottom two quintiles. While housing prices and other cost-of-living factors may cloud the comparison somewhat, it seems clear that the ability to pay higher transportation prices is not distributed evenly around the state, but is higher in its metropolitan areas.

Other important points can be observed be examining the income quintile data. In particular:

  - Population is not distributed evenly among the quintiles. Higher income households tend to be larger, such that 23 percent of the population is in the highest quintile and 15 percent in the lowest quintile.

  - Auto ownership increases with income. 53 percent of the vehicles for personal use in California are owned by the top two quintiles, while only 27 percent are owned by the bottom two quintiles. This suggests that policies which cause a general increase in the cost of auto ownership may apply disproportionately to upper income groups.

  - Households with workers tend to have higher incomes than those which do not. 56 percent of the workers statewide are in the top two quintiles, while only 24 percent are in the bottom two quintiles. This suggests that policies which cause a general increase in the cost of commuting may apply disproportionately to upper income groups.

  - Autos per worker is consistently high in all income groups. Table 20 shows that quintile 1 - the lowest income group - has the highest auto ownership per worker. This counter-intuitive result is due to the large group of retirees falling into that quintile. Removing the retirees from the data base produces a ratio of autos to workers of 1.25:1 for each of the five quintiles. While this does not have direct implications for pricing policy, it does suggest that access to an automobile for the commute is widely distributed in California.

- Drive-alone share for commute travel rises with income. The drive-alone share statewide is about .59 in the lowest quintile and .78 in the highest quintile, with similar variation in each region. Putting the mode shares (including the shared ride data not shown here) together with the proportion of workers in each quintile, it becomes clear that only about 6 percent of the commute vehicles statewide will have drivers in the lowest quintile, while about 35 percent will have drivers in the highest quintile.

- Commute time per worker rises with income. The average self-reported commute trip time statewide is about 22.8 minutes for workers in the lowest quintile and 25.8 minutes for workers in the highest quintile, with similar variation in each region. Because many of the low income workers' miles are made by transit (or by foot) at speeds far below auto speeds, even on congested networks, it is clear that higher income workers' trips must be considerably longer (in VMT) than those of their lower income counterparts. This illustrates a crucial point for pricing studies: higher income workers are the largest contributors to work trip VMT, partly because high income jobs and high-end housing are relatively sparsely distributed around each region.

- Both low and high income workers are more likely to work at home. About 3.5 percent of workers in the highest quintile and 4.1 percent of workers in the lowest quintile listed home as the primary place of work in 1990, compared to 3 percent of workers overall. While these phenomena are not well understood, it is said that participation rates by upper income households have been increasing in recent years. This may indicate that upper income households have an important way to blunt the effect of large price increases, namely by choosing to work at home some of the time.

The PUMS data demonstrate one of the most important facts about equity of the current transportation system. Truly poor people make relatively little use of the highway system as it operates today and, consequently, would pay comparatively little under most transportation pricing scenarios (in absolute terms, not necessarily as a share of income).

Equity Analyses Using PUMS and STEP

An unstated implication of the PUMS analysis is that the lower middle class - say, quintiles 2 and 3 - would sustain much of the impact of pricing policies. This hypothesis was explored in a range of analyses using STEP, examples of which are shown in Tables B21 and B22. The STEP analysis framework allows us to examine equity issues in detail because it utilizes specific demographic information, at the individual household level, that can be associated directly with the effects of each pricing policy.

Table B.21

Equity Implications of a VMT Fee in the Los Angeles Region - 1991

VMT Fee (cents/mile)	Absolute Change in Daily VMT by Income Quintile Q1	Q2	Q3	Q4	Q5	Total
1	-1.8	-1.9	-1.4	-1.1	-0.5	-6.6
2	-3.4	-3.7	-2.8	-2.2	-0.9	-13.0
3	-4.9	-5.4	-4.1	-3.3	-1.5	-19.2
4	-6.2	-7.0	-5.5	-4.4	-2.0	-25.2
5	-7.4	-8.6	-6.8	-5.6	-2.6	-31.0
6	-8.5	-10.1	-8.1	-6.7	-3.2	-36.6
7	-9.5	-11.5	-9.3	-7.8	-3.8	-42.0
8	-10.5	-12.9	-10.5	-8.9	-4.5	-47.2
9	-11.3	-14.2	-11.7	-10.0	-5.1	-52.3
10	-12.0	-15.4	-12.9	-11.1	-5.8	-57.3
Base VMT (millions)	25.5	45.0	54.8	71.9	92.8	290.0
Per Capita Daily VMT	11.7	17.3	19.1	22.0	25.8	20.0

VMT Fee (cents/mile)	Percent Change in Daily VMT by Income Quintile Q1	Q2	Q3	Q4	Q5	Total
1	-7.0%	-4.2%	-2.6%	-1.5%	-0.5%	-2.3%
2	-13.3%	-8.2%	-5.1%	-3.1%	-1.0%	-4.5%
3	-19.1%	-12.0%	-7.5%	-4.6%	-1.6%	-6.6%
4	-24.3%	-15.6%	-10.0%	-6.2%	-2.2%	-8.7%
5	-29.1%	-19.1%	-12.4%	-7.7%	-2.8%	-10.7%
6	-33.5%	-22.4%	-14.7%	-9.3%	-3.5%	-12.6%
7	-37.4%	-25.6%	-17.0%	-10.8%	-4.1%	-14.5%
8	-41.0%	-28.7%	-19.2%	-12.4%	-4.8%	-16.3%
9	-44.2%	-31.5%	-21.4%	-13.9%	-5.5%	-18.0%
10	-47.2%	-34.3%	-23.5%	-15.4%	-6.3%	-19.7%

Note: Quintiles defined in terms of 1989 Census household incomes. VMT is vehicle-miles traveled in millions per day. Sales tax relief, improved transit, and other potential expenditures to mitigate impacts on lower income households are not reflected here.

Table B.22

Equity Implications of Congestion Pricing in the San Francisco Bay Region - 1991

Average Peak Fee (cents/mile)	Absolute Change in Daily VMT by Income Quintile					
	Q1	Q2	Q3	Q4	Q5	Total
1	-0.2	-0.2	-0.1	-0.1	0.0	-0.6
2	-0.3	-0.3	-0.2	-0.1	0.1	-1.1
3	-0.4	-0.5	-0.3	-0.2	0.1	-1.6
4	-0.5	-0.6	-0.4	-0.3	0.1	-2.1
5	-0.6	-0.7	-0.5	-0.4	0.2	-2.5
6	-0.7	-0.8	-0.6	-0.4	0.2	-2.9
7	-0.8	-0.9	-0.7	-0.5	0.3	-3.3
8	-0.8	-1.0	-0.7	-0.6	0.3	-3.6
9	-0.9	-1.1	-0.8	-0.7	0.3	-3.9
10	-0.9	-1.1	-0.9	-0.8	0.3	-4.2
Base VMT (millions)	7.2	14.0	19.6	30.3	44.0	115.0
Per Capita Daily VMT	10.0	15.3	16.8	19.5	22.6	18.3

Average Peak Fee (cents/mile)	Percent Change in Daily VMT by Income Quintile					
	Q1	Q2	Q3	Q4	Q5	Total
1	-2.2%	-1.2%	-0.6%	-0.2%	0.1%	-0.5%
2	-4.2%	-2.3%	-1.1%	-0.5%	0.2%	-1.0%
3	-6.0%	-3.3%	-1.7%	-0.7%	0.3%	-1.4%
4	-7.5%	-4.2%	-2.2%	-1.0%	0.4%	-1.8%
5	-8.8%	-5.0%	-2.6%	-1.2%	0.5%	-2.2%
6	-10.0%	-5.7%	-3.0%	-1.5%	0.5%	-2.5%
7	-11.0%	-6.4%	-3.4%	-1.8%	0.6%	-2.9%
8	-11.8%	-7.0%	-3.8%	-2.0%	0.6%	-3.2%
9	-12.4%	-7.5%	-4.2%	-2.3%	0.6%	-3.4%
10	-12.9%	-8.0%	-4.5%	-2.6%	0.6%	-3.7%

Note: Quintiles defined in terms of 1989 Census household incomes. VMT is vehicle-miles traveled in millions per day. Sales tax relief, improved transit, and other potential expenditures to mitigate impacts on lower income households are not reflected here.

Table B21 presents results for VMT fees in the Los Angeles region at levels ranging between 1 cent and 10 cents per mile. The STEP analysis shows that daily VMT is skewed heavily toward the upper income quintiles - the highest income quintile accounts for about one-third of total VMT, while the lowest quintile accounts for less than 10 percent. Nevertheless, the absolute drop in VMT resulting from a VMT fee is largest in quintile 2 (the second lowest income level) and smallest in quintile 5 (the highest income level). The absolute drop in VMT is of the same basic magnitude in each of the first four quintiles, and the percentage drop is progressively larger the lower the income level. (Percentages are shown in the second part of the table).

Table B22 presents results for congestion prices ranging from one cent to ten cents per mile, on average, for the San Francisco Bay Area. Here we find that absolute VMT decreases are roughly the same among the lowest four quintiles, while VMT for the highest quintile actually rises (as one would expect for high-value-of-time travelers).

Comparable analyses for parking fees in the San Diego region and fuel taxes in the Sacramento region (details not shown here) yielded similar results: The largest VMT decreases per capita are concentrated in the four lowest income categories. While the VMT drop should not be read as a pure decline in mobility, since some trips are still made by other modes, shortened, etc., it does show how the mobility impacts would be distributed in the absence of efforts to improve modal alternatives for impacted individuals.

Another way to think about equity is in terms of the per capita daily payment by each quintile. Based on Table B21, the quintile total payments for a 5 cent VMT fee in the Los Angeles region would be:

Quintile	Daily Payment (million $)
1	0.9
2	1.8
3	2.4
4	3.3
5	4.5

Out of a daily total of $12.9 million, 35 percent is paid by the top quintile and 61 percent is paid by the top two quintiles. Similarly, only about six percent of current fuel taxes are paid by members of the lowest income quintile and 10 percent by the second quintile. Thus, while the travel/mobility impact falls disproportionately on the lower income quintiles, the financial burden falls squarely on the upper income quintiles.

It is harder to say how VMT fees and vehicle emissions fees would affect different income groups; we can estimate impacts on trip making and location choice, and can forecast auto ownership levels by income group, but we have no direct evidence on how the various groups would change the type and age of the vehicles they own in response to new fees (our analyses on vehicle type and age changes were based on assumptions provided to the models rather than computed outputs of the models). Nevertheless, available data do provide some insights into equity impacts. Using data collected by Caltrans as part of a statewide travel survey, we find that about 55 percent of the vehicles over eight years old are owned by the top three income quintiles, mostly as second, third, or even fourth or fifth cars. The remaining 45 percent of the older cars are owned by the two-fifths of the households with low or moderate incomes. To the extent that vehicle registration fees fall most heavily on these older vehicles, they also would fall somewhat more heavily than proportional on low and moderate income households.

Implications

As with any change in tax policy, the distributional consequences of the proposed change should be carefully examined. The distribution of the burden of the proposed tax among income groups should be compared with the distributional consequences of tax alternatives, including the current tax system. If adverse equity consequences are deemed to be significant, policies to ameliorate those burdens should be examined, including the use of tax revenues to benefit those who might be disproportionately affected by the tax change (such as increased funding for public transportation services, use of revenues to provide tax exemptions (life-line rates) for low-income users, or use of tax revenues to replace existing taxes that disproportionately burden low-income taxpayers).

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