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REPORT 689

Costs of Alternative Revenue-Generation Systems

TRANSPORTATION RESEARCH BOARD
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Mr. Patrick Balducci was the principal author of Chapters 1 and 6, and authored all sections of Chapters 2 and 4 dealing with motor fuel taxes. Dr. Gang Shao was the principal author of Chapters 3 and 5. Dr. Anthony Rufolo was the principal author of all sections of Chapters 2 and 4 focused on VMT fees. Mr. Albert Amos was the principal author of all sections of Chapters 2 and 4 focused on tolling, cordon/congestion pricing, and parking pricing systems.

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FOREWORD

By Andrew C. Lemer
Staff Officer
Transportation Research Board

NCHRP Report 689 presents an analysis of the direct costs incurred in generating the revenues that support federal-aid and state highway construction, operations, and maintenance. Federal and state taxation of motor-vehicle fuel is presently the primary mechanism for generating such revenue. Alternative revenue-generating mechanisms are used or have been proposed, including tolling and fees for road usage [for example, vehicle-miles of travel (VMT) fees]. There are costs associated with administering any of these revenue mechanisms, collecting the taxes, and ensuring compliance. This report presents a framework for analysis of these costs and uses that framework to estimate unit costs for fuel taxes, tolling, VMT fees, and cordon pricing schemes. The analysis will be helpful to departments of transportation (DOTs), departments of motor vehicles (DMVs), and other responsible agencies and policy makers concerned with generating revenues to support the surface transportation system.

The current system for generating the revenues to support federal-aid and state highways depends largely on federal and state fuel taxes. Tolling is used in a relatively few instances to generate funds to support particular roads, bridges, and tunnels. Several decades of public policy discussions, legislative actions, and executive decisions account for how these taxes and tolls are collected and by whom.

There are costs associated with administering any revenue system, collecting the taxes, and ensuring compliance. *Administrative costs* accrue to operations of the government agency, private company, or independent authority that implements and oversees revenue-producing activities. *Collection costs* are associated with receiving tax payments, placing and operating the equipment for tolls, and other such activities. *Compliance costs* are the result of efforts to ensure that taxes and charges are paid in full when they are due, to reduce evasion, and to collect past-due amounts. These costs may be incurred by multiple agencies. How costs are recorded and presented may vary from one agency to another. Understanding these costs and comparing costs among agencies and alternative revenue-generation systems is challenging.

Various proposals for alternative revenue-generation mechanisms are being considered in public-policy forums. Such schemes as tolls that vary over time, tolls that vary based on distance, area-based licensing, and charges based on VMT will each have their own pattern of costs, and those costs will influence the amount of revenue ultimately available for highways. This report is the product of NCHRP Project 19-08, research undertaken to provide information to support discussions by state officials and other policy makers of the costs of implementing and administering alternative revenue-generation mechanisms. While this research draws on practical experience of agencies in the United States and abroad, alternatives being considered exceed the scope and scale of that experience. In addition, much of the information required for comprehensive analysis is considered sensitive and private by government agencies and private operators concerned with protecting taxpayers' privacy and corporate competitive advantage.

The objective of NCHRP Project 19-08 was to develop a methodology that can be used to analyze and compare the administrative, collection, and compliance costs of highway revenue-generation mechanisms and to apply that methodology to a selected set of alternative mechanisms. Although the range of revenue systems is potentially quite broad, this project was limited to five usage-based charges: motor fuel taxes, tolling, VMT fees, congestion and cordon pricing, and parking fees.

A team led by Battelle relied initially on existing literature and discussions with knowledgeable experts to develop an accounting framework for the analysis and to gain understanding of the limitations faced in making cost comparisons. The team collected information from recent VMT-fee trials in Europe and the United States and from the experience of toll authorities. However, the research was limited by reluctance of private operators and government agencies to release data on their operations, as well as by the lack of experience with proposed alternative revenue-collection methods.

To facilitate comparisons of alternative methods, the research team worked to develop estimates of five indicators of efficiency or severity of the cost burden associated with each mechanism analyzed: (i) average cost per lane-mile, (ii) average cost per centerline-mile, (iii) average cost per thousand VMT, (iv) average cost per transaction or vehicle, and (v) percentage of total costs to total revenues. Using this last measure, for example, the current system of fuel taxation is very effective.

This report may be useful to analysts and policy makers at all levels of government, both as an initial assessment of the potential effectiveness of particular revenue-collection methods and as a template for developing more specific estimates of costs associated with particular methods.

CONTENTS

SUMMARY

Costs of Alternative Revenue-Generation Systems

This report was completed as part of NCHRP Project 19-08, which was designed to measure the administrative, collection, and enforcement costs of alternative revenue-generation systems in transportation. Five revenue-generation systems are evaluated in this report: motor fuel taxes, tolling, vehicle miles traveled (VMT) fees, cordon/congestion pricing, and parking fees.

Motor fuel taxes, which have been levied in the United States since 1919, have become the primary taxing mechanism used to fund the construction and maintenance of the nation's highways and other transportation facilities. Although tolling has a long history, it has been viewed, especially in recent years, as a supplemental revenue source to motor fuel taxes. A number of new tolling facilities, however, have been proposed and are under construction around the country.

In an effort to search for alternative revenue sources that can mitigate further decline in highway trust funds, interest in VMT fees and cordon/congestion pricing has been on the rise. Though VMT fee systems have been tested and proposed, no such systems are currently in use that levy fees for all vehicle types. Consequently, there is no hard cost data available except information developed for pilot tests or submitted by companies competing to build and operate the proposed VMT fee system in the Netherlands.

This report presents cost data collected for each of the aforementioned five revenue systems and presents a comparative analysis of them. For motor fuel taxes, the cost analysis is focused on eight states, which were chosen based on a set of criteria (e.g., geographic diversity, point of taxation). As part of this analysis, capital and/or operational cost data for 14 tolling agencies have been collected. These agencies include older turnpike systems, more recently established toll agencies, and private companies that operate toll facilities under concession agreements. For VMT fees, the costs examined in this report are based on the data for a proposed system in the Netherlands. For motor fuel taxes and tolling, 3 to 5 years of cost data have been collected. Cost data were also collected for four cordon pricing systems (London, Oslo, Stockholm, and Milan) and one parking pricing system (Westminster, United Kingdom).

To normalize the comparisons among the three revenue systems for which detailed information was available (motor fuel taxes, tolling, and VMT fees), the following unit measurements have been used in the analysis: (i) average cost/lane mile, (ii) average cost/centerline mile, (iii) average cost/thousand VMT, (iv) average cost/transaction (or average cost/vehicle when data are available), and (v) percentage of total costs to total revenues. Table S1 provides a summary of the cost comparison for 2007.

Based on the results presented in Table S1, a number of observations can be made for the costs of operating the five revenue-generating systems. Note that operating costs, as used here, are composed of administrative, collection, and enforcement cost elements. See Section 4.1 for

Table S1. Cost comparison between revenue systems.

	Fuel Taxes[1]	Tolling[1]	VMT Fees[2]	Cordon Pricing	Parking Pricing
	Average Cost over States	Average Cost over Agencies	Average Cost over Providers	Average Cost over Providers	Cost of Single Provider
$ per lane mile	$50	$150,595	$4,042	N/A	N/A
$ per centerline mile	108	829,991	8,245	N/A	N/A
$ per 1,000 VMT	0.10	38.58	6.26	N/A	N/A
$ per vehicle	1.22	N/A	75.16	N/A	N/A
$ per transaction	N/A	0.54	6.95	N/A	N/A
% of total revenue[3]	0.92%	33.5%	6.6%	38.7%	56.6%

(1) For the fuel tax and tolling systems, data were collected from 2003 to 2007. To make a consistent and accurate comparison between the alternative revenue systems, only 2007 data were used in developing these averages.

(2) For the VMT fee systems, there is only 1 year of data available for comparison, and it is based on the revenue forecast to be collected in the Netherlands.

(3) System-generated revenues only.

a definition of each cost element and an overview of the cost accounting framework developed for this study. Principal observations derived from Table S1 are as follows:

- The fuel tax system is the most cost-effective revenue system among those examined in this report and has the lowest operating cost for all unit measurements. The operating cost for fuel taxes is only approximately 1% of tax revenue and averaged approximately $1.20 per vehicle to operate and manage.
- Although its annual operating cost may reach $75 per vehicle, the cost for the proposed VMT system is still reasonable when measured by the share of cost to revenue (approximately 7% in the Netherlands). It would be a larger share of typical revenues in the United States. Further, the capital cost will be quite high if the system must be installed for the collection of VMT fees.
- Although it might cost only $0.54 per transaction to operate and maintain the tolling systems, tolling agencies spent 33.5% of revenues for toll collection, administration, and enforcement activities in 2007.
- The operating costs for cordon pricing are comparable to tolling, at 38.7%.
- The costs to operate the Westminster parking pricing system are 56.6% of total revenue. Thus, of the five revenue systems, parking pricing was the most expensive to operate based on the very limited data collected for this study.
- For VMT fee systems, the biggest spending item is administration cost, which may reach 3.4% of revenue (based on the Netherlands system). Comparatively, collection and enforcement costs for maintaining a VMT fee system are relatively small. They may be near to or less than 1% of revenue. Collection costs for tolling systems are much larger than administration and enforcement costs. The evidence from the tolling agencies examined in this report indicates that approximately 20% of revenue may be spent on collecting tolls.

This report also examines several technologies with the potential to support the implementation of alternative revenue-generation systems for transportation. The selected technologies include the IntelliDrive^{SM} system, satellite-based and cellular-based fleet management systems (FMSs), commercial vehicle information systems and networks (CVISNs), and electric cars/smart charging software. The status of these systems varies. Some of them are still in the development and testing stage, such as IntelliDrive technology, while others have been deployed or tested for trucks only, such as FMS and CVISN.

For each system, the report discusses its objective, specifications, technology components used, and current status in terms of research, testing, and deployment. Table S2 summarizes and highlights the potential of and obstacles faced by each system examined in the report.

Table S2. Characteristics of the potential alternative revenue-generation systems.

System	Potentials	Obstacles
IntelliDrive system	• Adds two-way communication capabilities to vehicles and links them with transportation infrastructure • Has a tolling and electronic payment subsystem • Uses dedicated short-range communication (DSRC) and GPS	• Still in the testing stage • Several years away from broad deployment
FMS	• Capable of tracking vehicles • Uses satellite- and/or cellular-based technologies	• Needs to be tested on a large number and variety of vehicles • May need to merge satellite-based and cellular-based communication technologies
CVISN	• Successfully deployed in more than 20 states • Cost-effective design achieved by linking together existing states' information systems	• Lacks ability to track vehicle miles traveled and protect privacy • Not originally designed to support revenue-generation mechanisms
Electric cars and smart charging software	• Reduced emissions (zero tailpipe emissions) • Alternative fuels • Application of "smart charging" software to manage the supply and demand of the electric grid and to upload vehicle information	• Uncertainty of battery charging/switching • Costs of batteries • Uncertainty regarding the collection and distribution of utility taxes

This report includes a sensitivity analysis, which was designed to examine the impacts on operating costs caused by changing certain parameters (e.g., scale, technology costs, enforcement costs). It also assesses uncertainties and business risks involved in alternative revenue-generation systems and discusses issues related to evasion and implementation. Key findings of the sensitivity analysis include

- Demand for motor fuel is relatively unresponsive to price; however, there are a number of other factors, including inflation, market penetration of alternative fuels, and increased motor fuel efficiency, that hold the potential to significantly erode the motor fuel tax in the next 20 years. While there is evidence to suggest that motor fuel taxes suffer from a persistent problem with evasion, there are trade-offs between the costs of enhanced enforcement and increased collections through reduced evasion. With that noted, the FHWA reported that it receives $10 to $20 for each dollar spent on audits and criminal prosecutions (FHWA, 1999), and a state-level study estimated that diesel tax revenues were enhanced at the rate of $321 per auditing hour (CSG & CGPA, 1996).
- Tolling demand elasticity estimates are unique for each facility explored in this study, ranging from –.02 to –.42 (.2% to 4.2% reduction in demand for every 10% increase in price) for California I-15 to –.90 to –1.00 for California SR 91. Economic conditions present at communities adjacent to toll roads, facility length, and feeder/competing routes also affect toll-collection rates and revenues.
- Economies or diseconomies of scale and scope (e.g., the number of vehicles, geographic coverage, and range of uses for the system) affect both the cost and revenue of a VMT fee system. VMT systems have large costs associated with the onboard unit (OBU) needed to

determine the location of vehicle use and the distance traveled. Thus, the cost of each system depends to some extent on the technology required to implement it. While the OBU will be a major cost of a VMT system, there is widespread expectation that this cost will continue to decline. For example, the cost estimate for the proposed Dutch system declined from €180 ($225) per unit to a range of €85 to €140 ($106 to $175) in roughly 1 year (Ministry of Transport, 2009). In addition, most of the companies responding with cost estimates projected lower cost per unit in the future due to technological advances. Privacy and security measures are also important considerations, and failure of such systems would result in additional costs and other consequences.

- With the exception of Singapore and Bergen, every cordon pricing system was established within the past two decades. Due to their relatively recent establishment, the newer congestion and cordon pricing systems use electronic collections systems and video enforcement technologies. This reduces the potential range of implementation options, resulting in a narrower range of collection costs. However, it should be noted that the sample size for cordon systems is smaller than for toll systems, cordon pricing systems have differing objectives (e.g., revenue generation, reduced air emissions, congestion relief), cities with cordon pricing systems have differing levels of transit service, and cities with congestion pricing have different growth patterns and geographic constraints. Each of these factors affects both demand elasticity and the costs of implementing cordon pricing systems.
- There has been a great deal of analysis regarding the demand elasticities of parking rates, with results that include –0.46 (4.6% reduction in demand for every 10% increase in price) for single occupant vehicles in Portland, Oregon (Dueker, Strathman, and Bianco, 1998) and –1.2 for parking facilities in Chicago (Feeney, 1989). This broad range of demand elasticity values reflects the relative availability of lower-priced or free alternatives, the ability to shift parking duration, the ability to shift transportation mode, income, and other factors.

The research results presented in this report are designed to provide information needed not only to promote a better understanding of the costs associated with each of the revenue-generation systems but also to guide public- and private-sector decision makers and stakeholders in formulating policies. With this in mind, the report concludes with a plan for implementing research findings.

CHAPTER 1

Introduction

NCHRP Report 377: Alternatives to Motor Fuel Taxes for Financing Surface Transportation Improvements and subsequent studies have pointed out that continued improvements in fuel efficiency will likely diminish the effectiveness of motor fuel taxes as a method for financing highways. In addition, higher fuel prices, increased congestion, and telecommuting have resulted in shifting patterns of behavior, causing individuals to either travel less or switch to alternative modes. As a result of these trends, the motor fuel tax system faces uncertainties. Another factor affecting the motor fuel tax revenue system is that fuel tax rates have not been indexed for inflation or increased at the federal level since 1993. From 1993 to 2008, the purchasing power of the federal gasoline tax, which has remained at the fixed rate of 18.4 cents per gallon, has declined by 33%.

Given these concerns, the challenge faced by transportation policy makers is how to expand revenue generation beyond the traditional reliance on motor fuel tax revenues. Thus, the implementation of innovative strategies to reduce congestion and generate alternative sources of revenues to finance infrastructure development and rehabilitation has become a top priority. The recent observable efforts have involved the modification of existing pricing schemes of toll systems as well as the examination of potential financing sources for transportation infrastructure. For example, some toll systems have begun to implement variable pricing schedules. There has also been increased emphasis on the development of high occupancy toll (HOT) lanes. Since 2001, an innovative approach has been undertaken by the State of Oregon, which has tested a usage-based fee system by charging fees for vehicle miles traveled (VMT) to complement motor fuel tax revenues. Although the initial tests on area pricing in multiple zones in the state were successful and encouraging, the requirements to install equipment in vehicles and gas stations make the implementation costs high. Internationally, the United Kingdom and Singapore have implemented cordon/congestion (or area) pricing, which charges users that travel by car to central business districts (CBDs) during peak periods. The high costs of implementing cordon pricing pose a serious issue to policy makers. Although recent reports on the London cordon pricing program indicate that the program will generate excess revenues, the capital and operating costs have made this program more expensive than initially anticipated.

In today's environment, it is in the public's best interest to look beyond existing revenue-generation systems and more closely examine the feasibility of alternative approaches. However, there is no clear indication of which approach will succeed in the long term. As a result, it is likely that transportation agencies will implement existing and innovative approaches in combination to maximize funding and achieve mobility and connectivity objectives in the near and medium term. In order to provide a better understanding of the potential implementation costs, it is essential to analyze and compare collection, administrative, and compliance costs for existing and alternative revenue-generation systems.

1.1 Research Objectives

The objectives of this research are to (1) examine, compare, and present the administrative, collection, and compliance costs of usage-based revenue-generation systems, such as motor fuel taxes, tolls, and VMT fees; and (2) examine the potential feasibility of alternative revenue-generation systems that have been implemented on a pilot basis or are in the conceptual stage.

In addressing these research objectives, this report presents a cost analysis relating to the administrative, collection, and enforcement costs for the following revenue systems used to finance road infrastructure: (1) motor fuel taxes, (2) tolling, (3) VMT fees, (4) cordon/congestion pricing, and (5) parking fees. It also provides a comparative analysis of these revenue collection systems and examines several technologies that show promise for enabling revenue-generation systems. Finally, this report also lays out the methodologies and data structure for analyzing the costs of alternative revenue systems for transportation.

1.2 Report Audience

The research results presented in this report provide information needed not only to promote a better understanding of the costs associated with each of the revenue-generation systems, but also to assist public- and private-sector decision makers and stakeholders in formulating policies. The primary potential users of the research results, therefore, are the FHWA, state departments of transportation (DOTs), state departments of taxation/revenue, metropolitan planning organizations (MPOs), toll authorities, academia, energy providers, and consultants.

1.3 Report Structure

This report is divided into six chapters, including this introduction. The remainder of this report is structured as follows:

- Chapter 2 presents an overview of the existing motor fuel tax system and a number of alternative revenue-generation systems.
- Chapter 3 examines several technologies that have the potential to advance alternative revenue-generation systems for transportation. The selected technologies are the IntelliDrive system, satellite-based and cellular-based fleet management systems (FMSs), commercial vehicle information systems and networks (CVISN), and electric cars/smart charging software.
- Chapter 4 presents a cost accounting framework established for this study and then presents administration cost estimates for the five transportation revenue-generation systems examined in this report.
- Chapter 5 defines unit measurements for the purpose of comparison within and among revenue-generation systems and uses them to examine costs between revenue systems. This chapter also presents the results of sensitivity analyses conducted on each revenue-generation system examined in this report.
- Chapter 6 presents study conclusions.

In addition to the main body of the report, appendices present an overview of the Oregon VMT pay-at-the-pump system, a survey used to collect motor fuel tax-related administrative cost data, parameter data and detailed cost estimates, and a list of acronyms.

CHAPTER 2

Overview of Existing and Alternative Revenue-Generation Systems

Historically, the bases of taxation underlying transportation revenue-generation systems have focused on specific factors that tie vehicle ownership and operation to individual motorists or motor carriers. Since 1919, when Oregon implemented the nation's first gasoline tax, motor fuel taxes have served as the primary source of funding for our nation's roads and bridges; however, there is a broad spectrum of revenue systems that are either in operation or have been proposed across the United States. These systems can be organized into the following categories based on the basis of taxation:

- Vehicle ownership
  - Registration fees
  - Licensing fees
  - Personal property taxes
- Highway user fees
  - Toll roads
  - Congestion/cordon pricing
  - High occupancy toll lanes
  - VMT fees
- Energy consumption
  - Motor fuel taxes
  - Sales taxes on motor fuels
  - Utility fees
- Beneficiary and local option fees
  - Beneficiary charges/value capture
  - Transportation impact fee
  - Local option sales taxes
  - Local option property taxes

The alternative revenue-generation systems examined in this chapter move beyond the traditional methods of raising revenue based on motor vehicle ownership and fuel consumption toward systems that tie tax payments more directly to system usage. Movement in this direction would enhance the efficiency, equity, and long-term stability of the nation's transportation revenue system.

This chapter presents an overview of the existing motor fuel tax system and the alternative revenue-generation systems of tolling, VMT fees, cordon/congestion pricing, and parking pricing. Each of these revenue-generation systems has been applied both within the United States and internationally. In addition to providing an overview of these systems, this chapter examines the lessons learned from real-world applications.

2.1 Motor Fuel Taxes

Revenues from motor fuel taxes represent the primary funding source supporting the nation's highway programs. In 2007 alone, state motor fuel taxes raised more than $37 billion for the improvement of highway facilities (FHWA, 2008). In recent years, the financial limitations of the current system have become evident as revenues have failed to keep pace with the demands for additional highway investment. Furthermore, a number of constraints could collectively limit the long-term viability of the motor fuel tax as a major funding source, including increased fuel efficiency, market penetration of alternative fuels, price inflation, and volatility with respect to motor fuel prices.

In addition to the aforementioned revenue constraints, there is evidence to suggest that motor fuel taxes have historically suffered from a persistent problem with evasion. Historic changes in administrative and enforcement practices designed to address the evasion issue (e.g., diesel fuel dyeing, taxation of kerosene and other alternative fuels, enhanced auditing practices, moving the point of taxation up the distribution chain) have increased revenues deposited in highway funds across the nation.

2.1.1 Motor Fuel Tax Administration and Enforcement Practices

In the United States, motor fuel taxes are collected by states at the terminal, first receipt/sale, distributor, or retail level. From an administrative cost standpoint, there are trade-offs associated with moving the point of taxation up the distribution chain. Taxing at the retail level vastly increases the number of

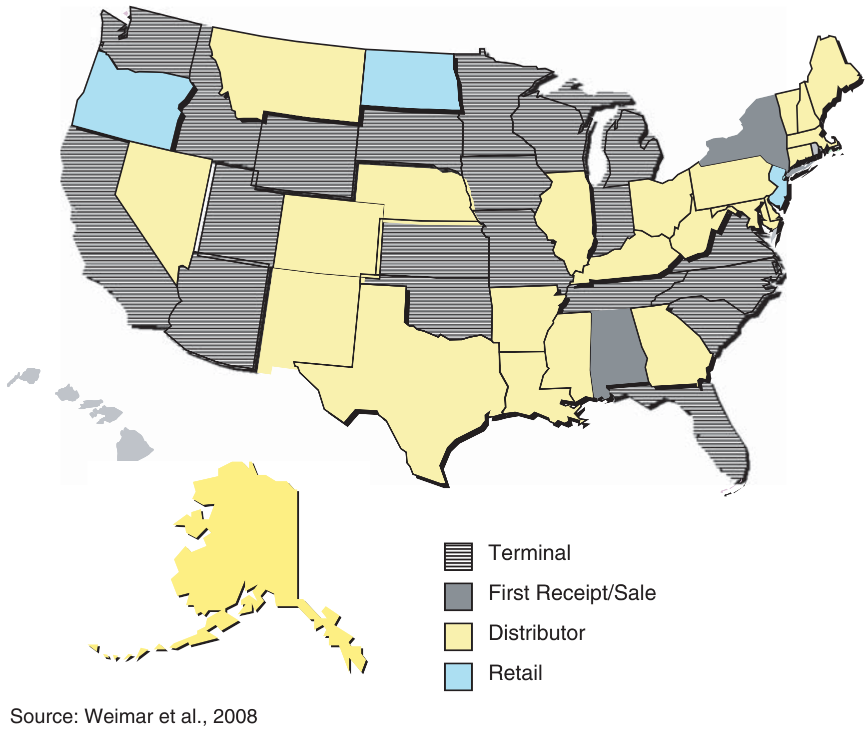


Figure 1. State points of taxation for diesel fuel.

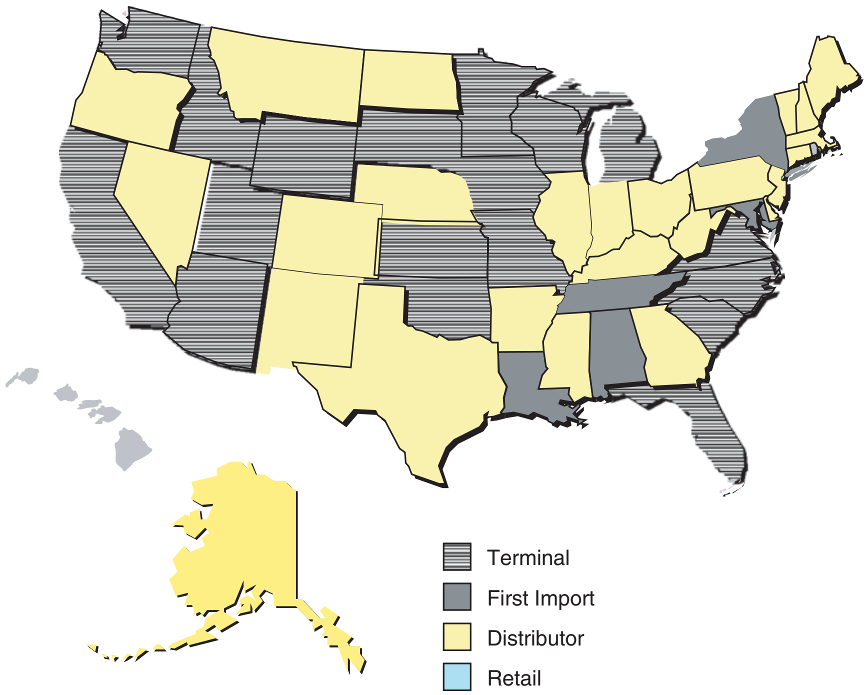
taxpayers. Consequently, there are more motor fuel tax returns to process and operations to audit. Moving the point of taxation up the distribution chain, while reducing the population of taxpayers and greatly reducing the number of audits, requires a refund program, including associated auditing requirements. Figure 1 and Figure 2 document state points of taxation for gasoline and diesel fuel (Weimar et al., 2008).

The Omnibus Budget Reconciliation Act (OBRA) of 1993 mandated the dyeing of tax-exempt diesel fuel. This provision enabled law enforcement officials to detect visible evidence of tax-exempt fuel during roadside inspections. When caught using tax-exempt fuel on-road, motor carriers were assigned a federal penalty of $1,000 or $10 per gallon (Baluch, 1996). In 1994, the first year the law took effect, federal diesel fuel tax collections grew by $1 billion, leading the FHWA to attribute $600 to $700 million of that amount to the administration and enforcement provisions contained within the 1993 OBRA (GAO, 1996).

As of 2008, 38 states had enacted dyed fuel statutes. In order to be effective, however, these dyed fuel statutes must be accompanied by on-road inspections, which can be expensive and time consuming. Some states have left the inspections up to the 150 Internal Revenue Service (IRS) officers nationwide dedicated to conducting dyed fuel inspections. Many states, however, use designated officers to conduct fuel dipping in order to detect the misuse of dyed fuel. The costs associated with on-road dyed fuel inspections vary from state to state based on the number of inspections and the type of personnel used. Dyed fuel inspections can be performed during the operation of other safety inspections, or they can be the responsibility of state police officers. Dyed fuel inspections can be conducted at checkpoints, weigh stations, or when vehicles are pulled over by police officers. On-road state enforcement sample statistics are presented in Table 1.

As evasion techniques have evolved so too have auditing practices, with compliance agencies focusing more resources on field audits and joint state–IRS audits. The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 authorized the allocation of $5 million in annual federal Highway Trust Fund (HTF) proceeds to the states and the IRS for enhanced audit and enforcement operations. Programs established with these funds have led to greater coordination between states. The Federation of Tax Administrators (FTA) established a uniformity subcommittee that issued a model-legislation checklist for states moving the point of taxation up the distribution chain and also established an 11-point plan for enhancing uniformity between states (FTA, 2003).

The goal of eradicating all forms of evasion, however, is not only unachievable, it is inefficient. When focusing enforcement and collection resources, there is a theoretical optimum level of tax evasion. The optimum level of evasion is at the point of equilibrium between marginal revenue losses and marginal enforcement costs. That is, it is impractical and inefficient to



Source: Weimar et al., 2008

Figure 2. State points of taxation for gasoline.

spend $2 million to reduce evasion by $1 million. With that noted, there is evidence to suggest that most states have not yet met the point of equilibrium.

The costs associated with enhanced motor fuel tax auditing and enforcement operations can serve to discourage states addressing budget shortfalls and uncertain financial outlooks. In an analysis of a proposed replacement of the Oregon weight-distance tax with a motor fuels tax, the Oregon Department of Transportation (ODOT) concluded it would take 15 full-time equivalent (FTE) employees to implement a refund program and 30 FTEs to conduct distributor and International Fuel Tax Agreement (IFTA) audits. Further, the report concluded that

Table 1. On-road enforcement sample statistics, 1995–2004.

States with On-road Dyed Fuel Enforcement	Total Samples	Total Violations	Violation Rate	Total Assessments
Alabama	84,823	824	0.97%	$874,000
California[1]	161,690	752	0.47%	$612,248
Minnesota	31,840	587	1.84%	$670,260
Montana[2]	42,855	273	0.64%	$34,125
Nebraska	44,570	506	1.14%	$409,375
Nevada	43,303	326	0.75%	$170,070
North Carolina	12,107	125	1.03%	$90,000
Pennsylvania[3]	162,341	788	0.49%	$1,198,092
Texas	3,175	29	0.91%	$63,050
Virginia	21,239	280	1.32%	$606,346
West Virginia[4]	23,901	231	0.97%	$198,271

[1] California – Total penalties assessed are from years 1999 to 2004 only.
[2] Montana – Data cover the 2002–2004 time period only and were supplied by MDT.
[3] Pennsylvania – 164 kerosene inspections were conducted resulting in 46 violations for illegal use of the untaxed fuel.
[4] West Virginia – No samples were taken in first quarter of 2003 due to weather.
Source: Balducci et al., 2006

the costs of administering the motor fuel tax could exceed $10 million annually (Jones, 1995).

The literature suggests that while it is expensive to effectively audit and enforce motor fuel tax codes, enhanced compliance activities yield positive returns on investment. From October 1992 through 1993, gasoline tax revenues reported in 38 states averaged $443 per auditor staff hour. Over the same time period, diesel tax revenues were enhanced at the rate of $321 per auditing hour (CSG & CGPA, 1996). Finally, FHWA reports that it receives $10 to $20 for each dollar spent on audits and criminal prosecutions (FHWA, 1999).

2.1.2 Previous Administrative Cost Estimates

Historically, relatively few studies have attempted to estimate the administrative costs associated with motor fuel tax collection, and while study findings have varied, results indicate that motor fuel administrative costs are likely less than 1% of gross collections minus deductions for distributor collection allowances, refunds, and other allowances for handling losses and evaporation.

In 1994, *NCHRP Report 377: Alternatives to Motor Fuel Taxes for Financing Surface Transportation Improvements* estimated motor fuel administrative costs at $200 million for all states (Reno and Stowers, 1994). In 1993, when this research was performed, net receipts from state motor fuel taxes totaled roughly $24.9 billion (FHWA, 1994b). Using net collections as the denominator to the administrative cost numerator, the aforementioned cost estimate presented in this publication represented 0.8% of total tax collections.

In 1995, in response to a proposal to eliminate Oregon's weight-distance tax and replace it with a tax on diesel, ODOT compared the administrative costs of the proposed system to that of the existing one. ODOT found that despite a reduction of 20 FTEs and a cost reduction of $1.4 million associated with the registration and reporting of tax records by out-of-state operators, net administrative costs would grow under the motor fuel tax due to the expanded workload associated with IFTA audits (3 FTEs, $250,000) and an expanded refund program (15 FTEs, $1.3 million). Assuming that the proposed motor fuel tax program would have been revenue neutral with respect to the weight-distance tax system it was designed to replace, estimated administrative costs would have been in the 4.5 to 5% range (Jones, 1995).

The costs to administer motor fuel tax programs have ranged in recent years from 0.2% (Peters and Kramer, 2003) to 1.0% (HDR, 2009). The higher-end estimate was presented in an HDR report prepared for the U.S. Department of Transportation and was based on data reported by states in Form 556 to FHWA for presentation in *Highway Statistics.* This estimate includes all deductions by state collection agencies, expenses of collecting and administering motor fuel taxes, expenses of inspecting motor fuel, and other costs or deductions by the collecting agencies.

2.2 Tolling

This section summarizes the current practices and future trends that will affect toll-collection activities. Due to the long history and widespread use of tolling in the United States, this section provides an overview from an extensive body of literature on toll systems, management practices, governance frameworks, system configurations, and pricing policies.

2.2.1 Overview of Tolling Systems and Current Practices

Toll roads have been in existence since the early days of the United States. The first toll road in the United States was the Philadelphia–Lancaster Turnpike, which was developed in the 1790s. Throughout the 1800s, a number of turnpikes were established in the United States. The first modern toll road with a toll-road agency was the Pennsylvania Turnpike, which opened in 1940. This was followed by additional tolled turnpikes in Connecticut, Delaware, Florida, Illinois, Indiana, Kansas, Maine, Maryland, Massachusetts, New York, New Jersey, New Hampshire, Ohio, and Oklahoma. These roads were managed, administered, operated, and maintained by the state highway agency and/or a dedicated toll-road agency that reported to the state government. Although there are some exceptions, these facilities have historically been categorized by relatively high labor costs, reduced operational and maintenance expenditures, and cash collection at tollbooths. Moreover, these agencies are often constrained either politically and/or legally from increasing toll rates on a timely basis to cover increases in costs.

The next important development with regard to the development and administration of toll roads involved the creation of local toll-road agencies [e.g., the Harris County Toll Road Authority (HCTRA) in Houston, Texas, and the Orlando–Orange County Expressway Authority in Orlando, Florida]. Moreover, a number of bridges and causeways have been developed and managed by city, county, and regional government agencies. The advantage of this approach is that revenues generated by the toll road system, which are drawn primarily from commuters, are plowed back into the local economy rather than being dispersed over a wide geographic area.

Finally, a growing number of toll facilities are operated by private entities under concession agreement. Private financing has been used for asset monetizations as well as for the development of new toll road facilities. Table 2 lists the roughly 90 toll agencies in the United States and Canada.

Table 2. State, local, and private toll agencies.

Mature State Agencies	Mature Local & Regional Toll-Road Agencies	Maturing and Ramp-Up Public Toll-Road Agencies	Private Toll-Road Agencies
Alligator Alley (FL)	Bay Area (CA) Toll Authority, California	Alamo Regional Mobility Authority (TX)	Adams Avenue Turnpike, LLC (UT)
Caltrans (CA)	Blue Water Bridge Authority	Bay Area Toll Authority (CA)	Ambassador Bridge
DelDOT (DE)	Buffalo and Fort Erie Public Bridge Authority	Cameron County Regional Mobility Authority (CCRMA) (TX)	B&P Bridge Company (TX)
Florida's Turnpike Enterprise (FTE)	Cameron County (TX)	Camino Real Regional Mobility Authority (CRRMA) (TX)	Brownsville and Matamoros Bridge Co. (TX)
Georgia State Road and Tollway Authority (SRTA)	Cape May County Bridge Commission (NJ)	Central Texas Regional Mobility Authority (CTRMA)	Chicago Skyway
Illinois State Toll Highway Authority (ISHTA)	City of Del Rio (TX)	Connector 2000 Association Inc., (SC)	Dulles Greenway
Kansas Turnpike Authority (KTA)	City of El Paso (TX)	Eagle Pass (TX) Bridge	Foley Beach (AL) Express
Louisiana Department of Transportation & Development	City of Pharr (Pharr-Reynosa Bridge)	Foothill/Eastern (CA) Transportation Corridor Agency	Indiana Toll Road (ITR)
Maine Turnpike Authority	Chesapeake Bay (VA) Bridge and Tunnel	Grayson County (TX) Regional Mobility Authority (GCRMA)	I-495 HOT lanes, Virginia
Maryland Transportation Authority (MdTA)	Delaware River and Bay Authority (DRBA)	Hidalgo County Regional Mobility Authority	Northwest Parkway Public Authority (CO)
Michigan Department of Transportation (MDOT)	Delaware River Joint Toll Bridge Commission (DRJTBC)	Lake of the Ozarks Community Bridge (MO)	Pocahontas Parkway Association (VA)
New Hampshire Turnpike	Delaware River Port Authority (DRPA)	McAllen (TX) International Toll Bridge, Texas	South Bay Expressway (CA)
New Jersey Turnpike Authority (NJTA)	E-470 Public Highway Authority (CO)	Metropolitan Washington Airports Authority (MWAA)	Starr Camargo Bridge Company
New York State Thruway Authority (NYSTA)	Galveston County (TX)	Minnesota Department of Transportation (Mn/DOT)	Toronto 407 Intl Inc.
New York State Bridge Authority	Golden Gate Bridge, Highway and Transportation District (CA)	North Carolina Turnpike Authority (NCTA)	United Toll Systems (AL)
Oklahoma Turnpike Authority (OTA)	Greater New Orleans Expressway Commission (GNEOC)	North East Texas Regional Mobility Authority (NETRMA)	
Ohio Turnpike Commission (OTC)	Harris County (TX) Toll Road Authority (HCTRA)	North West Arkansas Regional Mobility Authority	
Pennsylvania Turnpike Commission	Lee County (FL)	Orange County (CA) Transportation Authority (OCTA)	
Pinellas Bayway (FL)	Massport (MA)	Osceola County (FL)	
Rhode Island Turnpike and Bridge Authority (RITBA)	Metropolitan Transportation Authority (MTA) Bridges & Tunnels	San Diego Association of Governments (SANDAG)	
South Carolina Department of Transportation (SCDOT)	Miami-Dade Expressway System (MDX)	San Joaquin Hills Transportation Corridor Authority (SJTCA)	
Sunshine Skyway Bridge (FL)	Mid-Bay Bridge Authority (MBBA)	Santa Rosa (FL) Bay Bridge Authority	
West Virginia Parkways Authority	Niagara Falls Bridge Commission	Sulphur River Regional Mobility Authority (TX)	
	North Texas Tollway Authority (NTTA)	Texas Turnpike Authority (TTA)	
	Orlando–Orange County Expressway Authority (OOCEA)	Utah Department of Transportation	
	Port Authority of New York and New Jersey (PANY/NJ)	Washington Department of Transportation (WSDOT)	
	Richmond Metropolitan Authority (VA)		
	South Jersey (NJ) Trans. Authority		
	Starr County (TX)		
	Tampa (FL) Hillsborough Expressway Authority		

Source: Jacobs Engineering Group, 2010

2.2.2 Practices and Trends Affecting Tolling Systems

In the last 10 to 20 years, five practices and major trends have had a dramatic impact on toll road operations:

- The change in governance structures of toll agencies, including the establishment of multimodal agencies and the introduction of private equity capital,
- The adoption of electronic toll-collection (ETC) systems, which permit free-flow movement at toll gantries,
- Improved traffic flow conditions due to higher throughput in the ETC lanes,
- Congestion management and the introduction of variable pricing schedules,
- The use of leakage rates to measure the rate of driver non-payment, and
- The charging of administrative fees and/or the criminalization of toll violations.

These practices and trends will continue to have an impact on the costs of toll collection, administration, and enforcement.

2.2.3 Change in Governance Structure of Toll Agencies

The majority of toll facilities are operated by a public agency that is part of or reports directly to a state, county, or municipal government. The functional responsibilities of these agencies primarily focus on the administration, operation, maintenance, oversight, and enforcement of the toll facilities under their respective jurisdictions. Non-transportation related activities are limited to the leasing or operation of food and gas concessions, real estate transactions near the highway, and financial transactions related to the management of new and outstanding debt issues. A notable exception is the management of an arts facility by the New Jersey Turnpike Authority (NJTA, 2007).

The decreased availability of funding from fuel tax revenues has encouraged state and local agencies to consider a variety of new approaches that can be used to finance highway infrastructure. This has resulted in the establishment of new governance structures for tolling systems, such as

- Multi-jurisdictional agencies, which have been granted toll authority as well as the responsibility to develop new toll roads: An example of this governance structure is the Central Texas Regional Mobility Authority (CTRMA), which is developing toll roads in two counties in the Austin metropolitan area in Texas. Other Regional Mobility Authorities (RMAs) include the Alamo RMA (San Antonio), Cameron County RMA (Brownsville–Harlingen), Camino Real (El Paso), Grayson County Regional RMA (Sherman, Denison), North East Texas RMA (NETRMA, Tyler), Hidalgo County RMA (McAllen), and the Sulphur River RMA (Paris). To date, CTRMA and NETRMA are the only RMAs within Texas that operate completed toll roads within their respective jurisdictions.
- Multimodal agencies that operate toll roads in addition to other transportation facilities: A traditional example is the Port Authority of New York and New Jersey, which operates airports, transit lines, and the Port Authority Trans-Hudson (PATH) rail system in addition to toll bridges and tunnels. A newer example is the Metropolitan Washington Airports Authority, which began to operate the Dulles Toll Road (DTR) in 2008 after operations of this facility were transferred from the Virginia Department of Transportation (VDOT). The DTR is being used to help finance the extension of a transit line in the Washington, D.C., area. In addition, the Orange County Transportation Authority (OCTA) manages and operates SR-91 and bus transit lines in California.
- Private capital: In several states, a number of toll facilities have been developed or are being developed using private equity and debt capital. This includes project delivery using design–build (DB) contracts as well as project development and long-term operations through design–build–finance–operate (DBFO) contracts. Recent examples include the South Bay Expressway in San Diego, California; the Toronto 407 in Canada; the SH 130 Segments 5 & 6 between Austin and San Antonio, Texas; and the I-495 HOT lanes in Northern Virginia. A parallel trend is the monetization of older facilities, such as the Chicago Skyway and the Indiana Toll Road (ITR). Due to the incentive to maximize profits, the introduction of private capital has led to the assessment of higher toll rates, improved revenue collection, and pressures to reduce toll administration and collection costs. Enforcement activities typically remain the responsibility of the public sector.

A number of public agencies, including multi-segment, multi-jurisdictional, and/or multimodal toll-road agencies, may cross-subsidize between facilities. An example is the New York State Thruway Authority's (NYSTA) operation and financial support of the Erie Canal. The extent of cross-subsidization between facilities may depend on the existing legislation, corporate charters, and the bond agreements for these agencies.

2.2.4 Electronic Toll Collection and Video Tolling

Beginning in the late 1980s, ETC based on radio frequency identification (RFID) technology emerged, having been technically proven for use in revenue operations. Over the past few decades, many toll agencies have turned to electronic toll transponders or tags affixed to vehicles for drivers to pay tolls. In addition to providing added convenience to drivers and enhancing vehicle throughput, toll tags help reduce congestion by eliminating the need for cars to stop for the payment of tolls. Toll tags also help reduce air pollution by eliminating stop-and-go traffic and the idling of cars at staffed toll lanes. Beyond improving customer service for drivers and toll lane throughput for toll agencies, a recent study conducted by the Massachusetts Institute of Technology (MIT) claims that ETC has had one additional impact that has political ramifications—drivers are much less aware of toll rates when they pay electronically (Finkelstein, 2007).

Because of the largely proprietary nature of first-generation ETC systems, tags are not interoperable across systems, just as VHS and Beta technologies were not compatible for videocassettes, and computer programming languages are not universally compatible. Over time, different approaches have been used to provide interoperability. In the early 1990s, the E-ZPass Interagency Group (IAG) created a seven-state, fully interoperable ETC network in the northeast United States by selecting common tag and reader technology and developing account reciprocity procedures, allowing customers to use E-ZPass at any equipped facility with only one customer account. The IAG has expanded significantly since then to include 13 states and 24 different agencies. Toll authorities in a number of states have worked out similar cooperative agreements that allow a transponder from one toll authority to function properly on a road in another part of the state. Texas, Florida, California, Washington, and Colorado have statewide interoperability programs. Other possible approaches to interoperability are being evaluated by the recently formed Alliance for Toll Interoperability, which has over 30 participating toll agencies. Under this initiative, toll-road agencies are exploring the application and widespread use of video tolling interoperability and exchange of license plate or ETC account information.

As ETC has expanded, some toll agencies have moved toward open-road tolling (ORT), where traditional toll plazas have been modified or removed entirely to allow for higher speed express lanes. ETC tags are detected by readers that are mounted on overhead gantries. Figure 3 shows an ORT installation in Austin, Texas. Tolls are collected electronically, either through customers' already-established ETC accounts or by using automatic license plate recognition technology to read the license plates and obtain identification and address information for billing drivers. Toll authorities are beginning to consider converting to open-road and all-electronic tolling. At the very least, a number of agencies are implementing hybrid systems.

Three basic toll-collection concepts are currently in use. The toll-collection concepts are (i) controlled ticket system (closed system), (ii) fixed-rate barrier system (open system), and (iii) hybrid tolling system. A description and a schematic representation of each toll-collection system are provided in the subsequent sections.

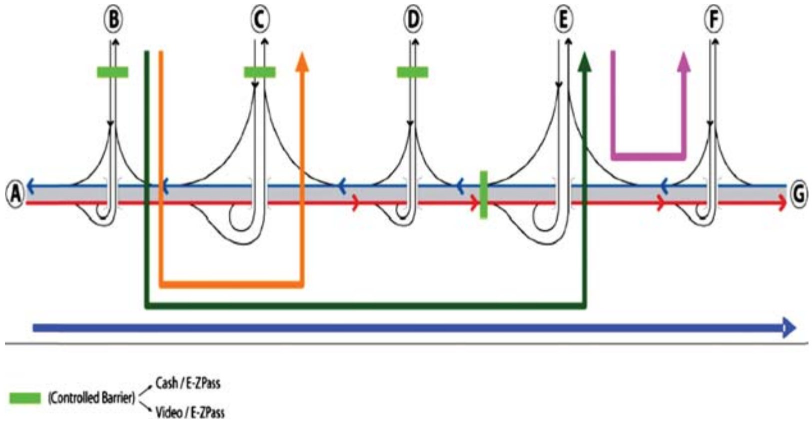
Source: CTRMA, 2008

Figure 3. Electronic toll collection on US 183A, Austin, Texas.

Controlled Ticket System or Closed Toll System

A toll-collection system is considered to be a controlled ticket system (or closed system) when all vehicles entering and exiting the system are monitored and tolls are calculated on the basis of vehicle class and distance traveled. In a controlled ticket system, both mainline toll barriers and ramp toll plazas are situated such that no toll-free traffic movements are permitted. Typically, a patron traveling without a transponder will receive a ticket upon entering the system and submit that ticket to a toll collector upon exiting. The toll collector will collect the toll, which is based on the vehicle class and distance traveled. In cases where electronic toll collection is available, entry and exit from the system can be processed electronically. A representation of the controlled ticket system concept is presented in Figure 4. As demonstrated in the figure, a mainline toll barrier is located between interchanges D and E, and ramp toll plazas are located at interchanges B, C, and D. The controlled system is assumed to continue to the left of the schematic, whereas interchanges E and F are located to the right of the mainline toll barrier and, therefore, are considered outside of the controlled system. A trip from B to C (shown in orange) will incur a toll based on the distance traveled between interchanges B and C. Similarly, a trip from B to E (shown in green) will incur a toll based on distanced traveled between the ingress point and the egress point to the controlled section of the road.

For toll-road users, the primary obligation is to carry sufficient cash, use a debit or credit card, or maintain a valid transponder to pay for each trip. With a closed toll system, there is a greater risk of collisions at the cash lanes. During Congressional hearings, the National Transportation Safety



Source: Jacobs Engineering Group, 2010

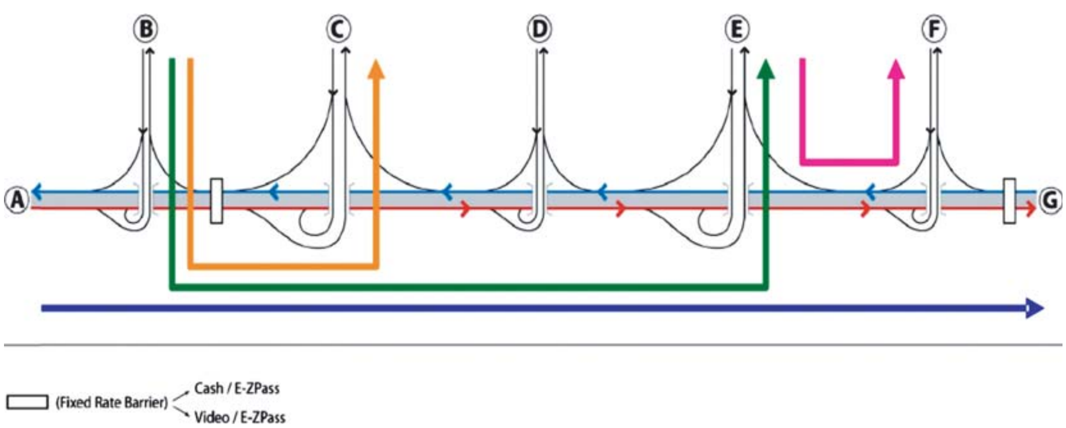
Figure 4. Controlled system.

Board (NTSB) stated that "toll booths are the most dangerous place on the highway" (Miller, 2006). There is also increased fuel consumption and higher emissions as vehicles idle at tollbooths. Peters and Kramer (2003) estimate that on the Garden State Parkway, pollution costs constitute 20.93% of the total societal cost of toll collection, or 8.32% of revenue collected.

Fixed-Rate Barrier System or Open Toll System

A fixed-rate barrier system (open system) is a toll system in which a toll is collected for all users at specific points along the roadway. A fixed-rate barrier system is different from a controlled system in that all trips throughout the system are not monitored, nor are tolls based on distance traveled. Toll barriers are located at strategic points, often across the mainline. A representation of the fixed-rate barrier system is presented in Figure 5. Mainline barriers are shown between interchanges B and C, as well as between interchanges F and G at the limit of the diagram. Patrons with trips originating from point B traveling to the right would pay at the toll barrier located between interchanges B and C. The toll is a fixed-rate toll based on vehicle class only; trip length may vary depending on the entry and exit points. In this same example, if the trip continued past interchange F, the patron would pay another toll at the barrier located before interchange G.

ORT can be applied along the entire toll facility or along part of the toll system. Full implementation of ORT entails the payment of tolls at highway speeds only. Examples of ORT facilities are (i) the Westpark Tollway within the HCTRA toll network in Texas; (ii) the Tampa Hillsborough Expressway in Florida; (iii) Toronto 407 Express Toll Route (ETR) in Canada; (iv) CityLink in Melbourne, Australia; (v) Loop 49 in Tyler, Texas; (vi) SH 121 in the Dallas–Ft. Worth area; and (vii) four toll roads in Santiago, Chile. Partial implementation of this kind of system is in use today on toll facilities such as the Orlando–Orange County Expressway (OOCEA), New Jersey Turnpike and Garden State Parkway, Tappan Zee Bridge (NYSTA), Illinois Tollway, Georgia 400, and Massachusetts Turnpike. Pay-



Source: Jacobs Engineering Group, 2010

Figure 5. Open road system.

ment is typically conducted through debit and credit cards. Typically, transponder holders maintain a minimum balance, which must be replenished once their account balance falls below a minimum threshold or becomes negative.

Open toll-road collection systems require the installation of toll gantries, the installation of intelligent transportation systems (ITS) with the concomitant purchase of hardware and software, and the construction of a customer service center (CSC). The CSC is intended to oversee the distribution or sale of transponders, maintain and update customer accounts, answer questions, resolve disputed transactions, and interface with toll enforcement activities. Toll transponders may be purchased from the toll agency or a third party provider. Toll agencies have introduced various strategies related to the distribution, sale, and pricing of transponders. These approaches include charging potential customers full cost, selling transponders below cost, linking transponder purchase to discounts on toll transactions, and giving transponders at no cost. By offering transponders at no or reduced cost to potential users, toll agencies have attempted to increase transponder penetration and increase throughput. Moreover, the distribution of transponders at below or no cost also attempts to address environmental justice issues related to the cost of purchasing transponders as well as the lack of access to credit/debit cards by low-income users. There are also administrative expenses related to the reconciliation of out-of-area or out-of-state transactions as well as marketing expenses to promote toll road and transponder use. To convert an existing closed system to open road (or hybrid) toll collection, it is also necessary to remove tollbooths, modify or add highway lanes, and increase signage.

The primary advantage to users of open toll systems is that they improve traffic flow and permit free-flow movements and faster travel speeds, subject to general traffic conditions. Toll-road users no longer have to stop at tollbooths, nor do they need to wait while other drivers pay for their transactions. As a result, the open toll-collection system has a quantifiable and potentially significant value of time benefit for users, especially commuters. Due to decreased stopping and idling, open toll-collection systems may lead to reduced fuel consumption and emissions. In addition, ORT facilities have improved safety conditions because the potential for rear-end collisions at tollbooths is reduced.

To allow for free-flow movements and to avoid discriminating against individuals who do not have a credit or debit card, toll agencies have been implementing video tolling options for toll-road users. There are two forms of video tolling: unregistered and registered accounts. Unregistered video-tolling systems permit users without access to a credit/debit card to pay for the use of a toll road facility. Specifically, unregistered video tolling systems look up vehicle registration information from the state department of motor vehicles (DMV) database. Upon motorist use of a facility, a bill is then mailed to the address listed with the DMV. Bills can be paid using check, money order, or other methods.

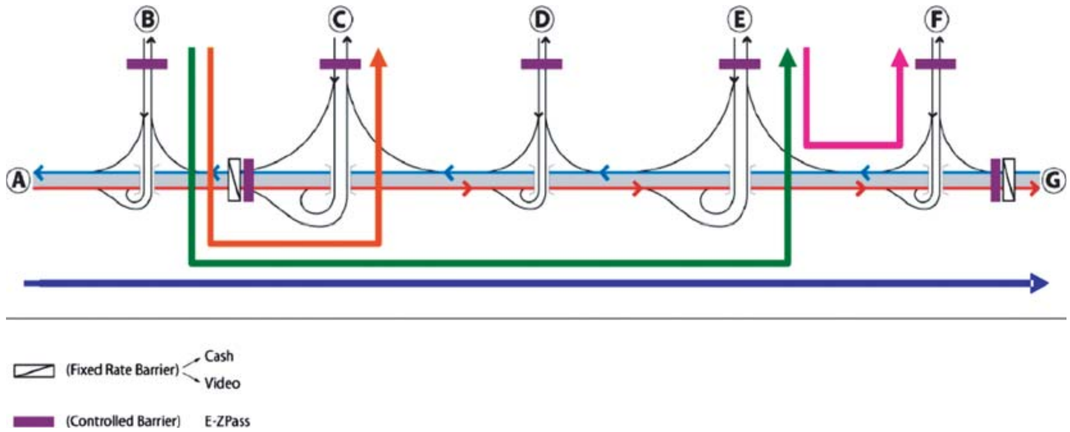
With registered video tolling, the motorist must first register the vehicle's plates with the tolling agency and then establish an account by depositing funds or arranging some other method of payment prior to using the toll system. The toll system will associate the plate images with the account holder and debit the toll amount to the account. However, toll-road users with access to a credit/debit card may still pay the toll amount through an unregistered video-tolling account if they opt not to register their license plates with the toll agency.

Video tolling systems may require toll-road agencies to purchase additional hardware and software needed for implementation. Video tolling also requires interagency coordination if the DMV database is operated and updated by a separate agency. Additionally, video tolling may require additional administrative staff to review the accuracy of toll transactions and process payments received by mail.

With respect to ETC and video tolling, users may have concerns relating to the privacy of credit/debit card information, vehicle information, and home address information. There are additional concerns associated with billing errors related to toll amount, the inaccurate assessment of late fees, and ghost transactions. These errors increase compliance costs since the responsibility for rectifying toll accounts is placed on the customer. Customers may also have concerns with respect to delayed payment or nonpayment, which typically result in the receipt of letters and telephone calls from collection agencies asking for full (or partial) payment of toll transactions along with administrative and/or late fees. In an effort to improve the accuracy of customer billing and payment processes, toll agencies, especially those that operate open road facilities, have been examining and implementing a variety of information technology improvements. However, this has had the effect of increasing variable costs over time due to the integration between new and existing IT systems, operations and maintenance activities, and the replacement of obsolete hardware and software.

Hybrid Tolling System

A hybrid tolling system is a combination of both a closed/controlled ticket system and an open/fixed-rate barrier system. Hybrid systems give customers the option to pay by various methods. ETC equipment monitors the entry and exit of transponder users to and from the toll road as in a controlled system. Electronic tolls are charged based on both vehicle class and distance traveled. Cash customers, on the other hand, pay a fixed-rate toll based on vehicle class at a designated mainline toll-barrier location regardless of their point of entry or exit between toll plazas. Figure 6 provides a schematic of a hybrid tolling system. Purple bars represent ETC gantries,



Source: Jacobs Engineering Group, 2010

Figure 6. Hybrid system.

and diagonally dashed bars represent mainline fixed-rate barriers applicable only to cash customers. Since there is only one mainline plaza between C and F, cash-paying travelers originating at interchange B destined for either C or E pay the same toll despite the differences in distances traveled.

Comparison of Toll-Collection Systems

For users of toll facilities, open or hybrid toll-collection systems have the advantage of faster traffic movements, improved travel times, and improved safety conditions. However, the development of open road or hybrid systems requires the installation of an ITS system and the establishment of a customer service center, which represents an ongoing cost for the toll-road agency. Open toll-road systems also require ongoing operational costs relating to customer account maintenance and violation enforcement. Open and hybrid toll-road systems tend to increase throughput, resulting in increased use and revenue generation. However, there may be an increase in revenue losses because violators have greater opportunities to avoid payment. Because video tolling can be used in either an open or hybrid toll-collection system, it has been described as a separate system. Table 3 compares the payment and enforcement methods as well as the advantages and disadvantages between closed, open, and hybrid toll-collection systems.

2.2.5 Congestion Management

Toll-road facilities designed for congestion management purposes—express lanes and HOT lanes—have been designed specifically to improve traffic flow, especially during peak periods. These facilities are typically located adjacent to non-tolled, general-purpose lanes in congested urban highways. Access is gained by drivers only if they pay a toll or meet designated vehicle occupancy requirements. Free access to mass transit vehicles is also typically offered. Access requirements and pricing structures for express/HOT lanes vary. In some cases, only single occupant vehicles (SOVs) are required to pay a toll, while in other cases, SOVs are not permitted access at all, HOV-2 drivers (those with only two occupants) pay a toll or monthly fee, and HOV-3+ drivers (those with three or more occupants) travel toll-free. Some HOT lanes have charged constant rates, but increasingly, HOT lanes use some form of value pricing (sometimes also called congestion or variable pricing), which adjusts tolls based on traffic periods or conditions. Tolls are highest during peak travel periods and lowest in off-peak periods, with the rates designed to maintain free-flowing traffic conditions.

To manage congestion, toll agencies have implemented variable pricing, in which the toll rate charged depends on the time of day (variable/static) or congestion levels (variable/dynamic). Variable/static pricing is defined as having a set schedule of tolls that vary throughout the day, often in hourly increments based on recent historical data. Variable/static pricing often includes peak period pricing, which uses price disincentives to discourage facility use during peak periods. Facilities that have implemented variable/static pricing include the Tappan Zee Bridge in New York, I-25 in Colorado, SR-91 in California, Toronto 407, and two bridges operated by Lee County, Florida.

Under variable/dynamic pricing, the toll rate fluctuates based on real-time traffic information. This pricing method requires variable message signs that display the toll rate before the decision point (e.g., the point where a motorist must decide whether to take the toll route or an alternate route). The use of variable/dynamic pricing requires the monitoring of vehicle speeds, volumes, and/or traffic density. Toll rates are set according to a predetermined algorithm. Tolls on existing facilities can change as often as every 3 to 6 minutes. San Diego's I-15 express lanes and Minneapolis's I-394 MnPass express lanes are examples of facilities that use variable/

Table 3. Comparison of closed, open, and hybrid toll-collection systems.

Toll System Option	Closed Toll Collection	Open Toll Collection	Hybrid
Description and payment method	• Drivers pay at manned tollbooths or at automated coin machines (ACMs) • Lanes have gates	• Gantry-mounted collection equipment • ETC-only lanes • Gates possible but not likely	• Mixture of barriers, ETC, and/or video tolling
Enforcement method	• Gates • Video cameras • Toll attendants • Police	• Video cameras • Police • Bills are mailed	• Some gates • Video cameras • Toll attendants • Bills are mailed • Police
Advantages	• Fewer violations if gated • Lower probability of customer account errors	• Increased throughput along the facility • Increased revenues • Minimum violation rate at gated areas • Strategically placed gates	• Balances increased throughput and traffic flow with lost revenues
Disadvantages	• Gates decrease throughput • Cost for tollbooths and attendants • Bottlenecks at tollbooths • Employee theft • Equipment malfunctions • Increased potential for accidents at tollbooths • Lower throughput can result in lower revenue generation	• Account management and back office costs • Violation processing and collection costs, (e.g., court, collection agencies, liens) • High violation rate without gates leading to more lost revenues • Legal actions can result in negative publicity	• Incurs both barrier system and ETC costs • Bottlenecks/accidents at collection points due to driver confusion • Higher violation rate than gated system

Source: Jacobs Engineering Group, 2010

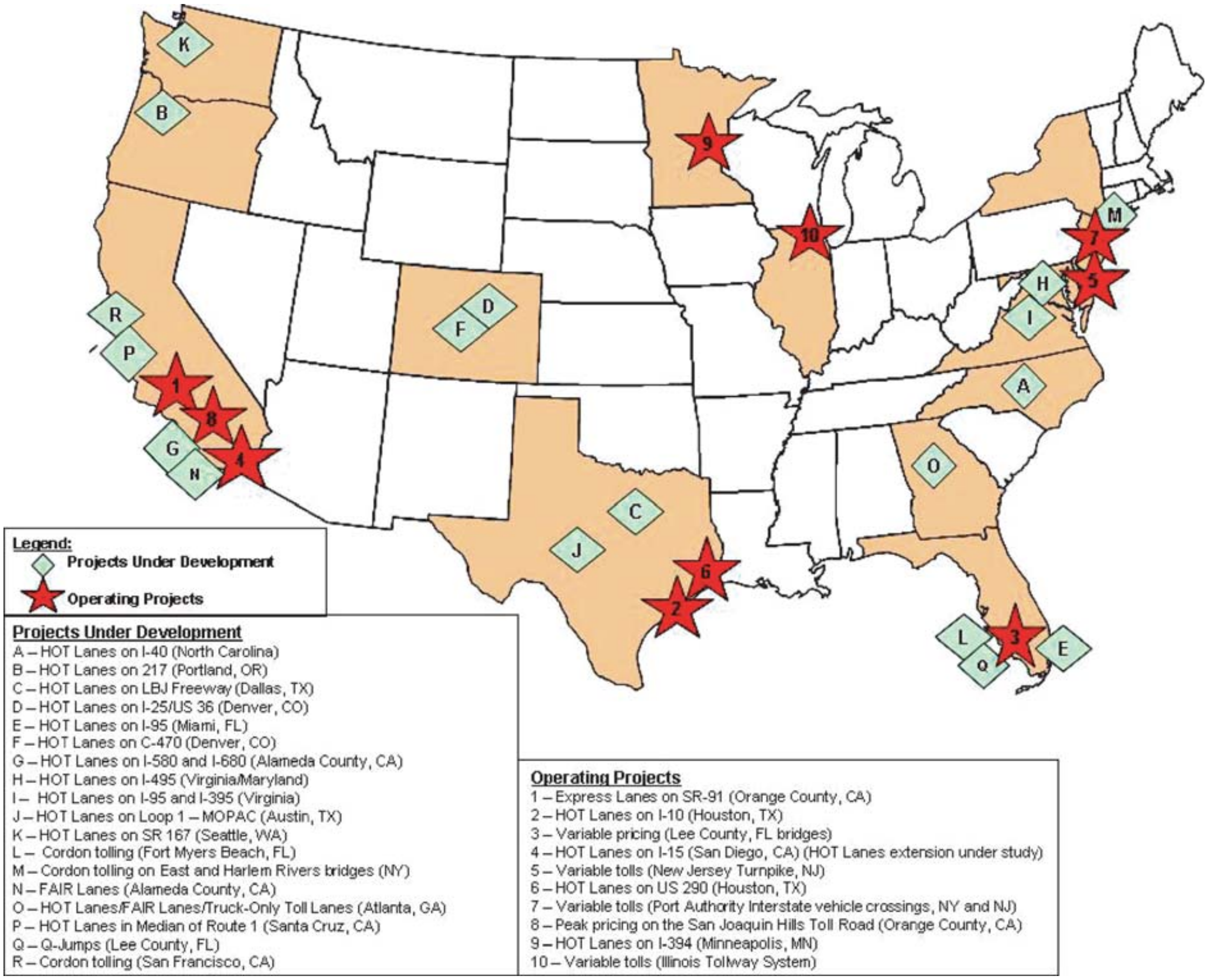
dynamic pricing. Figure 7 summarizes the existing and planned projects in the United States that involve the development of HOT lanes, express lanes, or variable pricing mechanisms.

2.2.6 Leakage Rates

The calculation of leakage rates is a common practice used by toll agencies to estimate the number of transactions for which they have not received payment. Below are the definitions used by the International Bridge, Tunnel and Turnpike Association (IBTTA) with regard to toll violations and leakage:

- Leakage: Transactions where no revenue has been collected or revenue is not fully collected. Leakage does not include non-revenue or violation transactions wherein the vehicle is either not permitted to cross the barrier or where a violation image is taken.
- Variance: An error in the toll communication system that occurs when something between the onboard and roadside dialogue has failed.
- Violation: A record of an unpaid toll that occurs when a customer does not pay the proper amount.
- Transaction: A time-framed event occurring in the toll lane representing either a cash or electronic toll. The transaction is identified by all or a combination of the following parameters: location, time, date, vehicle class, vehicle ID, and toll amount.

Because of the different disclosure requirements, system configurations, technologies employed, and metrics used, it is relatively difficult to provide a direct comparison of toll agencies with respect to toll leakage. While some agencies will disclose debt that has been written off and/or disclose the amount of revenues that may not be collected, the manner in which these numbers are derived and the factors that influence these



Source: AE COM, 2006

Figure 7. Congestion management projects in the United States.

parameters are not always apparent. It should be noted that industry rules of thumb estimate toll system leakage to be between 5% and 10%. Below are some of the main issues that influence the reporting of toll leakage:

- Limited information disclosure: Because of the sensitivities involved, some toll-road authorities may be reluctant to publicly report leakage information, especially if leakage rates are relatively high. The publication of leakage information could have negative impact on existing debt obligations as well as potentially encouraging additional violations. Similarly, private-sector developers that are publicly traded tend to avoid the publication of this information since this could have a negative impact on their stock price.
- System configuration: System configuration will also affect toll-system leakage rates. Toll systems with more access and entry points will likely have higher leakage relative to comparable toll systems with fewer entry points. Similarly, toll systems that use and maintain a higher percentage of physical barriers throughout the system (e.g., gates, retaining walls, and/or Jersey barriers) will likely have lower leakage rates. Along these same lines, it is more difficult to directly make the following comparisons: (i) systems with single-project authorities versus multi-project toll systems, (ii) urban versus rural systems, and (iii) toll systems with mostly long-distance roads versus bridge systems.
- Technology used for enforcement: The estimation of leakage rates will also be affected by the extent to which the system uses cash rather than electronic toll collection. A mostly cash system will place greater reliance on more physical measurements of road usage such as gates, in-lane traffic count equipment, eyewitness reports, and traffic citations. In contrast, ETC systems will rely more heavily on camera and video recognition systems. Similarly, leakage rates may differ on systems that collect front and back license plate information versus ETC systems that use only back license plate information. The inability to trace temporary or other paper license plates will also affect toll-system leakage rates.

- Different metrics used: At present, there is no formal, standard industry metric for determining and reporting toll leakage, and a number of agencies use more than one metric. These metrics can be based on total annual transactions, total annual revenues, or some combination of these parameters. Even if some toll agencies use the same metric, there is considerable variability in how the formulas are calculated. This can lead to different conclusions with respect to total toll leakage as well as creating an incentive for smoothing the results.

2.2.7 Administrative Fees and Criminalization of Toll Violations

Toll-violation enforcement is a significant issue for all toll-collection methods. There is a direct correlation between the type of toll-collection method used and the type of violation enforcement measures that should be considered and installed. This correlation relates to the ability to prevent violations and to collect payments from violators. Enforcement activities are either undertaken in-house or are contracted out to third party (public) agencies. Issues related to violation enforcement include (i) the physical detection and prevention of toll violations and (ii) the prosecution and accountability of toll violators using legal methods.

Detection and Prevention

Detection and prevention of toll violations can be undertaken using the following methods:

- Gates: Gates will not open until payment is registered.
- Toll attendant observation: An attendant records the license plate number of the vehicle that he or she observed not paying. Information is logged on paper or electronically and is cross-referenced against motor vehicle records to determine vehicle ownership.
- Camera/video enforcement system: A picture of the license plate is taken if the system fails to record an ETC or cash payment associated with that vehicle. The license plate is cross-referenced against motor vehicle records to determine vehicle ownership.
- Police/law enforcement: Police observe nonpayment and pursue violator.

Accountability and Prosecution

Toll violators can be made accountable for their actions using the following legal methods:

- Traffic offense: Failure to pay may result in traffic citation.
- Civil offense: Failure to pay may result in collection efforts, including sending notices of nonpayment, filings in civil courts, use of collection agencies, placing property liens, credit reporting, driver's license or license plate holds, and vehicle impounding.
- Criminal offense: Failure to pay may result in charges of theft with restitution required.
- Administrative fees: Failure to pay may result in additional administrative fees.

The main differences between civil and criminal enforcement typically are the costs of administration relative to the level of deterrence desired or needed. Specifically, civil enforcement is less expensive to administer and offers greater control in processing violations, but it may provide less of a deterrent to violations. Examples of toll facilities that use civil enforcement include the Illinois State Toll Highway Authority and the Orange County Transportation Authority.

Criminal enforcement is a stronger deterrent against toll violations because of the possibility of the imposition of larger fines and possible imprisonment. However, criminal enforcement may be more expensive to administer and more difficult to coordinate since it involves prosecution under criminal court proceedings. Criminal enforcement requires coordination with police authorities, courts, and prosecutors. From a cost perspective, a toll agency would need to determine if the costs of the desired enforcement mechanism are reasonable given the projected return in revenues and fees. Examples of toll agencies that use criminal enforcement are the Delaware River Joint Toll Bridge Commission in Pennsylvania and New Jersey and the Harris County Toll Road Authority in Texas.

In either circumstance, civil or criminal, unless specifically prohibited, the state always retains (or should reserve) the right to pursue the collection of fees and penalties owed to it through all available means, including withholding privileges administered by the state such as vehicle registration. Whether toll data are subject to legal proceedings and can be released to outside parties (e.g., those involved in non-highway criminal, civil, or matrimonial issues) depends on the existing statutes within each state. Generally, state public information or open records laws require the release of information that a governmental entity collects or that is retained on its behalf. Because electronic tolling requires the collection of personal information (name, address, phone number, credit card, vehicle description, license plate, etc.), states have amended their statutes to prevent the unauthorized release of this information and to limit release to certain circumstances. This can include court order, toll enforcement, and the investigation of a felony offense. The retention of personal data is typically limited to only the period necessary to collect outstanding toll and fee amounts due to the agency.

With the increase in the number of electronic toll facilities around the country, the collection of personal data has generally had a limited impact on user acceptance. Ease of travel has

Table 4. Comparison of civil and criminal enforcement systems.

Civil Enforcement		Criminal Enforcement	
• Fewer administrative costs • Less evidence required to render a violation decision • Can better control processing for quicker resolution • Trial location may be more flexible	• Less effective a deterrence, especially for repeat offenders • Typically shorter statute of limitations	• Increased seriousness of the offense can lead to stronger deterrence • Typically longer statute of limitations	• Higher administrative costs • Requires great coordination efforts and involves more individuals/ processes over which the agency may have no control.

Source: Jacobs Engineering Group, 2010

typically outweighed privacy concerns. Nonetheless, some agencies offer anonymous ETC accounts for individuals who do not want to divulge personal information. Additionally, many state laws limit toll violation photos to license plates. Table 4 summarizes the main differences between civil and criminal enforcement systems.

2.2.8 Tolling Administrative Cost Estimation and Comparisons

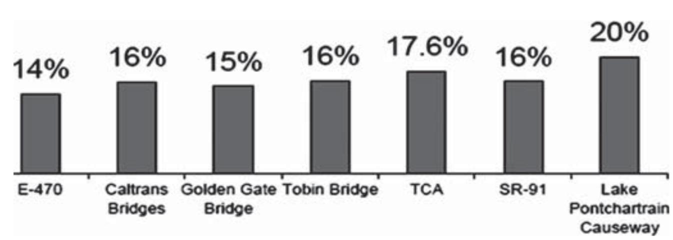
In a report prepared for the U.S. Department of Transportation, HDR estimated the differences in administrative costs for various revenue-generation systems as alternatives to the fuel tax (HDR, 2009). The report analyzed a video-based tolling system, an automatic vehicle identification (AVI) based tolling system, and a GPS-based tolling/VMT system. The study found that the administrative costs of video- or AVI-based systems were significantly higher than the costs of collecting the fuel tax. At the national level, the GPS-based system had the lowest costs among the technologies employed, but it was still much higher in cost than the fuel tax system if the hardware was included as part of the cost.

Comparative Analysis of Tolling Systems in the United States

Although a wide body of literature has been published on tolling-system activities, only a few reports compare the costs of toll collection among toll systems. Most toll agencies are extremely cautious in releasing their financial data because this could have an impact on their cost of capital for upcoming bond issues, their bond covenant requirements, and intergovernmental agreements among toll agencies. Toll systems financed with private capital have additional concerns relating to stock prices (if publicly traded). Because of the increased shift toward the implementation of ETC systems and other broad shifts within the tolling industry, this section focuses on reports that have compared tolling systems within the last 3 to 5 years.

A report commissioned by the Washington State Department of Transportation (WSDOT) in 2007 examined the costs of toll-collection activities for seven toll systems. The intent of this report was to develop a comparative cost estimate with respect to toll-collection activities for toll systems that are similar to the Tacoma Narrows Bridge (TNB), which was scheduled to open later that year. The WSDOT report used annual financial reports as its primary data sources. In addition, each agency was contacted to collect information at a level that would be useful for comparison to the estimated operational costs for the TNB. In an effort to normalize cost data between toll systems, the analysis performed in the WSDOT report accounted for variations in traffic volumes, toll-collection methods, governance structure, violation rate, accounting practices, and bond covenants. The report attempted to exclude capital and maintenance costs related to physical infrastructure. The analysis found that toll-collection costs as a percent of revenues ranged from 14% to 20% (Figure 8). Moreover, the cost per transaction ranged from $0.23 to $0.56 (WSDOT, 2007). The study found that collection costs did not vary significantly between toll systems with high rates of ETC use versus lower rates. However, the analysis did not attempt to differentiate between administrative, collection, and enforcement costs.

Another report commissioned by the U.S. DOT attempted to compare the costs of fuel taxes, VMT, and tolling systems. With respect to tolling, that analysis developed a financial



Source: Washington State Department of Transportation, 2007

Figure 8. Toll-collection costs as percentage of revenues.

Table 5. Comparison of capital and operating costs between toll-collection systems.

	Video		AVI		GPS	
Corridor length	10-mile	1000-mile	10-mile	1000-mile	10-mile	1000-mile
% of revenues	151%	14%	111%	10%	53%	12%
VMT (000)	$2,259	$225,930	$2,259	$225,930	$2,259	$225,930

Source: HDR, *Comparing Administrative Costs of Collecting Highway Revenues: Fuel Tax vs. Direct User Charge*, Prepared for the Office of Economic and Strategic Analysis, U.S. Department of Transportation, February 2009

model that was used to forecast toll-collection costs and revenues over 20 years. The analysis included both capital costs for implementation and operating and maintenance (O&M) costs. The model was based on a 10-mile corridor and a 1,000-mile corridor, with three lanes in each direction and tolling points every 20 miles. The cost data for that study were derived from seven toll systems, including the I-394 project in Minnesota and proposed projects in California, Georgia, and Florida. The study also looked at video-based, AVI-based, and GPS-based systems for toll collection (Office of Economic and Strategic Analysis, 2009).

That analysis did not find much variation in the initial capital costs related to these toll-collection systems. As a result, toll collection and administrative costs were identical with respect to VMT over 20 years (Table 5). Although video-based tolling was more expensive to operate over the 1,000-mile corridor (14% of revenues), it did not differ substantially from the methods using AVI (10%) and GPS (12%). For the 10-mile corridor, the video and AVI methods were cost prohibitive, with the capital and operating costs exceeding the revenues. However, this analysis did find that GPS-based systems were less expensive to operate over a 10-mile corridor (53% of revenues) than the other two methods in that corridor (HDR, 2009).

Comparative Analysis of Tolling Practices Outside of the United States

A report presented at the 2006 Conference on Road Charging Systems in Paris studied a number of European and Asian toll and cordon facilities. The Austrian, German, and Swiss systems use tolls to raise funds for financing highway operations and expansion in addition to congestion management. The other three systems (London, Stockholm, and Singapore) are cordon tolling systems designed to cut congestion in CBDs. For the tolling systems, capital and operating costs as a percent of revenues ranged from 8% in Switzerland to 23% in Germany. Capital and operating costs as a percent of total revenues for cordon pricing programs ranged from 40% in Stockholm and Singapore to 55% in London (Table 6) (Oery and Trans, 2006).

2.3 VMT Fees

VMT fees can be implemented in a variety of ways. They can be limited to specific areas or facilities or they can be comprehensive. They can be collected based on simple odometer readings or calculated based on careful evaluation of all travel done by a vehicle. They can be a flat fee for each mile driven or can be varied by time of day, class of road, geographic area, or direction of travel. It may even be feasible to set separate prices for each lane of a road. They can be the same for all vehicles or varied based on vehicle characteristics.

The simplest type is a flat fee or charge that is based on the number of vehicle miles driven. Where vehicles are driven outside of the jurisdiction levying the charge, there will likely have to be a method to determine where the miles were driven. Charging for all VMT could be viewed as unfair for those with substantial travel in other jurisdictions, and if multiple jurisdictions impose charges, there will be concern about the allocation of revenue. Under fuel taxes, the state tax on gasoline is collected based on the location of the service station. This works reasonably well for people on long trips since they are likely to purchase gas in some proportion to the miles driven in each state. However, people who live in one state and work in a bordering state may have substantial use of roads in a state where they seldom purchase fuel. For diesel use by heavy vehicles, the tax is allocated under the IFTA based on where the vehicle is operated rather than where fuel is purchased.

2.3.1 Prices Set to Improve Management of the Road System

VMT charges can be varied based on level of congestion, class of road, road damage done by the vehicle, or pollution and other externalities generated by the vehicle. Such charges are fairly rare, but there is growing interest in using the price system to better manage the road system (CBO, 2009).

The economically efficient set of charges would generate incentives for the most efficient use of the road system, but there are complications and trade-offs. Perhaps the most important complication is that the efficient prices may not generate the appropriate amount of revenue. For cars and other

Table 6. Approximate costs and revenues for selected tolling and cordon systems outside the United States (2005).

	FACILITY					
	Tolling Systems			Cordon Systems		
	Austria*	Germany*	Switzerland*	London*	Stockholm***	Singapore
Operating costs	€35 m/a	€620 m/a Toll collect (incl. capital costs) €50 m/a BAG****	€35 m/a	€133 m/a	€40 m/a (€20 m/a estimate for permanent system)	€7 m/a
Average charge	€0.27/km (40 t truck)	€0.12/km (40 t truck)	€0.67/km (40 t truck)	€7.4/day (now €11.8)	€2.7/day	€0–2 per trip
Fee income	€770 m/a	€2 860 m/a	€800 m/a	€275 m/a	€80 m/a	€39 m/a
Operating costs as a % of revenues	9%	16%**	4%	48%	25%	7%
Annualized costs (incl. capital costs) as a % of revenues	12%	23%**	8%	55%	40%	40%

* Presentation by Bernhard Oehry, Rapp Trans; data for London facility does not include the Western Extension.
** Including costs of deployment, construction, operation, and development of the infrastructure network.
*** Stockholm figures for 2006.
**** For enforcement under the Bundesamt für Güterverkehr (BAG), or Federal Office of Freight Transport.
Source: Conference on Road Charging Systems, Technology Choice and Cost Effectiveness, Paris, June 1, 2006

light vehicles, the primary concern is congestion. The impact on congestion will depend on the level of congestion, and this is likely to vary for several reasons. First, there is systemic congestion, which is associated simply with the number of people using the road. This is subject to certain patterns of congestion as well as to random variation. Second, there is bottleneck congestion, which is associated with capacity constraints on a road, either due to physical differences, such as reduced number of lanes, or operational conditions, such as on-and-off traffic. Finally, there is incident congestion, associated with accidents, weather, or other factors that may interfere with traffic flow (CBO, 2009). When setting prices for congestion, there is a trade-off between the ability to manage congestion efficiently and the ability of the driver to make decisions based on the efficient price. Prices set in advance may not accurately reflect conditions at any given time, but prices that vary dynamically may not allow the driver sufficient advance information to change behavior. Charges based on congestion management would generate little or no revenue on low-volume roads, especially outside of urban areas.

Charges for externalities that vary with miles driven could also be included in efficient VMT fees. Externalities can be different under different circumstances and may be mileage based or based on other characteristics, such as amount of fuel used (Parry, Walls, and Harrington, 2007).

For heavy vehicles, the cost imposed on the road relates to the size of the vehicle and to the operating characteristics. Because of the size and possibly slower acceleration, more room for braking, and problems with steep road grades, heavy vehicles are often compared with light vehicles in terms of road capacity used by means of passenger car equivalent (PCE) measures. The PCE will vary based on a variety of characteristics, including the level of congestion and steepness of road grade, and this may be the best determination for congestion-related charges to heavy vehicles. In addition, heavy vehicles cause substantial damage to road pavement based on the weight per axle and certain other characteristics of the vehicle. This damage also varies with the ability of the road to withstand heavy loads. Thus, the efficient charge for a heavy vehicle would also vary with the class of road, weight of the vehicle, and number of axles (Small, Winston, and Evans, 1989).

2.3.2 Review of U.S. Experience

VMT fees are not directly used for most road financing in the United States; however, there have been a number of experiments with distance-based charges, and several states have used weight-mile taxes for heavy vehicles. Most of the experiments have been based on using GPS to determine the location of the vehicle; however, Donath et al. (2009) proposed a system that would rely on location data related to cell phone towers as a promising near-term solution to determining where a vehicle is being operated. This system has not been tested, and no cost estimates were provided. There is interest in odometer-based or self-reported VMT systems, but Sorenson et al. (2009) reviewed near-term options for implementing VMT fees and concluded that odometer-based systems would require major changes to DMV operations and databases.

Oregon VMT Experiment

The Oregon mileage-charging experiment has generated substantial interest (Rufolo and Kimpel, 2008; Whitty, 2007; and Kim et al., 2008). In the experiment, participating vehicles were charged a mileage fee and received a refund of the state gas tax when they fueled at participating stations. Some vehicles were charged a flat fee for all miles driven in Oregon, while other vehicles were charged a premium rate for driving in the Portland metropolitan area during weekday rush hours and were charged a discounted rate for all other driving in Oregon. Vehicles were not charged for driving outside of the state and did not receive rebates for gas taxes paid to other states.

There are several distinct advantages to this system as a mechanism for collecting revenue. Since the fuel tax is the default, the majority of revenue for the system is collected from the distributors who pay the fuel tax. This substantially reduces the potential for evasion and the need for enforcement mechanisms. People who do not pay the mileage fee default to paying the gas tax. In addition, the state has limited need to audit or monitor individual motorists or vehicles. It should be relatively simple for a computer system to compare gas tax refunds with miles driven to flag vehicles with anomalies for audit. In general, the state would regularly have to audit the service stations only with respect to the net difference between the mileage fee collected and the gas tax included in the wholesale purchase of fuel. The system shows promise as a method to transition from the fuel tax to a mileage-based fee, and it could support congestion pricing at some point. Despite the positive aspects of the experiment, there appear to be both technological and non-technological issues that deserve further consideration.

While the system is compatible with congestion pricing, congestion pricing is only feasible if the majority of vehicles are participating. Yet the system is projected to be installed only on new vehicles. Since the phase-in period is expected to be fairly long, this does not seem to be a reasonable short-term system for using pricing to address congestion problems. Also, the system does not distinguish factors that affect the impact that a vehicle has on the level of congestion (e.g., class of road or direction of travel), although it does charge for each mile driven in the defined area.

The technological improvements required relate to the cost and reliability of the system. In general there is going to be a trade-off between cost and reliability. For the system tested, estimates of the mileage by zone were compared with the odometer mileage for some vehicles, and the differences were as high as 20% (Kim et al., 2008). In addition, the geographic refinement of the zones was limited. For a revenue collection system, users must be convinced that the system is fair, and discrepancies in the determination of location or mileage may create problems. Hence, costs may have to come down substantially to allow a system with enough reliability to be used for revenue collection, or some capabilities may have to be omitted during the phase in. If the capabilities (e.g., for congestion pricing) are left out of the early vehicles, then the implementation for congestion pricing could be further delayed.

The system relied on radio frequency (RF) communication between the vehicle and the fuel pump. For fueling transactions, the signal strength was required to reach a pre-specified level before the vehicle was clearly identified as fueling at a specific pump. This appears to have resulted in a substantial number of transactions that were not identified as being for participating vehicles. Spacing of the pumps, the level of RF interference, and other factors may have affected the reliability of the system, and failed connections created some problems for the system. If not identified as a participant, the vehicle was charged the state gas tax and not the mileage fee. At the next transaction, the mileage fee from the last identified connection would be charged, but the refund would only include the gas tax on the current purchase. The owner had to submit a receipt showing the gas tax paid in the interim fueling to get the appropriate refund of the state gas tax. Greater reliability is needed for an operational system, and this is likely to increase the actual deployment cost relative to the cost incurred in the experiment.

Miles driven with no GPS signal were not charged. The GPS was left on at all times to minimize the number of miles driven that could not be allocated, but this resulted in battery problems for a large number of vehicles.

Behavioral responses may not all be positive. Even with a flat fee per mile that approximated the gas tax, some people reported reducing driving simply because they became more aware of short trips and cost. There was some evidence that the flat fee induced people to group trips. This reduced the total number of trips, but since drivers appeared to group these trips with their rush-hour trip to or from work, it may have increased rush-hour travel. If the grouping resulted in more travel on uncongested local streets, it would not be a problem; however, if the travel were on congested arterials or other roads, the flat fee pricing may have a negative effect on congestion. This could be exacerbated if it increased the amount of stopping and starting (e.g., through more on-street parking) and further disrupted traffic. The effect of a flat mileage fee on rush-hour travel should receive further analysis.

Finally, major oil companies did not agree to allow their gas stations to participate in the Oregon experiment. Since they represent the majority of stations, the reasons for their refusal should be clarified and addressed.

Puget Sound Regional Council

The Puget Sound Regional Council sponsored a project to equip vehicles with a device to track all road usage in the area and set prices based on the class of road and time of travel. Detailed information on all travel by a vehicle was collected and uploaded regularly by cellular transmission. The system is reported to have worked well, but complete details have not yet been released.

A number of issues were identified that need to be addressed before the system can be implemented (Puget Sound Regional Council, 2008). These include further refinement of the system and design of enforcement and billing systems. In particular, there was no enforcement mechanism in the design of the experiment, and an enforcement system would have an additional cost. Dense road networks without access controls were identified as a concern for the pricing system. The trade-off between having data processed on the vehicle with summary data sent to the billing center versus uploading of all data for processing at a central location was identified as having privacy implications as well as communication cost implications. The detailed information on travel collected did not appear to be a concern for the participants, but it would almost certainly be a concern if participation were not completely voluntary. Implementation of a full-scale system is projected to have a mechanism for non-participants that could also maintain anonymous usage. Also, the area subject to the pricing seems to have been limited by the storage capacity of the system. The cost of the initial installation of the GPS and communication costs were identified as key concerns, but declining costs over time for each were also noted.

Iowa Pooled Fund Study and Extension

The Iowa Pooled Fund study designed a GPS-based system that could track miles driven by area and could include a variety of areas with varying degrees of overlap and separate pricing systems. All data are maintained in a secure environment, with only total amounts owed by the vehicle to each jurisdiction generally available. The data were uploaded regularly using a smart-card system. If there were a dispute regarding amounts owed, the vehicle owner could decrypt the data to show detailed travel information (Forkenbrock and Kuhl, 2002).

A system similar to this is undergoing extensive testing over a number of years and seven locations. It will be some time before the conclusions from this extended study will be available. However, the basic design is likely to follow that described by Forkenbrock (2008). It is likely to be somewhat different from the initial experiment. The onboard computer will have the capability to store polygons so that charges can be varied by geographic area but not by road. It is expected that there will be differentiation by state but that local governments could also add charges for travel within their jurisdictions. The computer may have the capability to use more detailed files to identify class of road so that differential prices could be charged for different roads. For periods without a GPS signal, the information from the odometer will be used to generate charges, and the comparison between the GPS mileage and the odometer mileage will be used to monitor the system. Billing data will be uploaded once per month to a central billing operation. The billing center will only receive information on the total bill and the apportionment among jurisdictions. During the upload, updated fee files could also be sent to the vehicle. The fee structure could be specific to vehicle classes, with characteristics such as fuel efficiency and emissions affecting the rate charged.

Pay-as-You-Drive Experiments

Several of the experiments in the FHWA's Value Pricing Pilot program were designed to convert some of the fixed costs of driving to variable costs. These used different types of technology and helped to identify some of the potential methods to collect a mileage-based user fee (MBUF) as well as some of the potential drawbacks of these approaches. One such study conducted in Minnesota used a commercial system that plugs into the OBDII (an onboard diagnostic system) port to obtain mileage data and tracked total mileage and time for each trip. This allowed for differences by time of day in pricing but would not allow for differences based on location of travel or class of road. In addition, data had to be manually downloaded, and the system is not compatible with all vehicles (Abou-Zeid et al., 2008). A separate account must be set up for each participant and there would have to be a billing or payment system.

Georgia tested a system similar to the one tested in Iowa, but without the encryption, as a method to charge flat VMT fees. An extension appears to be having delays due to instability with the hardware and software.

Lessons from Experiments

The costs associated with the experimental approaches appear relatively high, and operational improvements would be required for implementation of any of the systems on a large scale. Nevertheless, they show that these types of systems are feasible. Since the experiments typically used prototype equipment on a small scale, the expectation is that per-vehicle cost for an operational system would be lower. This would be particularly true if the technology is already in the vehicle for other reasons.

Oregon Weight-Mile

Oregon charges heavy vehicles for mileage based on the declared weight of the vehicle and the number of axles. The charge is intended to equitably allocate the cost of road damage to heavy vehicles since the amount of road damage increases with vehicle weight but decreases with additional axles for a given weight. The system is based on monthly or quarterly reports by owners of heavy vehicles. Only mileage totals are reported. The rate is based on the registered weight of the vehicle and the number of axles to avoid the need for detailed monitoring of load changes. Certain vehicles, such as log trucks, have the option of paying a flat fee, but most vehicles must pay the weight-mile tax. The charge is levied in lieu of the diesel fuel tax; Oregon does not levy a diesel fuel tax on fuel purchased for use in a vehicle paying the weight-mile tax. The mileage reports are based on owner fleet records, and the system is well established (Rufolo, Bronfman, and Kuhner, 2000). Oregon is one of four states in the nation with a weight-distance tax, with the others being New Mexico, New York, and Kentucky.

2.3.3 Review of International Experience

A number of countries levy mileage charges on heavy vehicles, with the German system being the most studied. The Dutch have proposed charging all vehicles for all road usage, with the charge varying based on both vehicle and road characteristics.

German Truck Fee

The German system levies a fee based on the road, distance traveled, number of axles, and emission class of the truck. The fee is charged on the autobahn system but has the potential to be expanded to other roads. Truck drivers have the option of paying manually at various point-of-sale (POS) systems for trip permits or of having a GPS-based system installed that allows for automatic collection of the tolls. The large majority of tolls are paid using the GPS. The GPS determines the location of the vehicle and uses the location information to determine tolls based on 5,200 toll segments in the system. The information on tolls is then transmitted to a billing system. In addition to the GPS, the system has a dead-reckoning capability for times when the GPS signal is not available. The cost of the GPS is paid by the toll authority, but installation costs are paid by the user. The global system for mobile communication (GSM) is used to communicate with the computer center. The system has additional communication capabilities for enforcement and for interoperability with other European communication systems. The initial start-up had substantial cost overruns, and the units are fairly expensive (Samuel, 2005 and Kossak, 2006). The system used in the Puget Sound study is a simplified version of the German system.

Dutch Proposal

The Dutch have a detailed proposal to move to VMT charges for all road use, although there is still much uncertainty about the specifics of the system. They have compiled a substantial amount of information. Since the system has not been implemented yet, the information compiled in the Dutch system is still somewhat speculative. However, the Dutch completed detailed cost studies and continue to move toward implementation. It appears that the intent to implement road pricing for heavy vehicles starting in 2011 has now been postponed.

2.3.4 Discussion of Issues Related to VMT Fees

A VMT charge will have to be collected and enforced. This has not been a concern for many of the experimental approaches since they did not actually collect any money from participants. The typical procedure was to set an endowment account that was expected to cover the charges a vehicle would incur with no change in miles driven. The mileage charges were then deducted from this account and any balance was given to the user at the end of the experiment. This procedure gave the marginal pricing incentives without creating actual cost or financial risk for the participants. However, it also meant that the experiments were not completely realistic, lacking any bill-paying mechanism and any method to enforce collection when the bill was not paid.

As noted earlier, the Oregon system had a relatively simple mechanism for payment; the charge was adjusted at the pump when the vehicle was fueling. Under full implementation, virtually all collection activity would occur at the fuel pump, and most of the actual revenue would come from the fuel distributors, who would still be liable for the state fuel tax. All of the other systems require that some form of bill-paying system be implemented. In addition, some methods of enforcement and auditing will be required. Finally, some method of reconciliation when customers dispute their charges must be implemented.

There are substantial trade-offs between system capabilities, cost, and complexity. The simple systems just keep track of total miles traveled. Somewhat more complex systems keep track of mileage by geographic area. The most complex systems are those that require identification of class of road. Aside from the need for more detailed information, the potential for error in identifying roads typically requires additional capabilities to improve accuracy.

Both the Oregon and Minnesota systems get data from the OBDII port. It appears that the OBDII port may be problematic as a general requirement. First, it was only required in vehicles starting in 1996, but some vehicles with the port do not meet all of the specifications. Both experiments had problems with certain vehicles due to issues with the OBDII port. In Minnesota they were excluded from participation, and in Oregon these vehicles were equipped with an alternate system that simply used the GPS to calculate miles traveled. Also, in the Oregon experiment, there were discrepancies between the miles driven as calculated using speed data from the OBDII port and miles from the odometer reading.

Any system to collect revenue will be subject to evasion and avoidance behavior. Both may be relevant in terms of evaluating a VMT system. Some systems will be designed to induce avoidance (e.g., congestion pricing systems), but others may induce inefficient behavior. For example, a system like Oregon's, which charges by the mile in-state but has no charge for out-of-state mileage, could induce a driver to make a long trip along the Washington side of the border with that state. This would reduce the amount of mileage fee owed to Oregon without affecting the gas tax rebate. Evasion is a larger problem. With a GPS-based system, this might be accomplished by blocking the antenna to prevent signal acquisition. Since signals may be problematic in some areas, such as those with large buildings or forests, it may be difficult to determine whether there has been purposeful interference or a natural problem.

There must be a mechanism for audit and reconciliation if there are differences between the amounts that the system charges motorists and their view of an appropriate level of charges. If integrated with the gas tax, the POS software requires substantial modification to allow the system to interact with the mileage-fee system. Some determination of the cost for this conversion and determination of who will be responsible should be made. It would also be necessary to substantially improve the ability to detect which pump a vehicle is being fueled at since missed reads create both an accounting and a customer-relations problem. The accuracy of the system will be more important as the number of vehicles participating increases, since there would be more possibility of interference or incorrect association between a vehicle and a pump.

For more complex systems, information on prices must be communicated to vehicles and displayed to drivers. There should also be a method to update information. This is likely to be necessary if there is any intention to change fees over time.

There are several equity issues that must be addressed. If the fee is simply a mileage fee for equipped vehicles, equity between equipped and non-equipped vehicles will be an issue. One possibility would be to refund an estimate of the gas tax based on miles driven and EPA mileage estimates. Other equity concerns relate to equity between vehicle classes, geographic equity, and equity relative to income.

If the system is to be used for road management, some determination must be made of how the system will be phased in and what level of coverage is needed to make the system effective. For example, congestion pricing is not likely to be effective unless most vehicles face the congestion charge.

There may be a need to pass enabling legislation or apply for existing exceptions allowing for a charge to be levied on the Interstate highway system. To encourage interstate commerce, the legislation creating the Interstate system prohibited the use of tolls on the system. A number of toll roads were incorporated into the system and allowed to continue using toll revenue; however, roads built from that point on as part of the Interstate system could not have tolls levied. ISTEA allowed for some exceptions to this prohibition, but it generally still prevails. Detailed discussion of the prohibitions, exceptions, and legal issues are presented in Fishman (2009, pp. 20–28). Information on the use of tolls on the Interstate system can be found in FHWA (2009a).

2.4 Cordon Pricing

Cordon pricing systems have been implemented in Singapore, London, Oslo, Stockholm, Milan, Malta, and several small cities in Norway. The objectives of implementing cordon pricing systems are to reduce congestion in congested areas with relatively high densities, to raise funds to finance infrastructure development, and to reduce vehicle emissions. Additionally, public agencies have used congestion pricing policies to manage vehicle ownership rates in areas with high population densities, encourage greater walking or cycling, and induce transit usage. Other potential benefits of cordon pricing include reductions in vehicle emissions, decreased fuel consumption, and improved safety conditions.

Public acceptance is one of the major obstacles encountered in the implementation of the cordon pricing system. For example, in the early 1980s, Hong Kong implemented a cordon pricing system on a pilot project basis, but it was later discontinued due to public opposition. Cordon pricing systems were also considered in Edinburgh, United Kingdom, which held a referendum on the implementation of a two-cordon system. More than 74% of voters rejected the cordon pricing scheme in a referendum held in 2005. Concerns were raised regarding the potential fairness to local residents who live in outlying areas as well the potentially negative impact on local businesses. Table 7 summarizes the locations in which cordon (or congestion) pricing systems have been adopted or considered. In this section, the operational and financial performance of the Singapore, London, Oslo, Stockholm, and Milan systems will be examined in greater detail. The financial performance of four of these systems (not including Singapore) will also be compared with tolling systems in the United States and Canada.

The remainder of this section is divided into six subsections. The first five subsections describe cordon pricing systems that have been implemented in a country or major cities, and the last subsection provides a summary analysis for the five systems presented.

2.4.1 Singapore

Overview of the Singapore System

The Singapore system was the first cordon pricing system ever implemented, initially instituted as a manually based

Table 7. Summary of operational and proposed congestion pricing systems.

Location	Date Adopted	Coverage Area	Status
Singapore	1975	Central business district, 66 gantries	Operational
Hong Kong	1983	Toll tunnels linking Hong Kong and Kowloon Pensinsula	Demonstration project cancelled in 1985
Bergen, Norway	1986	Urban ring road, eight toll stations	Operational
Oslo	1990	Urban ring road, 19 toll stations	Operational
Trondheim, Norway	1991	Urban ring road, 22 toll stations	Operational
Kristiansand, Norway	1992	Partial ring road, five toll stations	Operational
Rome	1998	6 km^2 area	Operational
Stavanger, Norway	2001	Urban ring road, 21 stations	Operational
Durham, U.K.	2002	Single streets	Operational
Namsos, Norway	2003	Urban toll road, three toll stations	Operational
London	2003	Central business district, expanded in 2007	Operational
Tønsberg, Norway	2004	Urban ring road, six toll stations	Operational
Stockholm	2005	Two zones	Pilot project adopted
Valetta, Malta	2007	Urban cordon	Operational
Milan	2008	Urban 8.2 km^2 cordon area, 43 gates	Operational
Edinburgh, U.K.	N/A	Two cordons, Edinburgh Bypass and Central Business District	Referendum rejected
Manchester, U.K.	N/A	Two cordons	Referendum rejected
New York, NY	N/A	N/A	Considered, but not adopted
San Francisco, CA	N/A	N/A	Considered, but not adopted
Auckland, New Zealand	N/A	N/A	Under study

Source: Jacobs Engineering Group (2010) and Bain and Plantagie (2003)

scheme (i.e., paper tickets checked at various control points) in 1975. This system was developed to manage congestion and system demand, especially within the more congested parts of the CBD, which was designated as a restricted zone (RZ). The RZ covered 610 hectares at the beginning and then was expanded to 725 hectares to include reclaimed land along the seafront as well as newly commercialized areas. The congestion pricing periods have been expanded over time. When the system was first opened for operation, the congestion charge was applied during the morning peak period from 7:30 to 10:15 a.m. except for Sundays and holidays. In the late 1980s, the charging period was expanded to cover the evening peak period from 4:30 to 7:00 p.m. In 1994, the congestion pricing period was modified to cover the off-peak period of 10:15 a.m. to 4:30 p.m., essentially extending the congestion pricing throughout the workday (Yap, 2005).

Operations and Enforcement of the Singapore System

Before being replaced by an electronic system in 1998, cordon pricing was administered manually though the use of paper permits that were checked at 31 control points demarcated by overhead gantries. Additionally, 13 park-and-ride facilities were established at the outer edges of the RZ. To gain access to the RZ during the congestion charge periods, drivers were required to purchase and display a specially marked monthly or daily license. Monthly licenses could be purchased at the post office, while daily licenses were sold at post offices, roadside sales booths, gas stations, and convenience stores. Different-shaped licenses were used for various vehicle classifications. To deter fraud and support enforcement activities, license colors were changed each month. The other manual pricing system in Singapore involved the use of special licenses for use on local expressways during the morning peak period. The congestion zone licenses were also valid. This system was enforced at five separate checkpoints.

Technological improvements permitted the implementation of an electronic vehicle recognition and enforcement system in 1998. The electronic road pricing (ERP) system supported enforcement along a wider area in addition to the manual checkpoints. Moreover, the ERP system reduced the evasion technique of transferring licenses among vehicle owners. This system uses in-vehicle transponders, smart cards, electronic gantries, and a central control center, which processes payment transactions, reviews violation images, and sends out violation notices.

The ERP system is intended to be user-friendly. As a vehicle passes through the ERP gantry, the appropriate charge is deducted from a smart card. If a driver lacks a smart card or is carrying an insufficient balance, then the ERP system will take a picture of the vehicle. The image will be sent to the control center, which will retrieve the vehicle registration number using optical character recognition (OCR) technology. Drivers

Table 8. Singapore traffic statistics, 2004–2008.

Year	Total Vehicles Owned	ERP Gantries	Average Speed (km) Highway	Average Speed (km) Arterial	ADT(*) Entering City	Average Annual VKT per Vehicle Autos	Motor-cycles	Private and School Buses	Light and Heavy Trucks
2004	727,395	45	62.7	26.1	246,000	20,298	13,744	34,266	45,237
2005	754,992	48	63.0	27.2	244,000	20,603	13,711	34,008	46,905
2006	799,373	48	61.6	27.1	270,400	21,100	13,700	34,850	47,300
2007	851,336	58	62.4	26.9	278,300	20,800	13,800	35,250	48,500
2008	894,682	66	63.3	26.7	278,100	19,700	13,300	34,950	46,350
CAGR	**4.2%**	**8.0%**	**0.2%**	**0.5%**	**2.5%**	**-0.6%**	**-0.7%**	**0.4%**	**0.5%**

(*) ADT denotes average daily traffic

Source: Land Transport Authority of Singapore, 2009

without a valid smart card are assessed an administrative charge to cover processing costs (Menon, Gobinath, and Kian-Kong, 2004). Additionally, penalties are assessed for nonpayment in excess of 28 days and violators are required to appear in court.

Impact of the Singapore System on Traffic

The initial decrease in traffic was 44%, which was largely due to a reduction in through trips. During the 1980s, traffic levels within the congestion zone steadily increased as a result of increases in population, economic activity, and vehicle ownership. Because fees are assessed each time a vehicle enters the congestion zone, the ERP system had the immediate impact of reducing the number of multiple trips. To better manage congestion, the congestion charge increases or decreases in accordance with traffic levels, as described below.

To maintain traffic flow, the Singapore Land Transport Authority, which oversees the congestion pricing system as well as the public transit, has instituted an 85th Percentile Speed Measurement Mechanism, in which congestion charges vary to meet an 85th percentile benchmark. The average speed for roads located within the CBD is targeted at 20 km/hour to 30 km/hour. For expressways, the average speed is targeted to be from 45 km/hour to 65 km/hour. When the average speeds exceed the upper threshold, the congestion charge is decreased to optimize road capacity for that facility. To discourage road use during heavy travel periods, congestion prices increase when average speed falls below the lower threshold.

Although financial data on the ERP system are not available, the Singapore Land Transport Authority has compiled statistical information that indirectly measures the effectiveness of this approach. From 2004 to 2008, the ERP system added 21 gantries, which has increased enforcement and helped to maintain traffic speeds on local highways and arterials despite the estimated 4% increase in the number of vehicles per annum. Additionally, the average daily traffic entering into the city has increased at a roughly 2.5% compound annual growth rate (CAGR) per annum. Depending on vehicle classification, the average vehicle-kilometers traveled (VKT) per vehicle have either decreased or remained relatively constant during this period. Table 8 summarizes traffic data within Singapore from 2004 to 2008.

A unique aspect of this cordon pricing system is that Singapore has three separate international ports of entry, including one ferry terminal and two land connections. Foreign vehicle owners can purchase temporary transponders and smart cards. Because some foreign visitors need to enter into Singapore on a regular basis, a number of vehicle owners have found it to be more cost effective to purchase a permanent in-vehicle transponder.

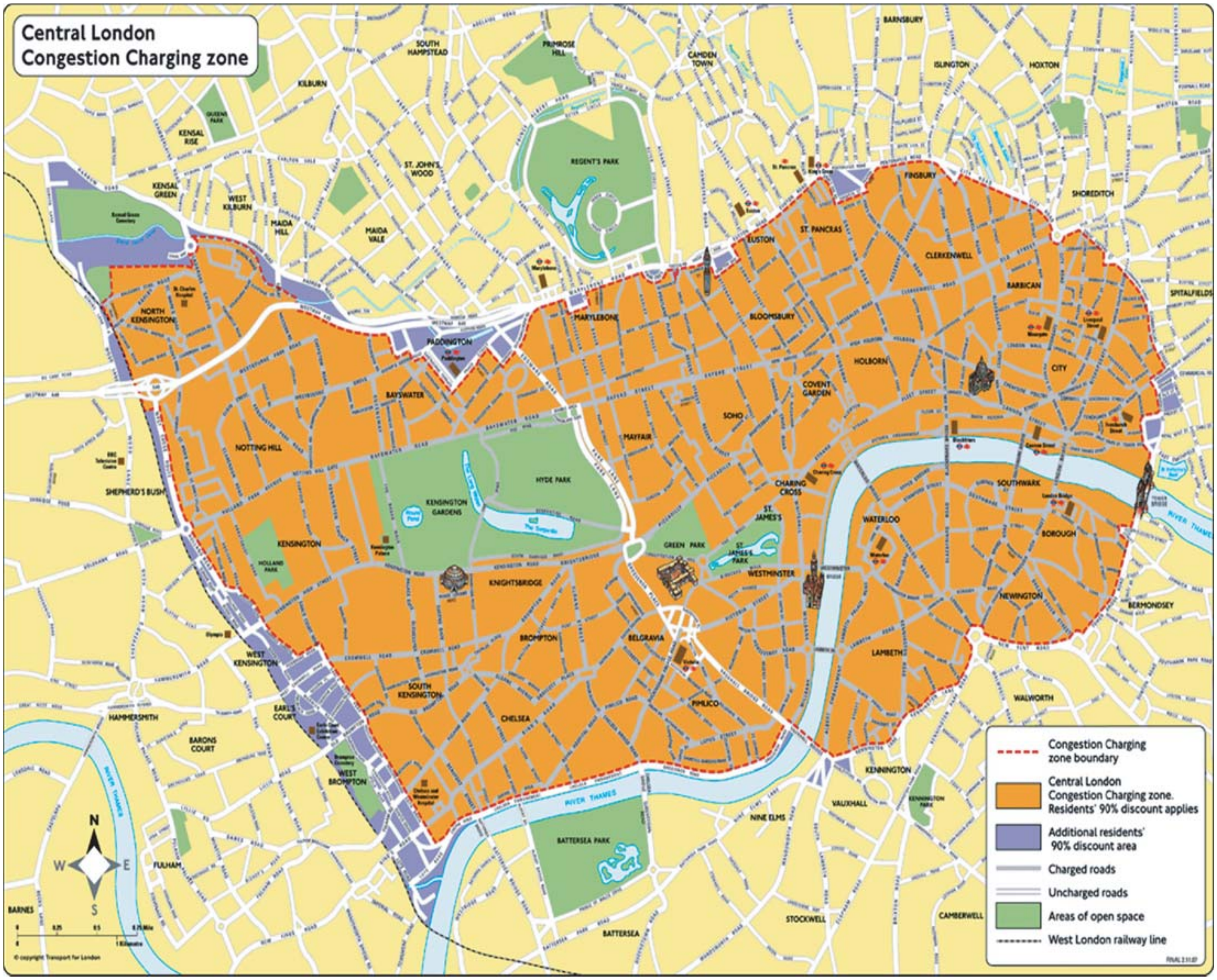
2.4.2 London

Overview of the London System

As a means of reducing traffic congestion within the London CBD and to raise revenues, the City of London instituted a fee for private automobiles in 2003. Cordon charges are imposed weekdays from 7 a.m. to 6 p.m., but are not based on distance traveled or location. In the first year that the congestion charge was implemented, the average daily traffic decreased from 378,000 to 324,000, or 14% (Transport for London, 2007). In 2005, the daily congestion charge was increased from £5/vehicle to £8/vehicle (as of December 22, 2009, $1 = £0.625977). In 2007, the congestion zone was expanded to include parts of inner west London, including Westminster, Kensington, and Chelsea (see Figure 9). This expansion has nearly doubled the size of the congestion zone. Although the western zone experiences high levels of congestion throughout the day, it is relatively residential, with two-thirds of the traffic (in terms of VKT) of the original congestion zone.

Operations and Enforcement of the London System

To enforce the congestion pricing systems, Transport for London (TfL), which operates the payment system within the congestion zone, has installed video cameras at entrances, exits, and within the congestion zone to read vehicle license plates.



Source: Transport for London

Figure 9. London congestion charge zone.

There are currently over 300 camera sites that monitor every lane of traffic at all entry and exit points to and from the charging zone. License plate images are checked against a database to determine whether the vehicle owner has already paid the charge, is exempt from payment, and/or is eligible to receive a discount. Once the vehicle registration number (VRN) has been matched, then the photographic images of the vehicle are automatically removed from the database. The images captured by the cameras form the evidential record (ER), which is used to confirm possible violations. The ER is a compilation of images that provides evidence that a vehicle was in the zone during the congestion charging period. A black and white camera takes a close-up image of the vehicle license plate, while a color camera takes a wider image of the vehicle. All of TfL's cameras have an integrated automatic number plate recognition (ANPR) computer system. The ER is encrypted and transmitted to the data center over a dedicated and secure broadband link. The main elements of London congestion pricing are

- Weekends, public holidays, and the period between December 25th and January 1st are free.
- There are signs on or at the side of the road, but no barriers or tollbooths.
- Residents who live within the congestion zone receive a 90% discount for one vehicle, providing that owners register their vehicles with TfL. Additional vehicles must pay the full congestion charge.

- "Blue badge" holders (e.g., disabled persons) are eligible to receive a 100% discount.
- TfL has also initiated a congestion charging fleet auto pay, which provides a £1/vehicle discount for vehicle fleets of more than 10 vehicles.
- Payments can be made at selected retail outlets, payment machines located in the zone, online, and by cellular text messaging.
- Vehicle owners can purchase weekly, monthly, and annual passes.
- Nonpayment days result in a £120 fine, which is reduced to £60 if paid within two weeks.
- A free passage route runs through the congestion zone (Transport for London, 2007).

The congestion zone is bordered by a high-capacity route, which allows drivers to make through-trips with ultimate origins and destinations outside the zone without paying the charge. Additionally, the Inner Ring Road, which runs through the expanded congestion zone, remains free of charge to users and essentially serves as a free north–south route through the congestion zone. The elevated section of the A-40 Westway that runs east–west through the western extension zone is also free to users. However, it is not possible to enter into or exit from the A-40 within the congestion zone. Figure 9 summarizes the boundaries of the London congestion zone.

Impact of the London System on Traffic

TfL reported that the initial benefits (e.g., reduced traffic, emissions) of the congestion pricing scheme initially exceeded expectations. However, these benefits have since eroded due to interventions and incidents that have removed capacity from the central London road network. TfL, which also operates the London Underground, buses, and the Dockland Rail Line, has found that there has been a significant shift toward the use of public and non-motorized transit. Since 2003, there has been a 45% increase in bus ridership and a 43% increase in cycling within the zone (Transport for London, 2007). Additionally, the economic impact of the congestion pricing system within the zone is considered to be neutral. Table 9 summarizes the impact of the congestion zone in the first 5 years of operations.

Financial Performance of the London System

Initial projections were that the congestion charge system would generate £160 million annually in revenue but would have annual operating costs of approximately £64 million. The cost/revenue ratio would be roughly 40%. In a review of TfL's financial statements, both actual revenues and expenditures have exceeded initial projections. From FY 2004 to FY 2007, operational revenues averaged £228 million per year, while annual operational expenditures averaged £126 million. During this period, operational costs/revenues and gross margin averaged 55% and 45%, respectively. Gross margin is defined as revenues minus the cost of goods sold divided by revenues. These results exceeded initial projections. Moreover, the addition of non-operating costs, which are defined as financial assistance to other entities, depreciation, and administration and capital costs relating to the western extension improvements, averaged £16 million per annum, adding to the overall cost structure for this system. Consequently, operating margin has averaged 37.1% from FY 2004 to FY 2007. Operating margin is defined as earnings before taxes and interest divided by revenues. Table 10 summarizes the financial performance of the London congestion pricing system during this period.

Table 9. Impact of the London congestion zone, 2003–2007.

Impact	2003 (Year 1)	2005 (Year 3)	2007 (Year 5)
Traffic and congestion	• Traffic adjusted rapidly to the introduction of the congestion charge with few traffic problems. • TfL found that there was an increase in traffic on the Inner Ring Road. • VKT decreased by 15%. • Average daily traffic in the congestion zone during charging hours decreased by 14%.	• 8% decrease in congestion in the original zone compared to 2002 levels. • VKT on the Inner Ring Road again fell slightly during 2005, returning to pre-congestion charge levels.	• 3% decrease in total vehicles and VKT from 2006 to 2007. • With the introduction of the expanded zone, traffic entering into the original zone increased by 5%. • Traffic within the western expansion zone decreased by 10% compared to 2006. • Traffic on the boundary route along the western extension increased by 4% compared to 2006. • Congestion has returned to 2002 levels in the original zone.
Total vehicles*	324,000	316,000	405,000

*Total vehicles in 2007 include both the original and expanded congestion zone. Source: Transport for London.

Table 10. Financial performance of the London congestion zone (£ million), FY 2003/04–2006/07.

Fiscal Year	03/04	04/05	05/06	06/07	Average
Operational Activities					
Operating revenue	186.7	218.1	254.1	252.4	227.8
Operating expenditures: toll facilities and traffic mgmt	122.9	121.4	130.3	130.4	126.3
Gross income	63.8	96.7	123.8	122.0	101.6
Non-Operating Expenditures					
Financial assistance	—	—	—	2.5	
Depreciation	1.1	1.6	2.8	4.8	
Administration & services	—	—	9.8	13.4	
Western extension zone	—	—	3.8	12.2	
Deferred charges	17.2	1.7	—	—	
Capital financing charges	0.2	0.4	—	—	
Subtotal non-operating expenditures	18.5	0.3	16.4	30.4	16.4
Net income	45.3	96.4	107.4	89.1	84.6
Benchmarks					
Operating costs/revenues	65.8%	55.7%	51.3%	51.7%	55.4%
Gross margin	34.2%	44.3%	48.7%	48.3%	44.6%
Operating margin	24.3%	44.2%	42.3%	35.3%	37.1%

Source: Transport for London

2.4.3 Oslo

Overview of the Oslo System

Despite a total population of 4.9 million and a relatively low population density, Norway has a long history of using tolls to finance the development and construction of road infrastructure. In 2005, tolls accounted for roughly 35% of funding within the annual road construction budget. Toll road projects in Norway are generally based on local initiatives, requiring local political agreement and approval by the national parliament. Among the major cities, Oslo, Trondheim, and Bergen have established urban toll systems, which include cordon pricing schemes. Additionally, cordon systems have also been established in smaller cities such as Stavanger, Kristiansand, Tønsberg, and Namsos. The latter community has a population of only 12,000 inhabitants. The Norwegian Public Roads Administration is responsible for planning, building, and operating toll road projects as well as for planning and building the toll-collection systems. Once approved, toll roads are managed and operated by a dedicated toll road company owned by the local governments where the toll road is located.

Oslo and its surrounding suburbs, with a total population of 1.1 million, have nearly 23% of Norway's population. To manage congestion, a cordon pricing system was adopted in 1990, with 19 toll stations composing the Oslo toll ring, which demarcates the toll cordon around Oslo. The Oslo toll ring is managed and operated by Fjellinjen AS, which is owned by the Oslo City Council (60%) and the Akershus County Council (40%) (Waersted, 2005). Each car that enters into the Oslo central district passes through a toll station and pays a fixed toll amount regardless of distance traveled. Vehicles can exit the Oslo central district without paying a toll. Within the toll cordon, seven out of the 19 toll stations have five or more lanes. Previously, the toll stations had electronic payment lanes, lanes with coin machines, and manually operated lanes with toll attendants. In 2008, Fjellinjen AS replaced the tollbooths with an all-electronic toll-collection (AETC) system and completed the installation of new toll stations on the Bærum toll ring along Oslo's western edge. Figure 10 shows the location of the Oslo Toll Ring stations (red) and the Bærum toll stations (black).

Operations and Enforcement of the Oslo System

When the cordon system was originally adopted, the intent was to remove the tolls after 15 years. Because financial resources are still necessary to develop additional transportation infrastructure in the area, the planned date for removing tolls has been extended twice. Tolls are currently scheduled to be removed in 2027. (Although scheduled to have been removed in 2001, tolls in Bergen were also extended for an additional 15 years.) Excess income is used to finance the development of transportation infrastructure, with approximately 20% earmarked for public transit (Firth, 2002). An increase in toll rates was approved in July 2008. Without a valid AutoPASS subscription account, automobiles pay NOK 25 (Norwegian

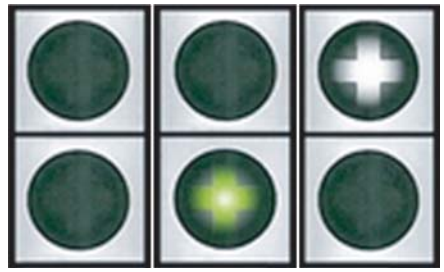
Source: Fjellinjen AS

Figure 10. Map of Oslo toll ring and Bærum toll stations.

Kroner) at the Oslo Toll ring and NOK 12.50 at the Bærum cordon. Trucks pay NOK 75 and NOK 37.50 at the Oslo and Bærum crossing, respectively (as of December 22, 2009, $1 U.S. = NOK 5.87511). With a valid AutoPASS subscription, drivers can obtain a 20% discount. Tolls assessed at the Bærum cordon are in addition to the cordon charge assessed for crossing into Oslo, decreased by the applicable discount for having a subscription account. Invalid accounts are assessed a surcharge, which increases by 50% if payment is not received after three weeks of notification. AutoPASS transponders are interoperable with similar toll and ferry payment systems in Denmark and Sweden, allowing for a single invoice to users.

Toll payment is based on a subscription system in which users have the option to prepay for an unlimited number of trips within a defined time period or a certain number of trips ranging from 25 to 350. The Oslo toll ring has no-stop lanes that allow for free-flow conditions. Payment and enforcement are generally similar to the approach used on other toll facilities with ETC systems. Toll transponders are attached behind the rearview mirror inside the windshield. As the vehicle passes through the payment lane, the station computer confirms whether the tag number corresponds to a valid subscription account. Once the account check has been completed, the driver will receive a plus signal at the end of the payment lane, signifying a valid account. A green plus signal will be displayed if the account has a sufficient balance, while a white plus signal will be shown if the account has a low balance. An insufficient account balance will result in no signal, requiring account replenishment. Figure 11 illustrates the signals that are used in the Oslo toll cordon system.

As a result of recently completed improvements, toll stations now have three toll gantries located at each crossing point. The first gantry has a camera and an infrared flash, which takes an image of the rear license plate. The second gantry is fitted with a scanner that reads the AutoPASS number and measures the size of the vehicle and determines its position on the roadway. Finally, the third gantry has a double set of cameras and infrared flashes that capture an image of the front license plate. The toll gantries are also fitted with equipment that is used to take images of vehicles attempting to swerve into opposite traffic lanes to avoid detection. Historically, poor weather and light conditions have resulted in a 30% failure rate of video images (Waersted, 2005). As a basis of comparison, some vendor contracts require video image success rates of over 98%. With the installation of new equipment, the number of unread license plates is expected to decrease significantly.



Valid Account *Low Balance* *Invalid Account*

Source: Fjellinjen AS

Figure 11. Oslo and Bærum toll station signals.

Impact of the Oslo System on Traffic

While the tolling system has relieved bottlenecks in certain locations, the overall impact on traffic has been relatively small. After an initial 5% decrease, traffic returned to pre-cordon pricing levels within a few months, increasing steadily thereafter. Independent estimates have found that toll rates should be 3 to 5 times higher to have a measurable effect on the vehicular traffic levels. At the end of fiscal year 2008, Fjellinjen AS had approximately 570,000 valid subscriptions, and an estimated 260,000 vehicles pass through its toll stations every day. The ETC lanes have a throughput capacity of 1,600 vehicles per hour, while lanes with coin machines have an estimated throughput capacity of 200 to 400 vehicles per hour.

Financial Performance of the Oslo System

In the year after the ETC improvements were completed at the toll stations, subscription account revenues increased by 23% and total revenues increased by 29%. Revenues from video invoicing increased from zero to NOK 385 million in FY 2008. Because Fjellinjen AS is phasing out the manual operation of its toll lanes, revenues from manual toll collection decreased by 93%. From FY 2003 to FY 2008, the total cost of operating the cordon toll system in Oslo accounted for 10% to 11% of revenues. In addition to staffing costs, additional costs that were incurred in FY 2008 were (1) losses on accounts receivable and provision for bad debts, (2) invoice forms and postage, (3) maintenance and operation of IT systems connected with toll collection, (4) removal of old tollbooths, (5) tollbooth operations, and (6) other operational activities. Losses on accounts receivable represented the single largest operating cost item, representing 17% of total operating costs. Additionally, losses on accounts receivable were equivalent to 2% of revenues in FY 2008.

Gross margin has averaged about 89.4% from FY 2003 to FY 2008. Fjellinjen's operating margin during this period has averaged 59.4% during this period, ranging from 32% in FY 2006 to 72% in FY 2003. Lower operating margins are a result of the depreciation costs associated with the acquisition of toll-collection rights from the national Public Road Administration, particularly the "Oslo Package 3." Moreover, there were additional depreciation costs associated with the implementation of the ETC system, video imaging equipment, and the installation of new tollbooths. Fjellinjen's financial results from FY 2003 to FY 2008 are summarized in Table 11.

2.4.4 Stockholm

Overview of the Stockholm System

In June 2003, the Stockholm City Council adopted a proposal to carry out a pilot program for cordon charging. During the following year, the Swedish parliament enacted the Congestion Charging Act, which authorized a cordon charge pilot program; the program ran from January 2006 to July 2006. The Stockholm cordon charge system had the following objectives: (1) reduce the number of vehicles passing into and out of the congestion zone during peak periods by 10% to 15%, (2) improve traffic flow along the busiest streets, (3) reduce vehicle emissions, and (4) improve the urban environment (TRANSEK AB, 2006). The pilot program was developed and administered by the City of Stockholm, the Swedish Road Administration, and Stockholm Transport. Following the implementation of the pilot program, the winning parties in the 2006 general election in Sweden announced that the Stockholm congestion tax would be made permanent. Parliament approved the congestion tax in June 2007, and the congestion tax came into effect on August 1, 2007.

Operations of the Stockholm System

The development of the congestion charge system in Stockholm was modeled from the Oslo system. Oslo has population and demographic characteristics similar to those of Stockholm. The initial capital costs to operate the pilot program were estimated to be 1.82 billion Swedish Krona (SEK), or roughly $266 million ($1 U.S. = 6.842 SEK as of December 31, 2006) (TRANSEK AB, 2006). Capital costs

Table 11. Financial performance of Fjellinjen AS, 2003–2008 (NOK million).

Fiscal Year	2003	2004	2005	2006	2007	2008	Average
Operating revenues							
Subscription revenues	746.6	800.8	849.8	876.2	910.9	1176.2	
Video invoicing	—	—	—	—	—	385.2	
Manual payment	316.3	370.3	346.3	332.7	330.0	23.1	
Surcharges	19.7	21.6	23.7	39.4	39.6	50.1	
Remuneration to issuer	—	—	—	—	4.3	5.8	
Subtotal	1,082.6	1,192.7	1,219.8	1,248.3	1,284.7	1,640.4	**1,278.1**
Operating costs							
Payroll	12.2	12.0	14.1	15.3	17.4	19.9	
Toll operating costs	96.9	107.6	111.2	118.3	126.7	164.5	
Subtotal operating costs	109.1	119.6	125.3	133.6	144.1	184.4	**136.0**
Non-operating costs							
Depreciation	200.7	250.7	300.6	400.5	730.1	414.6	
Write-down of intangible assets	—	—	—	—	—	0.6	
Subtotal non-operating costs	200.7	250.7	300.6	400.5	730.1	415.2	
Net income	772.8	822.4	793.8	714.2	410.6	1040.8	**759.1**
Financing activities							
Interest received	11.7	6.8	11.1	9.8	7.2	5.9	
Interest paid	60.8	27.8	12.9	9.0	3.0	0.4	
Income before contributions to roads projects	723.7	801.4	792.0	715.0	414.8	1046.4	**748.9**
Benchmarks							
Operating costs/revenues	10.1%	10.0%	10.3%	10.7%	11.2%	11.2%	10.6%
Gross margin	89.9%	90.0%	89.7%	89.3%	88.8%	88.8%	89.4%
Operating margin	71.4%	69.0%	65.1%	57.2%	32.0%	63.5%	59.4%

Source: Fjellinjen AS

include system development, equipment installation, staff education and training, testing, and public outreach activities. Initial capital expenditures also included the (planned) decommissioning of the congestion charge system, which could be deferred or decreased if the pilot program were to be extended.

Initial charges were set at SEK 10 to 15 ($1.25 to $2.50) per crossing. Payments could be made at kiosks and at convenience stores through 2008. During the pilot program, a monthly or annual subscription account service was not established. As a result, it was found that payment processing costs were relatively high due to the need to process individual transactions. The pilot program encountered difficulties in recognizing exempted vehicles traveling to/from the Lindingö area of Stockholm, which were not required to pay the charge if they completed passage through the cordon area within 30 minutes.

Impact of the Stockholm System on Traffic

To evaluate the impacts of the pilot program, Stockholm commissioned a cost–benefit analysis that examined the impact on congestion, public transit usage, and vehicle emissions (TRANSEK AB, 2006). The following were some of the key findings from this 2006 study:

- VKT declined by 2.8%;
- Fuel tax revenues decreased by SEK 53 million ($7.7 million) (fuel prices in Sweden were roughly constant during this period);
- Public transit ridership increased by 4.5%;
- Road maintenance expenses decreased by SEK 1 million ($140,000);
- Vehicle emissions of climate gases—carbon dioxide (CO_2) and Volatile Organic Compounds (VOCs)—in the county of Stockholm were estimated to have declined by 2.7%;
- Vehicle emissions of climate gases in the central area within Stockholm were estimated to have decreased by 14%; and
- Due to the decline in traffic, it was estimated that the number of traffic accidents decreased by 3.6%.

The cost–benefit analysis also estimated that the initial capital costs for the congestion pricing system could be repaid within approximately 4 years. This estimate also took into account the value of shorter and more reliable travel times, the reduction in vehicle emissions, revenues generated from congestion charges and public transit services, safety improvements, the cost of operating the congestion price system, and the expansion of transit services to accommodate greater demand.

A follow-up study that was conducted by the City of Stockholm Traffic Administration in 2009 found that:

- Traffic in 2008 in the cordon area decreased by 18%, as compared to 2005 levels;
- The number of registered alternative-fuel vehicles, which are exempt from congestion tolls, increased from 5% of the total vehicle fleet in 2006 to 14% in 2008; and
- To avoid driving in the inner city, traffic on ring (orbital) roads increased between 5% and 10% in 2008 compared to 2005 (City of Stockholm Traffic Administration, 2009).

Financial Performance of the Stockholm System

During the pilot program, it was estimated that the congestion charge system would generate roughly SEK 763 million ($111.5 million), with estimated operational costs of approximately SEK 220 million ($32.2 million). As a result, costs would account for about 29% of revenues. The operating margin for the congestion charge system was estimated to be approximately 65%. During 2007 and 2008, actual revenues generated from the charge system were SEK 230 million ($31.6 million) and SEK 559 million ($71.3 million), respectively. However, no operational cost information was available during this period. Table 12 summarizes the estimated financial performance of Stockholm's congestion charge system during the pilot program.

Table 12. Estimated financial performance of the Stockholm congestion price system, 2006 pilot program (SEK million).

Fiscal Year	2006
Operating revenues	763.0
Operating costs*	220.0
Operating income	543.0
Depreciation	50.0
Net income	493.0
Operating costs/revenues	28.8%
Gross margin	71.2%
Operating margin	64.6%

*Annual operating costs were estimated by the Swedish Road Administration based on a similar system in Norway
Source: City of Stockholm, TRANSEK AB (2006)

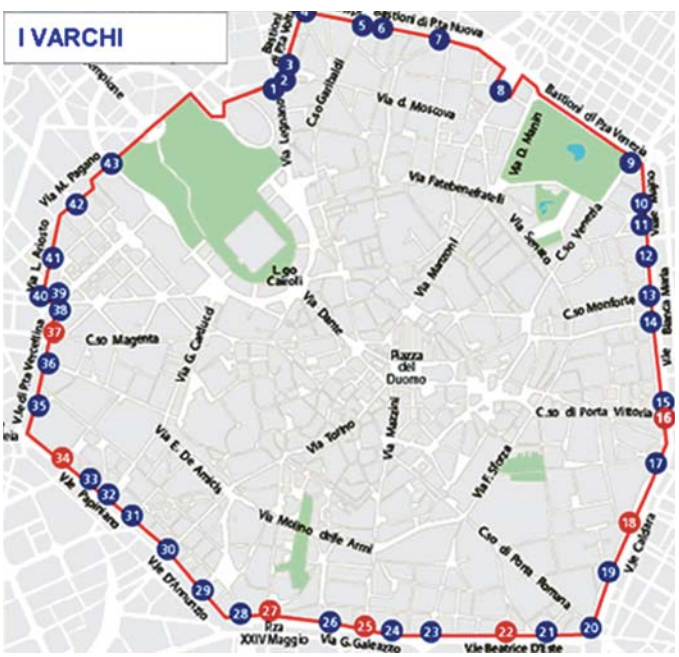
2.4.5 Milan

Overview of the Milan System

The Ecopass program in Milan was designed primarily to reduce vehicular emissions and congestion within the urban center of Milan (Bloomberg.com, 2009). The congestion charges are assessed within an 8.2 km^2 area that is known as the restricted zone (zone a traffic limitato, or ZTL). In January 2008 the Ecopass system was implemented as a 1-year trial program, which is a similar period to other congestion programs. The program was subsequently extended and remains in force. The Ecopass area is demarcated by 43 toll stations with a number of major landmarks included within the restricted zone (Figure 12). Ecopass fees were temporarily suspended for 3 weeks during August 2008 because traffic levels typically decrease by roughly 30% in that month.

Operations and Enforcement of the Milan System

The cordon charge is assessed on weekdays from 7:30 a.m. to 7:30 p.m., and the amount charged depends on the vehicle's engine emissions levels. Free access is granted to alternative fuel vehicles and for conventional automobiles that meet the highest levels of European emissions standards. In particular, liquefied petroleum gas (LPG), compressed natural gas (CNG), hybrid, and electric vehicles (EVs) are exempted from paying a congestion charge within the restricted zone. Newer and lower polluting gasoline-powered automobiles pay €2, older gasoline-powered automobiles and lower polluting diesel powered vehicles pay €5, and older and heavy diesel powered vehicles pay €10. Residents living within the restricted zone are exempted only if they own or drive higher emissions standard vehicles. Vehicle owners with non-exempted vehicles can receive a discount if an annual pass is purchased. The cost of an annual pass ranges from €50 to €250 depending on the emission classification of the vehicle. Daily and multiple-day passes are also available. Trucks longer than 7 meters are restricted from entering into the restricted zone from 7:30 a.m. to 9:00 p.m. However, trucks can make deliveries within the restricted zone during the non-congestion charge period.



Source: Ecopass

Figure 12. Milan Ecopass area.

Enforcement is carried out through digital cameras located at the 43 electronic gates. Violators are required to pay fines that vary from €70 to €275, depending on vehicle emissions classification. The Ecopass fee can be paid before entering the congestion charge zone or up to midnight the next day. Payment of the fee can be made via the Internet, by telephone, in designated banks, or via debit cards and credit cards. However, users have complained that the Ecopass' Internet interface for making payments has broken down on several occasions. Additionally, there have been some delays in implementing the court process for violations and appeals.

Impact of the Milan System on Traffic

After completing the first year of the pilot program, the City of Milan evaluated the impact of the Ecopass system with respect to congestion, public transit usage, and vehicular emissions (Comune di Milano, 2009a). For most indicators, the Ecopass program was compared with the 2007 average. However, traffic levels within the restricted zone were compared with actual traffic within the Ecopass area during 10 business days from October 22, 2007, to November 16, 2007. The City of Milan found the following impacts:

- Traffic levels in the Ecopass area, –14.4%;
- Traffic levels outside the Ecopass area, –3.4%;
- Public transit ridership, +5.7%;
- Congestion (as measured by traffic flow/capacity), –4.7%;
- Congestion (as measured in VKT), –25.1%;
- Average traffic speeds in the Ecopass zone, +6.7%;
- Particulate matter in the Ecopass zone, –14%;
- Nitrous oxide emissions in the Ecopass zone, –11%;
- CO_2 emissions in the Ecopass zone, –9%;
- Travel time savings of 759,000 hours; and
- Economic impact valued at €9.3 million ($13.1 million) ($1U.S. = €1.4095 as of December 31, 2008).

A related impact of the Ecopass program was that it created an incentive for residents to purchase newer automobiles, which would be exempted altogether from paying the Ecopass charge or would be charged at lower rates. The number of

Table 13. Ecopass financial performance, 2008 (€ million).

Fiscal Year	2008
Operational revenues	
Passes sold through retailers or at booths	8.5
Passes sold online	2.1
Passes paid with debit cards	1.5
Subtotal operational revenues	12.1
Operating costs	6.5
Costs/revenues	53.9%
Gross margin	46.1%
Operating margin	N/A

Source: Ecopass

exempted vehicles as a percentage of total vehicles increased from 58% in January 2008 to 80% by December 2008. In all, there were an additional 677,000 new vehicles located within the Ecopass zone that complied with Class 1 or Class 2 European emissions standards.

Financial Performance of the Milan System

In its first year of operation, it was found that the Ecopass system generated roughly €12.1 million, with operational costs of approximately €6.5 million. Based on these data, costs accounted for about 54% of revenues generated, exceeding the 34% average that was found for U.S. and Canadian tolling systems. Table 13 summarizes the financial performance of Ecopass during 2008 (Comune di Milano, 2009a). Capital costs and depreciation costs were not available.

2.5 Parking Pricing Systems

As an alternative to tolling, parking pricing (or parking management) systems are growing increasingly attractive to manage congestion and generate revenues. Parking management systems can take on many different forms, but the guiding principle behind all parking management systems is the idea that there is no such thing as free parking (Naparstek, 2007). The cost of parking has several components. The first and most obvious is the cost to the driver in cases where a fee is charged. For a metered space, drivers realize that they must pay a certain fee for set increments of time. Similarly, drivers understand that they must often pay a fee to park in a staffed parking garage or lot. However, to the driver, curbside spaces without meters or permit requirements are often perceived as free and are therefore more desirable. There are many hidden costs associated with these free parking spaces, including:

- Congestion: Vehicles circle in search of free parking spaces, spending excess time on the road, affecting through traffic and leading to increased congestion.
- Environmental impacts: As congestion increases and vehicles spend more time on the roads, the amount of vehicle emissions also increases.
- Financial burden on the owner or operator (such as the municipality): The owner or operator must come up with funds to maintain parking areas (e.g., paving, snow removal, regulation enforcement).
- By charging an explicit fee for parking spaces through meters or permits, revenues are generated, which can help to offset capital and operating costs. Moreover, these systems can help to manage parking demand and availability to improve the parking experience for all, including providing increased convenience and easier location of parking for drivers, decreased congestion on the roadways, and increased turnover for area businesses.

A limited number of parking pricing systems have been implemented. A city-run parking system in Westminster has evolved into an efficient and technologically advanced example of a parking pricing system. In Chicago, city officials recently leased the city's metered parking spaces to private investors for a term of 75 years to attract capital to upgrade the existing parking system. In San Francisco, local agencies are working to build a system using real-time parking data to manage congested streets and relieve a parking shortage. The next sections will focus on these three parking systems in various phases of implementation. The design of each system will be discussed along with technology employed, impacts on the city, and costs of the systems.

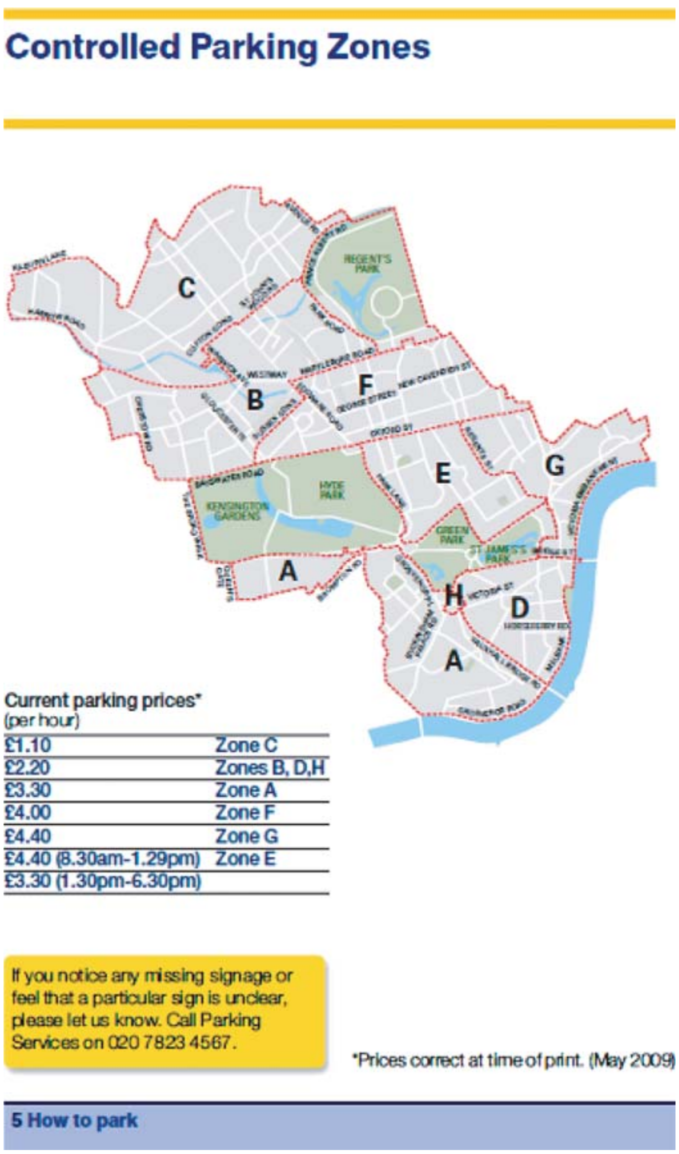
2.5.1 Westminster City Council's Parking Program

Overview of the Westminster City Parking System

The City of Westminster, which is contained within London, has slowly grown its citywide parking pricing program into a larger and more efficient revenue-generation system. This program controls all public parking spaces in the city, including curbside spaces, lots, and garages.

The Westminster parking pricing system is divided into eight controlled parking zones, with each zone having its own fees and restrictions. Maps of the zones as well as specific parking locations, fees, and restrictions, such as time restraints, are available on the Westminster website (City of Westminster, 2009). An excerpt from the ParkRight guide showing zones and hourly parking rates is shown in Figure 13. Also posted on the website are the terms of service, parking rules, instructions on how to pay for parking, and how to settle or argue any parking tickets.

Parking in city spaces is paid for at pay boxes, by telephone, or with scratch cards, or prepaid permits. The scratch cards offer a prepaid cashless option and work somewhat like a lottery ticket. Scratch cards are available at various locations around the city, with costs of £2.20 and £4.40. To use these cards, drivers must scratch off the time and date that they have parked and display the scratched card on their dashboards.



Source: ParkRight, Your Guide to Parking in Westminster. Westminster City Council, 2009a.

Figure 13. Westminster parking zones.

Since the amount of parking time the card purchases varies by zone, multiple scratch cards may be used to provide for longer parking durations.

As the parking system in Westminster has evolved, the city council has been able to adjust to factors that could present significant complications to a new parking system, such as

- Security,
- Visitor parking,
- Disability parking,
- Construction and dumpster allowances,
- Resident parking,
- Event parking, and
- Loading and unloading zones.

Operations and Enforcement of the Westminster City Parking Program

Several factors set the Westminster parking system apart from other parking management systems. The first is the institutional integration of the system, which is operated and managed by a single entity, the Westminster City Council. The second is the technology that has been implemented throughout the city. Not only does the Westminster parking program offer many payment choices, including cashless payment via telephone, but the city has also been outfitted with an enormous wireless network, including a vast network of closed circuit televisions (CCTVs) (Thomas, 2004). This system has had an enormous impact in improving the efficiency of operations and maintenance activities as well as improving the safety of parking areas. Piloted in 2002, the city has had nearly a decade to fine-tune its parking system.

The recent technological focus has been on improving payment methods. Improvements have been made to the pay-by-phone service, and the scratch cards were introduced. Additionally, new measures have been added to protect the privacy of pin codes and chip readers. Westminster has also been piloting a visitor's parking scheme as well as an "Every Older Person Matters" pilot program to target inconsiderate drivers who obstruct sidewalk accessibility features. The parking system has evolved to include a car-sharing program, called the Car Club, which is being developed through a partnership with Zipcar. In addition to reducing the overall demand for parking, this program has given local residents the ability to avoid congestion tolls on small trips within the city. Although discouraging the use of private vehicles could have an adverse effect on parking revenues, the ability to maintain or increase the availability of parking spaces for those who wish to park may sometimes outweigh potential revenue losses.

Impact of the Westminster City Parking System on Traffic

It is difficult to point out specific effects of the parking program in Westminster because it has evolved gradually and a true "before" and "after" is difficult to determine for comparison. However, as the program has evolved, it has become more efficient in the enforcement of parking regulations and has supported improved safety conditions in the area. The addition of CCTV has greatly improved the efficiency of conducting maintenance activities and has improved safety monitoring (including assisting in drug crime arrests). Also, the new pay-by-phone cashless payment option is perceived as being more user-friendly and convenient. Most importantly, the parking pricing system has remained flexible and continues to evolve year after year to meet the city's needs (Westminster City Council, 2009b).

Financial Performance of the Westminster City Parking System

Detailed financial data from the *Annual Parking Report 2009* prepared by the City of Westminster is shown in Table 14. The annual on-street parking revenue collected over the previous 5 years has ranged from £65 million to nearly £85 million, averaging £75.6 million during this period. On-street parking revenue for the 2008/09 Westminster fiscal year decreased roughly 3.5% in comparison to the previous year. This was mostly due to the decreased number of parking tickets. During this period, on-street parking system expenditures ranged from just under £40 million to slightly over £47 million. Expenditures increased roughly 3% over the previous year. From FY 2004/05 to FY 2008/09, expenditures averaged £43.7 million. Overall, nearly 58% of parking revenue for the 2008/2009 year went toward expenditures, netting roughly 42% of gross revenue (Westminster City Council, 2009b). Fluctuations in the most recent year's revenues and expenses over previous years are largely due to the issuance of fewer penalty charge notices (PCNs) and the elimination of the clamping and removal program.

2.5.2 SF*park* Smart Parking Management Program

Overview of the SFpark System

Through an Urban Partnership Agreement with FHWA, the San Francisco Municipal Transportation Agency (SFMTA) is the lead agency for a pilot parking program called SF*park*. SFMTA is responsible for managing city-owned garages, lots, and on-street parking throughout San Francisco. Pilot testing of SF*park* was performed in the Embarcadero neighborhood in May 2009. Beginning in February 2010, the pilot program was expanded to several additional neighborhoods, including Rincon Hill, Hayes Valley, the Civic Center, the Financial District, the Mission, Fisherman's Wharf, the Marina, and the Fillmore District. In many sections of the city, a major contributor

Table 14. Westminster parking program financial performance, FY 2004/05 to FY 2008/09 (£ million).

Fiscal Year	2004/05	2005/06	2006/07	2007/08	2008/09	Average
Revenues						
Enforcement: PCNs	36.0	31.1	38.2	41.9	35.4	
Enforcement: clamp & removals	4.6	2.9	3.7	4.3	0.3	
Paid for parking	24.4	23.3	22.6	27.3	33.0	
Permits and suspensions	7.2	8.1	9.8	11.4	12.3	
Misc					0.7	
Subtotal	72.2	65.4	74.3	84.9	81.7	75.7
Expenditures						
Enforcement	29.4	29.6	30.5	34.4	32.4	
Paid for parking	2.0	2.0	2.0	2.3	4.3	
Permits and suspensions	1.2	1.4	1.3	1.4	1.9	
Other infrastructure	1.3	1.0	0.42	1.2	1.0	
Overhead	6.0	6.1	6.7	6.6	7.7	
Subtotal	39.9	40.1	40.9	45.9	47.3	42.8
Operating income	32.4	25.4	33.3	38.7	34.4	32.8
Operating Costs/ revenues	55.1%	61.1%	55.1%	54.3%	57.9%	56.7%
Gross margin	44.9%	38.9%	44.9%	45.7%	42.1%	43.3%

Source: *Annual Parking Report 2009*, Westminster City Council, 2009b to congestion is traffic caused by vehicles circling to find curbside spaces. According to the SFMTA, the intent of the smart parking program is to provide a system that makes parking more available by adjusting the price of parking to meet demand. SF*park* will also use websites, text messaging, and variable message signs to provide information about the availability and price of parking spaces to make it easier for drivers to find parking. By directing drivers more quickly toward parking spaces that fit their respective cost points, parking demand can be redistributed more efficiently, improving traffic flow for private vehicles and city buses alike (SF*park,* 2009).

The Port of San Francisco had previously conducted a pilot on-street parking study in 2006, which found that location and time of day were the biggest factors in parking demand. They also found that a significant number of people only pay for half of their stay, patrons parked an average of 75 minutes, and that there are a high number of disabled placards. Enforcement was also found to be relatively low. Revenue would be expected to increase with new parking sensors and payment systems that would assist enforcement efforts. After conducting the study, the Port of San Francisco worked with SFMTA on SF*park* so that parking rates between the two project areas could function under a single system (Moyer, 2008).

It is estimated that there are roughly 320,000 on-street parking spaces in the city of San Francisco. Approximately 25,000 of these on-street spaces are metered. Around 6,000 of these metered spaces are located in the SF*park* pilot areas. In addition to these 6,000 metered spaces, there are roughly 12,250 parking spaces in the SFMTA-owned garages and parking lots located within the SF*park* pilot areas. The goal of SF*park* is to maintain one available space for every 10 on-street spaces on each block (SF*park,* 2009).

Operations and Enforcement of the SFpark System

The project area is composed of 13 city-controlled parking garages, one city-controlled parking lot, and roughly 25% of the city's on-street metered parking (Loftus, 2008). A survey of all parking spaces in the project area was made, and parking locations were divided up into various zones. The parking regulations for each zone (and sometimes each block within zones) may differ from one to the next in terms of meter hours and time limits. Hourly rates for each zone or city block may vary as well, since the demand for parking within each zone will not be equal. Garages will follow similar protocols based on demand and availability, but will be priced lower than on-street parking rates in the same areas for hourly parking because garages tend to be used for long-term parking (SF*park,* 2009). Parking demand for special events may be higher than typical daily rates but will be based on the same supply-and-demand methodology (Roth, 2009). The SF*park* pilot areas are presented in Figure 14.

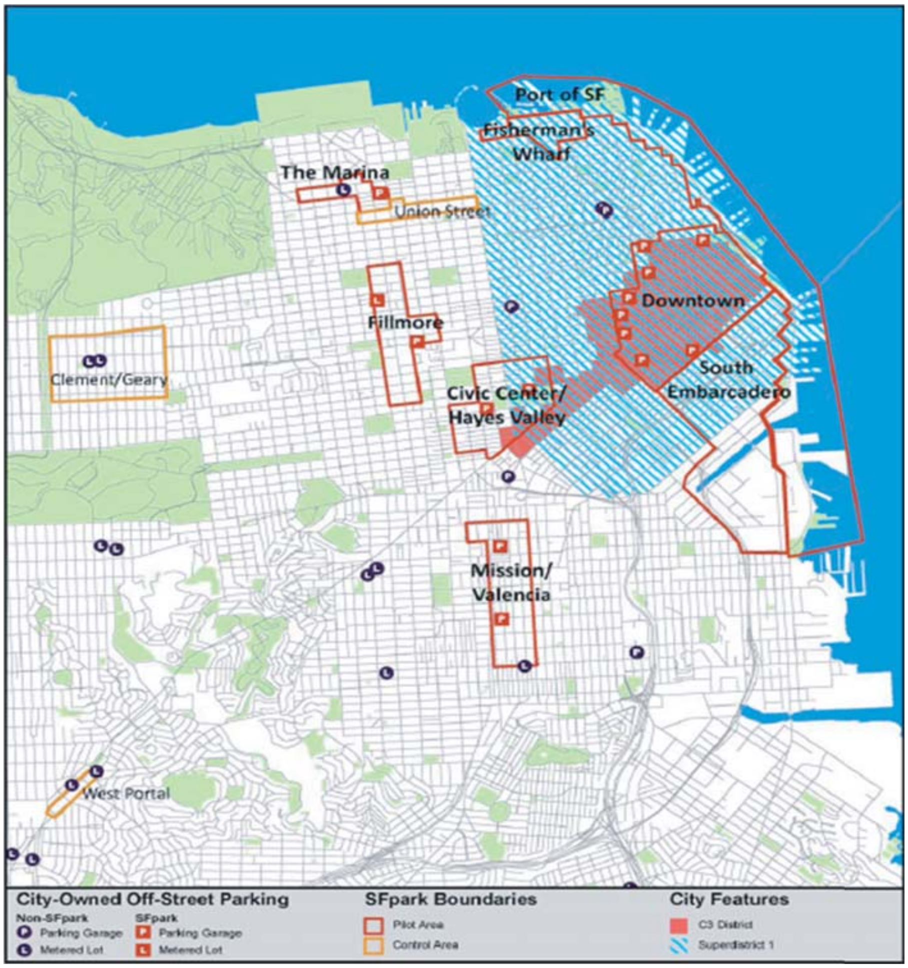
Prices for parking spaces will be the same from one day to the next, but will vary by time of day in an effort to smooth out demand during peak periods. It is hoped that as parking spaces become more expensive, some drivers will opt to park slightly further away from their destination to obtain a cost savings and/or shift their schedule to off-peak times. Parking prices will vary by city block. In this manner, it is hoped that parking demand can be redistributed to areas with higher available capacity, thereby optimizing usage and freeing up high-demand areas.

This pricing system will be re-evaluated every 4 to 6 weeks. To avoid large variations in parking rates after each review period, the maximum amount that parking prices can fluctuate per hour will be $0.50. On-street and SFMTA-managed lot rates will range from $0.25 to $6.00 per hour, and SFMTA-managed garage rates will range from $1.00 to $10.00 per hour. Payment for parking will be collected via multi-space meters that accept coins, credit cards, debit cards, and the SFMTA smart cards. In some areas drivers will be able to park for longer periods than current limits allow. The program will be coupled with a public outreach program to educate local residents on how the new program will work and to encourage drivers to shift to off-peak parking or transit.

To efficiently direct drivers to parking locations that will suit their needs, SF*park* will provide real-time information on parking availability, pricing, time limits, and payment options. This information will be imparted using SFMTA's website, text messages, and variable message signs to direct drivers to SFMTA garages with available parking. Sensors will need to be installed that can detect the presence of a vehicle in each on-street parking space included in the parking program. Parking meters and sensors will be wirelessly networked to a central database to provide real-time information to motorists. Parking data will also be relayed to wireless handheld devices carried by enforcement officials, and potentially, maintenance personnel. Software will be required to coordinate and upload real-time data, analyze data, and review parking rates.

Impact of the SFpark System on Traffic

The ability to monitor and manage parking demand is expected to increase the availability of parking spaces, reduce congestion, and improve traffic flow. Secondary benefits may include improved safety, a reduction in fuel consumption and vehicle emissions, and value-of-time savings to motorists. Any additional revenues generated by the SF*park* system can be reinvested into transportation infrastructure and parking areas operated by the agencies involved. One potential concern is that that smart cards and parking meters might be hacked into or vandalized in other ways to gain free parking. This impact can be mitigated by implementing greater security



Source: San Francisco County Transportation Authority, 2009

Figure 14. Map of SFpark pilot locations.

in the controlled parking areas (Loftus, 2008). SFMTA operates only a small portion of total parking spaces in city, which are primarily reserved for short-term purposes. As a result, the parking program is expected to have a limited impact on congestion in the city as a whole (San Francisco County Transportation Authority, 2009).

Financial Performance of the SFpark System

Prior to the implementation of the new parking program, SFMTA reported that parking revenues were $177 million during FY 2006/07. Approximately $22 million of this revenue was from a 25% tax on parking facilities, of which the city receives 40%. Additionally, administration and operations costs were about $15 million and enforcement costs were about $32 million during FY 2006/07. Debt service costs were roughly $8 million.

As of 2009, the SF*park* pilot program had incurred capital costs of roughly $25 million. The U.S. DOT's Urban Partnership Program funded 80% of this cost. It is not yet known what impact SF*park* will have on SFMTA's parking revenues when implemented since parking fees have yet to be determined. Although parking revenues may increase due to the assessment of higher hourly rates during high-demand periods, violation revenues may decline as a result of the advanced enforcement mechanisms that have been implemented. Program revenues are expected to be reported at the end of the 18-month pilot period.

Additionally, it is very difficult to estimate the capital, maintenance, and operating costs of the SF*park* program at this time. New multi-space parking meters (serving roughly 10 spaces) might be purchased and installed for around $10,000 each. San Francisco Planning and Urban Research Association (SPUR) estimates that the annual cost of this program would be around $4.6 million, assuming program management costs of around $3 million annually. However, this estimate does not appear to include installation or replacement of in-street parking space sensors, which would have a life of 5 to 10 years. SPUR also estimates that SF*park* could generate nearly $40 million per year in new revenue.

SFMTA has proposed that meter hours be extended into the evening in some areas and on Sundays. A preliminary estimate suggests that this could generate an additional $17.2 million in annual revenues. It is estimated that roughly $8.4 million would be spent annually on enforcement, meter maintenance, and coin collection systems. Start-up costs would include a one-time implementation cost of around $2.5 million (San Francisco Municipal Transportation Agency, 2009).

2.5.3 Chicago Parking System: Chicago Parking Meters, LLC

Overview of the Chicago Parking System

Beginning in February 2009, the operations and maintenance of roughly 36,000 metered parking spaces in Chicago were transferred to a private investment company, Chicago Parking Meters, LLC (CPM), through a concession agreement with the City of Chicago. CPM is a consortium led by Morgan Stanley Infrastructure Partners. Within this consortium, parking operations are handled by the concessionaire, LAZ Parking. The earlier concession of several Chicago parking garages was also to a division of Morgan Stanley (Dumke and Joravsky, 2009). This was the first private concession for a publicly owned U.S. parking system (Martin, 2008).

Operations and Enforcement of the Chicago Parking System

Per the concession agreement, approximately 36,000 metered parking spaces (34,000 on-street and 1,240 spaces in 18 metered lots) have been leased to CPM for a term of 75 years in exchange of a one-time payment of $1.157 billion (Waguespack, Piwinski, and Sajovec, 2008). During the term of the contract, CPM is allowed to keep parking meter revenues but is responsible for all operating and maintenance activities as well as system upgrades. The City of Chicago will continue to determine meter rates, locations, and hours of operation. Additionally, the City of Chicago retains the right to add new or remove existing on-street parking spaces in the future as well as restrict parking for special events or for safety reasons. However, if the concessionaire's revenues are negatively impacted by any of these decisions, the city will be responsible for the loss of revenues (Waguespack, Piwinski, and Sajovec, 2008).

Chicago also remains responsible for the enforcement of parking regulations and will continue to receive all enforcement-related revenues. One of the key terms of the concession agreement was that CPM would upgrade all meters to accept credit cards by mid-2011, which is faster than the city would have been able to do on its own (Martin, 2008). Since the concession contract was executed, CPM has been replacing older meters with centrally located pay boxes that accept coins as well as credit and debit cards. These new meters are not space-specific, so there is no finite number of spaces along each curb. This change may effectively create more parking capacity, depending on parallel parking behavior and the size of vehicles parked.

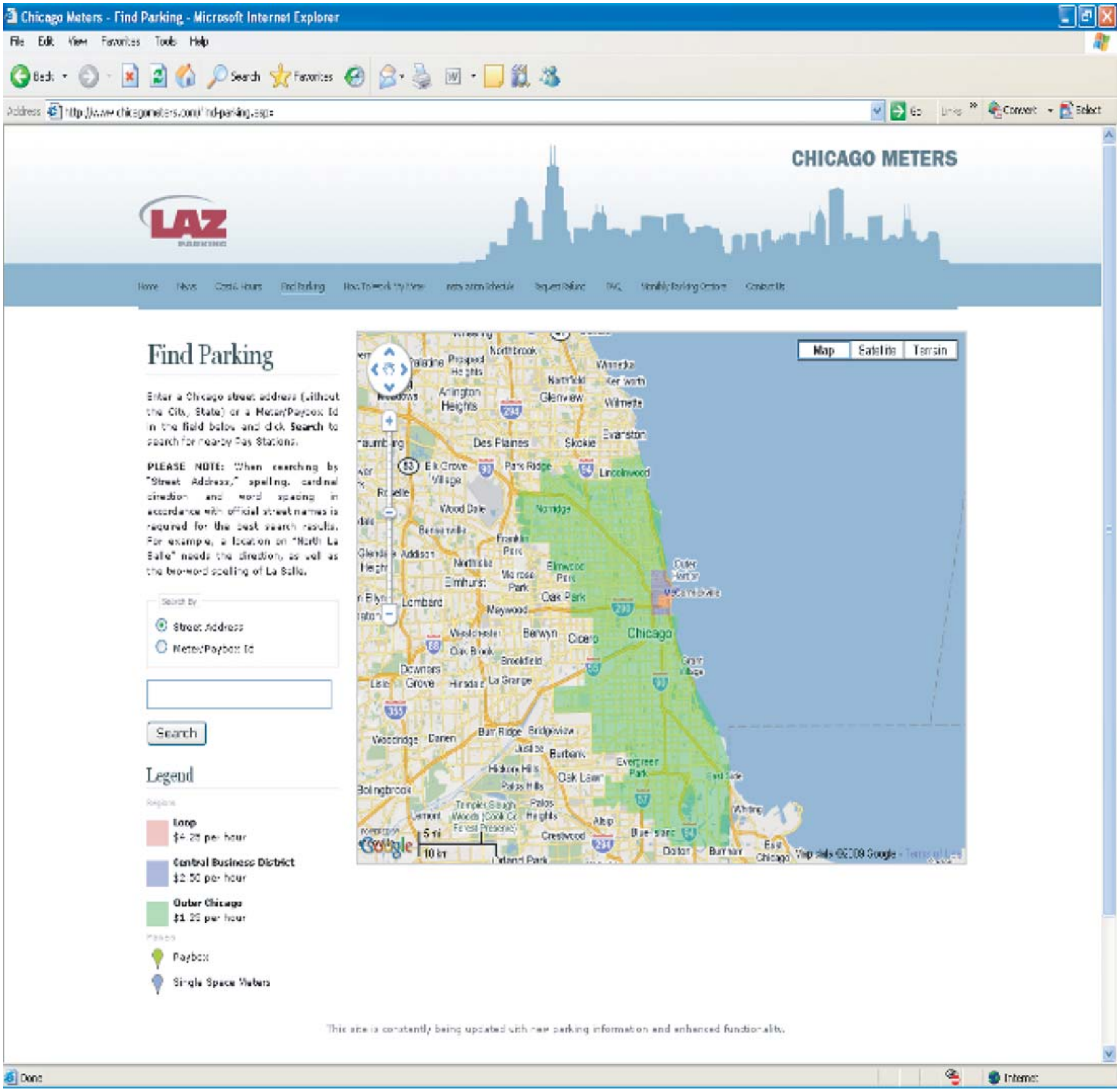
Parking rates vary by location, and rates will gradually increase over the first 5 years of the concession. While under the city's control, parking meters in Chicago were organized into six zones. With the change in management, these zones were consolidated into three zones. Figure 15 identifies the metered regions. Zones include the Loop, Central Business District, and Outer Chicago. As of January 4, 2010, these zones began transitioning to new rates of $4.25 per hour (Loop), $2.50 per hour (CBD), and $1.25 per hour (Outer Chicago). Future rate increases will take place in 2011, 2012, and 2013, with final rates as high as $6.50 per hour in the Loop region. Current and future parking rates are shown in Table 15.

As previously noted, CPM is replacing old single-space meters with centrally located pay boxes. These pay boxes will accept multiple forms of payment, including major credit cards, debit cards, and coins (quarters and dollars only). The pay boxes are not space-specific—a customer is given a receipt that is displayed on the vehicle dashboard. Additionally, the pay boxes are solar powered and are connected to a wireless network. Through this network, the pay boxes are able to communicate with a central server and alert personnel when maintenance is needed. Furthermore, information regarding meter malfunctions is shared with the City of Chicago, allowing for the automatic dismissal of some parking tickets. The CPM website provides links explaining how to use the parking meters and an interactive map to help find parking locations. There is also an around-the-clock customer service hotline available for reporting issues regarding the meters. In conjunction with the automatic alerts provided directly from the meters to the central server, repairs are often completed within a matter of hours.

Improvements that have been made since the system opened include the addition of portable time, in which parking receipts are transferrable to other spaces with the same or lower hourly rate until the receipt expires. This allows for greater convenience to users as well as making prepayment less daunting since the remaining time can be used elsewhere. Rather than only offering parking with 2-hour limits, many of the new meters offer payment options for varying time periods. Pay boxes also offer prepayment options. Other new programs provided by CPM include monthly discounts and the retrofitting of parking meters to provide protected parking for bicycles.

Impact of the Chicago Parking System on Traffic

Immediate impacts of the change in control of the Chicago parking meter system were two-fold. The $1.157 billion



Source: CPM website, 2009

Figure 15. Map of Chicago parking zones.

payment to the city significantly freed up cash flow for the city. However, the transition to private operations has been somewhat turbulent due to several operational and political challenges, including broken meters, inadequate signage, poor public outreach, and a large number of parking tickets being issued. These problems, combined with a surge in the number of vandalism incidents, resulted in negative media coverage with respect to the transfer to private operations.

For more than two-thirds of the city's meters, the hourly rate at the time of the concession had been fixed at $0.25 for over 20 years. By early 2010, parking rates increased to $1.25 per hour, representing a 400% rate increase. Although the rate increases were approved by the city and are on par with other cities, the change has been viewed negatively. However, a potential benefit to users is that the rate increase may increase the supply of available parking spots. To date, a lawsuit has

Table 15. Parking meter rates by zone (prior to the concession agreement with CPM).

Parking Meter Rates per Hour								
Current				Future Rates				
Old Zone	New Zone	Rate	Spaces	2009	2010	2011	2012	2013
6	Outer Chicago	$ 0.25	23,877	$1.00	$1.25	$1.50	$1.75	$2.00
5	Outer Chicago	$ 0.50	6,280	$1.00	$1.25	$1.50	$1.75	$2.00
4	Outer Chicago	$ 0.75	588	$1.00	$1.25	$1.50	$1.75	$2.00
3	CBD	$ 1.00	3,992	$2.00	$2.50	$3.00	$3.50	$4.00
2	CBD	$ 1.50	12	$2.00	$2.50	$3.00	$3.50	$4.00
1	Loop	$ 3.00	895	$3.50	$4.25	$5.00	$5.75	$6.50

Source: Waguespack, Piwinski, and Sajovec, 2008

been filed regarding the legality of the concession, including one alleging that the agreement violates the state constitution by using public funds to enforce regulations on a private system. The lawsuit also suggests that it is illegal for the city to lease out assets for a period of time that is long enough to deprive future councils of control over the parking system.

One less obvious impact of the new system has been that inclement weather has presented some issues with the new pay boxes. Credit card swipe slots have been known to fill with snow or ice, requiring clearing for the swipe to function properly. Additionally, some of the buttons and the credit card readers have been known to freeze over in extreme cold. In an effort to prevent snow and moisture from getting into the credit card reader, CPM has installed new covers on some pay boxes. Snow or ice accumulation can obstruct parking receipts from being displayed on dashboards. As a result, enforcement personnel have been instructed to refrain from issuing citations when they are not able to determine whether a receipt has been purchased.

Financial Performance of the Chicago Parking System

Records show that the 36,000 metered parking spaces generated roughly $19 million in 2007. Although the city had added roughly 5,000 meters in the previous 5 years, many meters are outdated (Mihalopoulos and Dardick, 2009). It was estimated that technical upgrades to the system would cost around $30 million. With the transfer to private operations and the increase in rates, independent estimates have concluded that the parking system may generate more than $1.1 million per week. According to an article in *The New York Times,* based on draft 2010 pro-forma numbers, CPM projects total revenues of more than $75 million and a net income of about $58 million in 2010 (Mihalopoulos, 2009). For the first 10 and a half months of operation under the concessionaire, it was projected that CPM's net income would be slightly over $32 million. However, it is unclear whether capital or costs were included in this calculation. (Chicago CFO Gene Saffold stated that replacement costs, such as $40–$50 million, would be required roughly every 7 years for replacement pay boxes.)

Other Issues

The Inspector General Office (IGO) of Chicago has generally been critical of this transaction. Specifically, the IGO prepared a report in June 2009 (City of Chicago IGO, 2009) that cited lack of information in the city's due diligence review, insufficient consideration of other alternatives (such as raising parking rates), and contract length as issues of concern. Additionally, the IGO estimated that the City of Chicago was paid an estimated $997 billion less than what would have been collected had the parking-meter system been retained by the city.

CHAPTER 3

Revenue Enabling Technologies

This chapter examines several technologies that have the potential to enable the revenue-generation systems presented in Chapter 2. The selected technologies include the IntelliDrive system (IntelliDrive is a registered service mark of the U.S. Department of Transportation), satellite-based and cellular-based fleet management systems, commercial vehicle information systems and networks, and electric cars/smart charging software. The status of these systems varies. Some of them are still in the development and testing stage, such as IntelliDrive technology and electric cars, while others have been deployed or tested for trucks only, such as FMS and CVISN.

For each system, the chapter discusses its objective; system specifications; technology components used; and current status in terms of research, testing, and deployment. Table 16 summarizes and highlights the potential and obstacles faced by each system examined.

3.1 IntelliDrive Technology

This section presents an overview of an emerging system, the IntelliDrive system, which could add communication capability to every vehicle on the road. If implemented, vehicles traveling on the road will be able to send and receive electronic information to other vehicles, roadside infrastructure, and traffic control centers. IntelliDrive technology will not only be able to track where vehicles are but could also automatically charge and collect tolls from all types of vehicles. Although the system seems to have promising potential for collecting and generating revenue, the system itself is at the proof-of-concept and testing stage, and a full deployment is still several years away.

3.1.1 Background of IntelliDrive System

In November 2003, the U.S. DOT announced an initiative called Vehicle Infrastructure Integration (VII). VII has since been renamed the IntelliDrive system. Its objectives are three-fold:

- Safety: Enable vehicles with 360-degree awareness and eventually lead to reduced vehicle crashes,
- Mobility: Provide real-time multi-modal information to travelers and transportation managers, and
- Environment: Reduce environmental impacts by helping travelers select alternative routes to avoid congestion and make their trips more fuel-efficient and eco-friendly.

The IntelliDrive initiative was envisioned to encompass a broader suite of potential technologies and capabilities. Since 2003, its design has been modified to cover a wider scope than originally designed. For example, as shown in Table 17, IntelliDrive technologies are now planned to cover all vehicle types instead of focusing only on light vehicles. Communication technology options other than exclusive use of dedicated short-range communication (DSRC) will also be considered.

Essentially, a fully deployable IntelliDrive system would use wireless communications to provide connectivity:

- Within and among vehicles;
- Between vehicles and the roadway infrastructure; and
- Among vehicles, infrastructure, and wireless devices (consumer electronics, such as cell phones and PDAs) that are carried by drivers, pedestrians, and bicyclists.

3.1.2 IntelliDrive Preliminary Proof of Concept

IntelliDrive is a relatively complicated system consisting of many components. According to a report prepared by the U.S. DOT Research and Innovative Technology Administration (2009), aspects of one of the test sites, the Michigan test bed located in Oakland County, Michigan (near the cities of Novi, Farmington, Farmington Hills, and Livonia), include the following:

- Covers 45 square miles,
- Covers 75 highway and arterial center lane-miles of roadway,
- Includes 55 DSRC roadside equipment (RSE) units,

Table 16. Characteristics of the potential alternative revenue-generation systems.

System	Potential	Obstacles
IntelliDrive system	• Adds two-way communication capabilities to vehicles and links them with transportation infrastructure • Has a tolling and electronic payment subsystem • Uses dedicated short-range communication (DSRC) and GPS	• Still in the testing stage • Several years away from broad deployment
FMS	• Capable of tracking vehicles • Uses satellite- and/or cellular-based technologies	• Needs to be tested on a large number and variety of vehicles • May need to merge satellite-based and cellular-based communication technologies
CVISN	• Successfully deployed in more than 20 states • Cost-effective design by linking together the existing states' information systems	• Lacks ability to track VMT and protect privacy • Lack of alternative revenue-generation systems at the state level
Electric cars and smart charging software	• Zero emissions from tailpipe • Alternative fuels • Application of smart charging software to manage the supply and demand of the electric grid	• Uncertainty of battery charging/switching • Costs of batteries • Uncertainty regarding the collection and distribution of utility taxes

- Uses the Michigan Service Delivery Node (MI SDN), and
- Uses the Michigan Network Access Point (MI NAP).

Figure 16 shows an architectural overview of the Michigan test bed. The Enterprise Network Operation Center (ENOC), located in Virginia, is used to monitor the performance of the Michigan test bed. Figure 17 demonstrates the locations of the RSE on the tested Michigan roads. This system has also been tested in California.

3.1.3 Technology Components of the System

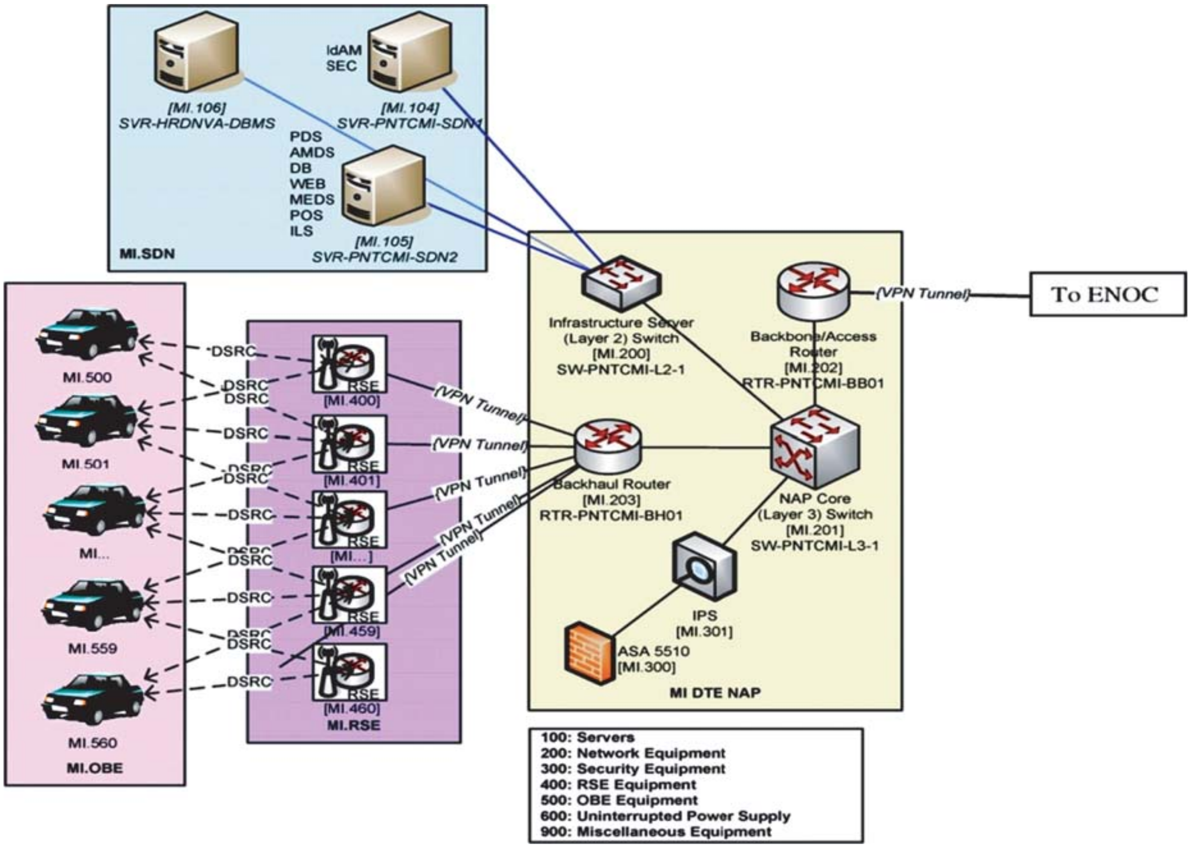
Within the IntelliDrive system there is a subsystem designed specifically for tolling and electronic payment. Key

Table 17. Changes to IntelliDrive, 2003 to 2009.

Previously Considered	Changed To	Unchanged
DSRC only	Technology options	Connectivity for V2V and V2I(*)
Original equipment manufacturer (OEM) production units only	Aftermarket and retrofit considered	National level interoperability – Open standards for communications and data
Light vehicle focus	All vehicle types	DSRC for safety
Prototyping/proof of concept	Focus toward deployment	Safety, mobility, and convenience applications
Limited stakeholders	Broader stakeholder engagement	Must not compromise on safety or security
Limited visibility by outsiders	Greater program transparency	Must protect privacy
U.S. focus	International harmonization	
Loosely coupled programs	Strong, collective U.S. DOT support, coordination, and leadership	Continued close collaboration among U.S. DOT, AASHTO/local agencies, and vehicle manufacturers

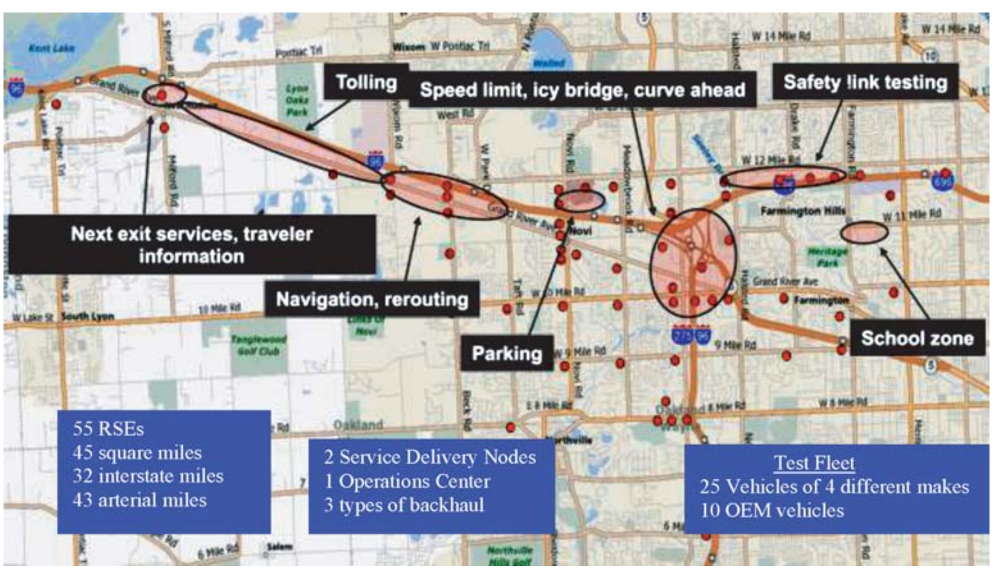
(*) V2V and V2I denote vehicle-to-vehicle and vehicle-to-infrastructure communication.

Source: Schagrin, 2009



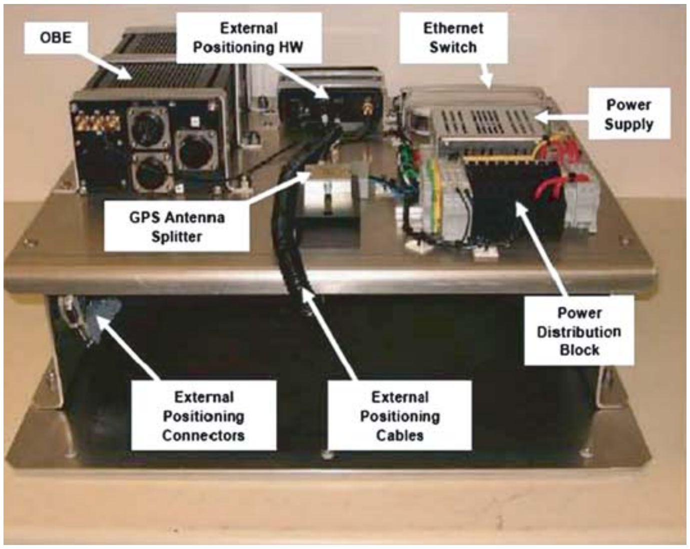
Source: U.S. DOT Research and Innovative Technology Administration, 2009

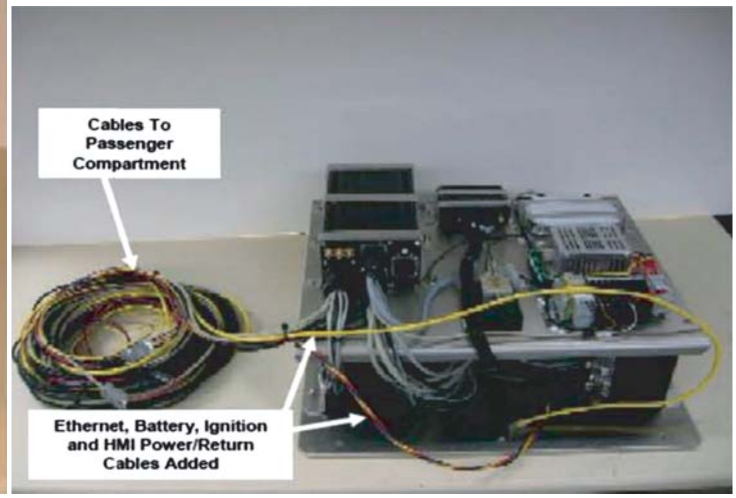
Figure 16. Architectural overview of the Michigan test bed.



Source: Schagrin, 2009

Figure 17. Michigan development test environment.



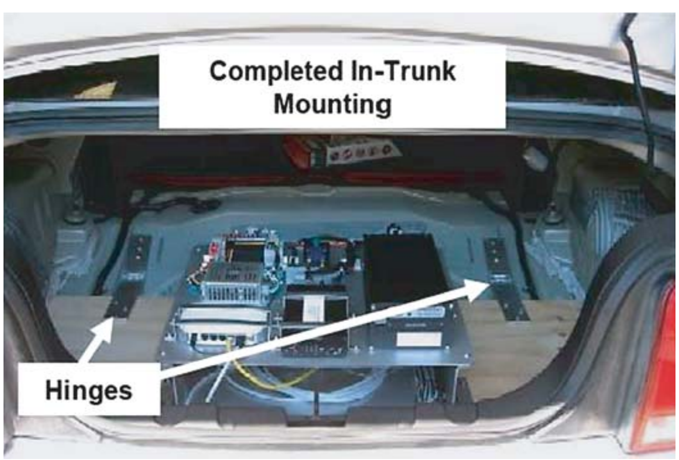


Source: The VII Consortium, 2009

Figure 18. OBE with other external parts (left) and cables (right).

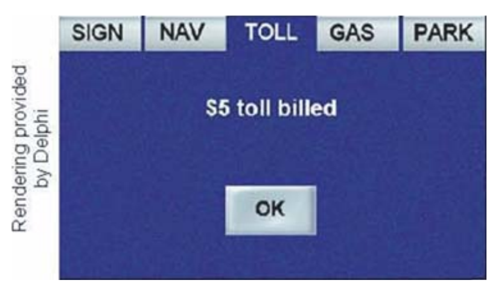
technological components of the tolling subsystem include onboard equipment (OBE), human–machine interface (HMI) manager, and antennas. The components are designed with the following capabilities:

- The OBE is a self-contained and independent computing system with its own hardware, software applications, and external parts. The OBE's central processing unit is designed on an Intel-processor–based computer using a Linux operating system with capabilities of communicating with network and RSE, and managing tolling and payments. Figure 18 shows the OBE with and without cables. Figure 19 shows the mounted OBE in a vehicle.
- The HMI is an interface between the OBE and humans. The HMI is capable of providing visual and audio messages. Figure 20 displays a tolling-related message. In addition, the HMI is capable of providing information related to signs, navigation, gas, and parking.
- Antenna for DSRC/GPS: The OBE has two types of antennae to meet the requirements of DSRC and GPS since they use different parts of the radio spectrum. DSRC requires good coverage in all azimuth directions, while GPS requires good coverage both in the vertical and azimuth directions for receiving signals from space. Also, the GPS antenna needs low-noise amplifiers to reduce noise in GPS signals received. Figure 21 shows an antenna with dual capabilities for DSRC/GPS, mounted on the rear roof of a van.
- The RSE is a self-contained unit installed in a location for sending and receiving signals between vehicles and the network. The RSE is capable of announcing the services offered



Source: The VII Consortium, 2009

Figure 19. The mounted OBE.



Source: The VII Consortium, 2009

Figure 20. Display of a tolling-related message.

Source: The VII Consortium, 2009

Figure 21. Dual DSRC/GPS antenna (left) mounted on a vehicle (right).

in the area where it is located. The RSE also has GPS for self-positioning and making corrections to vehicle positions. Figure 22 shows a mounted RSE.

Two other important elements of IntelliDrive technology include

- Service delivery node (SDN): The SDN contains the core service infrastructure of the IntelliDrive system, including servers, databases, and software systems. The IntelliDrive system may have multiple SDNs that form the network. MI NAP includes a server with low layer switches, routers, and security equipment.
- IntelliDrive system operators use the ENOC to control and manage the network.

Source: The VII Consortium, 2009

Figure 22. Typical RSE installation.

Privacy protection is one potential factor that could affect the design of IntelliDrive technology. To protect privacy, IntelliDrive technology:

- Cannot track an individual vehicle over any road segment longer than 2 km,
- Cannot identify any individual vehicle as violating a traffic law through publicly collected data, and
- Cannot identify a vehicle or a vehicle occupant or owner from messages sent to or through the infrastructure.

3.1.4 Tested Functionalities of the System

The VII Consortium, which is organized by auto manufacturing companies, has conducted tests in garages and labs, on tracks, and in the development test environment (DTE) for core functionalities of the IntelliDrive system. Specific tests conducted include

- Garage/lab tests
  - System services: OBE operation, DSRC communication, vehicle interface, vehicle interface, security, and networking.
- Track tests
  - System services: DSRC communication, security, positioning, and networking.

Figure 23. Tolling zones at the Michigan test bed (left) and cumulative vehicle passes (right).

– Application: Probe data, in-vehicle signage, and heartbeat. (Heartbeat sends and receives messages regarding speed and position of vehicles every 100 ms.)

- DTE tests
  – System services: Networking, urban canyon communication, and hilly terrain communication.
  – Application: Off-board navigation, in-vehicle signage, trip-path, payment parking, payment toll, heartbeat, and probe data.

The tests for the electronic tolls were performed at two separate locations, one at the Michigan test bed and another at the Dumbarton Bridge on California Highway 84. At the Michigan testing site, 10 tolling zones were set up. During the tests, vehicles had to pass the tolling zones at least once. Nine tests were conducted, all of which were successful. Figure 23 shows the tolling zones and cumulative vehicle passes (with red-colored lines).

At the California testing site, seven test runs passed through the bridge. For the first two runs, vehicles passed through the tolling plaza at a relatively low speed, while for the other test runs they passed the bridge at a speed of 40 to 60 mph. All but one of the test runs were successful. The metal structure of the tolling gantry was speculated to be the cause of the failure of the lone unsuccessful run. During the test runs, DSRC radio links were lost when vehicles passed beneath the gantry. Figure 24

Balloons with different colors indicate the stage of each test. For example, the "Collect 7" balloon indicates that Test #7 was in the collection stage, while the "Invoice 7" balloon indicates that an invoice was issued to Test #7.

Figure 24. Tolling test runs at the Dumbarton Bridge in California.

shows successful and unsuccessful tolling tests at the Dumbarton Bridge.

3.1.5 The Current Status of the System

As of October 2010, the status of IntelliDrive was as follows:

- Completed a major proof-of-concept test program
- Updating the concepts of operations, system requirements, and system architecture
  - Expanding program strategy to consider retrofit and carry-in devices
  - Expanding program scope to include communications options beyond just DSRC
- Opening up the Michigan test site for industry use
- Defining and executing the remaining research necessary to get to deployment
  - Includes regulatory decision points in 2013.

Funding for the IntelliDrive initiative was shared between U.S. DOT and the VII Consortium, with the U.S. DOT providing the majority share.

3.2 Fleet Management Systems

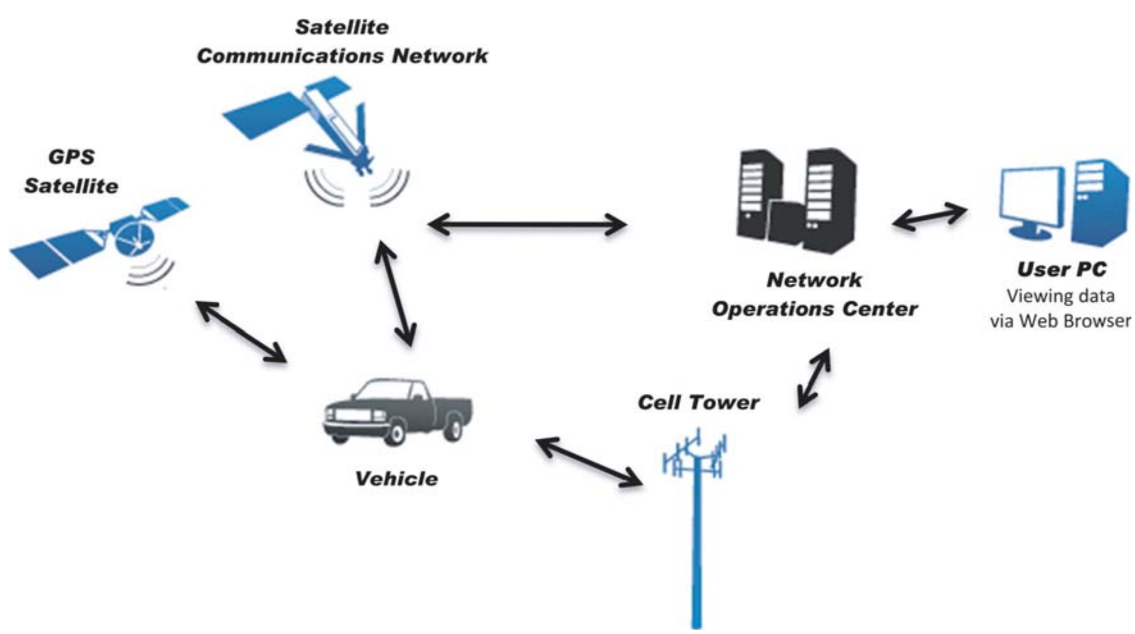
An FMS is a system that keeps track of a vehicle's location as well as its travel path, speed, fuel consumption, and idling time. FMSs have been used to monitor companies' vehicle fleets when providing services to internal or external customers. The industries and government agencies that have used FMSs include the oil and gas industry, the military, the construction and mining industry, and the logistics industry.

Technologies implemented in the name of fleet management have progressed over time. Within the last 30 years, a range of technologies has been implemented, from mobile radio, to analog, to paging networks, and, most recently, to satellite-based or terrestrial-based (i.e., cellular-based) mobile communications tracking systems. As shown in Figure 25, FMSs use either a satellite-based communications network or a set of cellular towers to track the movement of vehicles. This section presents examples of FMS based on two different communication methods.

3.2.1 Objectives and Benefits of Fleet Management Systems

The primary objectives of an FMS are to improve the management of vehicle fleets and to reduce their operating costs. The potential benefits FMSs may bring to operational management include

- Safety: By tracking vehicles in something close to real-time, businesses and government agencies have the potential to reduce liability caused by safety-related issues.
- Operations: By monitoring vehicles' idle time, businesses and government agencies are able to improve vehicle operational efficiency and reduce related operating costs.
- Drivers' behavior: By monitoring vehicles' movements, businesses and government agencies are able to reduce fuel consumption, detect unauthorized uses of vehicles, and bet-



Adapted from Fleet Management Solutions, http://www.fmsgps.com/frontend/overview.aspx

Figure 25. Components of fleet management systems.

ter manage both drivers' working behaviors and their organization's use of vehicles.

3.2.2 Satellite-Based Fleet Management: Expanded Satellite-Based Mobile Communications Tracking System

One of the communication methods implemented in an FMS is a satellite-based communications network. The satellite-based mobile communications system has been deployed to monitor and track hazmat, high-value cargo, and freight transportation. The system is effective in the areas not covered by cellular towers. It is particularly valuable for locating vehicles. The system also provides two-way communications between truck drivers and communication centers at regular time intervals. This information can be shared with carrier-authorized third parties such as public agencies.

As an example, this section presents an expanded satellite-based mobile communications tracking system tested by the U.S. DOT in Alaska and Hawaii (U.S. DOT, 2006, 2007). Because of special geographic characteristics in those two states, especially Alaska, communication equipment, such as antennae, has to be specially adjusted to ensure coverage and quality of signals.

Capabilities and Technology Components of the Satellite-Based System

The wireless satellite-based mobile communications tracking system tested by the U.S. DOT in Alaska and Hawaii has the following capabilities:

- Directs two-way data communication between the driver and the carrier with a driver interface unit for two-way text communications,
- Tracks the position of the tractor with the time and date of the transmitted message,
- Tracks tethered trailers, and
- Provides for panic/emergency alerts.

The technology components of the tested satellite-based communication system include satellites, in-vehicle communication units, antennae installed on trucks, tethered trailer tracking units installed on trailers, two panic buttons (one installed in the truck and another remote button), a network management center, and customer application software. Specific features of each technology component are as follows:

- Satellite selected: A geosynchronous earth orbit (GEO) satellite, Galaxy 10R, located at 123W with Ku-band, was selected for the test. The satellite was served by Pan AmSat. [The costs for lower earth orbit (LEO) satellites were prohibitively high because of low traffic demand in the tests.]
- In-vehicle communication unit and antenna: A satellite-based mobile communications terminal (SMCT) installed in a truck cab and a dome-shaped antenna GPS receiver mounted on the roof of a tractor (see Figure 26). Messages and position information, including latitude, longitude, and time, are transmitted through the over the air (OTA) messaging protocols.
- Tethered trailer tracking unit: To track trailers and to record time and location of trailer/tractor connections/disconnections (see Figure 27).
- Panic buttons: One installed in the cab and another wireless unit (See Figure 28).
- Network management center (NMC): NMCs may be located in different parts of the country. For instance, an NMC was located in San Diego, California, and a back-up NMC was

Source: U.S. DOT, 2007

Figure 26. In-vehicle communication unit and antenna for satellite-based systems.

Source: U.S. DOT, 2007

Figure 27. Trailer tracking unit.

located in Las Vegas, Nevada, for the U.S. DOT's tests in Alaska and Hawaii. The NMC is responsible for receiving and sending messages to drivers relayed through satellites on a 24-hour-a-day, 7-day-a-week basis.
- Internet communication: The communication between the customer fleet management center and the NMC is conducted using the Internet.

Tested Functionalities of the System

- Three technologies were tested: satellite-based mobile communications, panic buttons, and tethered trailer tracking. Test results indicated that
  - Satellite-based mobile communications improved two-way communication
    - Drivers can request assistance, convey information, and report delivery status and
    - Dispatchers can respond to drivers' requests, manage fleet movements, assign routes, and provide information back to customers.
  - The panic button improved emergency responses between drivers and dispatchers.
  - Tethered trailer tracking provided trailer status, connected or disconnected, to a trailer.
- Recording time: Trucks' locations were recorded every 15 min. The system would wake up, record its position, and take a reading to determine whether PamAmSat satellite coverage was available at that location. At hourly intervals, the first three position reports were archived and then sent with the fourth report at the end of the hour, along with other messages.
- Information recorded: In addition to the location of trucks, the status of satellite communication was also recorded to indicate whether the truck was in or out of coverage.
- Storage of records: All data went through the NMC in San Diego, CA.
- Out-of-coverage (OOC): For Alaska, 16% of the responses were outside of the coverage area, and the total miles recorded were 2,219. For Hawaii, OOC responses were 1% of the total responses, and the total number of miles recorded was 493.

Special Technical Requirements of the System

- Optimizing the mobile unit antenna for coverage in Alaska to maximize the signal strength throughout Alaska and to prevent signal drop-outs if vehicles were in mountain areas.
- Using a higher-powered 2W transceiver: A higher-powered 2W transceiver was used to ensure more reliable communi-

Source: U.S. DOT, 2007

Figure 28. Panic buttons.

cations than with the 1W transceiver typically used in the continental United States.

- Signal pass/fail criteria: E_b/N_0, energy per bit per noise power spectral density, was used.
- Maintenance and operations: Since all equipment was new and the test lasted just 3 months, hardware issues were minimal. Exceptions were a panic button malfunction and a faulty cable that caused the panic button to stick and the keyboard to lock up.

The Current Status of the System

The U.S. DOT conducted a 90-day pilot test of this system in monitoring hazmat and high-value cargo shipments in Alaska and Hawaii from November 2005 through January 2006. The system was installed on 100 tractors and 20 trailers in Alaska and five trucks in Hawaii. Some key test results were as follows:

- Improved communication coverage: During the pilot test, coverage extended beyond the major metropolitan areas.
- OOC reports: OOC occurred more in Alaska than in Hawaii because of the mountains. Also, the line of sight between the transceiver on the tractor and the satellite was interrupted because of buildings, overhead loading and unloading facilities, and urban canyons in downtown areas.
- Benefits experienced: Visibility of the status of the carriers' fleet was increased. Prior to installing this new system, Alaska drivers depended on relaying messages from one truck to another along the route, while Hawaii drivers depended on cell phones and e-mails to communicate with dispatchers. Though the coverage of the test for Alaska was not 100%, it clearly enhanced the communication between dispatchers and drivers.

Funding Sources and Feasibility

The U.S. Senate approved $2 million for the Federal Motor Carrier Safety Administration (FMCSA) to conduct the pilot tests of the expanded satellite-based mobile communications tracking system.

3.2.3 Cellular Technology-Based Fleet Management System

In addition to satellite-based systems, FMSs can also rely on cellular-based communication technology to monitor and track vehicles. The basic design for the cellular-based FMS relies on cellular towers to conduct two-way communications. Each vehicle needs three technology components: (i) a modem; (ii) an antenna; and (iii) power cables (see Figure 29). The modem and antenna enable reception of signals from a GPS satellite as well as the reception/transmission of signals to cellular towers. As shown in Figure 30, the FMS's signals are received by cellular towers, which pass the signals on to communication control centers. From there, users of FMS services are able to browse the signals via the Internet.

Figure 29. Technology components in a cellular-based FMS.

The benefits of a cellular-based FMS are two-fold. First, it uses cellular technology, which continues to improve rapidly. Some companies such as InstaMapper (see http://www.instamapper.com) already offer free tracking software that some cell phone users can download from the web. Second, because it makes use of the cellular technology already used by consumers, costs of using FMSs are likely to fall more quickly than a system founded on satellite-based technology.

To date, cellular-based FMSs have been implemented on just a limited number of vehicles. As a result, the ability of the system to handle large volumes of signals has not been tested. Hence, to truly analyze the feasibility of this approach for revenue generation and collection, tests should be performed to ensure that the system is capable of handling probable future signal volumes.

3.3 Commercial Vehicle Information Systems and Networks

The commercial vehicle information systems and networks program is designed to assist states in improving motor carrier safety and security, improving efficiency and freight mobility, and simplifying operations. CVISN provides access to safety and credentials information, state-to-state fee processes, and weight and size monitoring.

3.3.1 Objectives of CVISN

The primary objective of the CVISN program is to develop and deploy information systems that will support new capabilities in three areas that are core to CVISN:

- Safety information exchange: Provide carrier, vehicle, and driver safety information to roadside enforcement personnel and other authorized users. Data include inspection reports and snapshots.

- Credentials administration: Provide electronic application, processing, fee collection, issuance, and distribution of (at least) International Registration Plan (IRP) and IFTA credentials; support base state agreements; and electronic IFTA tax filing. State shares information via clearinghouses and snapshots.
- Electronic screening: Automatically screen vehicles that approach a roadside check station, determine whether further inspection or verification of credentials is required, and take appropriate actions. Currently, this screening relies predominantly on enrolled, in-vehicle DSRC transponders.

After implementing the core CVISN elements, states may choose to expand participation and deploy the expanded CVISN components, which continue to enhance the safety, security, and productivity of commercial vehicle operations (CVO). The expanded CVISN is designed to achieve the following:

- Driver information sharing,
- Enhanced safety information sharing,
- Expanded e-credentialing, and
- One-stop shops and electronic portals. A web portal or one-stop shop with a single sign-on access to all users can provide a way for a state to give a consistent look and feel across multiple applications for back-office users, enforcement, and motor carriers.

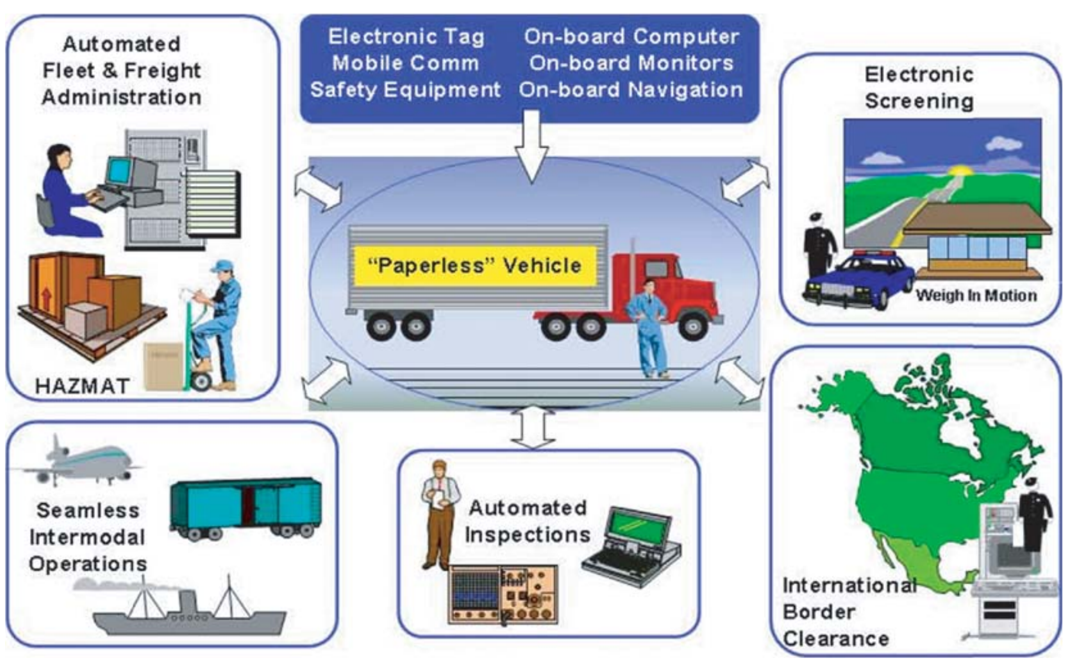
The long-term vision set by U.S. DOT is to create a paperless CVISN. Specifically, beyond the current core and expanded programs, the future CVISN will include other services and technologies that may hold potential for supporting revenue-generation systems. Some of the services and technologies may include

- Extension to integrate other CVO user services such as onboard safety monitoring, automated inspections, hazmat incident management, freight and fleet management, and intermodal freight functions;
- Closer integration with other ITS services for traffic management, traveler information, and incident response; and
- The use of DSRC at the 5.9-MHz frequency band, other means of RFID, and optical technologies (e.g., license plate readers) to identify vehicles.

To achieve the vision of a paperless vehicle, it is expected that vehicles produced in the future would have a set of advanced technology equipment such as mobile communications systems, navigation and tracking systems, onboard vehicle monitors, and electronic onboard recorders. Figure 30 illustrates the vision for CVISN in the long term.

3.3.2 Specifications of CVISN

Instead of building an information system for CVISN from scratch, the FMCSA has adopted a strategy of building a common interface to link together the existing databases and infor-



Source: U.S. DOT, FMCSA, 2008

Figure 30. Vision: safe and efficient shipping operations.

mation systems that states have developed and implemented across the United States. To integrate the existing state systems, FMCSA has applied open architecture and standards as well as a common technical framework for development and deployment of CVISN. The characteristics of the open architecture and the common technical framework are as follows:

- Open architecture and standards: CVISN uses this approach so that the systems developed by individual states can be linked together and communicate to each other.
- Common technical framework: CVISN provides a common technological framework and a basis for developing interface standards. Examples of key features of the CVISN architecture include
  - States' choices: The CVISN architecture does not specify a particular design for states or carriers, which are free to make their own design(s) to meet their needs.
  - Interoperability and compatibility: Systems and components deployed by different organizations (or by the same organization) work together to accomplish shared functions.

3.3.3 Technology Components of the System

To conduct roadside electronic screening (or e-screening) of trucks, CVISN requires the following specific technological components:

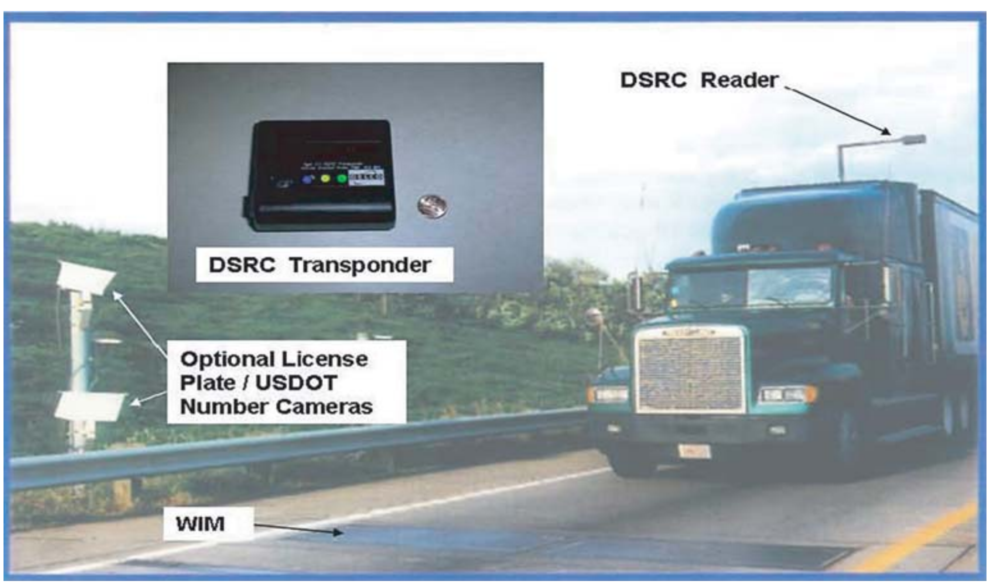
- DSRC transponder: A transponder is mounted on the windshield and has red/green indicators. Because each transponder is enrolled (registered) and installed on a specific vehicle, a direct link between the transponder ID and the vehicle identification number (VIN) is established.
- License-plate readers and U.S. DOT number readers: For those trucks without a transponder, license-plate readers and number readers will be implemented. For the basic CVISN, it is an optional technical component but is required in the expanded CVISN. The quality of reading is 40% to 65%, depending on lighting, reflectivity, contrast, and other factors.
- Weigh-in-motion (WIM) scales.
- Roadside readers: To obtain VIN from the transponder.
- Roadside operations computer (ROC) in the weigh station.

Figure 31 shows electronic screening equipment needed for roadside inspection. Figure 32 demonstrates an operational scheme for CVISN that shows how roadside screening equipment and fixed and mobile verification sites work together to ensure the safety of freight transportation.

3.3.4 The Current Status of the CVISN

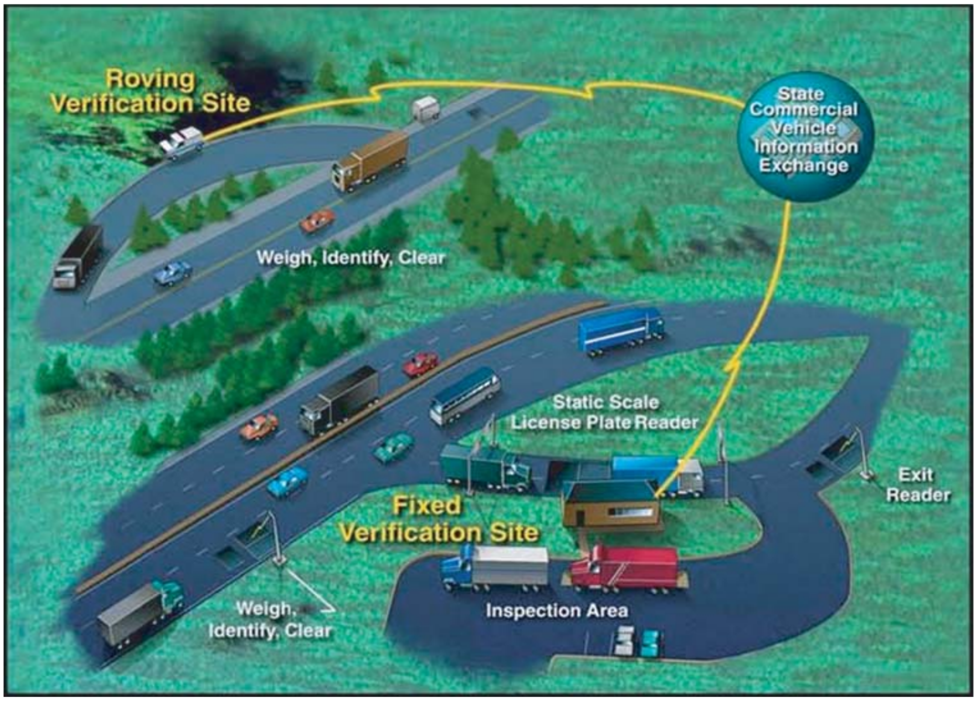
As of February 2010, the deployment status of CVISN was as follows:

- Expanded CVISN: 23 states have completed the deployment of the core CVISN and are deploying the expanded CVISN;
- Core CVISN: 23 states plus Washington, D.C., have deployed only the core CVISN; and
- Planning and design for the core CVISN: four states are at this stage.



Source: U.S. DOT, FMCSA, 2008

Figure 31. Example of electronic screening equipment.



Source: U.S. DOT, FMCSA, 2008

Figure 32. Components of CVISN's electronic screening system.

The deployment of CVISN across the United States indicates wide acceptance of the program among states. The CVISN program is a part of the national ITS architecture, which was defined and baselined in 1996.

Funding Sources

There are two funding sources for supporting the implementation of CVISN:

- SAFETEA-LU: A highway reauthorization act enacted in 2005 that has authorized $100 million in federal deployment funds to support states' implementation of the core and expanded CVISN functionality.
- State funding: States must match the federal funding.

3.4 Electric Cars and Smart Charging Software

Electric cars were popular in the late 19th century and early 20th century before internal combustion engines began to dominate the U.S. automotive market in the 1920s. Electric cars were outmoded in the 1930s as vast reserves of crude oil were discovered at the same time as mass production techniques reduced the costs of gasoline-fueled cars, which had the added advantage of being rapidly refueled.

High oil prices and concerns about the effect of hydrocarbon emissions on climate change have led to somewhat of a comeback for electric vehicles. Hybrid cars such as the Toyota Prius and the Chevrolet Volt, a plug-in hybrid electric vehicle, have gained increasing acceptance in the United States. The Nissan LEAF, a five-door family hatchback that was introduced in August 2009, will be the first mass-produced, all-electric, zero emission vehicle made available commercially in over a century. Nissan launched the LEAF in the United States in 2010, and U.S. production will begin in Smyrna, Tennessee, in 2012.

The increasing interest in electric cars in the United States has several implications for transportation infrastructure as well as for the nature of the way revenues and user fees would have to be generated to pay for the use of roadways. First, new infrastructure will be required to accommodate the charging and recharging of electric cars. Second, electric cars would render motor fuel taxes obsolete. Thus, as the share of electric car registrations rises in the United States, tax coffers for fuel taxes will likely experience severe declines, requiring policy makers to seek new revenue sources for building and repairing roads.

Over time, revenues from utility taxes will rise due to the burgeoning amount of electricity consumed by vehicles. This then begs the question of how either to find an alternative revenue-generation system unrelated to energy consumption or to distribute utility tax revenues generated from the recharging of electric cars to transportation-related investment. The remainder of this section of the report defines the technological components and infrastructure required for EVs and considers the potential for using smart charging software to upload vehicle information and assign user fees.

3.4.1 Objectives of Using Electric Cars

Two objectives of using electric cars are (i) reducing emissions from gasoline cars and improving the environment, and (ii) reducing global dependence on petroleum. A study on greenhouse gas (GHG) emission released by Pew Center (Greene and Schafer, 2003) indicates that transportation is the second largest source for GHG emissions both in terms of the volume and rate of growth. By 2020, the transportation sector alone will be responsible for 36% of total CO_2 emissions. The second objective has implications for U.S. national defense interests and economic independence.

3.4.2 Technology Components Related to Electric Cars

Key technical issues for electric cars are charging, recharging, and replacing batteries. To gain public acceptance and support, the charging or replacing of batteries in electric cars requires infrastructure for charging a car, preferably taking little more time than is required to refuel a gasoline-powered car. Technological components related to charging electric cars are batteries, a charge station, a switching station, and the electric car itself. Below is the description of each technical component:

- Battery: Several different types of batteries have been used in electric cars, such as
  - Lithium-ion batteries, which provide 200 to 300 miles per charge.
  - Lead-acid batteries, which provide up to 80 miles per charge.
  - Nickel-metal hydride (NiMH) batteries, which have higher energy density and may offer 120 miles per charge.
- Charge station (or charge at home): Charging batteries is one of the most challenging technical requirements of electric cars.
  - Charge station: Charge stations can be classified into levels based on voltage supply such as those shown in Table 18. The amount of charging time is closely associated with the voltage of the available electricity supply. Figures 33 and 34 show two examples of designs for charging electric cars. The charging post shown in Figure 33 is designed by Electric Transportation Engineering Corp. (eTec) for charging the Nissan LEAF, while Figure 34 demonstrates the design by Better Place, Inc. The eTec company plans to install more than 10,000 Level 2 charge stations in five states: Arizona, California, Oregon, Tennessee, and Washington.
  - Charge at home: A typical household in the United States has electric outlets of 1.5 kW (with 110 volt supply). Those in other countries may have outlets of 3 kW (with 220/240 volt supply). Charge times are reduced when higher power levels of electricity are available. However, it is likely that nearly all homes will require special wiring to receive the higher power levels needed for quick recharge of electric cars.
- Switching station: Instead of charging batteries, an alternative design is to switch or exchange depleted batteries. Batteries can be bought, leased, or replaced under a subscribed contract.
- Cars: Electric cars such as the LEAF, plug-in hybrid electric vehicle (PHEVs), or hybrid cars could be designed to work with charging and switching stations.

3.4.3 Electric Vehicle Implications for Revenue Collection

To the extent that electric vehicles are embraced by consumers, they could lead a revolution not only in how vehicles are powered but also in the way that highways are funded. When vehicle charging profiles are matched with periods of low demand, the existing grid could support a large transition towards plug-in vehicles. In fact, the results of a study recently conducted by the Pacific Northwest National Laboratory (PNNL) suggest that existing electricity generation and transmission infrastructure has the technical capacity to

Table 18. Levels of chargers and charge time needed for electric cars.

Level of Charger	Charge Time for Electric Cars	Charge Time for Plug-in Hybrid Electric Cars
Level 1 (110V)	8 to14 hours	4 to 8 hours
Level 2 (220–240V)	4 to 8 hours	2 to 4 hours
Level 3 (480V)(*)	15 minutes	15 minutes

(*) Level 3 uses a mint-charge technology.

Source: Electric Transportation Engineering Corp.

Source: http://www.etecevs.com/PHEV-activities/EcotalityEVbro093009s.pdf

Figure 33. Demonstrative design by eTec for charging the Nissan LEAF.

supply power to up to 73% of the light-duty vehicle fleet (Kintner-Meyer, Schneider, and Pratt, 2007).

An important feature of EVs for revenue generation and collection is that at some point they must be connected to the grid, or docked, in order to replenish stored energy. The coming vehicle-to-grid communications software could be used to: (i) adjust the timing and pace of charging to meet the needs of the customer while minimizing the demand placed on the grid; (ii) upload real-time performance data and vehicle information such as the car battery's size, current state of charge, elapsed time since the last charge, and VMT; and (iii) enable EVs to charge during periods of low-demand and return stored energy back to the grid during peak periods. The 2nd feature highlighted above could be used to implement a VMT fee or a utility-based tax.

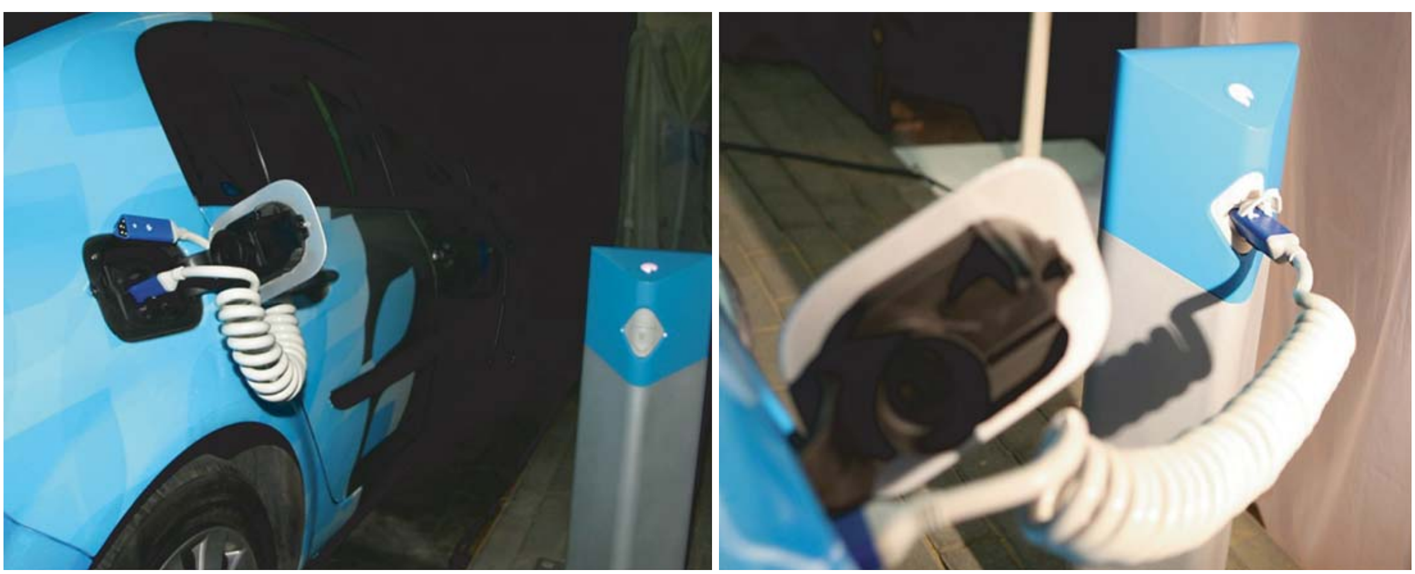
There are several pilot tests being deployed across the United States that are being used to examine various charging management strategies. For example:

- The Idaho National Laboratory is leading a field test of 57 PHEVs with real-time data captured from vehicles in Washington, Oregon, California, and Hawaii;
- Seattle City Light is operating a field test on 13 Toyota Priuses to investigate the impact of a PHEV fleet deployed in an urban environment; and
- Duke Energy, Progress Energy, and Advanced Energy are leading a field test involving the smart charging of 12 Toyota Priuses to examine the requirements of supporting vehicles as they roam between service areas (V2 Green, 2010).

3.4.4 Regional Influences on Electric Vehicle Market Penetration

In 2008, the five states with the greatest percentage of EVs operating on-road were California (53.1%), New York (14.2%), Arizona (6.7%), Massachusetts (4.4%), and Michigan (3.4%). The percentage of EVs in use in California reflects the state's commitment to improving air quality through the adoption of a number of standards and programs (e.g., the Zero Emission Vehicle Program) designed to reduce vehicle emissions.

Regional differences in market penetration depend largely on state policies that affect the cost to own and operate EVs. Figure 35 presents a map of state incentives either proposed or in place. As shown, incentives are either planned or provided throughout the western United States and Northeast. For example, Arizona lowers licensing fees for EVs, and California offers rebates of up to $5,000 for battery electric vehicles (BEVs), $3,000 for PHEVs, and $1,500 for electric motorcycles. Oregon recently put $5,000 tax credits in place to offset conversion or purchase costs for PHEVs, and allows $1,500 tax



Source: http://www.betterplace.com/images/photos/IMG_3220-N.JPG (left) and http://www.betterplace.com/images/photos/IMG_5317-N.JPG (right)

Figure 34. Charging electric car—designed by Better Place.

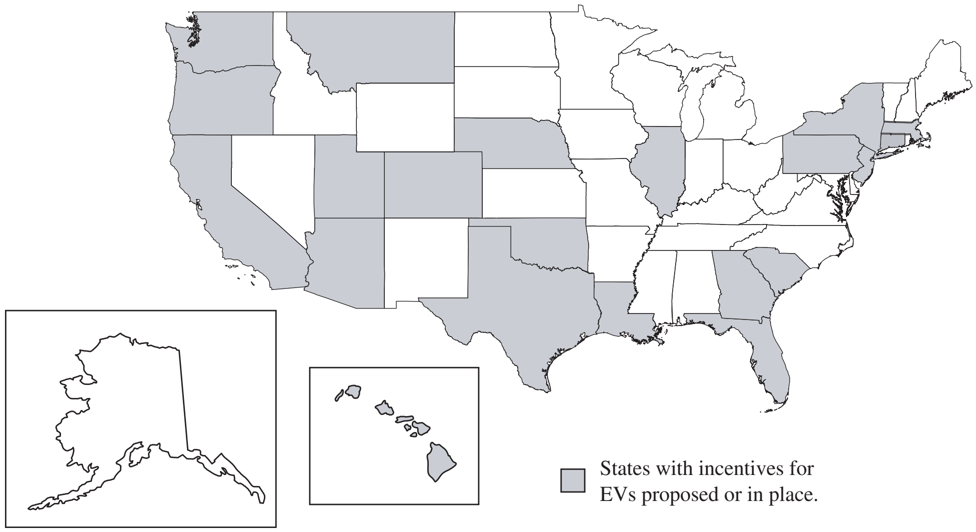


Figure 35. State incentives for electric vehicles.

credits for BEVs. These incentives are in addition to federal tax credits of $2,500 to $7,500 for EVs and PHEVs, depending on battery size.

The market success of EVs and PHEVs is also influenced by regional differences in the prices of electricity and motor fuel. As retail prices for electricity increase relative to the price of gasoline, demand for EVs and PHEVs would be expected to decline.

3.4.5 The Current Status of the System

Based on U.S. DOE Energy Information Administration (EIA) data, the number of EVs operating on-road reached 26,823 in 2008, representing roughly 0.01% of all light-duty vehicles in use. EV sales were small in 2008, representing less than one-tenth of 1% of the light-duty-vehicle market share (U.S. DOE, 2010a). Customer acceptance of the EV will be put to the test in 2011 with the newly introduced Nissan LEAF and its 100-mile all-electric range. The Nissan LEAF has an MSRP of as low as $32,780, or $25,280 after all federal tax credits. Tesla offers a premium sports car version of the EV called the Roadster, which is commercially available at an MSRP of as low as $109,000, or $101,500 after federal tax credits.

The number of light-duty EVs in use is forecast to decline in future years to 4,177 by 2030; the projected decline in EVs in use does not reflect a trend away from alternative vehicle technologies but rather a transition towards more competition among alternative technologies, some of which have not yet entered the marketplace.

The U.S. DOE forecast presented in the 2010 Annual Energy Outlook (AEO) is conservative (e.g., limited technology gains, moderate oil prices, conservative assumptions regarding tax credits for consumers who purchase electric vehicles) compared to a small number of recent forecasts prepared by industry. While some forecasts estimate ultimate hybrid electric and EV penetration of the light-duty vehicle market in the 8% to 16% range (Greene, Duleep, and McManus, 2004), a study prepared by Becker and Sidhu of the University of California, Berkeley's Center for Entrepreneurship and Technology (2009) estimates market penetration rates for the EV with switchable batteries of 64% to 85% by 2030. The low-end estimate relies on oil price data presented in the EIA AEO's reference case, while higher-end estimates use the EIA high oil price case and assume operator subsidies in the form of tax credits.

3.4.6 Funding Sources

The U.S. DOE encourages EV development through investments outlined in the American Recovery and Reinvestment Act and U.S. DOE's Advanced Technology Vehicle Manufacturing (ATVM) loan program. Together, these programs are supporting the "development, manufacturing, and deployment of the batteries, components, vehicles, and chargers necessary to put millions of electric vehicles on America's roads." The Recovery Act includes a $2.4 billion program designed to establish 30 manufacturing facilities for electric vehicle batteries and components. For each dollar of federal funds invested in the program, private partners are investing at least one dollar. U.S. DOE's Advanced Research Projects Agency—Energy (ARPA-E) is providing an additional $80 million to transformative research and development projects designed to advance battery and electric drive component technology beyond current frontiers. The ATVM loan program to date has provided nearly $2.6 billion to Nissan, Tesla, and Fisker to establish electric vehicle manufacturing plants in Tennessee, California, and Delaware, respectively. These investments in electric vehicle battery, component, and manufacturing technologies are designed to achieve a number of objectives:

- Lower the cost of some electric vehicle batteries by 70% by 2015,
- Enable U.S. manufacturers to produce a sufficient number of batteries and components to support the annual production of 500,000 electric-drive vehicles by 2015, and
- Boost the production capacity of U.S. manufacturers to 20% of the world's advanced vehicle battery supply by 2012 and 40% by 2015 (U.S. DOE, 2010b).

The U.S. DOE encourages the development of PHEVs in the U.S. marketplace through its Vehicle Technologies Program. The U.S. DOE supports research into advanced vehicles and fuels, hybrid and electric vehicle systems, energy storage, and materials technology. The U.S. DOE supports the FreedomCAR and Fuel Partnership with the goal of developing emission- and petroleum-free cars and light trucks and supporting infrastructure. Toward the development of PHEVs, the U.S. DOE has established several long-term goals designed to make PHEVs cost competitive by 2014 and ready for commercialization for volume production by 2016:

- $3,400 marginal cost of PHEV technology over existing hybrid technology,
- 40-mile all-electric range,
- 100 mile-per-gallon equivalent, and
- PHEV batteries that meet industry standards regarding economic life and safety (U.S. DOE, 2007).

CHAPTER 4

Administrative Cost Estimates for Motor Fuel Taxes and Alternative Revenue-Generation Systems

This chapter presents a cost analysis for five transportation revenue-generating systems, including motor fuel taxes, tolling, VMT fees, cordon/congestion pricing, and parking pricing. Motor fuel taxes, which have been levied in the United States since the 1920s, are one of the main revenue and funding sources of the federal HTF for constructing and maintaining the nation's highways and other transportation facilities. Although tolling has a long history, it has been viewed, especially in recent years, as a supplemental revenue source to motor fuel taxes. A number of new tolling facilities have been proposed and have been under construction around the country.

In an effort to search for alternative revenue sources that can mitigate further declines in the HTF, interest in VMT fees has been rising. Although some VMT fee systems have been tested and proposed, there is not a single VMT fee system in use that levies fees for all vehicle types. Consequently, there is no real cost data available except information that has been submitted by companies that competed for building and operating the proposed VMT fee system in the Netherlands.

This chapter provides an overview of a cost accounting framework established for this report and then presents the cost data collected for each of the five systems. For motor fuel taxes, more detailed cost analysis is focused on eight selected states, which were chosen based on a set of criteria (e.g., geographic diversity, point of taxation). As part of this analysis, capital and/or operational cost data for 14 tolling agencies have been collected. These agencies include older turnpike systems, more recently established toll agencies, and private companies that operate a toll facility under a concession agreement. For VMT fees, the costs examined in this report are based on the data from the proposed system in the Netherlands. Due to data limitations, only 1 year of cost data for the VMT fees has been gathered, while 3 to 5 years of cost data for motor fuel taxes and tolling have been collected. For cordon pricing, cost data were collected for five existing cordon pricing systems. For parking pricing, three systems were examined.

4.1 Cost Accounting Framework

This section describes the cost accounting framework that was used to estimate the costs required to administer each transportation revenue system presented in this chapter. The general methodology for analyzing administrative, collection, and enforcement costs involved the following:

- When feasible, financial data were collected from 2003 to 2007;
- To normalize the data between tax systems, it was necessary to differentiate between and separately analyze capital and operational costs;
- Annual operational expenditures were examined and sorted between administrative, collection, and enforcement activities;
- Revenues generated from ancillary activities, such as food and fuel concessions along toll road facilities, were excluded from this analysis; and
- Enforcement activities could be conducted by a private or public agency.

Administrative costs included in this analysis involved the following:

- Wages and salaries, employee benefits, social security taxes, and pensions of administrative and collection staff;
- Finance and accounting activities, especially if involved in the processing of (i) customer transactions and tax forms; (ii) the settlement of interagency transactions; (iii) the processing of bulk transactions from rental car companies, local delivery trucks, and auto dealers; (iv) the exclusion of transactions by non-revenue vehicles (e.g., police, ambulance, and fire vehicles); and (v) processing of refund requests;
- Management and professional services;
- Procurement and purchasing of equipment;
- Office supplies and equipment;

- Planning activities related to system development and expansion; and
- Buildings, utilities, and insurance for administrative staff.

Collection costs included the following components:

- Operation and maintenance of tollbooths and other facilities related to each transportation revenue system;
- Customer account management, payment processing, and banking charges;
- Inventory, distribution, and sale of transponders; and
- Cash counting, payment processing, transportation, and vault services.

Enforcement costs encompassed:

- Catching violators and auditing taxpayers,
- Assessing administrative fees and fines,
- Settling accounts before violations reach court,
- Inspecting motor fuel, and
- Prosecuting violators (court costs).

Enforcement costs also included police services, which could also include incident management and communication expenses.

4.2 Cost Estimates for Motor Fuel Taxes

State motor fuel tax administration and compliance programs are regulated by state legislatures and state agencies, including state DOTs and departments of revenue (DORs). Thus, state motor fuel tax programs vary significantly across the nation. To analyze the costs of administrating motor fuel taxes, a two-tiered approach was taken to collecting cost data from both federal and state government agencies. To carry out the approach, the following three-step data collection process was performed:

1. Collect data for 2003 through 2007 reported to FHWA on Form 556. Form 556 is used by states to report state motor fuel tax receipts and initial distribution by tax collection agencies, and includes adjustments to total receipts such as collection, administration, and enforcement costs. Data collected through Form 556 are reported in a series of tables in *Highway Statistics,* including Tables MF-1 (deductions by distributors for expenses), MF-3, and SDF (deductions for collecting motor fuel taxes and fees). Although the cost data presented in Tables MF-3 and SDF are called "collection" costs, the data actually represent the total costs of administering motor fuel taxes, including the costs associated with administration, collection, and enforcement.
2. Examine several factors that could be responsible for driving administrative cost differences between states (e.g., point of taxation, proximity to low tax state, presence of international border) and determine the administrative cost differential between states based on these characteristics.
3. Gather more detailed cost data from eight representative sample states in order to separate the collection costs reported to FHWA into administrative, collection, and enforcement cost categories, and examine cost data in greater detail. This final step explores the items that are attributable to the cost estimates, including the costs associated with building and maintaining motor-fuel tracking systems, the number of auditors employed by revenue agencies, the annual salary and fringe benefits paid to auditors, and the transaction costs associated with processing electronic payments.

4.2.1 Administrative Costs Reported in *Highway Statistics*

States report annual motor fuel tax administrative costs on Form 556, which is used to support a series of tables, including Tables MF-1, MF-3, and SDF, published annually in *Highway Statistics.* Since the cost data reported to FHWA cover administrative, collection, and enforcement costs, the term "operating cost" will be used hereafter. Annual operating cost data for all states were collected from *Highway Statistics* for 2003 through 2007. The cost data are used for a comparative analysis to show how the characteristics of certain programs, such as states with electronic motor-fuel tracking systems, may affect administrative costs.

For the eight states identified for further examination, completed Form 556s were obtained for 2006 and 2007. In the instructions accompanying Form 556, respondents are directed to input data covering distributor allowances, deductions by state collection agencies, expenses for collecting and administering motor fuel taxes, expenses for inspecting motor fuel, and other costs or deductions by the collecting agencies. The Form 556s obtained and reviewed for this analysis typically only included data regarding expenses of collecting and administering motor fuel taxes.

Distributor allowances are deductions provided to taxpayers for collection expense. In 2007, 25 states authorized distributor allowances totaling $184.8 million, or 0.5% of gross tax collections.

4.2.2 Determination of Sample States

The purpose of selecting sample states is to obtain detailed cost data used to separate the total operating costs reported to FHWA by states into administrative, collection, and enforcement cost categories. Eight states' motor fuel tax programs were identified for the more detailed analysis. The criteria for selecting sample states are designed in a manner to ensure that a range of characteristics that typically drive collection, administration, and enforcement costs will be examined. In so doing, the results of the sample states are designed to be representative and could be used to examine how these characteristics (e.g., proximity to international borders, state population, and point of taxation) correlate with higher or lower administrative costs. The criteria for the detailed analysis included

- Motor fuel tax rate,
- Border low tax state (yes or no),
- International border (yes or no),
- DOT reported administrative costs,
- Geographic dispersion,
- Points of taxation,
- Motor-fuel tracking system (yes or no), and
- State population.

Using these criteria, the states highlighted in Table 19 were selected for further analysis. Table 19 presents information for each of the criteria outlined above when applied to each state. The selection process captures states that embody a range of attributes defined within each criterion. That is, both relatively low and high tax rate states were identified, as were those with and without international borders. The remainder of this section describes the process used to select the states on a criterion-by-criterion basis.

Motor Fuel Tax Rate

High-, mid-level-, and low-tax states were identified for analysis. As motor fuel tax rates increase, profits associated with motor fuel tax evasion grow, thus requiring enhanced enforcement measures and higher administrative costs. The weighted average gasoline tax rate in the United States is 20.2 cents per gallon (FHWA, 2008). The weighted average state tax rates reported in *Highway Statistics* includes only taxes that are levied as a dollar amount per volume of motor fuel. Taxes that apply to all petroleum products are omitted, but local option taxes are included provided they have been adopted uniformly statewide. The weighted average tax rate does include the impact of several unique state-level fees, including a 2-cent-per-gallon inspection fee in Alabama, 0.4-cent-per-gallon environmental assurance fee in Arizona, a 1.4-cent-per-gallon petroleum environmental assurance fee in Kentucky, and a 0.7-cent-per-gallon oil discharge and disposal cleanup fee in New Hampshire. Presently, there are four states (Alaska, Georgia, New Jersey, and Wyoming) in the United States with gas tax rates that fall below 15 cents per gallon. One of these low-tax states (New Jersey) was targeted for further analysis. There are 21 states with gas tax rates between 15 and 20 cents per gallon, and four of these states (Florida, California, Tennessee, and Texas) were targeted for analysis. There are 25 states with gas tax rates in excess of 20 cents per gallon, and three such states (Colorado, Idaho, and Iowa) were targeted for analysis.

Border Low-Tax State

Large disparities in tax rates between bordering states within the United States create the potential for cross-border evasion, thus requiring enhanced enforcement in the higher tax state. To satisfy this criterion, the state must border one of the four low-tax states noted in the preceding paragraph, and the tax rate in the subject state must be at least 7 cents per gallon higher than the rate in the bordering low-tax state. Four of the selected states (Colorado, Florida, Idaho, and Tennessee) satisfy this criterion.

Table 19. Summary information for states identified for further cost analysis.

Criteria	CA	CO	FL	ID	IA	NJ	TN	TX
Motor fuel tax rates	Gas – 18¢, Diesel – 18¢	Gas – 22¢, Diesel – 20.5¢	Gas – 15.3¢, Diesel – 15.3¢	Gas – 25¢, Diesel – 25¢	Gas – 21¢, Diesel – 22.5¢	Gas – 10.5¢, Diesel – 13.5¢	Gas – 20¢, Diesel – 17¢	Gas – 20¢, Diesel – 20¢
Borders low-tax state	No	Yes	Yes	Yes	No	No	Yes	No
International border	Yes	No	No	Yes	No	No	No	Yes
Reported admin. costs	0.7%	0.4%	1.1%	1.7%	0.3%	1.0%	1.4%	1.0%
Points of taxation	Gas – terminal, diesel – terminal	Gas – distributor, diesel – distributor	Gas – terminal, diesel – terminal	Gas – terminal, diesel – terminal	Gas – terminal, diesel – terminal	Gas – distributor, diesel – retail	Gas – first receipt/sale, diesel – terminal	Gas – distributor, diesel – distributor
Tracking system	Yes	Yes	No	No	No	No	Yes	No
State population	36,756,666	4,939,456	18,328,340	1,523,816	3,002,555	8,682,661	6,214,888	24,326,974

Sources: HDR (2009) and FHWA (2008).

International Border

International borders also create opportunities to evade through cross-border evasion schemes, thus requiring expanded enforcement and higher administrative costs. To satisfy this criterion, the state must border Canada or Mexico. Of those states selected for analysis, three (California, Texas, and Idaho) meet this criterion.

DOT Reported Administrative Costs

The U.S. DOT's *Comparing Administrative Costs of Collecting Highway Revenues: Fuel Tax vs. Direct User Charge* and its analysis of motor fuel tax administrative costs to target high, mid-level, and low operating cost states is used as a reference (HDR, 2009). While the results of the surveys conducted in this study could differ from the findings of this U.S. DOT report, the findings of that report are considered an indicator of operating cost levels with each state. In the U.S. DOT report, average motor fuel tax administrative costs were estimated at 1.0% of total tax collections. Of the eight states selected for further analysis, two registered average operating cost levels (New Jersey and Texas), three were below average (California, Colorado, and Iowa), and three were relatively high operating cost states (Idaho, Florida, and Tennessee).

Geographic Dispersion

States were selected to capture multiple regions and achieve geographic dispersion. As shown in Figure 36, states were targeted in the Northeast, South, Midwest, Southwest, Mountain, and West Coast.

Point of Taxation

States with points of taxation at the terminal, distributor, first receipt/sale, and retail levels were identified. The point of taxation in the distribution system affects administrative costs because the number of taxpayers decreases as the point of taxation is moved up the distribution system.

Motor-Fuel Tracking System

In recent years, states have built motor-fuel tracking systems to track shipments of fuel between fuel suppliers. These automated tracking systems enable motor fuel tax enforcement authorities to detect discrepancies between reported and actual transactions between fuel suppliers. While these systems reduce evasion, there is a cost associated with their use. Further, their use is indicative of enhanced enforcement measures, which could generate additional costs while still yielding positive returns on investment through reduced evasion. Of the 15 states with automated motor-fuel tracking systems identified in *NCHRP Report 623: Identifying and Quantifying Rates of State Motor Fuel Tax Evasion,* three (California, Colorado, and Tennessee) were identified for further analysis (Weimar et al., 2008).

State Population

The selected states vary significantly based on population. The sample of states includes two rural, low-population states (Idaho and Iowa) and three high-population states (California, Texas, and Florida). The remaining states' populations range from 4.9 million (Colorado) to 8.7 million (New Jersey).

4.2.3 Identification of Responsible Agencies Within Sample States

Agencies and organizations within each of the sample states that are responsible for collecting, administering, and enforcing motor fuel tax programs vary from state to state. The agencies investigated for this analysis include

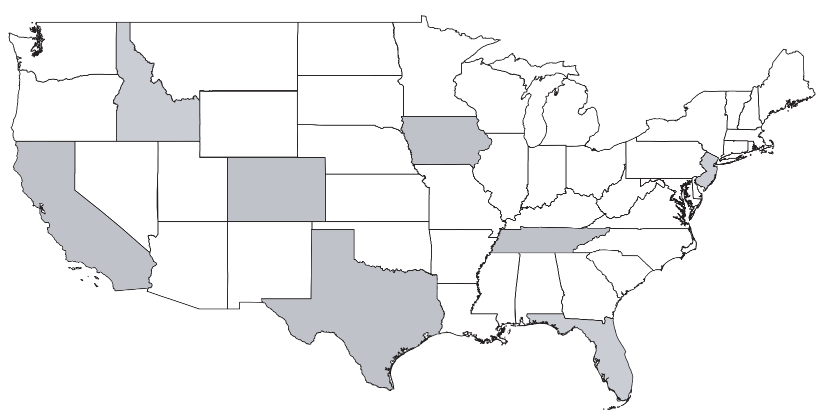


Figure 36. States targeted for detailed administrative cost analysis.

- State DOT, including the motor carrier services division, finance division, and motor fuel tax section;
- State DOR;
- Board of Equalization;
- Comptroller of Public Accounts;
- Department of the Treasury; and
- Department of Taxation.

Once the responsible agency was identified, individuals with knowledge of motor fuel tax administrative programs were contacted and follow-on data-collection activities commenced through the distribution of a survey.

4.2.4 Collecting Cost Data from State Agencies

To collect cost data from state agencies, a questionnaire (see Appendix B) was designed and distributed to the sample states. Once a survey was completed, an additional contact was made to discuss the data provided by the respondent. The questionnaire included the following information:

- The objectives of the study
  - Examine, estimate, and compare administrative, collection, and enforcement costs of motor fuel tax programs
  - Examine the factors that drive administrative, collection, and enforcement costs
- Topics covered
  - Background information: Name of respondent, agency responsible for tax collection and enforcement, and contact information
  - Auditing costs: The types of administrative costs currently incurred when implementing a motor fuel tax, the number of auditing staff required for motor fuel taxes, costs associated with licensing auditors, return on investment of auditing efforts
  - Enforcement costs: Presence and cost of motor-fuel tracking systems, on-road inspections of motor fuel, licensing and bonding of motor fuel tax distributors, capital and other indirect enforcement costs
  - Collection costs: Electronic reporting system costs, manual data input costs, transaction costs, collection allowances, costs associated with debt collectors, and other indirect costs.

Follow-up telephone interviews and data transfers were used to complete the data-collection process.

4.2.5 Analysis of Cost Data

As outlined in Section 4.2.1, the primary sources of data used to estimate the costs of administering motor fuel taxes are the Form 556 data reported to FHWA by states. Additional data were collected through surveys from eight sample states, which were chosen based on the criteria outlined in Section 4.2.2. This section presents the results of the cost analysis using the methodology described earlier in this chapter. Note that in all cases, motor fuel tax collection costs include those associated with both gasoline and special fuels. Results addressed in this section include

- Estimated tax collections and costs of motor fuel tax administration for the entire United States for 2003 through 2007,
- Estimated tax collections and costs of motor fuel tax administration in 2007 for every state in the United States,
- Administrative costs for states grouped together based on the criteria outlined in Section 4.2.2 (e.g., point of taxation or international border state),
- Detailed cost and system characteristics data for each of the eight states included in the sample frame, and
- Summary information acquired to date through completed surveys.

4.2.6 Summary Data for 2003 through 2007

As shown in Table 20, total motor fuel tax collections for all states have grown from $33.3 billion in 2003 to $39.4 billion in 2007. Data reported in Table 20 represent net collections with distributor allowances deducted from gross tax collections. Average annual collections during that time period were $35.7 billion.

Table 20. Net state motor fuel tax collections and collection expenses (2003–2007) ($000s).

	2003	2004	2005	2006	2007	Average
Net motor fuel tax collections	33,276,518	34,696,386	35,038,064	36,278,026	39,377,467	35,733,292
Collection expenses	326,377	494,404	309,325	373,615	405,096	381,763
Collection expense as percentage of tax collections	1.0%	1.4%	0.9%	1.0%	1.0%	1.1%

Source: FHWA, *Highway Statistics,* 2003–2007

During the 2003 to 2007 time period, states spent on average $381.8 million on administering diesel and gasoline motor fuel taxes. From 2003 to 2007, operating costs as a percent of total tax collections were very consistent, ranging from a low of 0.9% in 2005 to a high of 1.4% in 2004, with an average of 1.1%. The consistency in operating cost is a common phenomenon in mature tax systems, with costs associated with collections, administration, and enforcement programs experiencing limited growth from year to year.

The major operating cost elements reported by states surveyed for this report included

- Distributor, IFTA, and refund audit programs;
- Refund and distributor report processing;
- Motor-fuel tracking systems;
- Licensing and bonding programs;
- On-road dyed fuel inspections; and
- Electronic reporting transaction costs.

Among the states completing surveys for this study, the average salary plus fringe benefits for auditors ranged from approximately $50,000 to $75,300 annually. Other cost elements reported by states included indirect costs (e.g., training, human resources, office support, and information services), taxpayer education programs, and third-party debt-collection services.

4.2.7 State-by-State Data for 2007

Highway Statistics presents motor fuel operating costs for all 50 states plus the District of Columbia. In 2007, however, 19 states did not report collection expenses. Two steps were taken to fill in the gaps created by the unreported amounts. For states that did not report collection expenses during the 2003 through 2007 timeframe, the average collections expense rate of 1.0% was assigned. For states that reported data for at least 1 year during the 2003 to 2007 timeframe, the average values for years when the state did report data were used to fill in the 2007 value. In 2007, net state motor fuel tax collections in the United States reached $39.4 billion while operating costs were estimated at $405.1 million, or 1.0% of total tax collections. Most state-reported values were near the mean collection cost rate of 1.0%, though reported values did reach as low as 0.1% and as high as 3.7%. The collection cost rate for Indiana was estimated at 5.2%; however, that value was not reported by Indiana. The value reported in Table 21 was calculated by the research team based on previous years' reports from Indiana.

4.2.8 Data Grouped by Different Characteristics

Section 4.2.2 identified several factors expected to have an impact on the costs associated with administering motor fuel taxes. To measure the effect of these factors on collection cost rates, states that fell into each relevant category (e.g., distributor or terminal rack point of taxation) were identified and grouped, and the associated administrative costs are reported for each group. The results of this analysis are presented in Table 22 for the 2003 through 2007 time period.

- The average collection expense as a percent of total motor fuel tax collections among the 44 states reporting data was 1.1%.
- Motor-fuel tracking systems and the size of the motor fuel tax collections program had a negligible impact on operating cost levels.
- Operating costs in states that border low-tax states were slightly higher than average at 1.3% of total tax collections.
- Operating costs in states with international borders were lower than the mean estimated collection cost rate at 0.8%.
- The point of taxation had little effect on collection expense rates. There were too few states reporting at the first receipt/sale or retail level to derive any conclusions.

The finding on point of taxation could be construed as counterintuitive given that as the point of taxation moves up the distribution chain, there are fewer taxpayer forms to process and fewer taxpayers to audit; however, moving the point of taxation to the terminal rack also results in more refund requests and associated processing and auditing costs. The costs associated with the refund process could counterbalance the reduced distributor auditing and return processing costs.

4.2.9 Data from Eight Sample States

Table 23 presents more total operating cost and total tax revenue data for each of the eight sample states identified in the previous section. Data collected for each state will be used as the basis for the cost comparative analysis within fuel tax systems and with other revenue systems to be discussed in Chapter 5 of this report. In 2007, motor fuel tax collections in these states reached $11.4 billion, up from $10.3 billion in 2003. Motor fuel tax collections in these states represent 29.0% of the nation's total motor fuel tax collections.

The survey results presented in this section summarize the major operating cost characteristics reported by the states that have completed the survey: California, Colorado, Florida, and Idaho. The primary motor fuel tax administrative categories addressed in the questionnaire for each program are as follows:

- Auditing costs,
- Administrative program costs,
- Enforcement costs, and
- Collection costs.

Table 21. Motor fuel tax collections and collection expense, 2007.

State	Net Motor Fuel Tax Collections ($000s)	Collection Expenses ($000s)	Collection Expense as % of Tax Collections
Alabama	$680,013	$18,175	2.7%
Alaska [1]	31,638	316	1.0%
Arizona [2]	728,385	3,642	0.5%
Arkansas	462,190	17,191	3.7%
California	3,418,725	22,569	0.7%
Colorado	567,680	3,693	0.7%
Connecticut	676,813	4,615	0.7%
Delaware [2]	117,218	2,227	1.9%
Dist. of Col. [1]	26,776	268	1.0%
Florida	2,233,129	24,761	1.1%
Georgia	934,173	6,602	0.7%
Hawaii [2]	85,561	684	0.8%
Idaho	237,411	3,597	1.5%
Illinois	1,338,373	30,449	2.3%
Indiana [2]	879,793	45,749	5.2%
Iowa	444,086	1,258	0.3%
Kansas [1]	439,590	4,396	1.0%
Kentucky [2]	563,168	1,126	0.2%
Louisiana [1]	639,748	6,397	1.0%
Maine [2]	238,796	478	0.2%
Maryland	758,834	7,774	1.0%
Massachusetts [2]	669,357	6,024	0.9%
Michigan	1,027,933	8,903	0.9%
Minnesota	674,682	766	0.1%
Mississippi [1]	431,432	4,314	1.0%
Missouri [2]	704,183	2,817	0.4%
Montana [2]	193,453	1,161	0.6%
Nebraska	332,467	2,000	0.6%
Nevada	520,736	1,221	0.2%
New Hampshire [2]	151,965	608	0.4%
New Jersey [2]	589,571	5,896	1.0%
New Mexico	289,747	9,787	3.4%
New York [1]	2,197,646	21,976	1.0%
North Carolina	1,656,334	29,540	1.8%
North Dakota	124,839	874	0.7%
Ohio	1,894,435	15,773	0.8%
Oklahoma	410,639	1,000	0.2%
Oregon [2]	412,950	1,652	0.4%
Pennsylvania	2,106,731	13,708	0.7%
Rhode Island [1]	146,104	1,461	1.0%
South Carolina	535,261	1,347	0.3%
South Dakota	130,076	2,642	2.0%
Tennessee	849,662	12,239	1.4%
Texas	3,086,196	31,330	1.0%
Utah	372,747	2,677	0.7%
Vermont	94,961	693	0.7%
Virginia	932,996	7,573	0.8%
Washington	1,119,386	6,987	0.6%
West Virginia	1,107,615	1,525	0.1%
Wisconsin	1,006,012	1,368	0.1%
Wyoming	105,251	1,265	1.2%
Total	**39,377,467**	**405,096**	**1.0%**

[1] States that did not report collection costs during the 2003 to 2007 time period were assigned the average state collection ratio of 1.0%.

[2] For states that reported data for at least 1 year during the 2003 to 2007 time period, average values from the years that were reported were used to fill in 2007.

Source: FHWA, *Highway Statistics,* 2007

Table 22. Ratios of collection expenses for states with varying characteristics.

Measure of Characteristics	Collection Expenses as % of Total Tax Collections	Number of States
Average of all states that reported costs	1.1%	44
States with electronic tracking systems	1.0%	15
States with international borders	0.8%	17
States that border low tax states	1.3%	16
Top third tax collection states	1.1%	15
Mid third tax collection states	0.9%	15
Lowest third tax collection states	1.0%	14
States taxing at first receipt/sale	1.6%	1
States taxing at distributor level	1.0%	20
States taxing at terminal rack	1.1%	20
States taxing at retail level	0.7%	3

4.2.10 Analysis of Survey Results

As noted in Section 4.2, the questionnaires were distributed to eight states based on the aforementioned criteria. The purpose of the questionnaire was to gather more detailed cost data in order to disaggregate the total operating costs reported to FHWA by states. The primary cost categories targeted for data collection were as follows:

- Auditing,
- Collection costs,
- Enforcement costs, and
- Administrative costs.

Four states have provided information regarding the costs to administer the motor fuel tax. Though the states that returned surveys were able to provide detailed cost data, the

Table 23. Fuel taxes – total operating cost and revenue (in $000s).

State	2003	2004	2005	2006	2007	Average over years
Total Operating Cost						
California	$24,711	$26,551	$23,320	$22,530	$22,569	$23,936
Colorado	2,758	2,557	2,583	2,334	3,693	2,785
Florida	22,299	22,893	23,677	24,853	24,761	23,697
Idaho	980	2,978	3,162	3,649	3,597	2,873
Iowa	1,099	1,099	1,181	1,250	1,258	1,177
New Jersey	5,544	6,178	5,645	5,794	5,896	5,811
Tennessee	11,606	11,927	12,121	12,069	12,239	11,992
Texas	29,176	29,843	29,972	30,686	31,330	30,201
Average over sample states	12,272	13,003	12,708	12,896	13,168	12,809
Total Revenue						
California	3,176,019	3,531,929	3,299,559	3,258,087	3,418,725	3,336,864
Colorado	544,337	553,593	516,575	602,897	567,680	557,016
Florida	1,851,781	1,891,053	2,029,290	2,165,327	2,233,129	2,034,116
Idaho	205,772	211,337	213,646	219,360	237,411	217,505
Iowa	409,191	418,164	424,354	430,083	444,086	425,176
New Jersey	554,365	617,811	564,505	579,392	589,571	581,129
Tennessee	800,720	812,091	891,499	842,236	849,662	839,242
Texas	2,789,208	2,912,008	2,915,672	2,970,092	3,086,196	2,934,635
Average over sample states	1,291,424	1,368,498	1,356,888	1,383,434	1,428,308	1,365,710

Source: FHWA, *Highway Statistics,* 2003–2007 total operating costs reported often differed from the amounts reported to FHWA. For example, the data collected from Colorado indicate that operating costs in 2007 totaled approximately $2.6 million, which differs by $1.1 million from the total reported to FHWA in 2007. The following summary includes details of the survey results that have been received from each state.

California

Point of taxation: Diesel (terminal); gasoline (terminal).

The respondent from California was unable to provide a detailed breakdown of costs associated with motor fuel tax collection as outlined in the survey. Instead, the respondent broke down the 2007 administrative budget into five parts according to the state Board of Equalization budget allocations. Breakdown is as follows:

Registration: This section includes licensing new accounts and maintaining existing information in the licensing system. The total reported in this section was $3.1 million in 2007.

Return processing: California budgeted $7.2 million for all activities associated with processing returns, e-filing, advisory services, and the California matching program in 2007.

Auditing costs: Auditing costs for the State of California include auditing, refunds, and appeals. Total auditing costs in 2007 were $8.1 million.

Enforcement costs: California reported $1.9 million for on-road inspections of dyed fuel and other (unspecified) enforcement costs.

Collection costs: The respondent did not identify specific systems that were involved in collection costs but did indicate that these activities amounted to approximately $1.5 million in 2007.

In addition, the respondent noted that although the five categories have allotted budgets, there is a fair amount of overlap between cost elements, especially between auditing and enforcement and auditing and the matching process in return processing. All five categories include personnel service costs, operations expenses, and allocated overhead; personal service costs was estimated at approximately 76% of the allocated budget. Administrative costs budgeted by California totaled approximately $21.8 million, and actual spending amounted to $21.6 million. These amounts differ slightly from the $22.5 million reported by FHWA.

Colorado

Point of taxation: Diesel (distributor); gasoline (distributor).

Auditing costs: Auditing costs for the State of Colorado include labor overhead and indirect costs associated with motor fuel tax auditing activities. The respondent to the survey did not indicate costs associated with IFTA licensing or joint auditing expenses. Labor costs for 2007 totaled $373,697, which included salaries and benefits for supporting staff. Indirect costs include rent, utilities, training costs, materials/supplies, and personal services costs such as office support, management, HR services, information services, other services, and supplies. Indirect costs associated with auditing in 2007 totaled $58,943.

Enforcement costs: Colorado employs a motor-fuel tracking system with electronic filing, but system expenses are not included in enforcement costs since they are maintained by a third-party operator. The state performs on-road dyed fuel inspections at an annual cost of $735,102. The respondent also indicated that indirect costs associated with enforcement totaled $26,150 in 2007.

Collection costs: Colorado uses an electronic system to both process tax returns and receive tax payments. Costs associated with this system in 2007 amounted to $411,148, with an additional $90,834 in costs relating to manually processing tax returns and payments. Colorado did not identify any costs associated with payment transaction fees or debt collection expenses but did identify an additional $3,232 in indirect collection costs.

Administrative costs: Program administration costs, which include the overarching management of the motor fuel tax collection department, totaled $751,902 in 2007, which included $243,676 in indirect costs pertaining to program administration. Based on information gathered in the questionnaire, motor fuel tax administrative costs for 2007 totaled approximately $2.4 million, an amount which was $1.1 million less than the total reported to FHWA.

Florida

Point of taxation: Diesel (wholesaler); gasoline (wholesaler).

Auditing costs: Total annual labor costs associated with auditing activities were reported to be $794,039. Florida did not report IFTA auditing costs or conduct joint auditing with other states or the IRS. Additional indirect costs were reported as $214,391, bringing the total auditing cost in Florida to approximately $1 million annually.

Enforcement costs: Florida does not presently employ a motor-fuel tracking system but is in the programming stages of implementing one. Florida does conduct on-road inspections of dyed fuel through the Department of Agriculture, with costs reported to be approximately $6.8 million in 2007. The respondent at the Department of Revenue attributed an additional $4,893 to other inspection activities. Indirect costs associated with enforcement were reported to be $1,321, bringing total enforcement costs to approximately $6.8 million.

Collection costs: Florida requires electronic filing; however, a paper version is available for those taxpayers who request, qualify, and receive a waiver of this requirement. The state incurs a cost of $0.27 per transaction plus $1,500 per month to support electronic filing. In total, the processing of electronic payments costs the state $307,911 annually. Florida also allows distributors a 2.0% collection allowance. In addition, the respondent reported $51,266 in debt collection activities and $83,136 in indirect costs associated with collections.

Administrative costs: Program administration costs in Florida were reported as $345,115 in 2007, with an additional $501,390 in indirect costs. Due to the discrepancy between the $2 million reported by the respondent of the questionnaire and the $24 million reported to FHWA, a transportation analyst from the Department of Transportation was contacted. The respondent indicated that the FHWA total was reported by three departments broken down as follows:

- Department of Revenue: $14,010,475 withheld from administrative charge on fuel taxes,
- Department of Highway Safety and Motor Vehicles: $3,944,276 withheld from fuel use tax (permits), and
- Department of Agriculture and Consumer Services: $6,805,832 costs of inspection fuel.

Idaho

Point of taxation: Diesel (distributor); gasoline (distributor).

According to Idaho Code Section 63-2403, Idaho is a "first receiver" state, meaning the first fuel distributor to receive the fuel from an Idaho pipeline terminal or importer is responsible for paying Idaho fuel tax and transfer fees.

Auditing costs: Idaho employs 17 auditors who conduct distributor, IFTA, and refund audits. In 2007, the state spent $860,444 in labor costs associated with auditing activities. Of that total, $433,473 is dedicated to licensing IFTA auditors. Idaho receives a special grant from FHWA to conduct joint audits with the IRS and other jurisdictions, but does not include the grant amount in the overall auditing expenses. Indirect costs, such as rent, utilities, and training services, amounted to $233,238. Total auditing costs totaled $1,083,682 in 2007.

Enforcement costs: Idaho did not report any costs associated with enforcement activities.

Collection costs: Idaho allows distributors to file returns in either electronic or paper form. Further, it allows distributors to pay using electronic funds transfers (EFT). Costs associated with operations and maintenance of the electronic filing system amounted to $210,000 in 2007, and transaction fees totaled $8,760. The state spent an additional $108,714 on manually processing tax returns and payments. Debt collection activities conducted by state-employed personnel amounted to $303,686 in 2007, and an additional $230,000 was spent on indirect costs associated with collections. Collection costs totaled $861,160 in 2007.

Administration costs: Overarching program management costs not associated with auditing, enforcement, or collections in 2007 were reported to be $1,353,101, with an additional $351,057 in indirect costs. The respondent estimated a total of $3.6 million in total administrative costs associated with motor fuel tax collection in 2007, which is the same amount reported to FHWA.

4.3 Cost Estimates for Tolling

Although widespread, the ability to impose tolls on highways, causeways, bridges, and tunnels varies greatly throughout the United States. In some states (e.g., Florida and Texas), state and local agencies have broad authority to impose tolls on highway infrastructure. This authority, however, is typically limited to the development of new infrastructure; several states have statutes that expressly forbid the tolling of existing infrastructure. In other states, toll authority may be granted to either state or local public agencies, but not both. Other states restrict tolling to a few pilot projects and/or bridges.

Moreover, some states (e.g., Virginia) permit the development of concession agreements which allow private agencies to operate and collect tolls from road facilities, while current statutes in other states (e.g., Maryland) preclude private entities from developing and operating toll facilities. Finally, some states expressly prohibit the imposition of tolls (e.g., Nevada).

Additional restrictions focus on the tolling of existing federal Interstates, which is generally prohibited. In this manner, the selection of toll agencies for analysis was limited to the jurisdictions that permit tolling as well as have a reasonably long history in the collection of toll revenues.

4.3.1 Methodology

The general methodology for analyzing administrative, collection, and enforcement costs incurred by toll agencies involved the following:

- Selection of the toll agencies for analysis by taking into account facility type, system age, governance structure, and toll-collection systems.
- The collection of financial data from 2003 to 2007. Most of this data has been compiled from comprehensive annual financial reports (CAFRs). Operational statistics have also been compiled. All of the agencies under review have prepared data for at least 3 years.
- To normalize the data between toll agencies, it was necessary to differentiate between and separately analyze capital and operational costs for toll systems. Although most agencies have begun to install ETC systems, open road configurations, or video tolling systems, implementation rates tend to vary greatly.

- Examination of annual operational expenditures and sorting between administrative, collection, and enforcement activities.
- The mandate of all toll agencies involves the maintenance of road infrastructure, the extension of toll road systems, and other capital improvements that expand system capacity. To provide a more accurate representation of the costs that are specific to toll administration, collection, and enforcement, it was necessary to exclude the capital and operational expenditures related to physical infrastructure. However, toll collection and highway maintenance activities may share cost centers.
- Toll agencies that did not disaggregate annual expenditures (e.g., states that merged highway maintenance costs with toll activities within a single line item) were excluded from this analysis.
- Revenues generated from non-toll-related activities, such as food and fuel concessions along the road facility, were excluded from this analysis.
- Enforcement activities may be conducted by a public agency that is separate from the toll agency. In some cases, enforcement activities have not been listed as a cost item. As a result, additional data were collected related to enforcement costs. However, these data were not available for all toll agencies included in this analysis.

4.3.2 Toll Agencies Analyzed and Selection Criteria

The objective of this analysis was to review a diverse number of toll agencies in order to provide a comprehensive survey of toll agency costs. To accomplish this goal, the criteria for selecting the toll agencies for this analysis were

- System age. This analysis includes
  - Mature toll-road systems: The New Jersey Turnpike Authority (NJTA), the New York State Thruway Authority (NYSTA), and the Ohio Turnpike Commission (OTC)
  - Toll road systems that were first developed in the 1960s and have since undergone considerable expansion: The North Texas Tollway Authority (NTTA)
  - Relatively new toll-road systems: The Central Texas Regional Mobility Authority (CTRMA)
- Governance structure. This study covers toll system costs from a variety of governance structures, including:
  - State toll-road agencies: The Illinois State Toll Highway Authority (ISTHA), NJTA, and NYSTA
  - Toll roads administered by state DOT: The Dulles Toll Road in Northern Virginia (Virginia Department of Transportation transferred operations to the Metropolitan Washington Airports Authority in 2008.)
  - Regional government agencies that oversee toll roads across multiple cities and counties: NTTA
  - Metropolitan MPOs: The San Diego Association of Governments (SANDAG), which manages the I-15 lanes
  - Multi-modal agencies: OCTA, which oversees SR-91 and the Delaware River Port Authority (DRPA)
  - Private operations: Toronto 407 International Inc. and the Dulles Greenway
- Toll system type. This analysis includes
  - Single facility toll roads: SR-91, CTRMA (or US 183-A), E-470, and I-15
  - Multi-road toll agencies: NTTA, the Orlando–Orange County Expressway Authority (OOCEA), Florida's Turnpike Enterprise (FTE), and ISTHA
  - Bridges: The Delaware River Joint Toll Bridge Commission (DRJTBC) and the Delaware River Port Authority
  - HOT lanes: I-15 HOT lanes
- Toll-collection method. As toll systems are moving toward the implementation of all or partial ETC systems, the majority of toll systems under analysis have a hybrid toll-collection system in place. However, two systems—CTRMA and Toronto 407—use an AETC system.
- Geographic diversity. This analysis includes toll systems from all parts of the United States where tolling is permitted. To the extent possible, in the analysis of toll system costs, same states that were included in the analysis in the collection of fuel taxes were reviewed. There was an overlap in four states—California, Colorado, New Jersey, and Texas. In order to include a privately operated toll agency, Toronto 407 was included in the analysis.

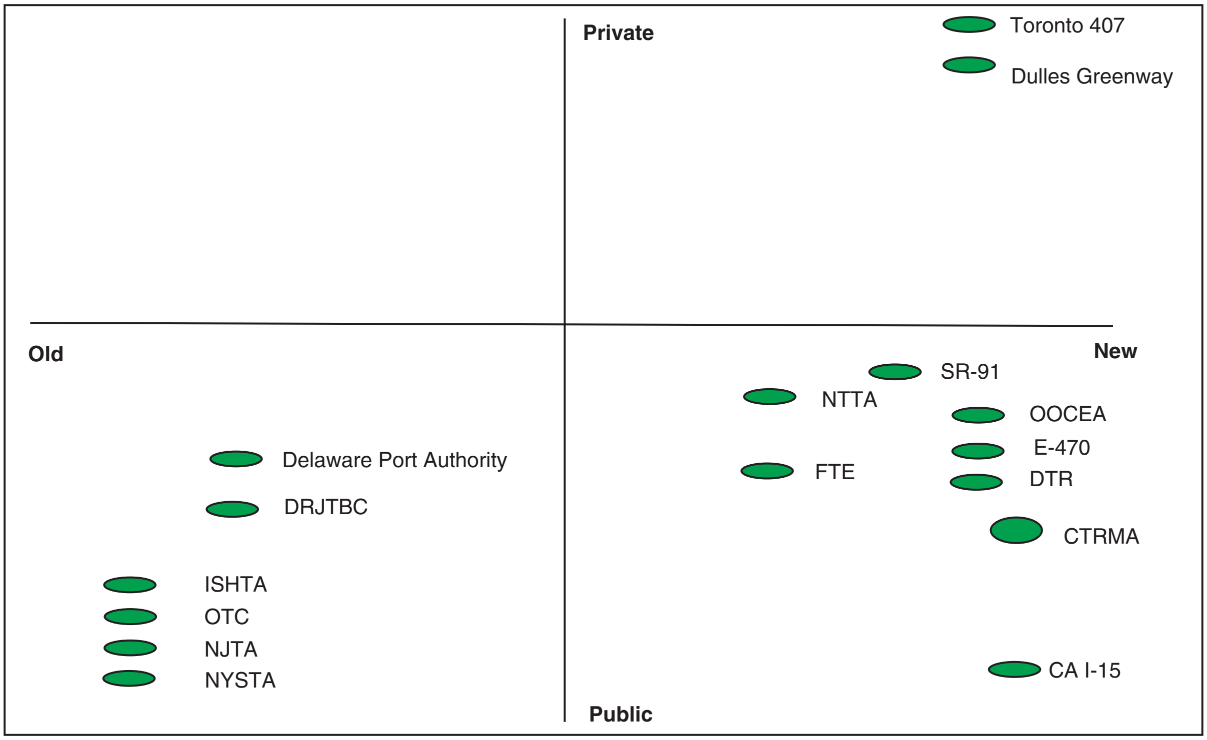
Figure 37 summarizes the toll-road agencies analyzed with respect to facility age and governance structure.

Table 24 summarizes the toll facilities operated and managed by each toll-road agency as well as the operational cost factors that are incurred by each agency.

4.3.3 Data Sources, Coverage, and Limitations

The analysis involved the review of financial data listed in the audited CAFRs for each agency from 2003 through 2007. Financial data were collected for a minimum of 3 years. The advantages associated with the use of audited CAFRs include (1) that the reports are publicly available and, therefore, easy to obtain and (2) that these reports have been audited according to Governmental Accounting Standards Board (GASB), Financial Accounting Standards Board (FASB), or similar accounting standards, permitting data comparability among agencies.

The primary disadvantage of CAFRs is that for some agencies, operational data have not been disaggregated between administrative, collection, and enforcement activities. For most of the agencies analyzed, operational data were adequately disaggregated. However, in the analysis of a couple of agencies, it



Source: Jacobs Engineering Group, 2010

Figure 37. Toll-road facilities analyzed.

was necessary to allocate costs between highway and toll-collection activities. In the financial statements for the privately operated ITR and the Chicago Skyway, annual operational expenditures were merged within a single line item without additional clarification. Because of the difficulty in disaggregating this data, these agencies were excluded from the analysis.

To the extent possible, expenditures related to the maintenance and/or rehabilitation of highway facilities have been excluded from the analysis. Engineering and design costs related to road infrastructure as well as snow removal costs have also been excluded. Because US 183-A in Austin, Texas, opened in March 2007, it has not been included in the analysis of operational costs due to the lack of historical data. However, 183-A has been included in the analysis of capital costs.

Although 3 to 5 years of operational cost data has been collected, the findings in this section are largely based on 2007 data. In reviewing the data, it was found that collection costs, for the most part, tended to increase gradually each year. As a result, the use of multi-year averages led to cost estimates that most closely approximated the mid-year of the analysis (e.g., 2005). To provide a more accurate representation of current costs, the most recent year, 2007, was used for analyzing administrative, collection, and enforcement costs.

Capital costs tend to vary greatly between agencies since some facilities have a fully installed ETC system (e.g., Toronto 407 and US 183-A) while other agencies still have a mixture of cash collection tollbooths and ETC systems. Moreover, agencies are moving at different rates with regard to the implementation of ETC, ORT, and video tolling systems. Among toll agencies, there may be variation in the level of implementation of ETC systems. For example, NTTA has recently completed the installation of an ETC system on the President George Bush Turnpike, but is gradually implementing ETC systems on its other roads. The transition to ETC depends largely on funding availability, political and regulatory requirements, and transponder penetration rates. As a result, capital costs are treated separately in this analysis.

4.3.4 General Findings—Operational Costs

Within the tolling industry, common benchmarks that are used to assess toll collection include (i) costs as a percentage of total revenues, (ii) cost per transaction, and (iii) cost per centerline mile. Centerline and lane-mile data presented in this report represent all public road mileage, including that owned by (a) the state highway agency; (b) counties; (c) federal agencies; (d) towns, townships, and municipalities; and (e) other jurisdictions. These parameters provide various conclusions with respect to the administrative, collection, and enforcement costs for toll roads.

With respect to costs as percentage of revenues, the toll agencies analyzed typically expended 33.5% of revenues to

Table 24. Summary of toll facilities, agencies, and operational costs.

Toll Road Facility	Location	Responsible Agency/Entity	Admin.	Toll Collection	Enforcement
• Dulles Toll Road[1]	Northern Virginia	Metropolitan Washington Airports Authority/VDOT			Transfers funds
• Dulles Greenway	Northern Virginia	Toll Road Investors Partnership II, L.P. (TRIP II)	✓	✓	✓
• Walt Whitman Bridge • Ben Franklin Bridge • Betsy Ross Bridge • Commodore Barry Bridge	Pennsylvania and New Jersey	DRPA	✓	✓	N/A
• Trenton-Morrisville Bridge • New Hope-Lambertville Br. • I-78 Bridge • Easton-Phillipsburg Bridge • Portland-Columbia Bridge • Delaware Water Gap Bridge • Milford-Montague Bridge	Pennsylvania and New Jersey	Delaware River Joint Toll Bridge Commission	✓	✓	✓
• E-470	Denver, Colorado	E-470 Public Highway Authority (E-470)			N/A
• Turnpike Mainline • Toll 589 • Toll 417 • Beachline Expressway • Polk Parkway • Sawgrass Expressway • Western Beltway	Florida	Florida's Turnpike Enterprise	✓	✓	Transfers funds
• S. TriState • N. TriState • Ronald Reagan Memorial • Jane Addams • Veterans Memorial	Chicago, Illinois	ISTHA	✓	✓	✓
• I-15 HOT lanes	San Diego, California	SANDAG		✓	Separate entity for enforcement
• I-90 • I-87 • Tappan Zee Bridge	New York	NYSTA	✓	✓	✓
• New Jersey Turnpike • Garden State Parkway	New Jersey	NJTA	✓	✓	✓
• Dallas North Tollway • Pres. George Bush Turnpike • Addison Airport Toll Tunnel • Mountain Creek Lake Bridge • Lewisville Bridge	Dallas, Texas	NTTA	✓	✓	✓
• SR 408 • SR 414 • SR 417 • SR 429 • SR 528	Orlando, Florida	OOCEA	✓	✓	N/A
• Ohio Turnpike	Northern Ohio	Ohio Turnpike Commission	✓	✓	✓
• SR-91	Orange County, California	OCTA	✓	✓	Separate entity for enforcement
• Toronto 407	Toronto, Ontario	Toronto 407 International Inc.	✓	✓	Transfers funds
• 183A[2]	Austin, Texas	Central Texas RMA	✓	✓	✓

1. VDOT transferred operations of the Dulles Toll Road in December 2008.
2. Until 2008, the Texas Department of Transportation (TxDOT) handled toll-collection activities on the behalf of CTRMA.

cover administrative, toll collection, and enforcement costs in 2007. The range of values was from 16.5% of revenues, which was incurred by the 407 International Inc., to 92.6% for I-15 HOT lanes in San Diego. Enforcement costs were not available for either of these facilities, which understate total costs. The relatively low costs incurred by the Toronto 407 International Inc. reflect the following: (i) the toll road is operated by a private concessionaire that has a strong incentive to maximize revenues and minimize costs so that greater profits can be accrued to its shareholders; (ii) toll rates are largely unregulated; and (iii) the facility is an urban expressway along the northern section of Toronto with limited competition from non-tolled facilities. The relatively higher costs as a percentage of total revenues on the I-15 HOT lanes may be reflective of the fact that the facility is primarily intended to relieve congestion—toll rates increase and decrease with demand. During off-peak hours, demand may be relatively low.

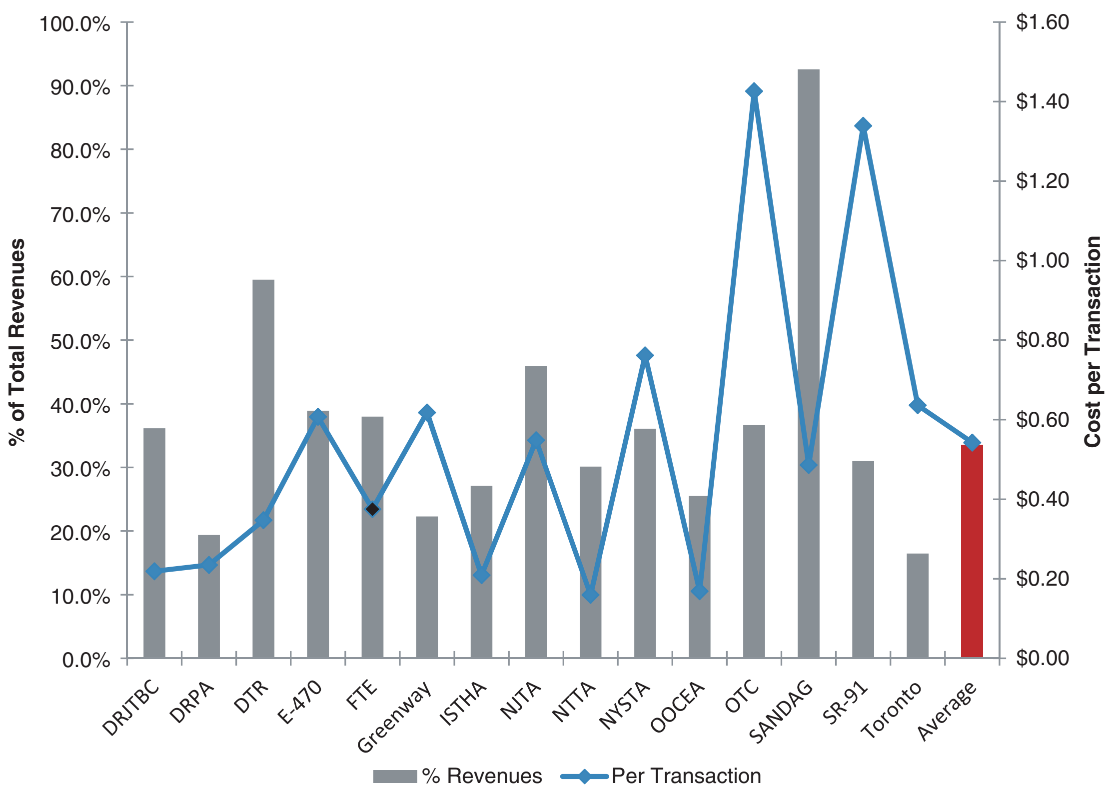
Newer toll agencies tended to be on the low end of this benchmark. In particular, OOCEA expended about 25.5% of revenues to collect tolls for their respective facilities in 2007. Facilities that have regulatory and/or political restrictions with respect to the implementation of toll increases were more likely to be at the high end of this range. This indicates that toll rate increases may not occur frequently enough to cover costs.

In 2007, the average cost per transaction for the agencies analyzed was $0.54. The costs for urban and multi-road toll-road agencies tended to have a relatively high number of related transactions, which tended to decrease the overall cost per transaction. In particular, NTTA and OOCEA recorded an average cost per transaction of $0.16 and $0.17, respectively. In comparison, single facility toll agencies had a higher cost per transaction. Specifically, total costs per transaction for the Ohio Turnpike and SR-91 were $1.43 and $1.34, respectively. Figure 38 summarizes the operational costs related to toll activities as a percentage of total revenues and per transaction for each toll-road agency in 2007.

4.3.5 Administrative Costs

In the analysis, administrative costs involved the following items:

- Wages and salaries, employee benefits, social security taxes, and pensions of toll-collection staff. (Pension costs include only the per annum costs reported by the toll agency in their CAFRs. Additional pension liabilities that may be incurred by other public agencies have not been included in these estimates.)



Source: Jacobs Engineering Group, 2010

Figure 38. Total operational costs by toll agency, 2007.

- Finance, accounting, and audit activities, especially if they involve the processing of (i) customer transactions; (ii) the settlement of interagency transactions—defined as drivers with interoperable transponders who incur toll transactions on other toll-road systems; (iii) the processing of bulk transactions from rental car companies, local delivery trucks, and auto dealers; and (iv) the exclusion of transactions by non-revenue vehicles (e.g., police, ambulance, and fire vehicles). Some agencies may also exclude city buses and government vehicles.
- Management and professional services.
- Procurement and purchasing of toll equipment and transponders.
- Office supplies and equipment.
- Planning activities related to toll-system development and expansion.
- Buildings, utilities, and insurance for tollbooths and customer service.

Depreciation, amortization, interest expense, and the current portion of debt obligations were excluded from this analysis. For toll agencies, these cost factors are more typically associated with capacity expansions, major rehabilitations, and maintenance activities. As a result, these cost factors have been excluded from this analysis.

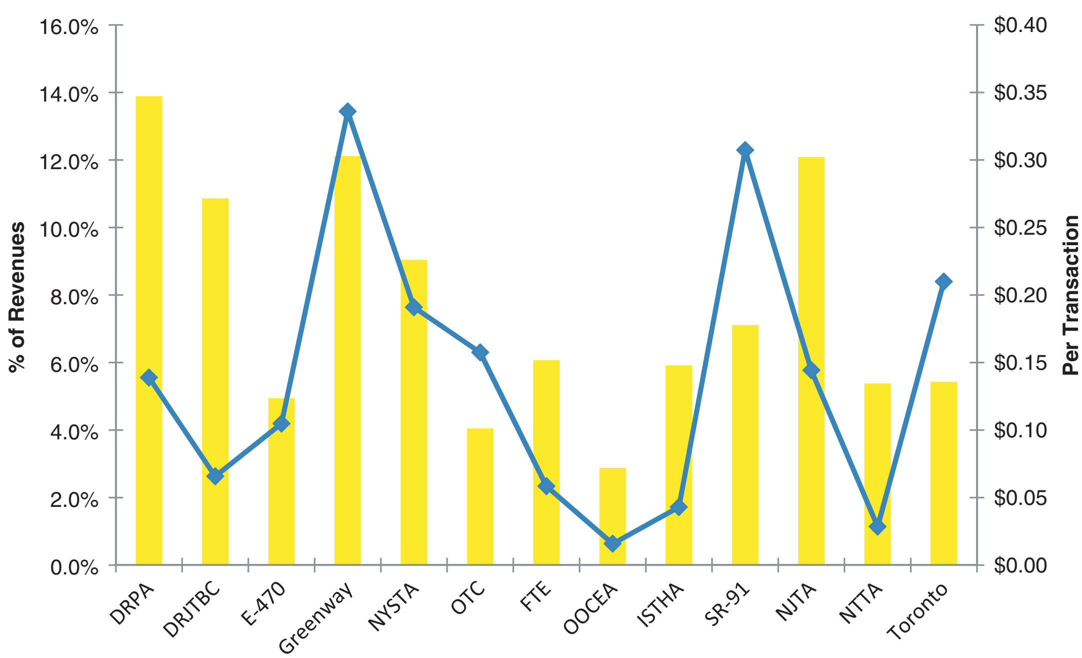
For the 13 agencies for which data were available, administrative costs averaged approximately 7.7% of toll revenues and $0.14 per transaction in 2007. OOCEA had the lowest administrative costs per transaction with $0.02, and the Dulles Greenway had the highest estimated administrative costs per transaction at $0.34. As a percent of revenues, OOCEA had the lowest administrative costs (2.9%) and DRPA the highest (13.9%). Figure 39 summarizes administrative costs by toll-road agency in 2007.

4.3.6 Collection Costs

Toll-collection costs include the following components:

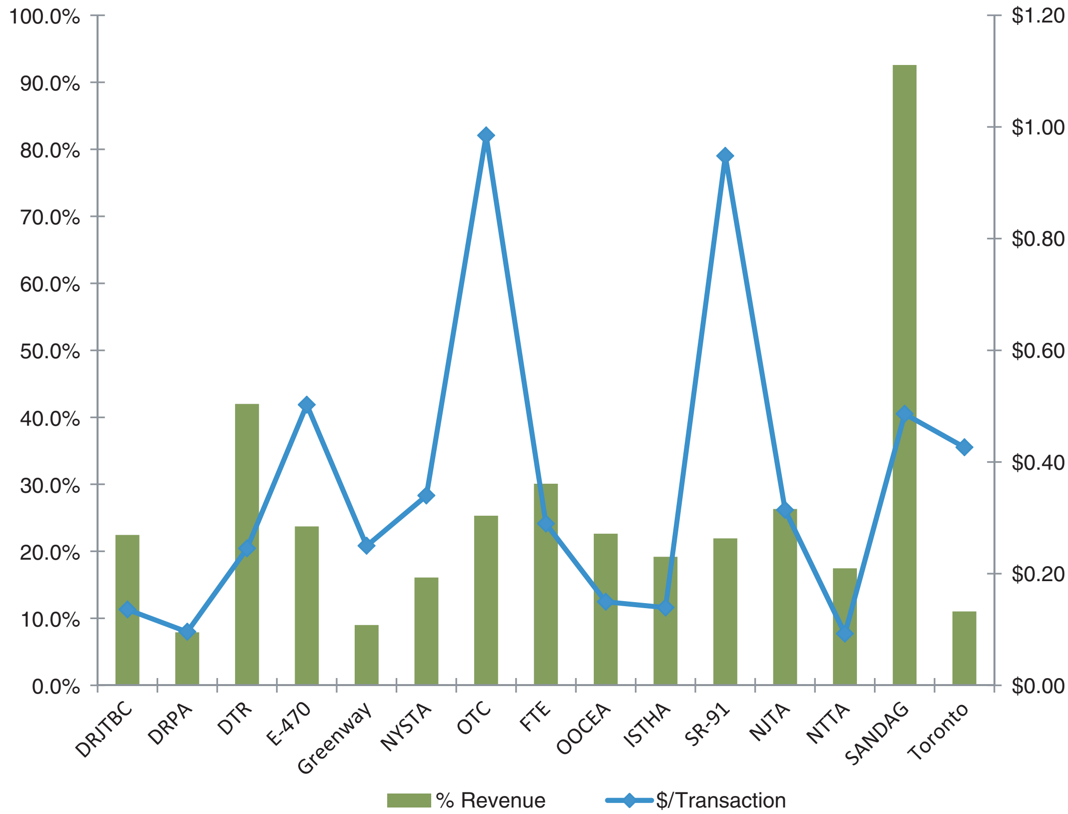
- Operation and maintenance of tollbooths;
- Operation and maintenance of ETC and video tolling systems as well as related information technology hardware and software;
- Customer account management, payment processing, and banking charges relating to toll accounts;
- Inventory, distribution, and sale of transponders; and
- Cash counting, transportation, and vault services.

Toll-collection costs for the 15 agencies included in this analysis averaged $0.36 per transaction and 25.8% of total costs in 2007. Toll-collection costs for the privately operated, all-ETC Toronto 407 were 11.0% of revenues and $0.43 per transaction. In comparison, toll-collection costs for NYSTA, a state agency with cash and ETC lanes, were 16.1% of revenues and $0.34 per transaction. Moreover, ISTHA recorded toll-collection costs of 19.2% of revenues and $0.14 per transaction.



Source: Jacobs Engineering Group, 2010

Figure 39. Administrative costs by toll agency, 2007.



Source: Jacobs Engineering Group, 2010

Figure 40. Toll-collection costs by toll agency, 2007.

Toll-collection activities were estimated to be $0.09 per transaction for NTTA, which was the lowest of the agencies examined. At the other end of the spectrum, OTC had toll-collection costs of approximately $0.98 per transaction. Toll-collection costs accounted for 92.6% of revenues for the I-15 HOT lanes in San Diego. This may be a function of relatively lower revenues generated for the I-15 lanes since this facility was primarily developed to support congestion management objectives. Figure 40 summarizes toll-collection costs by agency.

Leakage

To improve collections, toll agencies actively attempt to reduce leakage. Minimizing leakage is particularly difficult on open-road facilities since there are more opportunities for violators to avoid payment. To reduce opportunities for leakage, toll agencies have installed video-billing systems. Video billing involves taking an image of all vehicle license plates and mailing drivers without a valid transponder or with insufficient balances in their accounts a bill of toll activity. These systems involve capital expenditures related to video-billing equipment as well as account review by customer representatives to ensure accuracy of the bill statements that are mailed to toll-road users.

In general, toll agencies are reluctant to publicize leakage rates because high leakage rates tend to be viewed negatively by bondholders and shareholders. Moreover, toll agencies are concerned that public disclosure of a high leakage rate on their respective toll facilities may also discourage users from paying tolls. Within the industry, toll leakage typically ranges from 5% to 10%. Table 25 provides an estimate of toll leakage rates for toll systems in Texas, Colorado, California, Florida, Illinois, and New Jersey in 2006 and 2008. The payment of administrative fees and fines may result in a zero or even negative leakage rate (where the amount of revenues collected is greater than the amount of revenues owed) for a single year.

The increase in leakage rates estimated for ISTHA and SR-91 highlight the following issues: (i) leakage rates are partially determined by the accounting definition of leakage (e.g. doubtful accounts, net violations), which can include unpaid tolls as well as violation fees, and (ii) increased enforcement efforts may paradoxically result in higher leakage rates. For example, ISTHA increased its enforcements efforts, resulting in an increase in revenues from toll evasion recovery of $29 million in 2007 to $224 million in 2008. However, ISTHA still had $146 million in allowance for doubtful accounts on its balance sheet. A large percentage of this amount consists of

Table 25. Estimated leakage rates for selected toll agencies, 2006 and 2008.

	NTTA		E-470		ISTHA		SR-91		OOCEA		DRPA	
	2006	2008	2006	2008	2006	2008	2006	2008	2006	2008	2006	2008
Revenue ($M)	$199	$250	$92	$90	$585	$808	$44	$46	$193	$206	$200	$213
Leakage rate as % of revenues	6.6%	1.8%	0.5%	0.5%	5.0%	18%	8.6%	13.3%	0.3%	0.0%	2.5%	2.1%

Sources: 2006 and 2008 comprehensive annual reports from NTTA, E-470, OCTA, OOCEA, and DRPA.

unpaid fees rather than unpaid tolls. Lastly, leakage rates may also be affected by growth in total revenues. SR-91 generated roughly the same amount of revenues in 2006 and 2008, but the amount of net violations increased from $3.8 million to $6.2 million, respectively.

4.3.7 Enforcement Costs

Toll enforcement costs encompass:

- Catching violators,
- Assessing administrative fees and fines,
- Account settlement before the toll violation reaches court, and
- Prosecuting violators (court costs).

Included are police services, which can be directly carried out by the toll agency, outsourced to a public agency with monthly or annual payments for services rendered, or conducted independently by a public agency. Police services may also include incident management and communication expenses. Ten of the agencies under study recorded some type of enforcement costs. Because court activities tend to be conducted by a separate judicial agency, these costs have typically not been included in the analysis.

On average, enforcement costs accounted for 6.3% of total revenues and were about $0.09 per transaction. Enforcement costs ranged from $0.01 (DRJTBC) to $0.28 (OTC). In terms of total revenues, the Dulles Greenway had the lowest costs (1.2% of total revenues) and the Dulles Toll Road had the highest costs (17.5%). It should be noted that the $0.09 per-transaction average includes outliers at the high end of the data analyzed. As a result, this statistic may not be reflective of the enforcement costs of most of the agencies under analysis. With the exclusion of these outliers, enforcement costs averaged approximately $0.04 per transaction. Toll enforcement costs may be a function of the number of centerline miles to be covered by enforcement agencies as well as toll enforcement statutes, regulations, and policies. This estimate does not include court costs. Figure 41 summarizes enforcement costs.

4.3.8 Summary of Operating Costs

Table 26 summarizes the total operating costs and revenues collected by tolling agencies from 2003 to 2007. The table also presents the average operating cost and revenue for each agency for all years. Detailed administrative, collection, and enforcement cost data are summarized in Appendix C.

An additional measure of financial performance is operating margin, which is defined as net income as a percentage of net sales. Net income includes depreciation and amortization expenses but excludes taxes payable, interest expense, interest income, and nonrecurring expenses. Operating income is also known as earnings before interest and taxes (EBIT). Since some of the toll authorities are involved in other transportation and non-transportation activities, this definition has been refined slightly to include only net income from toll operations over toll revenues. High operating margins are an indication that a company or a public agency has effective control of its costs or that sales (revenues) are increasing at a faster rate than operating costs.

In 2007, the average operating margin for the toll agencies included in this analysis was 36.2%. The privately operated Toronto 407 had the highest operating margin of the agencies analyzed, with a 65.2% operating margin. The second highest was the Dulles Greenway, which had an operating margin of 60.0%. The lowest operating margin was recorded by NYSTA, which had an operating margin of –15.9%. This shortfall is due to the depreciation expenses, which account for nearly a third of NYSTA's operational expenditures. SANDAG (for the I-15 HOT lanes only) had the second lowest operating margin, at 7.4% in 2007. Figure 42 summarizes operating margins for the 15 facilities included in this analysis.

4.3.9 Capital Costs

Capital costs for toll-collection activities tend to vary considerably depending on (i) type of collection system implemented, (ii) system objectives, (iii) implementation rate, and (iv) funding availability. Start-up toll agencies such as CTRMA incur capital costs for the initial design and implementation of

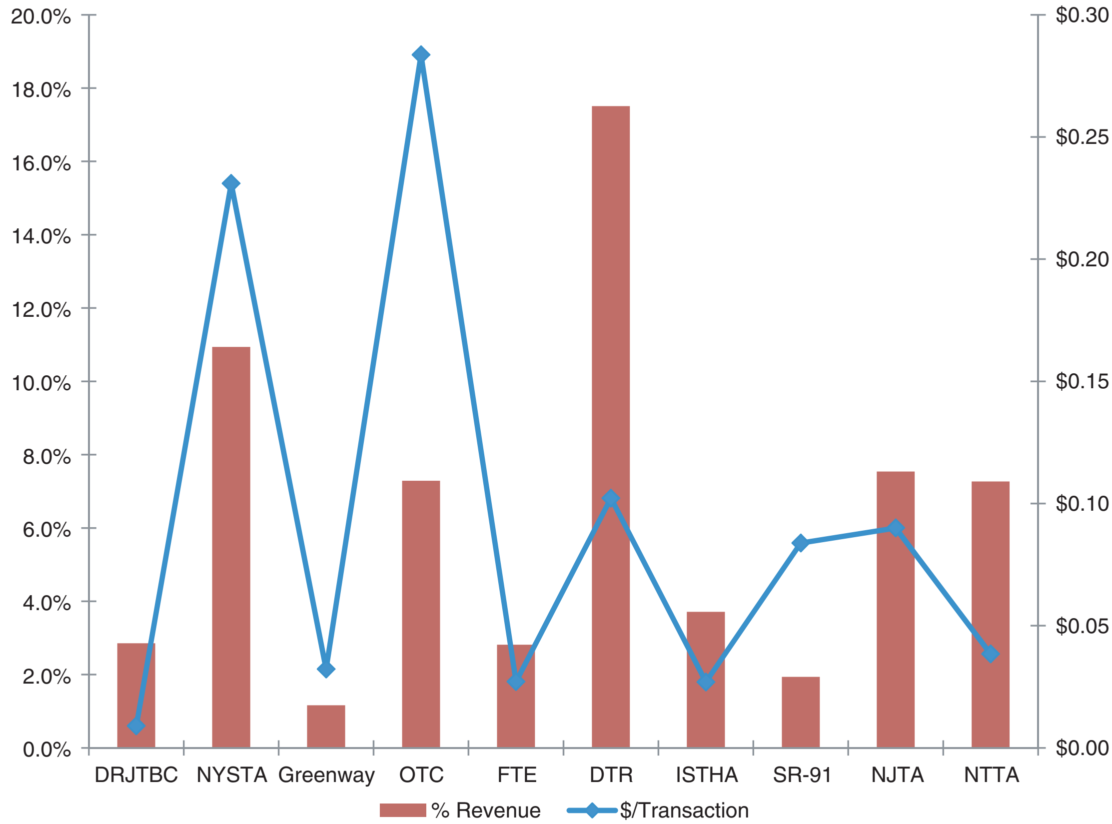


Figure 41. Enforcement costs by toll agency, 2007.

the toll-collection system, which may be expanded over time as the toll facilities are expanded or new roads are added to their respective systems.

In contrast, more mature toll agencies may decide to gradually retrofit existing tollbooths and traffic lanes to ETC (e.g., OTC) or continue to expand ETC toll collection to increase transponder penetration and improve traffic flows (NTTA, OOCEA, FTE, and Toronto 407). Given these differences, an accurate comparison of capital-cost–related expenditures for toll-road agencies may be too difficult to achieve.

Table 27 provides a sample of capital costs associated with toll collections incurred by seven toll agencies during the 2003 through 2007 time period.

4.4 Cost Estimates for VMT Fees

This section presents cost estimates for VMT fees based on the proposed Dutch VMT systems and also discusses the types of VMT fees in practice today. It also presents the method for generating the cost data in the Dutch VMT fee systems, presents cost classification and cost data, and discusses costs of other mileage-based systems.

4.4.1 Types of VMT Fees

Many types of charges may be considered to be a form of charge for VMT. For example, many toll facilities charge the toll based on the distance traveled on the facility. However, this section is concerned with systems that charge for all VMT for a vehicle. The charge may be flat or it may vary based on class of road, time of day, direction of travel, characteristics of the vehicle, or geographic location. Interest in such comprehensive charging systems has grown over time and has accelerated recently. For example, the National Surface Transportation Infrastructure Financing Commission recommended that Congress look toward using a VMT system as the major source of surface road funds in the future. In addition, the Dutch proposed moving to a comprehensive VMT-based charging system for all road use in the Netherlands by 2016. While the current government does not plan to implement road pricing, substantial work was completed to determine if it was a feasible option.

Actual experience with VMT systems, other than weight-mile taxes, is sparse. There have been some experiments in the United States with such charging systems, and heavy vehicles have some of their charges levied based on VMT. However, the actual experience provides very limited information on

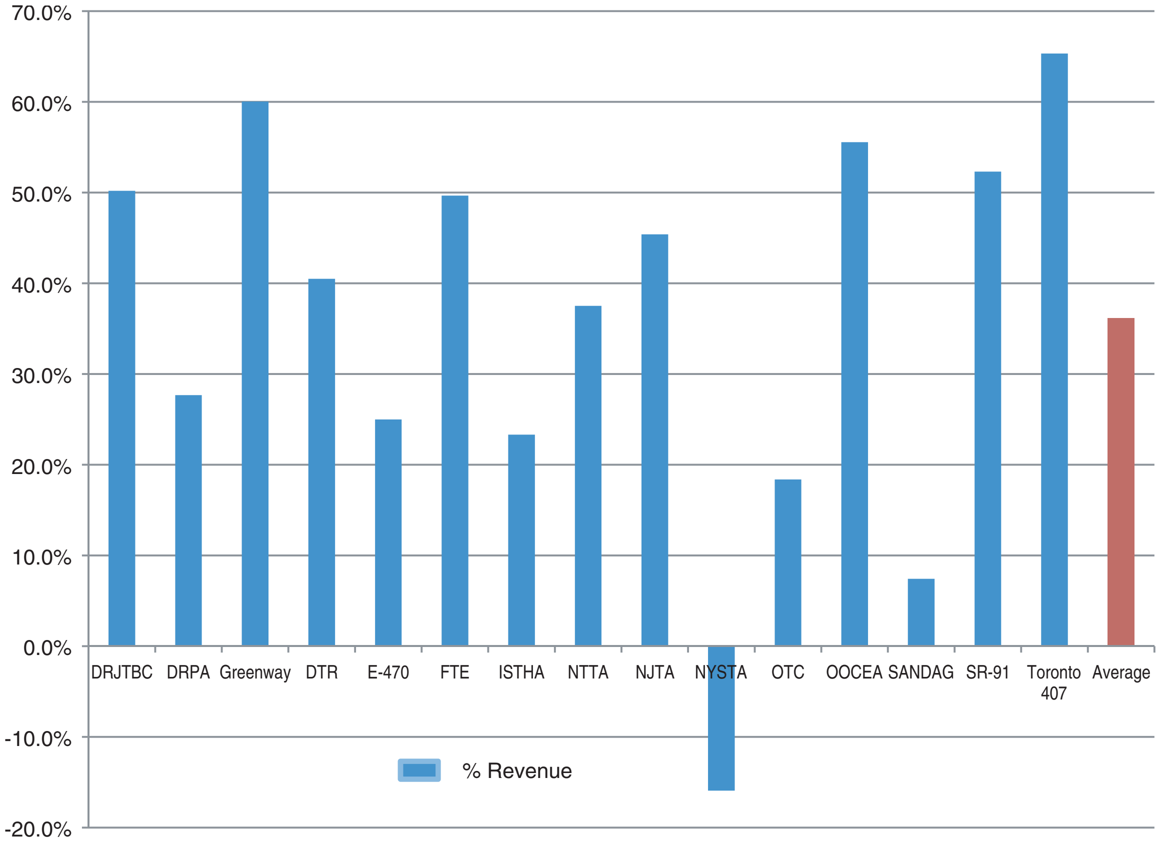
Table 26. Tolling—total operating cost and revenue (in $000s).

Cost Item/Tolling Agency	2003	2004	2005	2006	2007	Average over Years
Total Operating Cost						
DRPA	$29,460	$32,362	$31,516	$32,909	$33,994	32,048
DRJTBC		25,627	25,428	30,554	30,919	28,132
Dulles Toll Road			36,758	34,737	38,639	36,711
Greenway		9,706	13,164	10,868	12,468	11,552
E-470	21,393	29,180	25,746	26,419	36,717	27,891
FTE			227,238	254,883	258,891	247,004
ISTHA	127,900	134,995	148,808	149,949	164,888	145,308
NJTA	230,141	316,896	326,309	341,768	365,797	316,182
NTTA			48,796	52,794	61,047	54,212
NYSTA	160,820	173,726	182,406	212,303	194,960	184,843
OOCEA	38,027	45,620	46,211	52,563	52,206	46,925
OTC	64,071	67,333	73,057	72,035	73,468	69,993
San Diego I-15			2,225	1,541	1,385	1,717
SR 91		12,607	14,506	15,078	15,447	14,410
Toronto 407	62,825	66,141	68,800	67,945	86,522	70,447
Average over agencies	*91,830*	*83,109*	*84,731*	*90,423*	*95,157*	*85,825*
Total Revenues						
DRPA	130,399	139,471	141,057	143,843	144,835	139,921
DRJTBC		78,856	79,421	80,154	85,503	80,984
Dulles Toll Road			43,727	65,533	64,931	58,064
E-470	58,895	73,584	77,788	92,185	94,373	79,365
FTE			598,762	647,959	681,615	642,779
Greenway		40,725	45,433	55,294	55,925	49,344
ISTHA	433,495	418,721	612,237	585,095	608,440	531,598
NJTA	606,620	747,932	751,381	784,919	796,259	737,422
NTTA			177,472	191,434	202,676	190,527
NYSTA	427,184	439,583	511,191	554,363	540,321	494,528
OOCEA	154,726	169,725	178,830	194,292	204,641	180,443
OTC	182,740	192,451	182,014	186,945	200,471	188,924
San Diego I-15			2,211	1,617	1,496	1,775
SR 91		32,375	39,584	44,238	49,838	41,509
Toronto 407	265,511	318,109	361,995	391,375	525,365	372,471
Average over agencies	*282,446*	*241,048*	*253,540*	*267,950*	*283,779*	*265,753*

how a large-scale system would function and what it would cost. Hence, this section will focus largely on the data generated in support of the Dutch proposal, but it will start with a brief discussion of the other information available.

The FHWA Value Pilot Pricing program has sponsored several experiments that looked at alternatives for distance-based pricing. They take fairly different approaches, although all are based on some form of GPS location device to determine how mileage charges should be allocated.

Unfortunately, cost data based on experiments have very limited usefulness. While information from these experiments is useful, cost data based on experiments have substantial limitations. The cost of the experimental units tends to be quite high due to development costs and the small scale of production. Large-scale, standardized production should result in lower cost per unit, but it is difficult to determine what this lower cost would be. In addition, the experiments typically do not actually charge participants. Rather, they set up accounts against which charges are levied, with the participant getting any remainder at the end of the experiment. This gives the appropriate marginal incentives to participants and allows for collection of behavioral data; however, there are no issues with evasion, nonpayment of bills, or enforcement of the system. Hence, cost data from such experiments are not well suited for comparison to the actual cost of other revenue collecting systems.



Source: Jacobs Engineering Group, 2010

Figure 42. Operating margin by toll agency, 2007.

Table 27. Toll agency capital costs.

Toll-Road Agency	Improvement	Total Capital Costs	Cost/Year	Cost/Per Centerline Mile
CTRMA	• Design and installation of an ITS system	$20,010,000	$10,005,000	$1,725,000
Dulles Greenway	• Toll-collection equipment	56,137,545	11,227,509	4,009,825
FTE	• Intelligent Transportation System and Fiber Optic Improvements, Mainline • Intelligent Transportation System and Fiber Optic Improvements, Polk and Suncoast • Addition of Sun Pass Lanes • Open Road Tolling Plaza and Express Lane Conversion, Sawgrass • Open Road Tolling Plaza and Express Lane Conversion, Mainline • Toll System Technology Upgrades on the Mainline	166,200,000	41,550,000	$618,369
NTTA	• Toll equipment for Lewisville Lake Bridge and the NTTA system	5,742,321	N/A	N/A
OTC	• Conversion to ETC	9,703,412	9,703,412	N/A
OOCEA	• Toll equipment and buildings	156,978,000	31,395,600	1,569,780
Toronto 407	• Toll equipment, transponders, operations center, office equipment, and computer equipment	182,856,744	20,317,416	2,728,788

Sources: CTRMA (2005), Florida's Turnpike System (2007, 2008), NTTA (2007), OTC (2007, 2008), OOCEA (2007), Toll Road Investors Partnership (2007), and 407 International Inc. (2007).

Actual VMT-based systems exist for heavy vehicles but again offer a limited basis for cost comparison. Heavy vehicles in the United States traveling interstate have fuel taxes determined by the reported mileage driven in each state rather than by where fuel is purchased. Mileage and fuel purchases by state are reported based on IFTA. This information is used to calculate the fuel tax that would have been paid to each state if fuel for travel in that state had been purchased there. This is compared with the actual fuel taxes paid in each state and amounts due or overpayments by state are calculated. The trucking company then makes up any shortfall or receives a rebate of overpayment and IFTA settles the differences among the states. This relatively crude system is VMT based, but it does not provide a good basis for cost comparisons. First, the majority of the revenue is collected as fuel taxes so the system is directed more toward redistributing that revenue among the states and preventing strategic purchases of fuel to avoid state fuel taxes than toward actually collecting revenue. Second, most of the enforcement is left to the states. Third, most heavy vehicles in commercial operation must keep track of mileage for other reasons.

Germany instituted a mileage-based fee on heavy vehicles using its major roads. Some cost information is available from this program, as discussed below. However, the system is limited to heavy vehicles and specific roads. Oregon charges heavy vehicles a weight-mile charge based on mileage in the state. The system is well established, but it is based on self-reported mileage data. Most analysts conclude that self-reported mileage data are not suitable for a comprehensive system (Sorenson et al., 2009).

The cost data for the proposed Dutch VMT system is based on detailed estimates provided by large, reputable companies that have experience with the technology and customer service. One of the providers is Siemens, which makes the onboard unit used in Germany, and another is T-Systems, which manages the German system. Although the cost data are preliminary estimates and subject to adjustments in operation, they are the most realistic estimates that are available at the present time. Hence, these sources were chosen as the basis for the cost comparison. The original cost estimates were required to include a 15% contingency and a 19% value-added tax (VAT). It was decided to omit the VAT in converting the cost data from euro to dollar estimates for comparison with the cost of existing revenue systems in the United States. In addition, the euro-to-dollar conversion rate was based on the approximate rate at the time of the estimates. Also, the proposed system is quite complex and comprehensive. The cost estimates are a valuable benchmark for understanding the potential cost of such a system; however, it would certainly be possible to design less comprehensive systems that also had lower costs. On the other hand, it should also be recognized that these are cost estimates and actual implementation costs could be higher. One company did an analysis for the Dutch project looking at the potential cost savings of reducing various requirements and found that there was potential for substantial cost reductions if various requirements were relaxed.

4.4.2 Method for Generating Cost Data for Dutch VMT Fee Systems

The Ministerie van Verkeer en Waterstaat (Ministry of Transport, Public Works and Water Management) in the Netherlands worked with a number of private companies to develop cost estimates for a proposed system of road pricing. Some of the cost estimates focused on specific topics, such as the design and cost of different onboard units (OBUs), but four of the companies were asked to provide comprehensive cost estimates covering all aspects of the pricing system. These companies were provided with a long list of required features that were designed to reflect realistic operating requirements and create comparable cost estimates. An English translation of the report to the Dutch Parliament was published as "Cost Benchmark for Kilometer Pricing in the Netherlands." This report contains appendices with the reports from the individual companies, and these reports contain information on the approaches taken by the different companies and summary cost data for various categories. The four companies that provided comprehensive cost estimates were Siemens, DaimlerChrysler, T-Systems, and Vodafone. Unfortunately for this study, Daimler provided their data in a separate spreadsheet that was not included in the report. Hence, there are three estimates of cost based on initial start-up, annual operating cost, and annual depreciation, for five major categories.

The reports provide extensive discussion of many important issues accompanying the Dutch cost estimates. The following represents a brief summary of some key issues, including thick versus thin OBUs, communication and recording use, visitors and interoperability, and enforcement.

The major cost of such a system will be an OBU that is capable of determining the time, location, and distance traveled for each vehicle. While there are other options, the consensus was that the system would have to use satellite navigation systems (GPS/Galileo) as the basic method for determining location. One company did propose using cell phone communication towers as an enforcement mechanism to check the reported travel; however, all of the systems had the same basic technology to determine location and road usage. They did, however, differ on what functions should be performed in the vehicle and what should be done in the back office. The complexity of the pricing system affects the cost of the OBU since more complex systems require more precise location and travel information. In addition, the need to accommodate temporary users of the system was noted as generating a high cost relative to the revenue generated.

Thick Versus Thin Client OBU

There are two basic methods to charge for VMT based on GPS data. The "thick client" approach requires that the OBU have the capability to determine where the vehicle is being driven and to apply the appropriate toll rates. The system then only needs to communicate the toll due by jurisdiction to the back office for billing. With the "thin client" method, the OBU maintains location data that is regularly transmitted to the back office. The determination of where the vehicle was driven and the toll due is then done in the back office.

Most analysts have concluded that the thin client approach is preferable. The thick client requires substantially more capabilities in the OBU and requires that the units receive updated maps and toll information whenever there is a change. It does provide more inherent privacy and the potential to be used for other applications. The thin client must transmit more information to the back office but does not have to receive map and toll updates. Hence, the system is applied equitably to all users when there are changes in toll rates or road classification (e.g., a road is added to the "congested" category). Siemens and Vodafone chose to use the thin client approach, while T-Systems opted for the thick client approach.

Communication and Recording Use

Whether the calculations are done in the vehicle or in the back office, there is a cost to process the data and to communicate between the vehicle and the back office. The three proposed Dutch VMT systems for which there is data chose cellular communication for this purpose. Two of the systems also proposed DSRC systems for use in enforcement. Daimler chose the exchanging of a data carrier or short-range communication systems for all data exchange. This saved the cost of the cellular communication system and communication charges, but also involved expenses for creating and managing the infrastructure. The cost estimates for cellular service varied from €7.5 to €36 per user per year. The conversion factor at that time was about $1.25 per euro, yielding a cost estimate of approximately $9.38 to $45 per user per year. Apparently this variation was due to differing assumptions about the impact of 8 million new users on the cellular system and the impact of current excess capacity on pricing.

All systems were required to meet European directives regarding privacy requirements for users of the system. For example, where charges would be calculated in the back office, the procedure would be for the location data and an OBU identification number to be sent to one office. This would be used to calculate the amount due for that OBU. The OBU identification number and amount due would be sent to another office, where the identification number would then be associated with the person to be billed. Hence, no travel or location data other than the amount of charge owed would be associated with any vehicle.

Visitors and Interoperability

The Dutch government required that all users of the road system pay for using the roads. The companies took different approaches to this requirement. One option for visitors was to use a fixed toll that allowed either restricted or unlimited use of the road system for a specific period of time. Another was to require that everyone make use of an approved system. Under the required device option, visitors would use a device that could be acquired for temporary use and could be self-installed in the vehicle. In addition, Europe is developing an interoperability directive that requires toll-collection systems to be usable for all toll systems in any European country. This requirement affects the cost of the systems, and some of the expense of the OBU could be reduced without the extra capabilities.

Enforcement

The basic approach to enforcement of the system was to have DSRC communication with a series of fixed and moveable enforcement stations and to have mobile enforcement. The fixed enforcement stations would be on major roadways and would determine the unit ID for vehicles on the system, compare that to the license plate registration, and check to see if the observed time and place of operation were appropriately recorded in the back office. Moveable enforcement systems would perform the same basic function, but they would be moved around the road system on a regular basis. Mobile enforcement would be done from specially equipped vehicles.

One provider (Vodafone) called for a system that compared reported travel with cell phone tower sequence as an additional enforcement mechanism. In addition, they proposed using cellular communication for enforcement, and this eliminated the need for DSRC communication equipment.

Summary of Three Dutch VMT Fee Systems

The major components and their designs from three Dutch VMT systems are summarized in Table 28. The major components include OBU, data communication, method to accommodate visitors, and enforcement.

4.4.3 Cost Classification and Cost Data

The Dutch cost data were required to be reported for five categories: OBU, declaration and customer care, billing and

Table 28. Summary of three Dutch VMT fee systems.

Component	Siemens	T-Systems	Vodafone
OBU	Thin	Thick	Thin
Communication	Cellular & DSRC	Cellular & DSRC	Cellular
Calculation of charges	Back office	OBU	Back office
Visitors	Fixed tolls or temporary units	Fixed tolls or temporary units	Temporary units
Enforcement	Fixed, movable, and mobile	Fixed, movable, and mobile	Cellular & fixed, movable, and mobile

Source: Ministry of Transport, Public Works, and Water Management, 2006

payment, enforcement, and miscellaneous. Within these categories there were separate estimates of the initial setup cost, annual operational cost (excluding depreciation), and annual depreciation. The initial setup cost was an estimate of the total start-up cost, but the expectation was that this cost would be spread over a number of years. Hence, it is not expected that this cost will coincide with the full-scale operation of the system. In general, it was expected that an attempt to conduct an all-at-once start would increase cost and introduce other complications. The annual operating cost and annual depreciation were then based on the first year of full operation of the system. Given the downward trend in the cost of the OBUs, there were different assumptions about the cost at the time of initiation versus the historical cost.

The basic requirement was that the system had to accommodate 8 million Dutch vehicles and any foreign vehicles operated in the country. The systems took different approaches to fulfilling these requirements. One system required that all vehicles have permanent operational devices, increasing the number of units required. Other systems allowed for the use of fixed tolls for specific time periods and the option of using a temporary system. The fixed toll would allow unlimited use of the roads for a specific period of time and would be enforced with license plate recognition. The use of temporary units required that they be easy to install and remove and that payment accounts would have to be set up for each user.

Cost estimates were based on varying degrees of detailed cost calculations by the different responders. Some of the data were considered proprietary and were not made public. The required public level of detail is what is used in this report. More detailed data were available for some categories from some providers, but the data were not provided in any consistent manner across the providers.

Discussion of the Dutch VMT Cost Data

The general approach to the Dutch VMT system was largely determined by the required elements specified for the system. The system had to be able to charge all vehicles for using Dutch roads based on the amount of use and vehicle characteristics. Minimum standards were set for items such as enforcement, ability to accommodate all users, interoperability with other European toll systems, and privacy.

As a result, the cost estimates have similar orders of magnitude. However, there were substantial differences in both the technological approaches taken and the organization of tasks. These led to some real differences in the cost estimates and some differences based on where costs are allocated. For example, the costs allocated to the "miscellaneous" category differ quite substantially across the providers. In general, the cost of the OBUs was the single largest cost category, but this represents a capital cost and is not directly comparable to the annual costs. Further, the capital cost has the potential to be reduced if the system is developed for some alternative use and the pricing system is then an add-on to an existing system. Depending on the expected life of the OBU, the annualized cost would be the appropriate amount to compare to revenue.

The estimates of the annual operating costs are somewhat more surprising than the estimates for the OBU cost. These operating cost estimates vary significantly between systems. Each of the systems considered for the Dutch system had GPS-based OBUs and therefore required that the location data be converted into usage data that could then be used as the basis for charges. As noted earlier, the biggest issue here was the choice between onboard or back-office calculations of this information. T-Systems chose to calculate the information on board, while Siemens and Vodafone chose the back office method. Since the thick unit requires more computing power, storage capacity, and so on, it was expected to be the more expensive unit. However, the cost estimates show the OBU as being relatively less expensive based on expected cost in 2010. However, the need to update maps, tolls, and other information results in relatively high operation cost, and these costs are based on 2005 estimates.

Siemens based its cost estimates on a 2012 start, so its lower cost is at least partially due to an assumption that both capital and operating costs would continue to decrease over time. The Siemens approach was based on two types of OBU—one that is permanently installed in the vehicle and one that can be used temporarily. In addition, temporary or infrequent users would have the option to purchase a temporary fixed cost pass that would allow unlimited road use for a limited time period.

The Vodafone approach was to require that all users have an OBU, but they also identified four possible types of OBU. One was a unit that met all European interoperability requirements, the second was a system with only the communication capabilities needed for the Dutch pricing system, the third was a GPS system that could be attached to an existing cell phone for data transmission, and the fourth was a projection of cell phone technologies capable of implementing the pricing system. They also proposed a unique enforcement system based on cell records that supplemented the required enforcement system.

Table 29 shows the cost estimates converted from euros to dollars using an approximate ratio of 1.25 dollars per euro for the relevant time period. In addition, the 15% contingency allowance is included but the 19% VAT is not. The totals for the initial setup costs are very similar. However, the estimates of the annual operating cost and the annual depreciation vary quite substantially.

Relevant Parameters Used in Dutch VMT Cost Data

For this study, certain parameters of the system served were used to generate comparisons across different revenue-generation systems. Each provider may have made assumptions for certain parameters and estimated others. The key parameters included lane miles, centerline miles, VMT generated, number of vehicles, total revenue, average VMT fee rates (or tax rates), and number of staff. These parameters or the information from which they could be derived were included in some reports and omitted in others. Where data are missing for one vendor but available for another, the information is assumed to be the same since they were all developed under the same set of assumptions regarding the road system, number of vehicles, and so on. Appendix C shows the data for parameters that were found for each of the three different approaches designed by providers, converted from kilometers to miles and euros to dollars where appropriate. These data were used for the comparison across systems.

Discussion of Factors That Could Reduce Cost

As part of this study, EFKON AG was commissioned to identify systems that would not meet all of the requirements specified for the full cost study but would be lower in cost. A number of alternative systems are discussed in some detail, but there appear to be two basic findings of relevance for the cost analysis. The first is that the cost to meet the European interoperability requirements could be substantial. The system that

Table 29. VMT fees – cost estimates (in $000s).

Cost Category	Cost Item	Siemens	T-Systems	Vodafone	Average over Providers
Initial Setup Cost					
	OBUs	$1,890,411	$1,698,067	$1,664,625	$1,751,034
	Administrative	5,498	217,631	133,688	118,939
	Collection	85,531	41,397	41,687	56,205
	Enforcement	119,251	81,355	77,625	92,744
	Miscellaneous	202,225	201,285	304,750	236,087
	Sum	2,302,916	2,239,735	2,222,375	2,255,009
Annual Operating Cost					
	OBUs	165,938	126,908	37,375	110,074
	Administrative	111,132	510,427	406,813	342,791
	Collection	110,976	231,283	58,938	133,732
	Enforcement	11,883	80,751	54,625	49,086
	Miscellaneous	18,446	24,087	53,188	31,907
	Sum	418,375	973,456	610,939	667,590
Annual Depreciation					
	OBUs	41,508	267,006	232,875	180,463
	Administrative	4,550	31,973	27,313	21,279
	Collection	2,156	5,304	10,063	5,841
	Enforcement	8,947	14,257	10,063	11,089
	Miscellaneous	5,917	10,351	10,063	8,777
	Sum	63,078	328,892	290,377	227,449

Source: Based on data from Ministry of Transport, Public Works, and Water Management, 2006 comes closest to the others analyzed appears to be lower cost primarily by not meeting this requirement. The second is that it would be possible to simply charge for distance driven at a much lower cost than the system designed. Nevertheless, this system would still be quite expensive. There were a number of alternative systems discussed, but some idea of the limitations can be demonstrated by describing one of the low cost alternatives. It would be based on a written logbook of mileage by the driver that would also require an OBU to verify the mileage reports. This system would be lower in cost, but it would impose compliance costs on users and have substantial limitations relative to the goals specified for the pricing system.

4.4.4 Costs of Other Mileage-Based Systems

As noted earlier, some mileage fee systems are in use for heavy vehicles. Both IFTA and the Oregon weight-mile charge rely on self-reported mileage data. These systems have relatively low administrative costs but do not appear to be a good basis for comparison since there appear to be substantial issues with the use of self-reported mileage data. In particular, if the charge is expected to differ by jurisdiction, time of day, or other characteristics, then verification and enforcement of self-reported data become extremely difficult.

The German mileage system provides a much better basis for comparison. This information was indirectly included in the estimates generated for the Dutch system since the companies managing the German system were among the data providers. However, the limited number of vehicles and the focus on specific roads make the cost comparisons somewhat problematic. Nevertheless, there is substantial interest in the German system so basic data were collected.

In January 2005, the German truck toll system was initiated. The system is managed by a company called Toll Collect. Most of the tolls are collected via an OBU that tracks usage of the tolled roads and reports toll information to a billing system. Trucks not equipped with an OBU may pay tolls in advance either over the Internet or at one of over 3,500 toll-payment terminals. Tolls are levied on about 12,000 km of German autobahn as well as major trunk roads. The tax is based on kilometers driven, number of axles, and the emission category for the truck. The charge averages about €0.135 per kilometer. Collections average about €2.4 billion per year. The initial investment by Toll Collect is estimated at €700 million. It is estimated that by 2008 about 650,000 vehicles were equipped with the OBU, accounting for about 90% of the revenue collected. Enforcement is generated from about 300 toll checker gantries and a mobile enforcement fleet of about 300 vehicles (roadtraffic-technology.com).

Charges by Toll Collect to the German government reflect the cost of operating the system. For fiscal year 2008 (ending August 31, 2008), Toll Collect reported revenue from the German government of €581 million, employment of 531, and about 640,000 trucks equipped with an OBU. Based on the reported numbers, the annual operating cost is about 25% of revenue, or just over €900 per equipped vehicle. While the operating cost covers all of the manual and Internet toll collection as well, the cost per vehicle is high relative to revenue that is likely to be collected from light vehicles. The annual cost seems to have been fairly stable for the first 3 years of operation, but news releases indicate that operational efficiencies are being pursued to lower these costs.

4.5 Cost Estimates for Cordon Pricing Systems

In the implementation of cordon pricing systems, the largest single roadblock has typically involved political rather than technological concerns. A number of these systems first began as pilot programs and were later adopted (e.g., Stockholm) or discarded (e.g., Hong Kong) after public sentiment was considered. The major issues that have been raised to date include user costs, capital costs, fairness, enforcement, and privacy concerns. Cordon charge systems have generated considerable debate, especially in regard to the fee assessed on local residents living within the zone compared with the fee imposed on nonresidents living in suburban areas who travel into the congestion price zone during peak hours for work, education, or shopping. A separate question has involved the assessment of fees for through and multiple trips. Table 30 summarizes the general framework and main objectives of some of the congestion pricing systems in place around the world.

The general trend of the systems examined has been a temporary reduction in congestion, which has typically returned to historical levels over time. With the reduction in traffic, there has been a related decline in vehicle emissions. Given the recent implementation of these systems, it is too early to determine whether this is a sustainable trend or merely a short-term effect. Another potential issue is the economic impact of cordon price zones, particularly on retailers within the zone who rely on outside traffic for business. In studies conducted by the operating agencies, it has generally been found that the implementation of the cordon zone areas has not had a negative impact.

Based on a limited sample of cordon pricing systems, the cost of administering the system, collecting revenues, and enforcement is in line with the costs associated with tolling systems in the United States and Canada. Given their relatively long implementation history and demographic characteristics, the Oslo and London congestion pricing systems serve as reasonable comparators with tolling systems. For the Oslo system, operating costs averaged about 11% of total revenues, while the London system averaged about 55% of revenues. For

Table 30. Summary of congestion/cordon pricing systems.

	Singapore	London	Oslo	Stockholm	Milan
Charging method	85th percentile of average speed	Cordon with flat charge	Cordon	Cordon	Cordon
Primary objective	Demand management	Congestion relief	Revenue generation	Environmental	Environmental
Discounts	No	Yes	Yes	N/A	Yes
Charges for through trips	Yes	No	Yes	Yes	Yes
Exemptions	HOV 4+ and buses	Motorcycles and taxis; residents get a 90% discount	N/A	Clean vehicles, taxis, motorcycles, buses, and emergency vehicles	Vehicles meeting high emissions standards

most of the tolling systems studied, operating costs ranged from 17% to 60% of revenues.

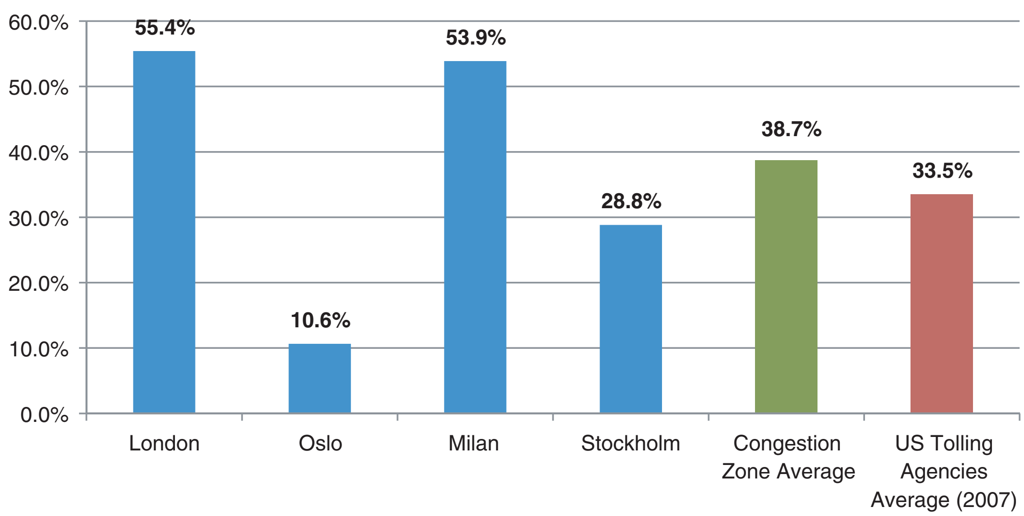
Additionally, the average operating cost as a percentage of revenues for the London, Oslo, Stockholm, and Milan congestion zones was 38.7%. Financial data were not available for the Singapore congestion pricing system. In contrast, operating costs for a sample of 15 tolling agencies in the United States and Canada averaged nearly 34% of operating revenues in 2007. Figure 43 summarizes the operating costs as percentage of revenues for the cordon price systems under review.

4.6 Cost Estimates for Parking Pricing Systems

Each of the three systems presented in Section 2.5 illustrates a different approach to parking pricing management:

- In Westminster, the municipal government manages parking directly;
- In San Francisco, a partnership of agencies led by SFMTA is managing the parking pricing system; and
- In Chicago, the responsibility for parking management has been handed over to a private party.

The primary objective of the public sector agencies that administer and operate these programs is to make parking in downtown areas less desirable than parking areas in outlying areas. For the Chicago system, the private sector partner also has the objective of maximizing revenues within the rate structure set by the rate framework established by the city. In contrast, the pricing structure for the San Francisco parking system is relatively more dynamic. The intent is to adjust parking rates to help shift the demand for parking from one area of the city to another (e.g., from the business district during the day to the



Source: Jacobs Engineering Group, 2010.

Figure 43. Operating costs as a percentage of revenues for congestion pricing systems.

Table 31. Summary of parking price management systems.

	Westminster	San Francisco	Chicago
Management	Municipal	Multiple public agencies	Private–public partnership
Primary objective	To control parking	To make parking easier and manage demand	To generate revenue
Primary method	Price cars out of high-demand parking zones	Price cars out of high-demand parking zones	Price cars out of high-demand parking zones
Technology	CCTV, pay-stations, wireless network	In-street sensors, pay-stations, wireless network	Pay-stations, wireless networks
Payment options	Coin, credit, debit, phone, scratch card	Coin, credit, debit, smart card	Coin, credit, debit
Rate schedule	Static	Variable by time of day	Static
2009 price range (per hour)	£1.10–£4.40	\$0.25–\$10.00	\$1.25–\$4.25
2013 price range (per hour)	TBD	TBD	\$2.00–\$6.50

nightlife areas in the evening) as conditions warrant. In this manner, San Francisco is going one step further since parking rates for on-street spaces are set at lower rates than off-street parking spaces. San Francisco also expects to have a broader range of rates than either Westminster or Chicago. Table 31 summarizes the parking management systems under study.

In some regions (e.g., Westminster), parking pricing systems may be combined with cordon pricing to support congestion management. Drivers heading into a city with cordon tolls not only must pay the toll to enter the city but must additionally pay parking rates that reflect the demand for the space chosen. When faced with congestion and parking charges, drivers may consider the trade-offs of public transit versus personal vehicles, potentially creating a synergistic effect that reduces congestion in urban areas. Notwithstanding, this approach may affect the amount of revenues generated from parking systems due to reduced demand for private vehicles entering into the city and using its parking areas. The impact of combining congestion management techniques would need to be carefully analyzed for any city or other jurisdiction considering implementation.

Although three parking pricing systems are presented in this report, financial data are only available for the Westminster system. Operating revenues and operating costs for the Westminster parking pricing system averaged \$136 million and \$77 million, respectively, over fiscal years 2004 to 2008. Thus, the average operating cost as a percentage of revenues was 56.6% over fiscal years 2004 to 2008.

CHAPTER 5

Cost Comparison Analysis

One of the key objectives of this research was to compare and examine costs of revenue-generating systems. The results of this cost comparison analysis will help researchers and policy makers understand the magnitudes of costs incurred for each of the revenue systems and provide a methodology for analyzing alternative revenue systems within transportation. The comparison analysis depends on the costs and other related data collected and described in Chapters 2 and 4.

This chapter begins by defining unit measurements for the purpose of comparison within and between the three revenue systems (motor fuel taxes, tolling, and VMT fees) for which data were available. This chapter also compares the operating costs of cordon pricing and parking pricing systems. The chapter is organized as follows:

- Section 5.1 introduces the unit measurements used in the cost comparison analysis,
- Section 5.2 compares the costs within each of three revenue systems,
- Section 5.3 compares costs between the revenue systems, and
- Section 5.4 presents the results of a sensitivity analysis.

5.1 Unit Measurements for the Cost Comparison Analysis

To carry out a quantitative comparison for revenue systems, it is necessary to normalize the collected cost data. Unit measurement or cost per unit of measurement is an ideal evaluator for normalization and cost comparison. The unit measurements used in this report for the three systems (motor fuel taxes, tolling, and VMT fees) for which data would support such an analysis are

- Average cost per lane mile,
- Average cost per centerline mile,
- Average cost per 1,000 VMT,
- Average cost per vehicle,
- Average cost per transaction, and
- Share of cost to total revenue.

Each unit of measurement has its own special characteristics. It is expected that lane miles and centerline miles would have minor changes over time. From 1984 to 2005, VMT tended to increase steadily. In periods in which there is volatility in gas prices and/or weak macroeconomic conditions, VMT has tended to decrease slightly. This has been the case in recent years. For example, the VMT for the tolling facility on NYSTA increased 2.6% from 2003 to 2004, but declined 3.4% between 2004 and 2005.

Average costs expressed in the six unit measurements cover average total operating cost, average administrative cost, average collection cost, average enforcement cost, and average capital cost (or average initial setting-up cost for VMT). For VMT fees, average OBU cost and average miscellaneous cost are also considered.

As observed from the cost data presented in Chapters 2 and 4, the costs vary by year from 2003 to 2007, except for the VMT fee systems that have only 1 year of reported data. In addition, the costs differ from one state to another for motor fuel taxes, from one facility to another for tolling and cordon pricing, or from one provider to another for the VMT fee systems. Parking pricing administrative costs are presented for only one system.

5.2 Comparison Within Revenue Systems

As the first step for the cost comparison analysis, the cost data within each of the three revenue systems are compared and analyzed. Per-unit measurements defined in Section 5.1 are implemented in the comparison analysis. The cost data collected from states for fuel taxes are examined first, and then the cost data for tolling and VMT fee systems are analyzed.

5.2.1 Motor Fuel Taxes

Relative to the alternative revenue-generation systems, fuel taxes represent an efficient revenue stream from an operating cost perspective. Annual motor fuel tax collection per 1,000 miles of travel averaged approximately $11 among the eight examined states, with tax rates ranging from a low of $8 per 1,000 miles in New Jersey to a high of $15 per 1,000 miles in Idaho. Note that in all cases, motor fuel tax collection costs included those associated with both gasoline and special fuels. Annual operating costs averaged 0.9% of total motor fuel tax collections (see Table 32). Thus, annual operating costs per 1,000 miles traveled averaged $0.10, ranging from $0.04 in Iowa to $0.19 in Idaho.

Table 32 also presents the average motor fuel tax operating cost per lane mile, centerline mile, and vehicle over the period of 2003 to 2007. The average total operating cost to manage the motor fuel tax per lane mile was $49, while the average cost per centerline mile was estimated at $105. Annual operating costs per lane mile ranged from a low of $5 in Iowa to a high of $90 in Florida. The total operating costs per centerline mile ranged from $10 in Iowa to $196 in Florida.

Annual motor fuel tax operating costs per vehicle were also estimated at low levels, ranging from a low of $0.35 in Iowa to a high of $2.38 in Tennessee. The average annual operating cost per vehicle across the eight states selected for more detailed analysis was estimated at $1.24.

In summary, the observations from the operating cost for the fuel taxes can be made as follows

- On average, only 1% of revenue, $49 per lane mile, $105 per centerline mile, $0.10 per 1,000 VMT, or $1.24 per vehicle was needed to operate the fuel tax collection system.
- The variation of the operating costs among the sample states is relatively small. The difference between the highest and lowest percentage of operating cost relative to revenue among the eight states is only 1.15%.
- Iowa has the lowest operating cost, which is consistent across all unit measurements among the eight sample states. The state spent only $5 per lane mile, or 0.28% of revenue, to operate fuel tax collection.
- Florida has the highest operating cost per lane mile or per centerline mile, reaching $90 per lane mile and $196 per centerline mile.

5.2.2 Tolling

The discussion and charts presented in Section 4.3 have demonstrated the difference in operating and capital costs among selected tolling agencies. To highlight the cost comparison, the following observations are made for tolling agencies selected for the analysis:

- In general, it took approximately 34% of revenues, $759,741 to $829,991 per centerline mile, or $0.54 per transaction to operate a tolling system. These values reflect averages over 3 to 5 years (Table 33).
- The variation of operating costs between tolling systems can be significant, ranging from 16.5% (Toronto 407) to 96.2% (San Diego I-15) in 2007. For the activities analyzed, toll operating activities typically account for approximately 30% of revenues. Without these outliers, toll operation costs averaged approximately 34% of revenues.
- Excluding the tolling agencies that primarily operate bridge facilities (DRJTBC and DRPA), the DTR had the highest operating cost per centerline mile ($2.8 million per centerline mile in 2007). In contrast, spending for E-470 was only $118,000 per centerline mile in 2007, which is the lowest for toll operations. In 2008, DTR operations were transferred from VDOT to the Metropolitan Washington Airports Authority.
- Among the detailed cost components, tolling agencies spent more on the collection cost than other components. This involved the implementation of toll gantries, ITS, a customer service center, hardware and software, customer account management, and other expenditures. On average, nearly 26% of revenues were needed just for collecting tolls in 2007.

Table 32. Comparison of total operating costs between state fuel tax systems – average cost over 2003–2007.

Cost Item	Average over states	CA	CO	FL	ID	IA	NJ	TN	TX
$ per lane mile	$49	$63	$15	$90	$30	$5	$69	$63	$47
$ per centerline mile	105	141	32	196	61	10	151	133	99
$ per 1,000 VMT	0.10	0.07	0.06	0.12	0.19	0.04	0.08	0.17	0.13
$ per vehicle	1.24	0.74	1.49	1.52	2.18	0.35	0.93	2.38	1.78
% of total revenue	0.94%	0.72%	0.50%	1.16%	1.32%	0.28%	1.00%	1.43%	1.03%

Table 33. Total operating cost comparison between tolling systems – average cost over 2003–2007.

Cost Item	DRPA(*)	DRJTBC(*)	DTR	Dulles Greenway	E-470	FTE	ISTHA	NJTA
$ per centerline mile	N/A	14,602,509	2,739,654	826,126	95,780	539,310	525,526	1,090,284
$ per 1,000 VMT	N/A	N/A	N/A	N/A	N/A	30.77	N/A	25.11
$ per transaction	0.59	0.20	0.33	0.54	0.51	0.38	0.18	0.44
% of total revenue	22.9%	34.7%	63.2%	23.4%	35.1%	38.4%	27.3%	42.9%

Cost Item	NTTA	NYSTA	OOCEA	OTC	I-15 HOT Lanes	SR 91	Toronto 407	Agency Average(**)
$ per centerline mile	1,003,933	288,236	484,767	290,427	221,826	720,475	1,051,284	$759,741
$ per 1,000 VMT	N/A	17.28	N/A	23.72	N/A	69.08	52.79	$36.46
$ per transaction	0.15	0.68	0.17	1.38	0.67	1.38	0.57	$0.54
% of total revenue	28.5%	37.4%	26.0%	37.0%	96.7%	34.7%	18.9%	33.5%

(*) Because DRJTBC and DRPA primarily operate short-distance bridge facilities, these agencies have not been included in the average cost over agencies for centerline miles.
(**) The average numbers calculated across agencies are based on the data in this table only.

5.2.3 VMT Fees

In this section, operating costs for VMT fee systems are compared with operating costs for the other systems. However, it should be noted that this is not a full cost comparison since the fixed cost of the OBU is not included. Different assumptions about the fixed cost and how it should be annualized would have substantial impacts on the comparison. In particular, if the OBU has other uses, the allocation of the cost between the VMT system and other uses would affect the comparison. It should also be emphasized that these are cost estimates and that actual costs may be different. Finally, the comparison to revenue is based on the estimated Dutch revenue, which is considerably higher than the revenue per vehicle currently collected in the United States.

For the VMT fee systems proposed in the Netherlands, the total operating cost is lowest for the Siemens system, while T-Systems is highest (see Table 34). The average over the three providers for comparative measurement is $4,042 per lane mile or $8,245 per centerline mile.

In terms of VMT generated annually, the total operating cost per 1,000 VMT of the three systems varies from $4.72 to $11, with an average across the three systems of $6.26. The annual operating cost estimates are all over $50 per vehicle, and some are over $100 per vehicle. This is a higher cost than the revenue currently collected per vehicle in the United States.

Also, VMT fee systems generate some concern relative to the revenue generated. The Dutch goal is to have operating costs no higher than 5% of the revenue collected. Siemens' system is a little above 4%, but the other two systems are all above the goal. Also, the revenue collected in the Netherlands is on the order of four or five times the amount of fuel tax per vehicle that is collected in the United States.

As discussed in Chapter 4, the total initial setup costs across the three systems are similar in magnitude. On the average over the three providers, the initial setup cost per vehicle is $254 and is more than 22% of total annual revenue that may be generated.

In summary, the observations from the operating cost for the Dutch VMT fee systems are that:

- Overall, it may take 7% of revenue, $4,000 per lane mile, $8,000 per centerline mile, $6 per 1,000 VMT, or $7 per transaction to operate a VMT fee system.
- Although different technologies have been proposed for administrating the VMT fee systems, the variation of operating costs between the VMT fee systems is reasonably small. The difference between the highest and lowest percentage of operating cost relative to revenue among the three systems is only 5.5%.
- The system proposed by T-Systems has the highest operating cost, while Siemens' system has the lowest operating cost.
- Among the detailed cost components, the average administrative cost is estimated at 3.4% of revenue. However, the average collection, enforcement, OBU, and miscellaneous costs are estimated at only 1.3%, 0.5%, 1.1%, and 0.3%, respectively, of revenue.
- It may require 22% of annual revenue to set up a VMT fee system.

5.2.4 Cordon and Parking Pricing

Table 35 summarizes the financial performance of a sample of cordon and parking pricing systems around the world. This sample includes the multi-year financial performance of the cordon systems in London and Oslo as well as the parking

Table 34. Cost comparison between VMT fee systems.

Cost Item	Average over Providers	Siemens	T-Systems	Vodafone
Per Unit of Total Operating Cost				
$ per lane mile	$4,042	$2,533	$5,894	$ 3,699
$ per centerline mile	8,245	5,167	12,023	7,546
$ per 1,000 VMT	6.26	4.72	10.99	6.90
$ per vehicle	75.16	51.33	114.66	61.05
$ per transaction	6.95	4.36	10.14	6.36
% of total revenue	6.6%	4.1%	9.6%	6.0%
Per Unit of Administrative Cost				
$ per lane mile	2,075	673	3,090	2,463
$ per centerline mile	4,234	1,373	6,304	5,025
$ per 1,000 VMT	3.22	1.25	5.76	2.85
$ per vehicle	38.59	13.64	60.12	40.65
$ per transaction	3.57	1.16	5.32	4.24
% of total revenue	3.4%	1.1%	5.0%	4.0%
Per Unit of Collection Cost				
$ per lane mile	810	672	1,400	357
$ per centerline mile	1,652	1,371	2,857	728
$ per 1,000 VMT	1.25	1.25	2.61	0.41
$ per vehicle	15.06	13.62	27.24	5.89
$ per transaction	1.39	1.16	2.41	0.61
% of total revenue	1.3%	1.1%	2.3%	0.6%
Per Unit of Enforcement Cost				
$ per lane mile	297	72	489	331
$ per centerline mile	606	147	997	675
$ per 1,000 VMT	0.46	0.13	0.91	0.38
$ per vehicle	5.53	1.46	9.51	5.46
$ per transaction	0.51	0.12	0.84	0.57
% of total revenue	0.5%	0.1%	0.8%	0.5%
Per Unit of OBU Cost				
$ per lane mile	666	1,005	768	226
$ per centerline mile	1,360	2,050	1,567	462
$ per 1,000 VMT	1.03	1.87	1.43	0.42
$ per vehicle	12.39	20.36	14.95	3.73
$ per transaction	1.15	1.73	1.32	0.39
% of total revenue	1.1%	1.6%	1.3%	0.4%
Per Unit of Miscellaneous Cost				
$ per lane mile	193	112	146	322
$ per centerline mile	394	228	297	657
$ per 1,000 VMT	0.30	0.21	0.27	0.60
$ per vehicle	3.59	2.26	2.84	5.31
$ per transaction	0.33	0.19	0.25	0.55
% of total revenue	0.3%	0.2%	0.2%	0.5%
Per Unit of Initial Setup Cost				
$ per lane mile	13,653	13,944	13,561	13,456
$ per centerline mile	27,852	28,443	27,663	27,449
$ per 1,000 VMT	21.15	25.99	25.28	25.08
$ per vehicle	253.87	282.57	263.81	222.08
$ per transaction	23.49	23.99	23.33	23.15
% of total revenue	22.2%	22.7%	22.1%	21.9%

Table 35. Cost and revenue for cordon and parking pricing systems ($ million)*.

	Cordon Pricing				Parking Pricing
	London	Oslo	Stockholm	Milan	Westminster
	Average over FY 2004–2007	Average over 2003–2008	2006	2008	Average over FY 2004–2008
Operating revenue	$431.3	$202.5	$111.5	$17.0	$136.0
Operating costs	$238.5	$21.6	$32.2	$9.2	$76.7
Non-operating costs	$31.9	$62.5	$7.3		
Operating costs/revenue	55.4%	10.6%	39.9%	53.9%	56.6%
Gross margin	44.6%	89.4%	60.7%	46.1%	43.4%

* To convert from foreign currencies to the U.S. dollars, the exchange rates at the end of each year were used.

pricing system in Westminster. Financial data for the other cordon systems are based on a single year and on an analysis of pilot programs. In the case of Stockholm, the financial data are only available for 2006, although the pilot program has been extended, while the financial data presented for Milan are for 2008. Based on this sample of the cordon pricing systems, operating revenues and operating costs averaged $191 million and $75 million, respectively. Moreover, operating costs as a percentage of revenues averaged approximately 38.7%.

Although three parking pricing systems are presented in this report, the financial data are only available for the Westminster system. As shown in Table 35, operating revenues and operating costs for the Westminster parking pricing system averaged $136 million and $77 million, respectively, over fiscal years 2004 to 2008. Thus, the average operating costs as a percentage of revenues were 56.6% over fiscal years 2004 to 2008.

5.3 Comparison Between Revenue Systems

For the purpose of examining costs incurred across revenue systems, the analysis performed in this section focuses on cost comparisons between the three revenue systems. Considering the fact that only 1-year cost data exist for the VMT fees, the cost comparison primarily focuses on the last historical year (2007) for which data are available for all three systems. Using the average costs calculated over states for fuel taxes, tolling agencies, and providers of VMT fees for 2007 in the cost comparison analysis avoids the potential pitfalls caused by missing cost data and differing time series data, thereby enhancing accuracy and ensuring data comparability for revenue-generation systems.

Based on the results presented in Table 36, the following observations can be made for costs of operating the five revenue-generating systems:

Table 36. Cost comparison between revenue systems.

	Fuel Taxes[1]	Tolling[1]	VMT Fees[2]	Cordon Pricing	Parking Pricing
	Average Cost over States	Average Cost over Agencies	Average Cost over Providers	Average Cost over Providers	Cost of Single Provider
$ per lane mile	$50	$150,595	$4,042	N/A	N/A
$ per centerline mile	108	829,991	8,245	N/A	N/A
$ per 1,000 VMT	0.10	38.58	6.26	N/A	N/A
$ per vehicle	1.22	N/A	75.16	N/A	N/A
$ per transaction	N/A	0.54	6.95	N/A	N/A
% of total revenue[3]	0.92%	33.5%	6.6%	38.7%	56.6%
Gross income over total revenues (gross margin in %)	99.1%	66.5%	93.4%	61.3%	43.4%

(1) For the fuel tax, tolling, and cordon pricing systems, data were collected from 2003 to 2007. To make a consistent and accurate comparison between the alternative revenue systems, only 2007 data were used in developing these averages.

(2) For the VMT fee systems, there is only one-year data available for comparison, and it is based on the revenue forecast to be collected in the Netherlands.

(3) System-generated revenues only.

- The fuel tax system is the most cost-effective revenue system among the first three and has the lowest operating cost for all unit measurements. The operating cost for fuel taxes is only approximately 1% of tax revenue, and the system averages approximately $1.20 per vehicle to operate and manage.
- Though the operating cost may reach $75 per vehicle, the cost for the proposed VMT system is still reasonable when measured by the share of cost to revenue collected in the Netherlands, which is approximately 7%. It would be a larger share of typical revenues in the United States.
- Although it may cost $0.54 per transaction to operate and maintain the tolling systems, tolling agencies spent roughly 33.5% of revenues for toll collection, administration, and enforcement activities in 2007. Among the five revenue systems, operating costs for tolling and cordon pricing are roughly comparable, at 33.5% and 38.7%, respectively.
- The costs to operate the Westminster parking pricing system are 56.6% of total revenue. Thus, of the five alternative revenue-generation systems, parking pricing was the most expensive to operate based on the very limited data collected for this study.
- For VMT fee systems, the biggest spending item is administration costs, which may reach 3.4% of revenue. Comparatively, collection and enforcement costs for maintaining a VMT fee system are relatively small. Note that operating costs are composed of administrative, collection, and enforcement cost elements. See Section 4.1 for a definition of each cost element. They may be less than or about 1% of revenue. As will be discussed in Section 6.2, collection costs for tolling systems are much larger than administration and enforcement costs. The evidence from the tolling agencies indicates that around or above 20% of revenue may be spent on collecting tolls.

5.4 Sensitivity Analysis

Motor fuel taxes and the alternative revenue-generation systems considered in this study face both internal and external uncertainties. The internal uncertainties faced by fuel tax systems, for example, involve improvements in fuel efficiencies that threaten the revenue generated from the fuel tax. External uncertainties may come from other systems if alternative revenue systems are implemented to supplement or replace the fuel tax system.

This section presents the results of a sensitivity analysis that was designed to examine the impacts on operating costs caused by changing certain parameters. It also assesses uncertainties and business risks involved in alternative revenue-generation systems and discusses issues related to evasion and implementation. For some systems, only qualitative analysis could be performed for certain parts of this assessment due to limited data availability. Further, some of the components of the sensitivity analysis outlined in this section were not applicable to specific systems or were replaced with other, more relevant elements. With that noted, the sensitivity analysis primarily focuses on the following elements:

- Economies or diseconomies of scale and scope: These can be considered and depend on the number of vehicles, geographic coverage, and range of uses for the system. For some systems, such as cordon pricing, the effectiveness may also vary with geographic coverage.
- Technology: The cost of each system discussed depends to some extent on the cost of the technology to implement it. Known costs should be carefully separated from estimated costs. Potential changes in cost due to technological progress or use of the technology for other purposes should be considered. This also relates to the possibility of sharing costs for a system that is interoperable over various toll systems. In addition, the cost estimates should be analyzed for the impact of large-scale deployment. For example, costs that are now low due to excess system capacity may be much higher if more capacity is needed.
- Revenue: All revenue systems are subject to potential variation due to various forecast errors such as elasticity of demand, recession, or alternatives available.
- Evasion and enforcement: Evasion estimates for existing systems are subject to great uncertainty, so the estimates for proposed systems will be even more open to debate. There will also be trade-offs between enforcement costs and levels of evasion that could be discussed.
- Implementation: There are a variety of risks associated with implementation. First, there is always the possibility of unexpected problems and delays, which raise costs and reduce revenue. There is also the possibility of changes in political support for a new system as it is being phased in, which can lead to termination of the project or other costly changes.
- Privacy and security: Any system will have to have provisions to maintain privacy and security. Failure of such systems will result in additional costs and other consequences.

5.4.1 Motor Fuel Taxes

Scale

As reported in Section 4.2.8, the size of the motor fuel tax collection program appears to have a negligible impact on operating cost levels. Collection data for the 50 states were used to rank the states and classify them into high-, mid-, and low-level collection states. The states that make up the top third in terms of total motor fuel tax collection incurred operating costs equal to 1.1% of total tax collections. Mid-level states incurred costs equal to 0.9% of total tax collections. States making up the bottom third of tax collectors incurred operating costs equal to 1.0% of total tax collections.

Technology

A number of technologies are used in motor fuel tax collections and enforcement, including diesel fuel dyeing equipment, CVISN systems tied to IFTA credentialing, and electronic reporting and payment systems.

Electronic reporting and payment has been advanced in many states as a means to reduce omissions and errors on motor fuel tax returns, enhance access to information for auditing and enforcement purposes, reduce labor costs, and eliminate the space requirements associated with maintaining paper files of tax records for a period of up to 5 years (Weimar et al., 2008). In point six of its 11-point plan, the FTA Uniformity Committee recommended that states adopt electronic systems with ANSI and ASC X12 standards for all electronic data interchange (EDI) applications (FTA, 2003).

In recent years, both the federal government and a number of states have invested in motor-fuel tracking systems. Motor-fuel tracking systems promote total fuel accountability by analyzing motor fuel industry records to identify discrepancies between the movement of fuel shipments and tax records.

Under the Transportation Equity Act for the 21st Century (TEA-21), Congress authorized funds to establish the Excise Files Information Retrieval System (ExFIRS), which is composed of 10 subsystems designed to collect and analyze data regarding motor fuel industry operations. These 10 subsystems include

- Excise Summary Terminal Activity Reporting System (ExSTARS): Collects and analyzes motor fuel distribution data,
- Excise Classification Information System (ExCIS): Gathers information on tax returns,
- Excise Automated Claims Tracking System (ExACT): Analyzes claims,
- Excise Customs Activity Tracking (ExCAT): Gathers information on imports and exports,
- Excise Fuel Online Network (ExFON): Integrates fuel tracking with case processing,
- Excise Tax Registration Authorization System (ExTRAS): Manages IRS Form 637 registration data (Application for Registration for Certain Excise Tax Activities),
- Below the Rack Information System (BTRIS): Holds below-the-rack motor fuel activity information such as fingerprinting, and
- Excise Tax On-Line Exchange (ExTOLE): Allows states to exchange information.

In addition to the federal systems, a number of states have adopted their own automated electronic tracking systems.

Table 37. State tracking systems.

State	Tracking System
Virginia	ACS
Nevada	ACS
Mississippi	ACS
Arkansas	ACS
Michigan	ACS
Colorado	Explorer
Wisconsin	Synergy
South Carolina	ZyTax
Tennessee	ZyTax
North Dakota	ZyTax
California	In-house
Illinois	In-house
Missouri	In-house
Nebraska	In-house
Montana	In-house

Source: Weimar et al., 2008

While some states have developed their systems in-house (e.g., California, Illinois, Montana), more have chosen to use third-party systems offered by ACS, Explorer, Synergy, or ZyTax (see Table 37). The costs of these systems vary by state.

The costs associated with these technologies are small when compared with those for the alternative revenue-generation systems examined in this chapter. Furthermore, the data presented in Section 4.2.8 demonstrate that operating costs for states with motor-fuel tracking systems were nearly identical to those without such systems (1.0% of total tax collections).

Revenue

A number of factors could have an impact on the demand for transportation, mode split, and, ultimately, motor fuel tax collections. Changes in the relative price by mode will affect the decisions made both by shippers and passengers. When considering price sensitivity, a product is considered relatively price sensitive (elastic) if the change in price generates a proportionally greater percentage change in quantity demanded. A product is relatively insensitive (inelastic) to prices if a change in price yields a less than proportionate change in quantity demanded. A survey of studies estimating price sensitivity for transport found

- Overall, transportation demand is relatively price-insensitive.
- Automobile and transit passenger transportation are relatively insensitive to price, with a 1% increase resulting in

- a 0.1% to 1.1% and 0.1% to 1.3% reduction in demand, respectively. The demand for peak-period travel is even less sensitive to price, with a 1% increase in price generating a 0.1% to 0.7% reduction in demand for both modes. However, one study found that price sensitivity with respect to mode choice was higher for automobiles, indicating that some motorists forgo highway travel in favor of public transport when user costs are exceedingly high.
- Freight transport is not very sensitive to price, with the exception of markets that are subject to intermodal competition (e.g., assembled automobiles, corn, wheat, primary metals, paper products) (Oum, Waters, and Yong, 1990).

Evidence suggests that in recent years, the sharp increases in motor fuel prices caused a slight reduction in passenger demand and a minor shift toward public transit. For the first time since 1980, the average number of miles traveled by motorists declined in 2005 (FHWA, 2006). In 2008, total VMT in the United States fell by 1.9% (FHWA, 2009b). Further, following a 2-year decline in ridership, the number of passengers reported by the nation's transit agencies in 2004 through 2006 grew by 7.1%. Between 1995 and 2008, public transit ridership grew by 36% (American Public Transportation Association, 2008). Evidence also suggests that higher fuel prices may provide more incentive to buy fuel-efficient cars without reducing VMT. In 2005 and 2006, the new purchase of light trucks declined for the first time since the 1980s.

In addition to price sensitivity, other factors such as inflation, market penetration of alternative fuels, and increased motor fuel efficiency hold the potential to significantly erode the motor fuel tax. In recent years, inflation has had a significant impact on motor fuel tax receipts. From 1993 to 2008, the purchasing power of the federal gasoline tax, which has remained at the fixed rate of 18.4 cents per gallon, has declined by 33% (National Surface Transportation Infrastructure Financing Commission, 2009).

While declines in revenues tied to enhanced motor fuel economies in the light-duty vehicle fleet have not yet materialized, several market penetration forecasts of hybrid and electric vehicles suggest that erosion of the motor fuel tax base is inevitable. While some forecasts estimate ultimate hybrid electric and EV penetration of the light-duty vehicle market in the 8% to 16% range (Greene, Duleep, and McManus, 2004), the Electric Power Research Institute (EPRI) and Natural Resources Defense Council (NRDC) were more aggressive, estimating PHEV market penetration rates under three scenarios, ranging from 20% to 80% (medium PHEV scenario estimate of 62%) in 2050 (EPRI and NRDC, 2007). In another study prepared for the University of California, Berkeley's Center for Entrepreneurship and Technology, Becker and Sidhu (2009) estimated market penetration rates for electric vehicles with switchable batteries of 64% to 85% by 2030.

Evasion and Enforcement

Evidence suggests that motor fuel taxes suffer from a persistent problem with evasion. Historic changes in administrative and enforcement practices designed to address the evasion issue (e.g., fuel dyeing, taxation of kerosene and other alternative fuels, enhanced auditing practices, moving the point of taxation up the distribution chain) have increased revenues deposited in highway funds across the nation. However, the results of joint audits performed under the FHWA's Joint Federal/State Motor Fuel Tax Compliance Project suggest that while evasion levels have been reduced through enhanced compliance and enforcement practices, evasion continues to persist (Balducci et al., 2006).

In 1992, FHWA estimated motor fuel tax evasion at $1.0 billion annually, which translates into evasion rates of 3% to 7% for gasoline taxes and 15% to 25% for diesel taxes (FHWA, 1992). In the past 15 years, numerous states have studied motor fuel tax evasion (e.g., Montana, New York, Oregon, Washington) with estimates ranging from $600 million to $2 billion for all states. The findings of several motor fuel tax evasion studies are summarized in Table 38.

The costs associated with enhanced motor fuel tax auditing and enforcement operations can serve to discourage evasion in states addressing budget shortfalls and uncertain financial outlooks. The literature suggests that while it is expensive to effectively audit and enforce motor fuel tax codes, enhanced compliance activities yield positive returns on investment. From October 1992 through 1993, gasoline tax revenues reported in 38 states averaged $443 per auditor staff hour. Over the same time period, diesel tax revenues were enhanced at the rate of $321 per auditing hour (CSG & CGPA, 1996). Finally, FHWA reports that it receives $10 to $20 for each dollar spent on audits and criminal prosecutions (FHWA, 1999).

Implementation, Privacy, and Security

Oregon implemented the first state motor fuel tax in 1919. The federal government implemented a motor fuel tax in 1932. The motor fuel tax system is, therefore, mature. Payments are collected from businesses engaged in the distribution and selling of motor fuels. Thus, there are limited implementation or privacy and security issues with this tested tax mechanism.

5.4.2 Tolling

This section examines the relative sensitivity of the factors that can have an impact on revenue and operating costs

Table 38. Summary of fuel tax evasion studies.

Author(s)	Date	Tax	Evasion Estimate	Method
Balducci et al.	2006	Gasoline and diesel taxes in Montana	$2.8 million (gasoline) and $12.0 million (diesel) annually	Econometric method, audit review method, inspections data analysis
Eger	2001	Wisconsin gasoline taxes due to falsified agricultural refund requests	Upwards of $4 million annually	Econometric method, comparison of predicted and actual agricultural refund requests
KPMG	2001	Federal diesel taxed due to jet fuel diversion	$1.7–$9.2 billion over 10 years	Comparison of fuel supplied to taxed gallons
Denison and Hackbart	1996	Kentucky fuel taxes	$26–$34 million	Survey of tax administrators, econometric analysis
Council of State Governments, Council of Governors' Policy Advisors	1996	All state fuel taxes	$952 million–$1.5 billion	Literature review, survey of state tax administrators, econometric analysis
WSLTC	1996	Washington fuel taxes	$15–$30 million	Literature review, border interdiction, random audits
Revenue Canada	1996	Canadian fuel taxes	$55–$110 million	Comparison of monthly motor fuel sales volumes with gallons taxed
Mingo et al.	1996	All state diesel taxes	21%	Comparison of fuel consumption to taxed gallons
Federal Highway Administration	1994a	Federal and state fuel taxes	$1 billion (fed. fuel taxes), $3 billion (fed./state fuel taxes)	Literature review, analysis of auditing data
Federal Highway Administration	1992	Federal gasoline and diesel tax	$466.1 million (gasoline tax), $1,087.5 million (diesel tax)	Literature/testimony review, analysis of auditing data
Mitstifer, National Association of Truck Stop Operators	1992	Federal diesel tax	$3 billion	Comparison of diesel fuel consumed (based on reports from truck stops) to taxed gallons
Addanki et al.	1987	Federal gasoline taxes	More than $500 million	Econometric analysis, comparison of fuel consumption with taxed gallons
Addanki et al.	1987	NY gasoline taxes	$168.4–$254.5 million	Econometric analysis

Source: Modified from Weimar et al., 2008

for tolling systems. The revenue portion of the sensitivity analysis examines, in general terms, the effects of price, scale, economic conditions, and competing facilities. Additionally, the sensitivity analysis also examines the impact on costs related to broad changes in scale, implementation, technology, enforcement strategies, and security that can be implemented for tolling and related systems. Scale affects both revenue-generation and cost structures. Table 39 lists the main categories and the specific factors within each category in the sensitivity analysis for tolling systems.

Tolling Revenues and Rates

Revenues and operating costs of tolling systems are subject to both internal and external factors. Internal factors, which are defined as controllable by the operating entity through

Table 39. Factors analyzed for tolling systems.

Category	Factor
Revenue	• Rates, charges, and fees • Economic conditions • Facility length and system capacity • Geographic area • Alternate routes
Implementation	• Collection costs • Market size
Technology	• Equipment purchases and upgrades
Evasion and enforcement	• Increased enforcement
Privacy and security	• Confidentiality of customer accounts and transponder data

policy, include enforcement, tolling, facility infrastructure, and technology. External factors are defined as being outside the control of the operating entity and include economic conditions, alternative routes, and motorist preferences. This section will discuss these factors in greater detail.

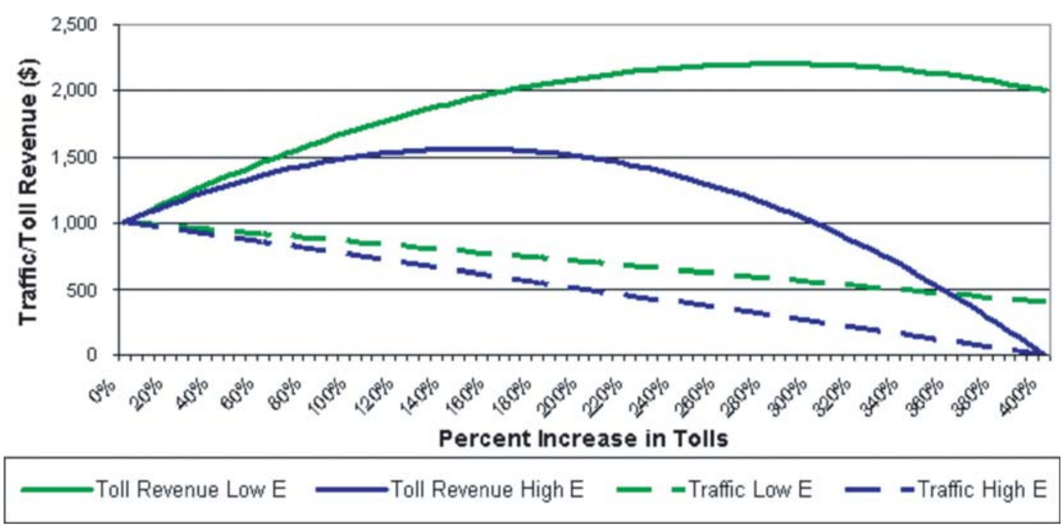
Toll revenues are a function of toll rates, economic conditions, facility length, and the roadway network. In this section, some of these factors will be analyzed qualitatively as to their respective impact on toll revenues.

Toll Rates. A key factor in revenue generation is toll rates (price), which includes the initial toll rate, toll escalation, and the implementation of variable pricing schedules. Typical toll rates range from a few cents per mile on older regional turnpikes to over $1 per mile for managed lanes in highly congested urban corridors. While toll agencies can typically obtain higher revenues through an increase in toll rates, there is a point where increases in tolls can no longer provide additional revenues. In this manner, toll roads are similar to other commodities—when tolls (prices) increase, demand (traffic) decreases. The quantification of this relationship is called the price elasticity of demand. When faced with a price increase, motorists have the following potential options:

- Continue using the toll facility at normal usage levels;
- Use the toll facility at a suppressed rate by consolidating trips;
- Divert to a less expensive, alternate route;
- Use another transportation mode (e.g., transit, bicycle, or walking, if available); or
- Avoid taking the trip altogether.

The severity of the decrease in traffic is a function of how much motorists value their trip, the travel time, and the relative attractiveness of the alternate routes or modes. Figure 44 illustrates two levels of demand elasticity for a generic toll facility. The dashed lines represent traffic levels, and the solid lines represent toll revenues. The blue lines (solid and dashed) represent motorists with higher elasticity, and the green lines represent motorists with lower elasticity. As the cost of travel increases, motorists with a high elasticity of demand decrease their road usage more precipitously than motorists with low elasticity. While the total number of motorists in both groups decreases as the toll is increased (as a percentage across the x-axis), toll revenues increase for both motorist groups when modest increases in price are introduced. This is because the increase in tolls is greater than the decrease in traffic. At some point, toll rates eventually reach a maximization point at which toll revenues begin to decrease. This is because the increase in toll rates cannot keep pace with the negative impact on traffic. The optimum point will differ for different facilities and different price (toll) levels.

Once the optimum point has been reached, toll agencies are unable to generate more revenues through increases in toll rates. Furthermore, this optimum point is a function of a myriad of variables, such as how much a toll facility is permitted to increase tolls or the setting of the initial toll rate for a new facility. The magnitude and timing of the toll increase that optimizes revenues is also unique to each toll facility. Variable pricing schedules may cause motorists to travel before or after peak periods to avoid the temporarily higher toll rates charged during peak periods. This change in driver behavior has an impact on total revenue collected. Table 40 summarizes estimates of demand elasticity for selected toll



Source: Jacobs Engineering (2010)
Note: E = elasticity.

Figure 44. Low and high elasticity impacts on traffic and toll revenue.

Table 40. Demand elasticities for selected toll roads.

Toll Facility	Estimated Elasticity	Sources
California SR 91	-0.90 to -1.00	Sullivan (2000)
California I-15	-0.02 to -0.42	SANDAG (1999)
New Jersey Turnpike	-0.06 to -0.18	Ozbay et al. (2005)
OOCEA	-0.45	Tollroadsnews (2003)
407 ETR	-0.30	Mekky (1999)
Metropolitan Transportation Authority (MTA)	-0.06 to -0.22	URS (2010)

roads and lists the study and publication dates for these estimates. As shown in the table, demand elasticity estimates are unique for each facility. For instance, the demand elasticity of SR-91 is estimated to be –0.9 to –1.0. This estimate is based on the ability of drivers to use the non-toll, general-purposes lanes or travel during off-peak periods to avoid paying the higher toll charges. In contrast, the 407 ETR around Toronto is estimated to have a demand elasticity of –0.30. This estimate may be based on the perceived lack of free, alternative routes to the 407 ETR. Notwithstanding, the methodology for calculating demand elasticity can differ depending on the analytical approach employed and the relative weights of the key parameters.

In addition to changes in price, traffic and revenue forecasts also take into account a number of factors that can have an impact on traffic and revenue levels. These parameters can include the length, condition, and capacity of the facility and parallel alternative routes; connections to and from feeder roads; travel times; economic conditions; income levels; gasoline price trends; vehicle operating costs; origin and destination points; payment options; and demographic trends.

Economic Conditions. Because of the impact on employment and income, economic conditions have a direct impact on the ability of toll facilities to generate revenues. During the most recent recession, employment levels decreased, as did VMT and toll revenues. Since a significant number of trips on toll roads are work related, decreased employment levels will generally depress traffic and revenue on tolled facilities. Other trips, such as shopping and recreational trips, are often curtailed during a recession due to a general decrease in the disposable incomes of motorists. During periods of economic prosperity, increased employment, residential development, commercial development, and entertainment facilities are trip attractors and generators for the roadway network. Increased levels of disposable income may result in additional trips to shopping areas, resorts, or amusement parks. Additionally, motorists value their time slightly more during periods of economic growth, which can make toll roads more attractive in relation to congested, non-tolled alternatives.

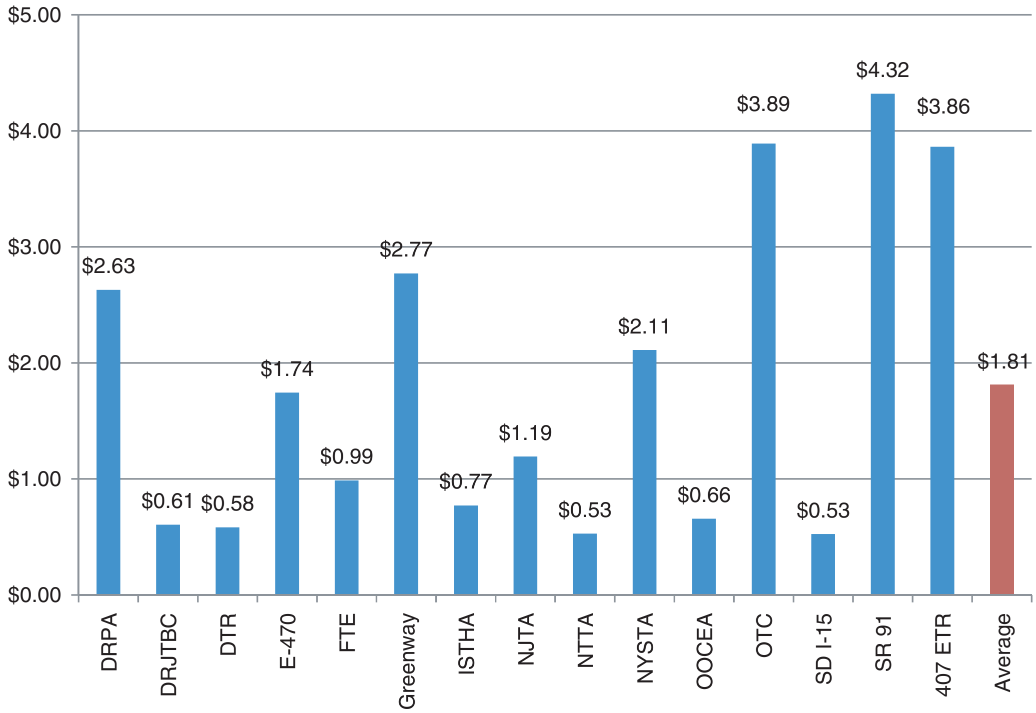
Facility Length. For tolling systems, a change in scale can lead to an increase in revenue generation since a longer road can attract greater traffic volumes, especially if the extended facility improves access to/from underserved origin and destination points. Moreover, additional capacity provided from a road widening project can potentially result in higher traffic volumes and increased revenue generation along the same number of centerline miles.

Feeder and Competing Routes. Changes to a roadway network that feeds or competes with the tolled facility can help or hinder toll revenue performance, respectively. Improvements to feeder roads can make the toll facility a more attractive route for motorists, whereas improvements to competing facilities will likely have the opposite effect. While long-range transportation plans that estimate future transportation infrastructure for a 30-year period are available in most areas, there is always a possibility of future widening, expansions, and the development of competing roadways that can affect toll revenue.

Revenue per Transaction Impact. An additional approach that can be used to assess and compare the sensitivity of toll revenues across facilities is to normalize toll revenues using a per-transaction or a per-centerline-mile metric for existing toll systems. For the toll systems included in this study, the average revenue generated per transaction was $1.81. The lowest amount of revenue generated per transaction was $0.53 (San Diego I-15), and the maximum was $4.32 (SR-91). Figure 45 summarizes revenue per transaction for 15 toll-road agencies in 2007. These benchmarks are a function of facility type, toll-collection scheme, pricing schedule, and location, but have been normalized to allow for comparisons among facilities.

Toll Systems Costs

The factors that affect revenue generation work in concert with the cost structures of toll systems. As noted previously, toll system costs are directly related to the potential system or facility improvements that a toll agency can elect to undertake with respect to collection and enforcement activities. Potential improvements or modifications can include the following:



Source: Jacobs Engineering Group, 2010

Figure 45. Average revenue per transaction (2007).

- Implementation (administrative costs)
  - Changes in marketing costs
  - Changes in the number of supervisory and administrative staff
  - Changes in wage and benefit policies
- Implementation (collection costs)
  - Changes in the barrier system in place (open, closed, or hybrid)
  - Updated approaches for storing, maintaining, and securing customer account information
  - Installation of and improvements to an electronic tolling system
  - Changes in technology
  - Changes in the payment methods offered
  - Changes in customer billing systems and the maintenance of customer accounts
  - Changes in account reconciliation practices, cash transportation services, or lockbox service providers
- Political, legal, and regulatory (administrative and collection costs)
  - Changes in accounting standards
  - Changes in toll rates and/or the introduction of variable tolling schedules resulting in additional marketing, billing, and signage costs
  - Changes in customer privacy standards and reporting requirements
  - Changes in governance structure
- Evasion and enforcement (enforcement costs)
  - Installation and maintenance of additional barriers
  - Additional signage
  - Increased police enforcement
  - Increased prosecutions
  - Change from civil to criminal enforcement
- Scale (administrative, collection, and enforcement costs)
  - Extension of an existing facility necessitating the construction of additional toll gantries, the purchase and installation of toll equipment, and additional signage
  - Expansion of customer base
  - Additional information storage hardware and software to manage customer accounts
  - Additional customer service center staff
  - Additional rent and utilities related to a new or expanded customer service center
  - Purchase of additional transponders

The intent of this sensitivity analysis is to measure the potential cost impact of these proposed changes in general terms. The sensitivity analysis is not intended to evaluate the potential impact of each of these improvements in isolation.

Scale

A change in scale can involve expanding the core market, which could increase or decrease costs. For most toll systems, frequent users (defined as making at least one trip per week) account for the majority of trips but make up a small percentage of total users. This leads to a situation in which frequent users account for the bulk of the revenues generated. Conversely, occasional users (defined as less than one trip per week) account for a lesser number of trips but make up the majority of roadway users. This can result in additional costs related to the establishment and ongoing maintenance of mostly dormant customer accounts.

Table 41 is a composite of several surveys of 1,500 toll-road users conducted by Jacobs Engineering Group. While it does not represent a particular facility, it illustrates the relationships between the total number of users, trip frequency, and the potential impact on costs. Frequent customers account for 11% of all customers but make 60% of total trips. At the same time, the toll agency absorbs the operational costs related to the 57% of customers who make 7% of total trips. For each toll facility, the per-transaction costs can vary depending on this frequency relationship.

Technology

As noted in Chapter 2, toll agencies are moving toward the implementation of electronic tolling systems, with some toll agencies further along the conversion process. At present, there are a number of facilities that have implemented AETC systems, including the 183A (Austin, Texas), the 407 ETR, and the recently converted E-470 (Denver) and President George Bush Turnpike (Dallas). Having recently incurred the costs of these systems, it is unlikely that these agencies will opt to invest in a new system in the near term. In contrast, other toll agencies are still transitioning from cash collection to electronic tolling. For these agencies, technology costs are a function of the implementation rate, the use of off-the-shelf technologies versus customized products, and the amount of time the technology being implemented has been on the market. Increased customization or newer technologies will likely result in increased costs. Additionally, toll agencies will have to replace some or all of their toll equipment over time depending on functionality, obsolescence rates, and the emergence of newer, more efficient technologies.

Evasion and Enforcement

An area where technology can have an impact on toll system costs is evasion and enforcement. As noted previously, toll-road agencies are increasing the use of video tolling and OCR systems, which capture license plate images of vehicles as they pass through toll gantries. Transponder holders are then charged against their respective account balances, while non-transponder holders receive a bill by mail for toll charges incurred. Enforcement strategies relating to the placement and coverage area of this equipment as well as the ability and eagerness to prosecute identified violations will affect enforcement costs.

Enforcement costs are listed as a range—from $0.04 to $0.09 per transaction—depending on whether a small number of outliers are included or excluded in the analysis. The estimated standard deviation that was generated from the risk analysis was $0.06 per transaction, which was relatively high in relation to the mean value. Notwithstanding, this value is consistent with the practical experience of toll agencies with respect to enforcement activities. In addition to improving technology, toll agencies have also attempted to decrease evasion by expanding police enforcement, increasing the number of court cases, and/or implementing more severe penalties for frequent violators. This strategy may have a short-term demonstration effect in which potential violators are dissuaded from nonpayment and some outstanding tolls and fees are paid off in a timely manner. However, the additional costs related to more vigilant police enforcement and additional court prosecution may exceed the amount of revenues generated from stepped up enforcement, especially over time.

Privacy and Security

Toll agencies may be required to increase expenditures to meet payment card industry (PCI) standards related to data

Table 41. Example of the user/trip relationship for a toll facility.

Frequency of Use	Trips on an Average Day	Percent of Trips	Customers per Trip in 1 Year	Number of Customers in 1 Year	Percent of Customers
Daily	500	33%	1	500	2%
1/week	400	27%	7	2,800	9%
2/month	300	20%	15	4,500	14%
1/month	200	13%	30	6,000	19%
2/year	100	7%	182	18,200	57%
Total	1,500	100%	N/A	32,000	100%

Source: Jacobs Engineering Group, 2010
Note: Because of rounding, percentages may not add up to 100%.

encryption. This may require the purchase of new or upgraded hardware and software to ensure that customers' sensitive financial data are not hacked, stolen, traded, and/or used for illegal purposes. Along these lines, it is also necessary for toll agencies to monitor their customer accounts to ensure that there have not been any security breaches. There are also additional costs related to the maintenance and storage of customer account records. While these costs may end up being significant in some cases, they may pale in relation to the risks involved. A widespread breach in security and the attendant negative publicity may create distrust and lead to a reduction in traffic and revenues.

Implementation and Enforcement Costs per Transaction

To obtain a rough estimate of the impact to costs with respect to a change in implementation and enforcement costs, a risk analysis was conducted for each general category using the per-transaction estimates for administrative, collection, and enforcement costs that were calculated for each agency in Chapter 4. The risk analysis entailed running 5,000 separate iterations to provide updated mean and standard deviation values for each major cost category. Table 42 summarizes the results of these risk analyses, including the pre- and post-risk analysis mean values, standard deviations, and the low- and high-cost cases.

Overall, the mean values for administrative, operations, and enforcement costs were higher after the risk analysis. A possible interpretation is that the actual mean value of per-transaction cost to administer, collect, and enforce toll systems may trend toward the higher risk-adjusted mean as toll agencies implement and modify their respective collection and enforcement strategies. These improvements will also have an impact on administrative costs.

Profitability

The main finding from these analyses is that the various strategies available for toll agencies with respect to the setting and increasing of toll rates, the implementation of toll-collection systems, the administration of customer accounts, and the introduction of measures for reducing evasion can result in higher revenues as well as higher costs. The magnitude of the potential increase in revenues and costs will differ for each toll agency. In some cases, increased revenue generation may be less than the overall increase in costs. Toll agencies that have struggled to meet traffic forecasts, have relatively low revenue generation, and/or have high cost structures could see profitability impacted negatively. However, other toll agencies may find that the potential increase in revenues is greater than the increase in costs, further improving financial performance.

These general conclusions require the caveat that this will affect toll agencies in different ways. Toll systems have differing governance structures, with some agencies having greater incentives and pressures to maximize profits. Toll agencies also have different cost structures for the operations and maintenance of physical infrastructure, which has not been factored into this analysis. Finally, toll agencies also have differing debt levels since some systems are highly leveraged while others have few or no debt obligations. The impact of debt tax rates and depreciation schedules of the physical infrastructure have not been factored into this analysis.

5.4.3 VMT Fees

Scale

Economies or diseconomies of scale and scope (e.g., the number of vehicles, geographic coverage, and range of uses for the system) may affect both cost and revenue in a VMT charging system. The VMT systems considered all have a large cost associated with the OBU needed to determine the location of the vehicle and the distance traveled. There are conflicting issues with respect to economies of scale related to such units. Large-scale implementation is generally expected to reduce the cost per unit to some extent. However, there is also substantial concern that implementation would have to occur over a period of time. Large-scale, short-term production would likely cause very high cost. This would also interact with implementation considerations, discussed later in this section.

Scale may also affect the cost of the system by affecting the number of visitors or non-registered vehicles. Various jurisdictions at different levels of government have considered using mileage-based systems. For practical purposes, it is unlikely

Table 42. Per-transaction cost impact by general cost category.

General Cost Category	Mean (Pre-Risk Analysis)	Mean (Post-Risk Analysis)	Standard Deviation	Low Case	High Case
Administrative	$0.14	$0.16	$0.07	$0.09	$0.23
Operations	$0.36	$0.46	$0.19	$0.26	$0.65
Enforcement	$0.04 to $0.09	$0.12	$0.06	$0.06	$0.18
Total	$0.54 to $0.59	$0.74	$0.32	$0.41	$1.06

Source: Jacobs Engineering Group, 2010

that a GPS-based VMT system would be adopted at less than the state level. However, states vary in terms of the number of resident versus nonresident vehicles on their highways as well as total size. Users from another state would have to be able to obtain a temporary unit, or participation would have to be voluntary. Participation by in-state users may also be voluntary for some period. Existing VMT charging systems and the studies of proposed ones all find that the cost of serving occasional users is much higher than the cost of serving regular users, especially relative to the revenue generated. For example, one estimate of the cost of the German truck system finds that the 10% of miles charged by methods other than the GPS unit constitute more than 30% of the total administrative cost (AASHTO, 2010).

The size of the area that is subject to the charges also determines the likelihood that a driver will want to register the vehicle. An occasional user would be much less likely to install the collection equipment than a regular user, and the wider the area covered, the more likely each user is to be a regular user. Hence, multiple state systems are more likely to have smaller percentages of occasional users than a set of state systems. Even if the states have different systems, some agreement on interoperability may make the use of an OBU feasible when outside of the home state. The benefit of having outside units capable of using the system may be somewhat offset by the requirement for the system to have interoperability, increasing the cost. The Dutch studies noted that the cost of dealing with outside users and incorporating European interoperability requirements was relatively high.

Technology

The cost of each system discussed depends to some extent on the cost of the technology to implement it. Known costs should be carefully separated from estimated costs. Potential changes in cost due to technological progress or to the use of the technology for other purposes should be considered. This also relates to the possibility of sharing costs for a system that is interoperable over various revenue systems. In particular, GPS is being used in a variety of devices, including cell phones, and it is anticipated that a system used for other purposes could have revenue functions added at a much lower cost than that of a standalone system. Further, if the system could be used to collect a variety of charges, the cost of the basic unit could be spread over the different functions.

The OBU will be a major cost of a VMT system, but there is widespread expectation that this cost will continue to decline. For example, the cost estimate for the proposed Dutch system declined from €180 per unit to a range of €85 to €140 in about 1 year (Ministry of Transport, 2009). In addition, most of the companies responding with cost estimates projected lower cost per unit in the future due to technological advances. Sensitivity analysis would have to account for both the possibility that technological progress would be slower than anticipated as well as the possibility of it being considerably faster.

Another concern with the technology is the ability for the system to adapt to technological advances in the future. One argument for the thin system OBU is that it would be easier for the central office to coordinate updates than for them to be distributed over many units. In addition, if there are multiple jurisdictions levying charges, the thin unit's simple functionality allows for adaptation to new or changing mechanisms in the back office. If charges are generated within the OBU, the addition of new charging jurisdictions may create large costs for adapting older units.

There are some considerations related to the accuracy of the OBU. Actual systems used for revenue generation typically have minimum accuracy requirements, which affect the cost of the system. There are issues with the GPS due to blocked or reflected signals, start-up signal acquisition, and battery issues if the unit uses power when the vehicle is off to maintain a rapid start of the GPS.

In addition, the cost estimates should be analyzed for the impact of large-scale deployment. For example, costs that are now low due to excess system capacity may be much higher if more capacity is needed. This is a concern for adding large numbers of new users to the cellular system. There may also be some considerations related to collecting revenue from vehicles that are operated in areas with limited cellular reception.

Revenue

All revenue systems are subject to potential variation due to various factors that can lead to forecast errors, such as elasticity of demand, a recession, or alternatives available. This will be particularly important for the start up of a new revenue system. The adoption of the new system may be either faster or slower than anticipated. For example, if the system relies on equipment in new vehicles, then a significant recession may delay revenue generation. This would be less of a problem with a system that replaces fuel taxes than for a new system that is intended to generate additional revenue.

The London system generated far less revenue than forecast, with net revenue about half the amount originally predicted (Leape, 2006). There have been problems with revenue forecasts for some toll roads. If price is varied by road classification, time, or geography, the revenue forecasting process is made more difficult. Such uncertainty would also affect the potential to borrow against the expected future revenue.

Some consideration also has to be given to the mechanism by which rates will be set and the incentives that a rate maker may have. One concern is that the rates that would optimally manage traffic may be quite different from the rates that would maximize revenue; rate makers may opt for the latter even if the intent was rates that optimize use. Political considerations related to acceptability may also influence the rate structure and affect both revenue and cost of operation. For example, the London system has a variety of charge rates for different vehicles, and proposals for VMT systems often differentiate based on environmental characteristics of the vehicle or other features. More complex rate structures may also affect enforcement reliability and cost.

Collection will also have some risk. Depending on the method of payment, the amount actually collected may vary relative to the amount owed. There may also be disputes related to the responsible party when a vehicle is sold or when rental vehicles change users.

Evasion and Enforcement

Evasion estimates for existing systems are subject to great uncertainty, so the estimates for proposed systems will be even more open to debate. There will also be trade-offs between enforcement costs and levels of evasion, but they must be carefully evaluated. In the initial proposals for the Dutch system, much higher levels of enforcement where expected than were planned in the later estimates. This reflects consideration that the initial requirements were excessive, but there was little discussion of the likely rate of evasion or of the trade-offs associated with different levels of enforcement. London had much higher rates of non-compliance than anticipated when first implemented (Leape, 2006).

Another issue is the difference between actual evasion and accidental misuse of the system. For example, outsiders entering a state at a remote location may have little knowledge of the system or how it works. Alternatively, a complicated pricing system may create a backlash among users due to difficulty in understanding the pricing structure or in changing behavior in response to price signals. Most analysts suggest keeping the system simple to start, but a simple system will not achieve some of the road management functions. More complex systems may also require more costly enforcement mechanisms.

Implementation

There are a variety of risks associated with implementation. First, there is always the possibility of unexpected problems and delays, which raise cost and reduce revenue. There is also the possibility of changes in political support for a new system as it is being phased in, which could lead to termination of the project or other costly changes.

The timing of implementation offers a number of trade-offs as well as risk factors. For example, several of the companies providing estimates for the Dutch system warned that an all-at-once start-up would be extremely difficult and would likely raise the cost per unit because of the need to produce a very large number of units in a short period of time. Hence, one area of risk is the time frame for adoption of the system. On the other hand, partial adoption limits the functionality of the system. For example, congestion pricing to manage roads would not be effective with partial implementation. In addition, voluntary implementation creates risks associated with the revenue function. Drivers would have an incentive to choose the system that minimizes their total cost, so if there are simultaneous systems in place there will be greater revenue risk.

The German experience with the actual implementation of untested technology was that the cost was higher than initially estimated. In addition, delay in implementing the system resulted in lower revenue than forecast. The Oregon experiment also resulted in higher cost per unit and delays in creating the units relative to initial estimates.

Privacy and Security

Any system will have to have provisions to maintain privacy and security. Failure of such systems would result in additional costs and other consequences. The proposed Dutch system had a high level of both privacy and security. Security issues arise around the collection and storage of data, communication of information, and calculation of amounts owed. Different systems address security in different ways, but each has cost implications, and breach of security must be considered a risk factor.

The proposed Dutch systems deal with privacy in two possible ways. The first is the use of the thick OBU, which calculates all charges in the vehicle and only sends information on the amount owed to the central office. In this case the security of the data on board is necessary to preserve privacy, but in general, there should also be some method to verify the data to allow for audit and enforcement. The second method used is for a thin OBU to transmit all location data to a back office where the charges are calculated. As noted previously, privacy is maintained by only sending an OBU number with the location data. The charge along with the OBU number is then sent to another office where the number is matched to an account for billing purposes. In this way, the location data is not directly matched with an account. Any system of privacy has the potential to be breached, and the consequences of such breaches are another risk factor. The major concern expressed by the public over the possibility of having "big brother" monitor movement indicates that there could be a substantial cost associated with any such breach even if no particular damage was done. This relates to the cost of getting and maintaining public support for the VMT system.

General Uncertainty

The Dutch government insisted that cost estimates include a 15% contingency for all capital and operating expenses.

Studies of other cost and benefit estimates find a consistent pattern of underestimation of cost and overestimation of benefits in public projects (Flyvberg et al., 2002). Hence it would generally be prudent to acknowledge the risk and tendency to err on the side of favorable estimates by producing a range of cost and revenue estimates.

5.4.4 Cordon Pricing

The general principles for undertaking a sensitivity analysis for tolling can also be applied to cordon pricing systems, especially since these systems use similar methods for collecting tolls, accepting payments, administering customer accounts, and reducing evasion. This section will examine the sensitivity of cordon pricing schemes with respect to demand elasticity, scale, implementation costs, and enforcement costs to the extent that these factors differ markedly from tolling systems.

Demand Elasticity

While the studies are not as extensive as for tolling, a number of historical analyses have estimated the demand elasticity for cordon pricing systems. Analyses that were conducted in the early to mid-1990s estimated that the demand sensitivity for the Singapore and Oslo cordon pricing systems (see references in Table 43) was –0.25 and –0.22, respectively. In a more recent analysis, TfL found that the demand elasticity for chargeable car trips was between –0.54 and –0.31 for all car trips within the London central charging zone (CCZ). These results refer to an increase in the congestion charge of from £5 to £8 rather than the introduction of new congestion charges. [With respect to the introduction of congestion charge rates (£0 to £8), TfL estimated that the demand elasticity ranged from –1.34 to –2.12 for the CCZ and from –0.93 to –1.92 for the western extension zone (WEZ).] The lower demand elasticity estimate for all car trips reflects the exemption of local residents from paying the full congestion charge.

Scale

Larger coverage areas can result in greater revenue generation, albeit with potentially higher implementation and enforcement costs. The expansion of the London congestion charge system to include the WEZ provides a practical example as to the effects of changes in scale. With the inclusion of the WEZ, the congestion charge area nearly doubled in size, and the total number of vehicles increased by nearly 25%. The year after the expansion, TfL's revenues increased by 30%, while its total costs (operating and non-operating costs) increased by 17%. Operating income increased by an estimated 53%, from £89.1 million in FY 2006/07 to £137 million in FY 2007/08. These results are for a single agency. For other agencies, increased costs may be associated with the collection of customer payments and enforcement activities, which may exceed the additional revenues generated from an increase in scale.

Cost Impact

With the exception of Singapore and Bergen, all of the cordon pricing systems have been established within the last two decades. Due to their relatively recent establishment, the newer congestion pricing systems primarily use electronic collection systems and video enforcement technologies. Notably, Singapore also electronically collects cordon charges.

This reduces the potential range of implementation options, which should provide a narrower range in collection costs. However, the following should be noted:

- The sample size for cordon systems is smaller than that for toll systems;
- The cordon pricing systems in place have differing objectives (revenue generation, congestion relief, and reduced air emissions);
- The cities with cordon pricing systems provide differing levels of transit service, which serve as alternatives to automobile usage; and
- The cities with cordon pricing systems have different historical and future growth patterns, geographic constraints, and availability of alternative road routes.

Finally, differences in the legal and regulatory framework in each country can also affect congestion charge levels, customer payment options, privacy levels, information security, enforcement strategies, and violation penalties. An analysis of the impact of the legal and regulatory framework across countries on revenues and costs was outside the scope and intent of this study.

Table 43. Demand elasticities for selected cordon pricing systems.

Facility	Estimated Elasticity	Sources
Singapore	-0.25	Menon, Lam, and Fan (1993) Gomez-Ibanez and Small (1994)
Oslo	-0.22	Jones and Hervik (1992)
London (CCZ)	-0.54 (chargeable car trips) -0.31 (all car trips)	TfL, Policy Analysis Division (2008)

Table 44. Comparison of demand elasticity by zone in Chicago, 2008–2009.

Zone	6	5	4	3	2	1
Elasticity	0.7	0.9	0.95	0.9	0.95	0.98

Source: Chicago Metered Parking System Concession Agreement: An Analysis of the Long-Term Leasing of the Chicago Parking Meter System, City of Chicago, 2008

Table 45. Enforcement costs and revenues for the Westminster parking system.

Year	2005/06	2006/07	2007/08	2008/09
Enforcement Costs	0.9%	2.8%	13.0%	-5.8%
Revenues	-9.4%	13.5%	14.1%	-3.5%

Source: *Annual Parking Report 2009*, Westminster City Council

5.4.5 Parking Fees

Parking Rates

Since the 1970s, there has been a great deal of analysis regarding the demand elasticities of parking rates. A study completed in the mid-1970s estimated a demand elasticity of –0.3 for parking garages in the San Francisco area (Kulash, 1974). More recently, a 1998 study conducted in the Portland area estimated that the demand elasticity for parking in urban Portland was –0.58 for SOVs and –0.43 for carpools. Corresponding values in suburban Portland were estimated at –0.46 for SOVs and –0.44 for carpools (Dueker, Strathman, and Bianco, 1998). Furthermore, demand elasticity for parking facilities in Chicago was estimated to be –1.2 (Feeney, 1989). This broad range of demand elasticity values reflects the relative availability of lower-priced or free alternatives, the ability to shift parking duration, the ability to shift transportation mode, income, and other factors.

A more recent study was undertaken by the City of Chicago that analyzed the demand elasticity of the privatized Chicago system. These results, which are summarized in Table 44, indicated that demand was relatively elastic, with values ranging from 0.7 to 0.98 depending on the parking zone.

Scale

The concepts underlying scale for parking systems are similar to those for cordon systems, with a larger coverage area potentially resulting in increased revenue generation. However, this would need to be counterbalanced with the higher capital costs associated with the purchase of additional parking equipment as well as the incremental costs for administering customer accounts, payment processing, and enforcement.

Cost Impact

In Chapter 2, three parking systems were studied with only one of these systems—Westminster—offering sufficient financial data to allow further analysis. In Chapter 4, the financial performance of the Westminster parking system resulted in enforcement costs of approximately 74% of total costs. In comparison, administrative and collection costs constituted 11% and 15% of total costs, respectively.

Based on the review of this data, there are some indications that an increase in enforcement activities can potentially lead to an increase in revenues, up to a certain point. This is evidenced in the analysis of enforcement costs and revenues for the Westminster parking system from FY 2005/06 to FY 2008/09, which are summarized in Table 45. During FY 2005/06, enforcement costs increased by approximately 1%, while revenues increased by nearly 14% for the following year. This analysis assumes a lag of up to a year with respect to revenue generation as a result of strengthened enforcement activities and a potential change in motorist behavior. Enforcement costs also increased by 3% in FY 2006/07, while revenues increased by 14% during FY 2007/08.

However, a different effect was evidenced in FY 2007/08, when enforcement costs increased by 13%, followed by a 6% decrease during FY 2008/09. These results indicate that other factors might affect revenue generation. In particular, the onset of the most recent economic downturn may have been a stronger factor on revenue generation in FY 2008/09 than increased enforcement. Specifically, decreased economic activity results in fewer work and recreational trips. Again, this analysis was conducted for a single agency over a relatively short period of time. Additional data and research would be necessary to draw a more precise conclusion between enforcement costs and the revenue impact on parking systems.

CHAPTER 6

Conclusions

NCHRP Report 377: Alternatives to Motor Fuel Taxes for Financing Surface Transportation Improvements and subsequent studies have pointed out that continued improvements in fuel efficiency will likely diminish the effectiveness of motor fuel taxes as a method for financing highways. In addition, higher fuel prices, increased congestion, and telecommuting have resulted in shifting patterns of behavior, causing individuals to either drive less or switch to alternative modes. Inflation also continues to erode the buying power of the motor fuel tax. As a result of these trends, the motor fuel tax system, which forms the backbone of the nation's transportation funding structure, faces long-term instability and uncertainty.

In today's environment, it is in the public's best interest to look beyond existing revenue-generation systems and more closely examine the feasibility of alternative approaches. However, there is no clear indication of which approach will succeed in the long term. As a result, it is likely that transportation agencies will implement existing and innovative approaches in combination to maximize funding and achieve mobility and connectivity objectives in the near and medium terms.

In order to provide a better understanding of the potential implementation costs, it is essential to analyze and compare collection, administrative, and enforcement costs for existing and alternative revenue-generation systems. Thus, this report presents cost estimates relating to the administrative, collection, and enforcement costs for the following revenue systems used to finance road infrastructure: motor fuel taxes, tolling, VMT fees, cordon/congestion pricing, and parking pricing.

6.1 Overview of Existing and Alternative Revenue Generation

This section presents general observations regarding each of the five revenue systems examined in this report. Conclusions regarding collection, administrative, and enforcement costs are presented in Section 6.2.

6.1.1 Motor Fuel Taxes

Revenues from motor fuel taxes represent the primary funding source supporting the nation's highway programs. In recent years, however, the financial limitations of the current system have become evident as revenues have failed to keep pace with the demands for highway investment. Furthermore, a number of constraints could collectively limit the long-term viability of the motor fuel tax as a major funding source, including increased fuel efficiency, market penetration of alternative fuels, price inflation, and volatility with respect to motor fuel prices. In addition to these revenue constraints, there is evidence to suggest that motor fuel taxes have historically suffered from a persistent problem with evasion. Historic changes in administrative and enforcement practices designed to address the evasion issues (e.g., dyed fuel testing, taxation of kerosene and other alternative fuels, enhanced auditing practices, moving the point of taxation up the distribution chain) have increased revenues deposited in highway funds across the nation; however, the long-term viability of the motor fuel tax remains uncertain.

6.1.2 Tolling

In the last 10 to 20 years, several practices and major trends have dramatically affected toll road operations:

- The change in the governance structures of toll agencies, including the establishment of multimodal agencies and the introduction of private equity capital;
- The adoption of ETC systems, which permit the free flow of traffic at toll gantries and can improve traffic flow conditions due to higher throughput;
- Congestion management and the introduction of variable pricing schedules;
- The use of leakage rates to measure the rate of driver nonpayment; and

- The charging of administrative fees and/or the criminalization of toll violations.

These practices and ongoing trends will continue to have an impact on the costs of toll collection, administration, and enforcement.

6.1.3 VMT Fees

With VMT systems, there are substantial trade-offs between system capabilities, cost, and complexity. The simple systems just keep track of total miles traveled. Somewhat more complex systems keep track of mileage by geographic area. The most complex systems are those that also require identification of class of road. Aside from the need for more detailed information, the potential for error in identifying roads typically requires additional capabilities to improve accuracy.

Any system to collect revenue will be subject to evasion and avoidance behavior. Both may be relevant in terms of evaluating a VMT system. Some systems will be designed to induce avoidance (e.g., congestion pricing systems), but others may induce inefficient behavior. For example, a system like that proposed in Oregon, which charges by the mile in state but has no charge for out-of-state mileage, could induce a driver to make a long trip on the other side of the Washington border. This would reduce the amount of the mileage fee owed to Oregon without affecting the gas tax rebate. Evasion is a larger problem. With a GPS-based system, this might be accomplished by blocking the antenna to prevent signal acquisition. Since signals may be problematic in some areas, such as those with large buildings or forests, it may be difficult to determine whether there has been purposeful interference or a natural problem.

There must be a mechanism for audit and reconciliation if there are differences between the amount that the system charges a motorist and his or her view of what the charge should be.

6.1.4 Cordon Pricing

In the implementation of cordon pricing systems, the largest single roadblock has typically involved political rather than technological concerns. A number of the systems considered in this report began as pilot programs and were later adopted (e.g., Stockholm) or discarded (e.g., Hong Kong) after public sentiment was considered. The major issues that have been raised to date include user costs, capital costs, fairness, enforcement, and privacy concerns. Cordon charge systems have generated considerable debate, especially in regard to the fee assessed on local residents living within the zone compared with the fee imposed on nonresidents living in suburban areas who travel into the congestion price zone during peak hours for work, education, or shopping. The general trend among the systems examined has been a temporary reduction in congestion that has typically returned to historical levels over time. With the reduction in traffic, there has been a related decline in vehicle emissions. Given the recent implementation of these systems, it is too early to determine whether this is a sustainable trend or merely a short-term effect. Another potential issue is the economic impact of cordon price zones, particularly on retailers within the zone who rely on outside traffic for business. In studies conducted by the operating agencies, it has generally been found that the implementation of the cordon zone areas have not had a negative impact.

6.1.5 Parking Pricing

Each of the three systems presented in Chapter 2 illustrates a different approach to parking price management:

- In Westminster, the municipal government manages parking directly;
- In San Francisco, a partnership of agencies led by SFMTA is managing the parking pricing system; and
- In Chicago, the responsibility for parking management has been handed over to a private party.

In some regions (e.g., Westminster), parking pricing systems have been combined with cordon or congestion pricing to provide support to congestion management. Drivers heading into a city with cordon tolls not only must pay the toll to enter the city but must additionally pay parking rates that reflect the demand for the space chosen. When faced with congestion and parking charges, drivers may consider the trade-offs of public transit versus the personal vehicle, potentially creating a synergistic effect that reduces congestion in urban areas. Therefore, this approach may affect the amount of revenues generated from parking systems due to reduced demand for private vehicles entering into the city and using its parking areas. The impact of combining congestion management techniques would need to be carefully analyzed for any city or other jurisdiction considering implementation.

6.2 Costs to Administer the Current and Alternative Revenue-Generation Systems Examined in This Report

Based on the methodology outlined in Chapter 4 of this report, the following conclusions have been drawn regarding the compliance, administrative, and enforcement costs associated with motor fuel taxes, tolling, VMT fees, congestion/cordon pricing, and parking pricing.

- The fuel tax system is the most cost-effective revenue system among those examined and has the lowest operating cost for all unit measurements. The operating cost for fuel taxes is only approximately 1% of tax revenue and averages approximately $1.20 per vehicle to operate and manage.
- Although the annual operating cost may reach $75 per vehicle, the cost for the proposed VMT system in the Netherlands is still reasonable when measured by the share of cost to revenue, which is approximately 7%. It would be a larger share of typical revenues in the United States. Further, the capital cost would be quite high if the system must be installed for the collection of VMT fees.
- Although it may cost only $0.54 per transaction to operate and maintain the tolling systems, tolling agencies spent nearly 33.5% of revenues for toll collection, administration, and enforcement activities in 2007. Among the systems examined for this study, the operating costs for tolling and cordon pricing are comparable at 33.5% and 38.7%, respectively.
- The costs to operate the Westminster parking pricing system are 56.6% of total revenue. Thus, of the five revenue systems explored in this report, parking pricing was the most expensive to operate based on the very limited data collected.
- For VMT fee systems, the biggest spending item is administration cost, which may reach 3.4% of revenue. Comparatively, collection and enforcement costs for maintaining a VMT fee system are relative small. They may be near or less than 1% of revenue. Collection costs for tolling systems are much larger than administration and enforcement costs. The evidence from the tolling agencies examined indicates that approximately 20% of revenue may be spent on collecting tolls.

6.3 Policy Implications

This report examines the administrative, collection, and enforcement costs associated with several alternative revenue-generation systems. This section explores the policy implications of these findings and identifies a number of considerations that policy makers should take into account when implementing revenue-generation systems:

- A good accounting system is necessary to accurately separate out administrative, collection, and enforcement costs. A better understanding of the cost of each activity can permit a more accurate assessment of efficiency and efficacy with and across revenue-generation systems.
- The technology selected for revenue collection strongly affects collection and enforcement costs, and the cost of each alternative revenue-generation system depends to some extent on the cost of the technology required to implement it. For example, the OBU will be a major cost of a VMT system, with the cost estimate for the Dutch system ranging from €85 to €140 ($106 to $175). While the technology costs are significant with these alternative revenue-generation systems, there is widespread expectation that technology costs will continue to decline. Most of the companies responding with cost estimates for the Dutch VMT system projected lower cost per unit at future times due to technological advances.
- Privacy and security measures are also key considerations for the alternative revenue-generation systems that require the tracking of vehicles and establishment/monitoring of accounts for the purpose of revenue collection. The failure of such systems would result in additional costs and other consequences.
- The technology selected for revenue collection will generate different user perceptions, depending on the use of data collected, privacy concerns, costs to the user, and the relative invasiveness of the technology used. This can have both a revenue and cost impact.
- Administrative, collection, and enforcement cost estimates for existing systems are subject to great uncertainty, so the estimates for proposed systems will be even more open to debate. While the Dutch cost estimates included a 15% contingency allowance, cost overruns for many projects far exceed this amount.
- While technology advancement requires capital expenditures, these investments often lower administrative and operations costs over the long-term. For example, there are a number of facilities that have implemented AETC systems, including the 183A (Austin, Texas), the 407 ETR, and the recently converted E-470 (Denver) and President George Bush Turnpike (Dallas). In contrast, other toll agencies are still transitioning from cash collection to electronic tolling. For these agencies, technology costs are a function of the implementation rate, the use of off-the-shelf technologies versus customized products, and the amount of time the technology being implemented has been on the market. Policy analysts should consider the long-term financial implications of alternative investments in new technologies prior to making them.
- There are trade-offs between the costs of enhanced enforcement and increased collections through reduced evasion. For example, enhanced motor fuel tax enforcement efforts have been found to net positive returns on investment. FHWA reported that it receives $10 to $20 for each dollar spent on audits and criminal prosecutions (FHWA, 1999), and a state-level study estimated that diesel tax revenues were enhanced at the rate of $321 per auditing hour (CSG & CGPA, 1996).
- The administrative, collection, and enforcement costs presented in this report vary significantly between facilities and jurisdictions. When implementing revenue-generation

systems, charges may vary by jurisdiction. There may also be overlapping jurisdictions or different charges based on class of road, time of day, or other criteria. Each of these factors greatly affects costs.

6.4 Implementation Plan

These research results provide information needed not only to promote a better understanding of the costs associated with each of the revenue-generation systems but also to assist public- and private-sector decision makers and stakeholders in the formulation of policies. The primary potential users of the research results, therefore, are FHWA, state DOTs, state departments of taxation/revenue, MPOs, toll authorities, academia, energy providers, and consultants.

6.4.1 Potential Impediments

Limitations inherent in preparing cost estimates for alternative revenue-generation systems could be viewed as impediments to implementation. Except for the fuel tax and toll systems, all other revenue-generation systems in this report are nascent, and there is limited experience in quantifying economies of scale for them in practice. Further, the financial performance of systems that are not currently deployed is subject to a degree of uncertainty relative to those of more mature systems. When some of these systems enter the stage of implementation, more data will become available and adjustments in the cost estimates will be expected. The research results presented in this report should be considered as a step forward to understanding the costs associated with other non-fuel-tax revenue-generation systems.

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APPENDIX A

Oregon VMT Pay-at-the-Pump System Case Study

A.1 Objectives of the Pay-at-the-Pump System

The 2001 Oregon legislature authorized the creation of the Oregon Road User Fee Task Force (RUFTF) to examine alternatives to the existing gas tax as a funding mechanism. RUFTF selected a user fee, or mileage-based charge, for further study as an alternative to the gas tax. FHWA sponsors the Value Pricing Pilot program, which seeks to change road usage behavior through the use of pricing. The Value Pricing Pilot program provided additional funding to the project to gain information on how vehicle users may change their behavior in response to price differences.

Oregon conducted a pilot test to evaluate an electronic alternative to the state fuel tax where on-vehicle devices were used to collect mileage information. With the aid of GPS technology, the system was capable of allocating mileage to specific zones based on where and when vehicles were operated. Information on mileage by zone was then transmitted to a centralized computer that interacted with the POS system to charge the VMT fee and deduct the gas tax when a vehicle was fueled at a participating station. The system was designed to be compatible with the gas tax and to be phased in over time. Under this system, vehicles with appropriate technology would pay the mileage fee instead of the gas tax while vehicles not equipped with this technology would continue to pay the gas tax.

A pilot test was used to test two types of mileage fees. The first was a simple replacement of the gas tax with a per-mile charge (VMT fee) that generates approximately the same amount of revenue as the gas tax. For example, for a vehicle that gets 20 miles per gallon of gas (the approximate statewide average), a charge of 1.2 cents per mile would be exactly equal to the state gas tax of 24 cents per gallon. The pilot system charged the same fee per mile for miles traveled in Oregon for all vehicles in this part of the experiment. The vehicles then either did not pay the Oregon gas tax when fueling at participating stations, or they sent receipts for gas purchases in Oregon to ODOT for a refund of the Oregon gas tax paid. There was no mileage charge for travel outside of Oregon, nor were there any refunds for taxes paid to other states.

The second type of mileage fee tested charged a premium for travel in congested zones at peak periods and offered a discount for other travel in Oregon relative to the gas tax. Vehicles in this category were charged 10 cents per mile for peak period travel in the congested zone but only 0.43 cents per mile for other travel in Oregon.

The Oregon experiment was a test of the equipment and business model for a system to transition from state fuel taxes to state mileage fees. The basic system simply kept a total of mileage driven in Oregon and mileage outside of the state. The mileage total was retained in the vehicle. When a vehicle participating in the system purchased fuel at a participating station, the system would transfer the mileage information to the station's POS system. The POS would communicate with a central computer and provide the current mileage total. The central computer would calculate the mileage driven since the last reading and inform the POS of this total. The POS would then add the mileage fee and subtract the state gas tax for the fuel purchase. Vehicles not equipped with the system would continue to pay the fuel tax.

The system was designed to provide a transition from fuel taxes to mileage fees. New vehicles equipped with the system would pay mileage fees while older vehicles would continue to pay state fuel taxes. The system has several other desirable characteristics as well. Most of the revenue would continue to be collected at the distributor level from fuel sellers. The state reconciled differences between mileage fees collected and fuel tax refunds with the service stations. Although the state maintained accounts for each vehicle, the state did not have to collect revenue from each driver. The system could be extended to alternative vehicles by requiring the owners to upload mileage data on a regular basis, although this procedure would also expand the collection requirements for the state.

The system tested also allowed for additional mileage charges to be levied by other jurisdictions or for variation of charges by time of day. This capability allows multiple jurisdictions to collect mileage fees with the same system and the imposition of congestion pricing within specific areas.

A.2 Specifications of the System

The system tested used a GPS unit to determine the time and location of operation of the vehicle. Speed information from the OBDII port was then used to calculate miles driven by time and location. Information in the test was collected for 31 different time and location combinations. When the vehicle was driven to a participating station, radio communication was used to identify a participating vehicle. At the fueling pump, the level of the signal was used to identify a transaction requiring a mileage fee calculation.

For a mileage fee calculation, the POS sent the mileage data and received information relating to the mileage charge. The mileage charge was added to the fuel bill, and the state gas tax was subtracted.

The central computer kept a record of mileage and fuel purchases by vehicle and calculated the new mileage by category whenever the vehicle was fueled at a participating station.

Only two stations participated in the experiment, so vehicles could be fueled at nonparticipating stations in Oregon. In this case, the next fueling at a participating station resulted in mileage charges based on the last fueling at a participating station, but the state gas tax was only subtracted based on the current fuel purchase. Therefore, ODOT allowed participants to send receipts for fuel purchased in Oregon at nonparticipating stations for a refund of the state gas tax. The refund process was also necessary when the system failed to recognize that a vehicle was participating. In that case, the state gas tax was not subtracted and no mileage fee was added; however, at the next fueling, the mileage fee for all miles was charged and the tax was only reduced for the current purchase. There was no refund for taxes paid when fueling in other states.

A.3 Status of the System

The proposed system is based on the installation of the required GPS and related equipment in all new vehicles operated in the state. Thus, the transition to complete use of mileage fees is expected to require substantial time. At some point, retrofitting of vehicles may become cost-effective, but it is not expected to be so in the near future. Implementation of the equipment requirement requires careful specification of the system characteristics and agreement by manufacturers to equip new vehicles to be used in the state.

It is intended that all fueling stations in Oregon would participate so as to eliminate the need for refunds of taxes paid at nonparticipating stations. Therefore, all stations would have to be equipped with the appropriate hardware, software, and communication capabilities before the start of the system. Major oil companies have not so far been willing to participate, and there is some uncertainty about the cost and other issues related to equipping all stations. Further, the technology needs improved reliability to be used for revenue collection. One problem noted was an apparent difference between the odometer readings and calculated mileage in a number of vehicles. Another was a relatively large number of vehicles detected at participating stations for which there was no fuel transaction. This may have occurred because no fuel was purchased, but it also occurred if the radio signal between the car and the pump was not sufficiently strong to clearly determine that a participating vehicle was purchasing fuel. Improvements in the reliability of detecting all relevant transactions are required before implementation.

A.4 Potential to Become an Alternative Revenue-Generation System

The system has considerable potential for a gradual phase in of mileage fees. The ability to allow multiple jurisdictions to charge separate fees and the potential to add time-of-day pricing make the system attractive. In addition, the ability to collect most of the revenue without collecting directly from the drivers greatly reduces the collection and enforcement cost relative to most other systems.

A.5 Cost

ODOT has generated estimates for some of the major cost components of implementing the system (see Table 46). The cost estimates for implementation are based on the best available information, but the specific systems would require additional development and testing. The cost elements are described in Table 47.

A.6 Alternative Cost Estimate

Peters and Gordon (2009) used information from Oregon as a basis to generate estimates for the VMT system for New York. The following estimates are from their report (see Table 48). Their estimate uses a 6-year expected lifespan for the collection technology based on 5 to 8 years of useful life.

They report their key assumptions as:

- VMT is projected at 136,740,000,000 (based on 2007 reported VMT);
- Vehicle count based on NY State DMV is 10,697,644;
- Onboard system costs estimated at $125 per unit to furnish, install, and tamperproof;

Table 46. Oregon VMT pay-at-the-pump system cost estimate.

	Initial Capital Costs ($ Million)	On-Going Operating Costs ($ Million Per Year)
Service station equipment hardware	28.6	N/A
Service station software	2.7	N/A
Onboard equipment – OEM gradual fleet replacement [the most likely alternative]	0 to ?	N/A
Onboard equipment – retrofit [the least likely alternative]	? to 1,179.0	N/A
Onboard equipment – service provider	Potentially $0 with a service contract for other mobility related services	0.0 for VMT fee portion
State back office capital	1.2	N/A
Service station communications	0.3	0.6
Additional service station accounting	?	?
Refund processing	N/A	Minor
State administration, auditing, enforcement, back office operations, etc.	0.2	1.8

Table 47. Oregon VMT cost category descriptions and explanations.

Cost Category	Description
Service station equipment hardware	Amount needed to add the necessary hardware and upgrade POS systems to 1,800 modern service stations, assuming an average of 1.5 sets of dispensers per service station. Oregon's pilot test replaced antiquated pumps/dispensers at one of the two participating service stations. Very few of this kind of dispenser remain. Estimate is slightly updated from Tables 4.1 and 4.2 of FHWA-OR-VP-03-07, "Technology Evaluation for Implementation of VMT Based Revenue Collection Systems" (2002), which was a part of the project.
Service station software	This is the software needed to run the additional hardware of the 1,800 service stations. POS system (hardware, software, and installation) expense is included with hardware, above.
Onboard equipment – OEM gradual fleet replacement [the most likely alternative]	Equipment would integrate existing systems (e.g., On-Star, onboard computer, communications). It would need to add additional memory and RFID/DSRC components, which are inexpensive. OEM equipment is designed to last the life of the vehicle in which it is installed. This is the most likely alternative for implementing the Oregon concept.
Onboard equipment – retrofit [the least likely alternative]	$1.179 billion is the maximum cost of retrofitting 3,000,000 vehicles. It represents the cost of purchasing and installing a limited run of custom-made onboard equipment in 2006. Improved technology and mass production could lower this cost by an order of magnitude.
Onboard equipment – service provider	If necessary data is collected and transmitted by equipment providing similar but different fee-based services, then capital cost could be zero.
State back office capital	This is the cost of purchasing two high-end servers, locating them in two different cities, and linking them electronically. The pilot test purchased one computer and housed it in an Oregon State University laboratory.
Service station communications	These are the capital and annual operating costs of having dedicated telephone lines from 1,800 service stations to the back office. Separately, there would be opportunities to piggyback this service on existing Internet lines, existing credit card lines, and existing POS lines. The pilot test used digital subscriber lines (telephone-to-Internet connections), one of which was not completely reliable.
Additional service station accounting	A cost incurred by service stations to make sure ODOT's back office processes are correct. Source data involving gallons purchased, gallons sold, and VMT fee collections should be the same for both ODOT and service stations and would mostly come from service station equipment (hardware and software). Data would need to be entered into bookkeeping systems. As the data is part of the electronic POS system, this process is reasonably assumed to be automated (this could require some initial set-up effort). Accounting staff would need to either send or receive one additional check per month to/from ODOT. These costs were not measured by the pilot test but are believed to be minor.

(continued)

Table 47. (Continued).

Cost Category	Description
Refund processing for vehicle owners	If all service station participation begins on one date, then refund processing is only necessary to adjust for equipment malfunctions. That would be the preferred alternative. If service station participation is phased in, then much larger refund processing expense for vehicle operators would be incurred. This would be a temporary expense. The cost of refund processing during Oregon's pilot test was not tracked and has not been estimated. The time involved was incorporated into pilot test management.
State administration, auditing, enforcement, back office operations, etc.	Base data to conduct pre-audits (vehicle identification, vehicle type, gallons purchased, VMT, etc.) is automatically collected at the pump and is automatically screened and flagged as part of data processing. This data would also be used for service station auditing. Data collection for these purposes was successfully accomplished as a part of the pilot test. A small staff of auditors, clerks, and IT specialists would be needed to administer the system. The operation is assumed to be about the size of the current fuel-tax-collection operation, but this is a rough estimate open to further analysis and discussion. Note that lower-than-average-MPG vehicles would have a strong incentive not to attempt VMT fee evasion, and the incentive for other vehicles to evade is weak. Also note that adding congestion pricing or green fee overlays would increase amounts needed for auditing and enforcement.

Source: Oregon Department of Transportation.

Table 48. Total annual cost for NY State VMT charge system – in-state vehicles only.

Vehicle transponders	$222,667,583	(Based on NY State vehicle count and 6-year exp)
Gas station equipment	$17,416,750	(Based on $15,000 per station for 6,966 stations)
Operating costs	$4,075,048	(Based on Oregon plan cost estimates scaled)
Total annual cost	$244,359,381	(Sum)
Expected revenue at $.01 charge per mile	$1,367,400,000	(Based on VMT estimates)
Net revenue	$1,123,040,619	(Net revenue)
Cost of collection %	17.87%	(Collection costs as a share of revenue)
User compliance costs	2%	(Based on limited consumer interaction)
Social cost of system	0%	(No expected environmental or traffic delay)

Source: Gordon and Peters, 2009

- Fuel station count is 6,967;
- Cost of station equipment is $15,000 per station;
- Useful life of technology is 6 years;
- System is phased in over a 6-year period; and
- Annual operating costs are prorated from the Oregon study based on vehicle counts.

The revenue stated is the revenue realized after six years of deployment with all vehicles equipped with transponders. To realize this amount of revenue during the initial year, the capital costs to fully deploy the system would require $1.337 billion for the onboard systems and $104.5 million for fuel station equipment.

APPENDIX B

Survey Questionnaire for Collecting Fuel-Tax–Related Cost Data

In this appendix we present the questionnaire designed and used for collecting detailed cost data from state motor fuel tax systems.

B.1 Background and Purpose

This questionnaire and the compilation of the survey results are an important part of the study designed to estimate the costs associated with alternative revenue-generation systems (e.g., motor fuel taxes, VMT fees, and tolling). All the research conducted falls under NCHRP Project 19-08, "Costs of Alternative Revenue-Generation Systems." The purpose of this study was to develop a methodology that can be used to analyze and compare the administrative, collection, and compliance costs of highway revenue-generation systems.

This survey focuses entirely on the costs of motor fuel tax administration. Part I of the survey covers background information. Part II of the survey is designed to obtain summary cost data for states that already possess detailed administrative cost information. Part III of the survey is designed to extract the information necessary to construct an estimate of administrative costs. Part IV includes contact information.

B.2 Specific Survey Questions

Part I Background Information

(a) What agency in your state is responsible for collecting motor fuel taxes?

____

(b) What agency in your state is responsible for auditing motor fuel taxpayers?

____

(c) What agency in your state is responsible for enforcement of the motor fuel tax code?

____

(d) Please provide contact information for the person responding to this questionnaire.

Name: Telephone:

E-mail address:

(e) At what point in the distribution system does your state tax gasoline and diesel (e.g., rack, distributor, retail)?

____

Part II Summary Administrative Cost Data

(f) Does your state have a dedicated budget for motor fuel tax collection, auditing, and enforcement or has it constructed an estimate of the costs of administering motor fuel taxes?

☐ Yes Please continue with question (g)
☐ No Please skim the questions that follow in this section and move ahead to Part III of this survey.

(g) Please provide the annual motor fuel tax administrative (i.e., auditing, enforcement, collection) budget or estimated administration costs for 2004 to 2008:

2004	2005	2006	2007	2008

(h) Please allocate the costs identified in (g) according to the categories outlined below for each year. If you are unable to disaggregate total costs into these subcategories, skip question (h) and go to Part III.

Capital Costs	2004	2005	2006	2007	2008
Physical equipment					
Operational equipment					
Facility					
Variable Costs					
Administration					
Labor					
Equipment O&M					
Hardware and software maintenance					
Materials					
Collection					
Account management					
Materials					
Communication					
Compliance					
Labor					
Materials					

Please note if items outlined in Part III are not included in the above estimates. Attempt to provide estimates of those cost elements in Part III or in a separate statement attached to the completed questionnaire.

Part III Questions Related to Tax Administration, Enforcement, and Collections

Auditing Costs

(i) How many full-time equivalent (FTE) positions are used to support motor fuel tax auditing efforts, including those related to distributor, IFTA, and refund audits? If your auditors conduct audits for several tax systems, attempt to estimate the proportion of auditing time spent on audits related to motor fuel taxes and allocate a proportionate share of FTEs accordingly.

____

(j) What are the annual costs associated with licensing auditors to conduct IFTA audits?

____

(k) What is the average annual salary plus benefits paid to staff in your state conducting motor fuel tax audits?

____

(l) Has your state been involved in joint audits with other states or the IRS? If so, what costs have been incurred while conducting these audits?

____

(m) What is the revenue impact, or return on investment, associated with your auditing activities?

____

(n) Other than costs identified previously in this section, please estimate the indirect costs associated with auditing activities (e.g., rent, utilities, training), materials/supplies, and indirect personal services costs (e.g., office support, management, HR services, information services, and other services and supplies). Provide as much detail as possible.

____

Enforcement Costs

(o) Does your state employ a motor-fuel tracking system? If so, when was it placed into operation, what was the capital cost of the system, and what is the annual cost to operate and maintain the system?

____

(p) Does your state perform on-road inspections for dyed fuel? If so, what are the annual costs associated with your on-road dyed-fuel inspection program? If unknown, please estimate the FTEs dedicated to conducting on-road dyed fuel inspections and provide an estimate of the annual salaries plus benefits paid to these enforcement/inspections officers.

____

(q) Does your state require licensing and bonding of all motor fuel tax distributors? If so, what are the annual costs to the state of processing these licenses/bonds and conducting any screening of applicants?

____

(r) Does your state perform taxpayer education activities (i.e., outreach activities to inform taxpayers of changes to forms or tax codes)? If so, what are the annual costs associated with these activities?

____

(s) Other than costs identified previously in this section, please estimate the indirect costs associated with enforcement activities (e.g., rent, utilities, training), materials/supplies, and indirect person services costs (e.g., office support, management, HR services, information services, and other services and supplies).

____

Collection Costs

(t) Does your state use paper, electronic methods, or a combination to process tax returns and receive tax payments?

____

(u) If your state has an electronic system in place, what was the capital cost of the electronic system? What are its annual operations and maintenance costs?

____

(v) If your state has an electronic system for receiving tax payments, are there transaction costs associated with processing these payments? If so, what are these costs?

____

(w) If your state processes tax returns and payments manually, what are the costs associated with manually entering taxpayer data? If these costs are unknown, how many FTEs are dedicated to this activity and what is the average salary plus benefits for individuals processing these returns?

____

(x) Does your state provide any sort of collection allowance in the form of a credit to taxpayers remitting taxes? If so, how much is the collection allowance as expressed as a percentage of total tax payments?

____

(y) Does your state employ debt collectors who notify taxpayers of delinquencies and work to secure past-due payments? If so, what are the annual costs associated with these debt-collection activities?

____

(z) Other than costs identified previously in this section, please estimate the indirect costs associated with collection activities (e.g., rent, utilities, training), materials/supplies, and indirect personal services costs (e.g., office support, management, HR services, information services, and other services and supplies).

____

APPENDIX C

Parameter Data and Detailed Cost Estimates

In this appendix (Tables 49, 50, and 51), we present parameter data collected from state fuel tax systems, tolling authorities, and the Dutch VMT fee systems. The parameter data were primarily used for the cost comparative analysis conducted in Chapter 5. In addition, we present the detailed cost estimates for administrative, collection, and enforcement for tolling.

Table 49. Parameter data from state motor fuel systems.

Parameter	2003	2004	2005	2006	2007
Lane miles					
CA	377,325	378,435	379,357	380,297	382,917
CO	180,174	180,992	181,982	182,926	183,252
FL	262,309	261,619	264,087	267,769	267,524
ID	96,189	96,604	96,703	96,696	99,342
IA	233,568	234,256	234,726	235,037	235,342
NJ	84,222	82,790	83,876	83,893	84,295
TN	186,476	187,567	190,758	192,911	192,404
TX	643,095	646,247	648,625	651,476	653,312
Centerline miles					
CA	169,549	169,791	169,906	170,290	171,154
CO	86,821	87,096	87,597	88,021	88,163
FL	120,375	119,529	120,557	121,995	121,526
ID	46,927	47,100	47,129	47,105	48,416
IA	113,516	113,835	113,971	114,084	114,193
NJ	38,952	38,122	38,552	38,561	38,752
TN	88,518	88,988	90,451	91,416	91,058
TX	301,987	303,176	304,171	305,270	305,855
VMT (000s)					
CA	323,592,000	328,917,000	329,267,000	327,478,000	328,312,000
CO	43,379,000	45,891,000	47,962,000	48,641,000	48,713,000
FL	185,511,000	196,444,000	201,531,000	203,741,000	206,121,000
ID	14,290,000	14,729,000	14,866,000	15,198,000	15,782,000
IA	31,108,000	31,538,000	31,060,000	31,355,000	31,253,000
NJ	69,778,000	72,844,000	73,819,000	75,371,000	76,152,000
TN	69,154,000	70,943,000	70,814,000	70,596,000	71,179,000
TX	223,418,000	231,008,000	235,170,000	238,256,000	243,443,000
Number of vehicles					
CA	30,248,069	31,399,596	32,487,477	33,182,058	33,935,386
CO	2,027,397	2,023,292	1,807,879	1,807,823	1,707,139
FL	14,526,125	15,057,473	15,691,438	16,373,565	16,473,908
ID	1,301,120	1,344,124	1,374,056	1,275,115	1,281,899
IA	3,368,915	3,369,431	3,397,604	3,345,951	3,360,196
NJ	6,711,601	6,224,256	6,261,501	5,957,988	6,247,130
TN	4,795,676	5,034,662	4,980,010	5,091,328	5,339,946
TX	14,888,780	16,906,714	17,469,547	17,538,388	18,072,148

Table 50. Parameter data from tolling authorities.

Parameter	2003	2004	2005	2006	2007
Centerline miles					
DRPA	N/A	N/A	N/A	N/A	N/A
DRJTBC	1.9	1.9	1.9	1.9	1.9
DTR	N/A	N/A	13.4	13.4	13.4
E-470	278.0	278.0	278.0	311.0	311.0
FTE	N/A	N/A	454.0	460.0	460.0
Greenway	N/A	14.0	14.0	14.0	14.0
ISTHA	274.0	274.0	274.0	274.0	286.5
NJTA	290.0	290.0	290.0	290.0	290.0
NTTA	54.0	54.0	54.0	54.0	54.0
NYSTA	641.3	641.3	641.3	641.3	641.3
OTC	241.0	241.0	241.0	241.0	241.0
OOCEA	92.0	92.0	100.0	100.0	100.0
SANDAG I-15	N/A	N/A	8.0	8.0	8.0
SR-91	N/A	20.0	20.0	20.0	20.0
Toronto 407	67.0	67.0	67.0	67.0	67.0
Average	215.5	179.4	175.5	178.3	179.2
VMT (000s)					
DRPA	N/A	N/A	N/A	N/A	N/A
DRJTBC	N/A	N/A	N/A	N/A	N/A
DTR	N/A	N/A	N/A	N/A	N/A
E-470	N/A	N/A	N/A	N/A	N/A
FTE	N/A	N/A	7,473,261	8,218,954	8,391,704
Greenway	N/A	N/A	N/A	N/A	N/A
ISTHA	N/A	N/A	N/A	N/A	N/A
NJTA	12,631,896	12,612,697	12,426,804	12,786,790	12,503,064
NTTA	N/A	N/A	N/A	N/A	N/A
NYSTA	10,800,326	11,076,541	10,698,582	10,487,222	10,414,180
OTC	2,833,770	2,911,505	2,990,509	3,040,293	2,978,442
OOCEA	N/A	N/A	N/A	N/A	N/A
SANDAG I-15	N/A	N/A	N/A	N/A	N/A
SR-91	173,217	204,265	226,131	230,703	208,579
Toronto 407	N/A	N/A	1,282,821	1,320,156	1,400,447
Average	6,609,802	6,701,252	5,849,685	6,014,020	5,982,736
Number of transactions (000s)					
DRPA	51,967	53,808	54,065	54,865	55,076
DRJTBC	N/A	136,600	135,500	140,100	141,300
DTR	N/A	N/A	113,483	111,723	111,286
E-470	38,800	46,900	51,500	52,000	54,100
FTE	N/A	N/A	617,930	661,368	690,485
Greenway	N/A	22,171	22,496	20,967	20,176
ISTHA	801,603	823,145	780,446	764,125	788,292
NJTA	671,032	856,284	749,963	681,210	667,253
NTTA	N/A	N/A	338,390	370,696	383,481
NYSTA	272,038	281,843	274,016	269,391	255,965
OTC	48,282	50,160	51,149	51,784	51,527
OOCEA	230,500	255,764	271,128	294,422	309,692
SANDAG I-15	N/A	N/A	2,300	2,560	2,849
Toronto 407	N/A	N/A	103,607	130,779	136,005
Average	248,885	243,570	241,909	243,075	244,036

Table 51. Parameter data estimated by providers of the Dutch VMT fee systems.

Parameter	Siemens	T-Systems	Vodafone
Lane miles(*)	165,160	165,160	165,160
Centerline miles	80,965	80,965	80,965
VMT (000s)			88,605,668
Number of vehicles	8,150,000	8,490,000	10,007,203
Number of transactions(**)	96,000,000		
Total revenue (000s)			10,146,250
Average tax rate (per mile)			
Heavy vehicles			0.26
Vans			0.20
Cars			0.08
Motorcycles			0.02
Staffing			
# of admin staff	240		
# of collection staff	170		
# of enforcement staff	161		

(*) It is assumed that motorways have four lanes and other roads have two lanes.
(**) The number of transactions represents annual number of invoices/bills.
An exchange rate of 1.25 is used to convert from euros to dollars, and a conversion factor of 0.62137 is used to convert from kilometers to miles.

Source: Ministry of Transport, Public Works, and Water Management, the Netherlands

APPENDIX D

Acronyms

ACM	Automated Coin Machine
AEO	Annual Energy Outlook
AETC	All Electronic Toll Collection
ANPR	Automatic Number Plate Recognition
AVI	Automatic Vehicle Identification
BEV	Battery Electric Vehicle
CAFR	Comprehensive Annual Financial Reports
CBD	Central Business District
CCTV	Closed Circuit Television
CCZ	Central Charging Zone (London)
CNG	Compressed Natural Gas
CPM	Chicago Parking Meters, LLC
CSC	Customer Service Center
CTRMA	Central Texas Regional Mobility Authority
CVISN	Commercial Vehicle Information Systems and Networks
CVO	Commercial Vehicle Operations
DB	Design–Build
DBFO	Design–Build–Finance–Operate
DMV	Department of Motor Vehicles
DOR	Department of Revenue
DOT	Department of Transportation
DRJTBC	Delaware River Joint Toll Bridge Commission
DRPA	Delaware River Port Authority
DSRC	Designated Short Range Communication
DTE	Development Test Environment
DTR	Dulles Toll Road
ENOC	Enterprise Network Operation Center
EPRI	Electric Power Research Institute
ER	Evidential Record
ERP	Electronic Road Pricing
ETC	Electronic Toll Collection
EV	Electric Vehicle

FASB	Financial Accounting Standards Board
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FMS	Fleet Management System
FTA	Federation of Tax Administrators
FTE	Full-Time Equivalents
GASB	Governmental Accounting Standards Board
GEO	Geosynchronous Earth Orbit
GPS	Global Positioning System
GSM	Global System for Mobile Communication
HCTRA	Harris County Toll Road Authority
HMI	Human–Machine Interface
HOT	High Occupancy Toll
HTF	Federal Highway Trust Fund
IAG	Interagency Group
IFTA	International Fuel Tax Agreement
IGO	Inspector General Office
IRP	International Registration Plan
IRS	Internal Revenue Service
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ISTHA	Illinois State Toll Highway Authority
ITR	Indiana Toll Road
ITS	Intelligent Transportation System
LEO	Lower Earth Orbit
LPG	Liquefied Petroleum Gas
MBUF	Mileage-Based User Fee
MINAP	Michigan Network Access Point
MISDN	Michigan Service Delivery Node
MIT	Massachusetts Institute of Technology
MPO	Metropolitan Planning Organization
MTA	Metropolitan Transportation Authority
NETRMA	North East Texas RMA
NHS	National Highway System
NiMH	Nickel Metal Hydride
NJTA	New Jersey Turnpike Authority
NMC	Network Management Center
NRDC	National Resources Defense Council
NTTA	North Texas Tollway Authority
NYSTA	New York State Thruway Authority
OBRA	Omnibus Budget Reconciliation Act
OBE	Onboard Equipment
OBU	Onboard Unit
OCR	Optical Character Recognition
OCTA	Orange County Transportation Authority
ODOT	Oregon Department of Transportation

OOC	Out of Coverage
OOCEA	Orlando–Orange County Expressway
ORT	Open Road Tolling
OTC	Ohio Turnpike Commission
PCE	Passenger Car Equivalent
PCI	Payment Card Industry
PCN	Penalty Charge Notice
PHEV	Plug-in Hybrid Electric Vehicle
POS	Point of Sale
RF	Radio Frequency
RFID	Radio Frequency Identification
RMA	Regional Mobility Authority
ROC	Roadside Operations Computer
RSE	Roadside Equipment
RZ	Restricted Zone
SANDAG	San Diego Association of Governments
SDN	Service Delivery Node
SEK	Swedish Krona
SFMTA	San Francisco Municipal Transportation Agency
SOV	Single Occupant Vehicle
SPUR	San Francisco Planning and Urban Research Association
TfL	Transport for London
TNB	Tacoma Narrows Bridge
U.S. DOT	United States Department of Transportation
VAT	Value Added Tax
VDOT	Virginia Department of Transportation
VII	Vehicle Infrastructure Integration
VIN	Vehicle Identification Number
VKT	Vehicle Kilometers Traveled
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound
VRN	Vehicle Registration Number
WEZ	Western Extension Zone
WIM	Weigh in Motion
WSDOT	Washington State Department of Transportation
ZTL	Zone a Traffic Limitato

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation