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# **Feasibility of Congestion Pricing as an Energy Conservation Measure**

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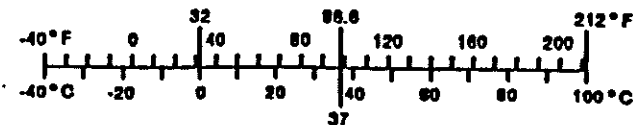
# METRIC (SI\*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
in	inches	2.54	centimeters	cm
ft	feet	0.3048	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	6.452	centimeters squared	cm <sup>2</sup>
ft <sup>2</sup>	square feet	0.0929	meters squared	m <sup>2</sup>
yd <sup>2</sup>	square yards	0.836	meters squared	m <sup>2</sup>
mi <sup>2</sup>	square miles	2.59	kilometers squared	km <sup>2</sup>
ac	acres	0.395	hectares	ha
<b>MASS (weight)</b>				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
<b>VOLUME</b>				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft <sup>3</sup>	cubic feet	0.0328	meters cubed	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.765	meters cubed	m <sup>3</sup>
Note: Volumes greater than 1000 L shall be shown in m <sup>3</sup> .				
<b>TEMPERATURE (exact)</b>				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
yd	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
<b>AREA</b>				
mm <sup>2</sup>	millimeters squared	0.0016	square inches	in <sup>2</sup>
m <sup>2</sup>	meters squared	10.764	square feet	ft <sup>2</sup>
yd <sup>2</sup>	kilometers squared	0.39	square miles	mi <sup>2</sup>
ha	hectares (10,000 m <sup>2</sup> )	2.53	acres	ac
<b>MASS (weight)</b>				
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1000 kg)	1.103	short tons	T
<b>VOLUME</b>				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m <sup>3</sup>	meters cubed	35.315	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	meters cubed	1.308	cubic yards	yd <sup>3</sup>
<b>TEMPERATURE (exact)</b>				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

These factors conform to the requirement of FHWA Order 5190.1A

\*SI is the symbol for the International System of Measurements



## ABSTRACT

This report is a feasibility study on the potential of congestion pricing as an energy conservation measure. Although congestion pricing entails many different strategies or schemes, this report primarily focuses on road pricing for highway type facilities. This report evaluates existing and planned toll roads for their involvement with automated vehicle identification and electronic toll collection as for these two technologies are viewed as a vital element in any congestion pricing program or scheme. The economic feasibility of congestion pricing is evaluated. Case studies are made in Singapore, Hong Kong, and Oslo, Norway. The impact on fuel consumption is made using a freeway simulation model. The analysis of fuel consumption focuses on using the HOV lane as a congestion priced facility. Issues associated with congestion pricing are discussed. Finally, conclusions and recommendations are made on the potential congestion pricing holds towards reducing fuel consumption.

## EXECUTIVE SUMMARY

In many urban areas throughout the nation, traffic congestion is increasing at an alarming rate. The increasing traffic congestion affects the economic welfare of our local and national economy by increasing the cost of doing business. Many hours of delay are wasted because of time spent inefficiently in traffic. A main cause of traffic congestion can be linked to the American desires and driving patterns. For many urban freeway facilities, the average occupancy rate is barely above 1.0.

Traffic congestion is predicted to worsen, but recent legislation enacted by Congress (the Clear Air Act Amendment of 1990) will limit the number of lane-miles of roadway facilities that can be constructed in most urban areas. In addition it is becoming increasingly expensive to add lanes and build new facilities. This is why many transportation agencies and policy makers are now looking a solutions that would alter or change the attitudes of their commuting population.

Congestion pricing is one demand management strategy that would effectively promote efficiency in the transportation system. Congestion pricing is a toll charged to the motorist for use of a facility during certain time periods of the day. The toll would vary by the amount of congestion present, so that the price is higher in peak hours or peak directions than other times or places. In practical terms, congestion pricing means that each traveler would pay a premium price in order to commute at a better level of service than is available without congestion pricing. Congestion pricing also means that travelers would pay for the congestion which their vehicle adds to the traffic stream of a particular highway segment at a particular time of day. The objective of congestion pricing is to shift some trips to off-peak periods, to higher-occupancy vehicles, or to routes away from congested facilities.

The concept of congestion pricing for highways is similar in nature to services we customarily accept; services such as the telephone long distance service and air travel. Congestion pricing has been experimented with in other countries. Singapore, Oslo and Bergen, Norway have pricing schemes to control entrance to a congested area. Hong Kong first tried a congestion pricing scheme in the 1970's but discarded it. Since then they have reactivated the program using advanced technologies for toll collection. The United States tried to get a congestion pricing demonstration project in operation during the mid-1970's, however, none of the urban areas contacted considered their congestion severe enough to warrant such a program.

Congestion pricing offers an opportunity to reduce traffic congestion by influencing public attitude using financial/market incentives to ride share, diverting trips to alternative routes or diverting trips to another time. Empirical studies on the impact of congestion pricing suggest that efficient peak-period road tolls reduce peak traffic volume anywhere from 10 to 25 percent. Reduced traffic volume through congestion

pricing offers an opportunity to improve air quality and reduce energy demand. Fewer vehicles reduce congestion, thereby improving the efficiency of vehicle operation. Reduced congestion also would reduce travel delay for transit and other vehicles, improving travel time reliability, personal productivity and economic productivity.

Depending on the location, duration and extent of the congestion problem, pricing can be applied to a network of expressways, to expressways and principal arterials within a congested travel corridor, to selected segments of an expressway, to congested bridge and tunnel crossings, and/or to surface street system within a congested zone. While the level of pricing (or charge) will depend on the level of congestion and other practical considerations, typical charges could be on the order of \$0.10 to \$0.25 per vehicle mile traveled (VMT) on congested expressways, up to twice that amount on heavily congested surface streets, and on the order of \$2.00 to \$4.00 for entry into a congested Central Business District (CBD) or bridge.

This report presents an overview of road pricing; both congestion pricing and toll road type pricing projects in an attempt to establish the feasibility of implementing congestion pricing in Texas for the purpose of energy conservation. However, the stated objective is not possible without an examination of several other factors that accompany such a program.

This report documents the past attempts at congestion pricing and discusses the results or outcome of the project(s). Analysis of past congestion pricing project indicates that they were met with limited success because of various reasons. Although most were characterized as a technical success, they were abolished due to political reasons.

Current and future congestion pricing projects are under construction or in various stages of planning and/or financing. Public, private, and public/private partnerships are being implemented in several states that will construct roadway facilities that feature congestion pricing. This report documents much of the technology used for automatic vehicle identification (AVI) and electronic toll collection (ETC) that is currently in use on toll roads and bridges or being evaluated for use on future road priced facilities.

An estimate was made on the amount of fuel consumed for a general-purpose roadway and a HOV lane facility featuring congestion pricing. Results indicate that congestion pricing would reduce fuel consumption only if carpools are formed, thus eliminating vehicles in the traffic stream. A program that does not reduce the number of vehicles on the roadway will not reduce fuel consumption. An initial hypothesis stated that by eliminating vehicles on the general-purpose lanes, thus reducing speed changes and increasing the travel speed, would reduce fuel consumption. However, results show that the faster traveling vehicles use more fuel.

This project has documented the past, present, and future attempts at congestion pricing. This project also demonstrates that congestion pricing is a feasible strategy to

reduce fuel consumption only if the project can alter the public's attitude to driving alone or during peak travel periods of the day.

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## **DISCLAIMER**

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## TABLE OF CONTENTS

	<u>page</u>
<b>LIST OF TABLES</b> .....	xv
<b>LIST OF FIGURES</b> .....	xviii
<b>CHAPTER 1. INTRODUCTION</b> .....	1
<b>CONGESTION PRICING</b> .....	1
The Problem .....	1
A Solution .....	2
Another Look .....	3
Potential Effects of Congestion Pricing .....	3
New Technology .....	4
Congestion Pricing Alternatives .....	4
Summary .....	5
<b>STUDY OBJECTIVES</b> .....	5
<b>ORGANIZATION OF REPORT</b> .....	6
<b>CHAPTER 2. CONGESTION PRICED FACILITIES</b> .....	9
<b>INTRODUCTION</b> .....	9
<b>PAST EXPERIENCE WITH CONGESTION PRICING</b> .....	9
Singapore .....	10
United States Experiment .....	14
UMTA's (FTA) Response .....	18
Hong Kong Congestion Pricing .....	19
Other Experiments with Congestion Pricing .....	21
Lessons Learned from Past Experience .....	21
<b>PRESENT EXPERIENCE IN CONGESTION PRICING</b> .....	22
Hong Kong Continued Interest .....	22
Singapore's Continued Operation of Area Licensing Program .....	22
Road Pricing in Bergen and Oslo Norway .....	23
<b>FUTURE CONSIDERATIONS OF CONGESTION PRICING</b> .....	25
State Route 91 .....	25
San Diego I-15 HOV Expressway .....	27

FEDERAL PERSPECTIVE .....	28
Current Status of the FHWA Congestion Pricing Pilot Project(s) .....	30
<b>CHAPTER 3. ROAD PRICED (TOLL ROAD) FACILITIES .....</b>	<b>33</b>
<b>TOLL ROAD DEVELOPMENT .....</b>	<b>33</b>
Types of Toll Roads .....	34
Public Toll Road/Bridge Operators in the United States .....	35
Toll Rates .....	35
Types of Financing .....	37
Toll Road Fare Collection .....	37
Future Toll Road Activity .....	39
Summary of Toll Road Activity .....	42
<b>CHAPTER 4. ECONOMIC THEORY OF CONGESTION PRICING .....</b>	<b>43</b>
<b>THEORETICAL MODELS OF CONGESTION PRICING .....</b>	<b>43</b>
Theory of Road Pricing .....	43
Economic Analysis of Congestion Pricing Versus other Congestion Reducing Means .....	46
Spatial Models of Urban Cities with Congestion .....	48
Comments on the Theoretical Soundness of Road Pricing .....	53
<b>EMPIRICAL ESTIMATES OF CONGESTION CHARGES .....</b>	<b>55</b>
Cost Benefit Analysis in Hong Kong .....	55
Congestion Pricing vs Revenue: The Oslo Case .....	57
Empirical Estimates of Energy Savings from Singapore .....	61
Empirical Analysis of Road Pricing and the Optimal Toll .....	61
Congestion tolls with HOV lanes .....	66
<b>CHAPTER 5. OPERATIONAL FEASIBILITY .....</b>	<b>69</b>
<b>TOLL COLLECTION .....</b>	<b>69</b>
Indirect Charging Mechanisms .....	69
Direct Charging Mechanisms .....	71
<b>ADVANTAGES OF ELECTRONIC TOLL COLLECTION .....</b>	<b>76</b>
AVI Operating Cost .....	76
Billing .....	77
Toll Facility Design .....	77
<b>STATE-OF-THE-ART PRACTICES FOR ROAD PRICING COLLECTION ON         SELECTED TOLL FACILITIES IN THE UNITED STATES .....</b>	<b>80</b>
Dallas North Tollway .....	80

Sam Houston and Hardy Toll Road .....	81
Crescent City Connection Bridge .....	81
Oklahoma Turnpikes .....	82
Lincoln Tunnel: The Port Authority of New York and New Jersey .....	82
<b>MOTORIST INFORMATION .....</b>	<b>83</b>
Changeable Message Signs .....	83
<b>CHAPTER 6. ESTIMATED ENERGY SAVINGS .....</b>	<b>85</b>
<b>HIGHWAY FACILITY CONGESTION PRICING .....</b>	<b>85</b>
General Information .....	85
<b>ENERGY CONSUMPTION ANALYSIS .....</b>	<b>87</b>
Application of Congestion Pricing to Reduce Energy Consumption .....	87
Congestion Pricing Model Used for Analysis .....	87
Application of Congestion Pricing on a Texas Highway Facility .....	88
Analysis of Facility Congestion Pricing .....	88
Controlled System .....	89
The Katy Freeway and HOV Lane .....	89
Analysis .....	91
Analysis of Fuel Consumption .....	94
Summary of Fuel Consumption Analysis .....	101
<b>CHAPTER 7. ISSUES ASSOCIATED WITH CONGESTION PRICING .....</b>	<b>103</b>
<b>ECONOMIC AND SOCIAL ISSUES .....</b>	<b>103</b>
Value of Time .....	104
Traveler Equity .....	104
Surveillance .....	105
<b>DESIGN, OPERATIONAL AND IMPACT ISSUES .....</b>	<b>105</b>
Project Design Issues .....	105
Legal Issues .....	107
Financial Issues .....	108
Management and Operations Issues .....	109
Impact Issues .....	110
<b>CHAPTER 8. CONCLUSIONS AND RECOMMENDATIONS .....</b>	<b>111</b>
<b>CITED REFERENCES .....</b>	<b>115</b>
<b>APPENDIX. PUBLIC TOLL ROAD OPERATORS .....</b>	<b>A-1</b>

## LIST OF TABLES

		<u>Page</u>
Table 2-1.	Vehicles Entering the Singapore Restricted Zone (1975-1979) .....	12
Table 2-2.	Motor Vehicles Entering the Restricted Zone Before and After the Area Licensing Scheme. ....	13
Table 2-3.	Bergen Toll Ring Charges .....	23
Table 2-4.	Percentage Change in Number of Trips .....	24
Table 3-1.	Toll and Per-Mile Rates For Selected Inter-City Toll Roads .....	36
Table 3-2.	Toll and Per-Mile Passenger Car Rates For Selected Urban Toll Roads .....	37
Table 4-1.	Expanding Highway Capacity vs Using an Optimal Congestion Toll .....	47
Table 4-2.	Welfare Results of Gasoline, AVI and On-board Metering Systems .....	53
Table 4-3.	Results of Hong Kong Area Licensing and Electronic Road Pricing Schemes, Compared to 1991 Base .....	56
Table 4-4.	Estimated Benefits for Various Cordon Toll Schemes in Oslo .....	59
Table 4-5.	Summary Results of Various Cordon Toll Schemes in Oslo .....	60
Table 4-6.	Estimates of Car Population and Energy Savings for Various ARF Rate Scenarios in Singapore .....	62
Table 4-7.	Results of Selected Studies .....	63
Table 4-8.	Comparison of Estimated and Simulated Congestion Costs in Toronto .....	65
Table 4-9.	Optimal Toll and HOV Vehicle Estimates for a Range of Vehicle Flows .....	68

Table 5-1.	Relative Comparison of ETC Technologies .....	77
Table 6-1.	Measures of Effectiveness, HOV Lane and Freeway General-Purpose Lanes, Existing Conditions .....	94
Table 6-2.	Comparison of Travel Speeds on HOV Lane and Freeway Under Scenario #1 .....	96
Table 6-3.	Total Fuel Consumption for Scenario #1 .....	96
Table 6-4.	HOV Lane and Freeway General-Purpose Lanes, Scenario #2 .....	98
Table 6-5.	Total Fuel Consumption for Scenario #2 .....	98
Table 6-6.	Potential Ride-Sharing/Carpooling Formation .....	99
Table 6-7.	Total Peak Period Fuel Consumption with a 25 Percent Carpool Formation .....	100
Table 6-8.	Total Peak-Period Fuel Consumption with a 50 Percent Carpool Formation .....	100
Table 6-9.	Total Peak-Period Fuel Consumption with a 100 Percent Carpool Formation .....	100

## LIST OF FIGURES

	<u>Page</u>
Figure 4-1. Marginal Cost of Congestion Pricing .....	44
Figure 4-2. Benefit-Cost Analysis of Road Improvements .....	49
Figure 4-3. Perverse Road Improvements .....	50
Figure 4-4. Road Improvements with Congestion Charges .....	51
Figure 5-1. Typical Automated Toll Collection Facility .....	79
Figure 6.1. Houston Area Freeways, Major Arterials, and the Katy HOV lane .....	90
Figure 6-2. Katy Freeway Mainlane Speed .....	93
Figure 6-3. Katy Freeway Mainlane Speed by Subsection and Hour .....	93
Figure 6-4. Katy Transitway Existing Condition Travel Speed .....	94
Figure 6-5. Katy HOV Lane Hourly Volumes .....	97

## CONGESTION PRICING

Because urban congestion has increased at a dramatic rate during the last couple of decades, many transportation agencies and policy makers are evaluating many alternatives to alleviate the congestion problem. Congestion pricing is just one technique.

This chapter provides a brief explanation of the urban congestion problem and how congestion pricing may help reduce congestion. A work plan is presented for the study of congestion pricing and the objectives of this report are also presented.

### **The Problem**

During the past decade, urban and suburban traffic congestion became the nation's major transportation issue. As for the future, the Federal Highway Administration (FHWA) predicts delay caused by congestion to increase by 400 percent between 1985 and 2005 if additional roadway capacity is not constructed (1). Traffic congestion in urban areas is increasing at an alarming rate. In fact, some urban areas vie to whose congestion is worst. Perhaps the general attitude of public officials in these urban areas is the worse their congestion, the greater the potential for obtaining additional highway funds.

Typical roadway improvement projects of the past increased the roadway lane-miles; either in width or length. Roadway improvements of this type only solve the problem of congestion temporarily. In many cases, and for various reasons, congested conditions return. One reason for reoccurring congestion is latent demand. Latent demand has been a significant factor affecting present and future traffic volumes on new and expanded highway facilities (2). Latent travel demand is the additional traffic that desires the use of an existing facility, but is discouraged from doing so by the unsatisfactory operation of the facility caused by high levels of congestion (3).

As a nation, we cannot build our way out of congestion. The supply of roadway lane-miles cannot stay ahead of the ever increasing demand because of economic and land constraints. The main causes of traffic congestion, especially peak-period congestion, are deeply rooted in American desires and behavior patterns. Some are even

built into the basic physical and social structures of U.S. metropolitan areas (4). Traffic congestion is predicted to worsen, but recent legislation enacted by Congress (the Clean Air Act Amendment of 1990) will limit the number of lane-miles of roadway facilities that can be constructed in most major urban areas. To aid urban areas with traffic congestion, other recent legislation passed by Congress (the Intermodal Surface Transportation Efficiency Act of 1991) will increase the emphasis of moving people rather than vehicles. This is why transportation agencies and policy makers are now looking at solutions that would alter or change millions of Americans attitudes to drive alone. Influencing drivers of single occupant vehicles to ride share would directly impact (5) the demand-side of the travel equation. Changing motorists driving behavior would make better use of existing roadway facilities.

## **A Solution**

One demand-side strategy attracting considerable attention is congestion pricing. Congestion pricing is a toll or other road user charge that would vary with the level of congestion, so that the price is higher in peak hours or peak directions than in other times or places (5). In practical terms, congestion pricing means that each traveler should pay a premium if they want a better level of service than is available to all travelers. The objective of congestion pricing is to shift some trips to off-peak periods, to higher-occupancy vehicles, to routes away from congested facilities, or by discouraging some trips altogether. Proponents claim that such congestion charges will result in savings in time and operating costs for both private and commercial vehicles, improvements in air quality, reductions in energy consumption, and improvements in transit productivity.

The use of peak and off-peak pricing differentials to improve the use of scarce time-sensitive resources is a well-established economic principle. For more than three decades, economists have urged that direct pricing for road use be employed in an effort to bring demand and supply into balance--as occurs in most other areas of our free-enterprise economy, such as public utility pricing, and airline pricing (6). The concept of congestion pricing for highways is now beginning to emerge.

Congestion pricing, which is essentially similar to road pricing, is not new; it has been used in this country since the earliest private toll roads. It is increasingly being considered in this and other countries as public funding has diminished. Singapore, and Oslo and Bergen, Norway have pricing schemes to control entrance to a congested area. A pricing strategy was tried in Hong Kong in the 1970's, but has since been discarded. The Urban Mass Transit Administration (now Federal Transit Administration, FTA) tried to get several urban areas to pursue a demonstration project that featured congestion pricing in the 1970's. All urban areas rejected UMTA's offer largely because of local opposition (elected officials and general public did not view their congestion



problem as bad, therefore did not warrant such a program) and many issues associated with pricing were not adequately achieved or addressed.

### **Another Look**

Increasing congestion and air quality problems in many urban areas have brought much greater attention to the possible use of pricing as a technique for creating a more efficient transportation system. As mentioned above, the Clean Air Act Amendment of 1990 has stifled new road construction. This is one reason why many urban areas are looking hard to find alternative solutions to their congestion problem.

In the early 1990's, congestion pricing was seen as a potential avenue to reduce Southern California's congestion problem. A seminar made up of local and national officials was organized to discuss vital issues associated with congestion pricing. The seminar was regarded as a success. Following California's lead, a national seminar on congestion pricing was held. In July 1991, FHWA and FTA jointly sponsored the seminar entitled *The Application of Pricing Principles to Congestion Management (7)*. A year later, FHWA and FTA sponsored a second seminar entitled *Symposium for Examining Congestion Pricing Implementation Issues (8)*. The feasibility of using market-oriented congestion management techniques is even being investigated in Texas. In January 1993, the University of Houston Center for Public Policy and the Citizens Advocating Responsible Transportation, jointly sponsored the *Southwest Congestion Pricing Conference*. Congestion pricing projects are now being considered or planned for urban areas such as, but not limited to, Los Angeles, San Francisco, Phoenix, Miami, Minneapolis, St. Paul, and Houston.

### **Potential Effects of Congestion Pricing**

Congestion pricing offers an opportunity to reduce traffic congestion by influencing public attitude using financial/market incentives to reduce traffic volumes by encouraging ride sharing, diverting trips to alternative routes or diverting trips to another time. Many empirical studies of the impact of congestion pricing suggest that efficient peak-period road tolls reduce peak traffic volume anywhere from 10 to 25 percent (9). It is noted that most of these studies that predict traffic volume reduction use simulation methods to estimate the impact of hypothetical pricing schemes; very few congestion pricing schemes have been implemented worldwide.

Because congestion pricing reduces traffic volumes, it may offer an opportunity to improve air quality and reduce energy demand. The lower volumes reduce congestion, thereby improving the efficiency of vehicles. Reduce congestion also reduce travel delay for transit and other vehicles, which improves travel time reliability, thus affecting both personal and economic productivity.

## **New Technology**

Practical implementation of direct pricing has been held back primarily due to technological problems. Recent advances in automated vehicle identification (AVI) now make congestion pricing a feasible alternative. Electronic toll collection technologies make it possible for a fee to be collected via electronic billing without making the motorist stop or slow their vehicle. Traveler information systems can inform the motorist of congested routes, thus, the motorist can decide on the most efficient route for their needs.

## **Congestion Pricing Alternatives**

Depending on the location, duration and extent of the congestion problem, pricing can be applied to a network of expressways, to expressways and principle arterial within a congested travel corridor, to selected segments of an expressway, to congested bridge and tunnel crossings, and/or to a surface street system within a congested zone. While the level of pricing (or charge) will depend on the level of congestion and other practical considerations, typical charges could be on the order of \$0.10 to \$0.25 per vehicle mile traveled on congested expressways, up to twice that amount on heavily congested surface streets, and on the order of \$2.00 to \$4.00 for entry into a congested Central Business District (CBD) or bridge (10).

Successful implementation strategies will depend on the ability to collect the appropriate user charges. Two primary alternatives that have received attention can be classified as time-of-travel charge (continuous pricing) or direct-point charge.

Time-of-travel charge requires each vehicle to purchase and display a special windshield sticker or license when using the designated roads during designated time periods. This strategy has been used successfully in Singapore since 1975 to administer an area-wide road pricing program in the downtown area.

The direct-point charge uses automated vehicle identification (AVI) technology. This strategy offers a better alternative for collecting congestion charges because motorists are not required to stop. Electronic licenses, most commonly referred to as toll tags, are mounted on vehicles which can be used to automatically identify and charge vehicles as they pass by roadside pricing points equipped with roadside or in-pavement electronic interrogators. Such licenses have been used successfully for toll collection on many toll roads, bridges, and tunnels in this country (Dallas North Tollway in Dallas, Texas, Crescent City Connection in New Orleans, Louisiana and the Lincoln Tunnel in Manhattan, New York). They are also being used to collect area entry charges in several European, Asian, and other Eastern cities. Hong Kong successfully tested downtown street system application of the AVI technology in a pilot program from 1983 to 1985.

And recently has moved forward to install AVI technology for the collection of tolls on the Aberdeen and Cross Harbor Tunnels (11).

## Summary

The time for congestion pricing may have arrived. The supply of transportation is tightly constrained, demand solutions to transportation needs have been relatively untapped in practice, there are critical and growing reasons to reduce traffic congestion, public attitudes seem to have reached a point of desperation where they will accept more onerous solutions, and the technology for charging users is available. In addition to reducing traffic congestion, congestion pricing offers an opportunity to address several other critical problems such as energy demand, air quality, the environment, and private sector participation in transportation services.

There are many issues that must be addressed in order to successfully develop and implement a congestion pricing project. Each of these issues needs to be carefully considered in order to define their importance and how to best assess and address them. Ultimately, these issues boil down to who benefits from premium transportation services, who should pay for that service, and who is hurt or otherwise impacted by that service. In the final analysis, there must be an equitable tradeoff of mitigation and compensation for inequalities among the beneficiaries, and those who do not benefit or are negatively impacted.

The primary issues which need to be considered in evaluating the feasibility of congestion pricing as an energy conservation measure include: the energy savings which will result from a congestion pricing project, the strategy to be used in establishing the pricing structure for a congestion pricing project, and the operational strategies needed to implement a congestion pricing project.

## STUDY OBJECTIVES

The intent of this project is to study the feasibility of congestion pricing strategies (tolls) to reduce highway related energy use. Three objectives of this study are:

- Objective 1:* Evaluate the economic feasibility of implementing congestion pricing as a means of reducing energy consumption and develop a strategy for establishing pricing levels.
- Objective 2:* Evaluate the operational feasibility of implementing congestion pricing as a means of reducing energy consumption and develop a strategy for implementing congestion pricing.

*Objective 3:* Determine the amount of energy that can be saved through the implantation of congestion pricing.

## ORGANIZATION OF REPORT

Following this introductory chapter is a discussion on congestion priced facilities (Chapter 2). The discussion covers historical, current and future plans for congestion pricing. For the historical projects, the congested conditions that existed at the time, the schemes that were considered, and the outcome of the project(s) are included.

Chapter 3 presents road pricing projects in general. Typically, road pricing projects are what we know of as toll roads. The historical development of road pricing, types of toll roads, road priced facilities, and example toll rates are presented. A major element of congestion pricing is the manner that fares are collected. Therefore, fare collection is discussed in this chapter and later in Chapter 5. Chapter 3 concludes with a discussion on future toll road activity.

Chapter 4 discusses the economic theory of road pricing. An economic analysis is made that compares congestion pricing to other congestion reduction methods. Chapter 4 discusses the theoretical soundness of road pricing. An economic cost benefit analysis is reviewed on the Hong Kong experiment with congestion pricing, and a case study on congestion pricing versus revenue is covered for the Oslo, Norway congestion pricing project. An empirical analysis is described for energy savings using the Singapore Area-wide Licensing Scheme. An empirical analysis is performed made of road pricing and the optimal toll. The end of Chapter 4 discusses congestion tolls with HOV lanes.

Chapter 5 discusses the operational feasibility of congestion pricing. This chapter discusses the various types of toll collection methods from traditional manual systems to the state-of-the-art in advanced electronic toll collection systems. State-of-the-art practices in toll collection systems are presented for toll facilities in North America. Because the advanced toll collection technology is credited with the re-emerging of congestion pricing as a feasible alternative to alleviate congestion, the advantages of electronic toll collection, and operating cost of several toll facilities are presented. Toll facilities that are currently being constructed or planned are also presented.

Chapter 6 presents congestion pricing on highway type facilities and potential reduction in energy consumption. An analysis was made that examines the fuel consumption following implementation of congestion pricing on an HOV lane facility. The chapter concludes with a discussion on the results.

Chapter 7 presents a short discussion on issues related to implementing a congestion pricing project. The issues are presented using comments and discussions

made at national conferences, published papers/journals/books, or personal conversations with professionals in the industry. This chapter is not all inclusive, however, it does present some of the most important issues.

Chapter 8 of the report concludes the topic of congestion pricing as an energy conservation measure and makes recommendations of alternatives to implement a congestion pricing project in Texas.

The remainder of the report contains the Cited References and the Appendix. The Appendix gives a list of public toll roads and bridges in the United States.

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CHAPTER 2

# CONGESTION PRICED FACILITIES

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## INTRODUCTION

The pricing of roads to reduce traffic congestion has been of interest to economists for many years. During the early 1920's, the debate between Pigou and Knight focused on road pricing (tolls). At that time, however, the issue of road pricing was used to illustrate the concept of social cost and how that related to the efficiency of private enterprise. Road pricing was not offered as a viable policy to address a specific social concern such as excessive congestion. In 1972, Singapore was the first to implement a congestion reducing scheme. This was not really a congestion pricing system by definition, but rather an area licensing scheme. In 1976, the United States pursued implementation of several congestion pricing demonstration projects. From 1983 to 1985, the government of Hong Kong attempted to institute a true congestion pricing system with state-of-the-art technology. Unfortunately, except for Singapore, the initial attempts to employ congestion pricing failed. Even given those failures, over the years congestion problems have become more widespread in cities throughout the world, and the interest in road pricing as a policy measure has increased.

This chapter explores the past, present, and future congestion pricing projects. For historical projects in congestion pricing, the existing conditions that lead up to the project, the schemes that were implemented and the outcome of the project are explored.

As discussed in Chapter 1, the Federal Highway Administration has shown great interest in congestion pricing by sponsoring symposiums made up of nationally recognized professionals knowledgeable of the subject. This chapter explains FHWA's perspective on congestion pricing, their policy, and what funding is available for demonstration projects.

## PAST EXPERIENCE WITH CONGESTION PRICING

Singapore, the United States, Hong Kong, and some European countries have implemented or experimented with congestion pricing. Each pricing project is studied and summarized in the following sections.

## Singapore

The city of Singapore was the first city to implement a system of motorist restraint to reduce congestion. The system was not a true congestion pricing system, but a licensing system as explained in more detail later. Several studies (12, 13, 14) have studied and evaluated the Singapore system during the 1970's and 1980's. The following analysis is taken primarily from the work by Button and Pearman (12).

### *Background Information*

The city of Singapore is the main center of employment for Singapore, with 70 percent of the jobs concentrated within an 8 km. (3 mi.) radius of the city. In 1973, the total population was 1.58 million. From 1962 to 1973, auto ownership grew at an annual rate of 8.8 percent. In 1975, the country had a auto to population ownership ratio of 1:16. In 1973, auto ownership was projected to grow 300-400 percent by 1992. As a result of increased auto ownership, the city suffered from severe congestion during the morning and evening peak periods of the day.

### *Congestion Pricing Scheme*

In 1975, the country instituted road pricing for the city of Singapore as one element in a pricing package. The intention was to slow the growth of car ownership and to encourage the use of public transportation. The pricing package was intended to reduce peak hour road traffic in the regulated area by between 25 to 30 percent. The package was combined with staggered working hours, increased vehicle taxation, land use planning policies, reduced transport needs, higher parking fees, and investment in park-and-ride facilities.

The road pricing scheme required all drivers entering through any of the 22 points located along the outskirts of the central business district between 7:30 and 9:30 a.m. to display a dated license plate on their windshield. The price of the license was S\$3<sup>1</sup> per day. Commercial vehicles (company cars) were charged at a rate double the standard price. To encourage ride sharing, those vehicles with multiple occupants were exempt from the license charge. Commercial vehicles (fleet), motorcycles and public transit vehicles were also exempt. Road pricing was applied only during the morning hours of 7:30 to 9:00 a.m.

S\$6.5 million was spent to establish 14 park-and-ride areas with a total of 10,000 spaces. Parking fees inside the city were increased to reflect congestion and were set to

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<sup>1</sup> S denotes Singapore dollars.

discourage long term parking. Guards were posted at each of the 22 entry points (gantry) and heavy fines were imposed on violating motorists.

### *Results of Congestion Pricing*

The immediate impact of the road pricing program was dramatic. The effect was greater than anticipated because relevant demand elasticities were not quantified prior to the implementation of the system. Table 2-1 shows the number and percent change in the number of motor vehicles entering the restricted zone before and after the implementation of the area licensing scheme.

Besides impacting the number of vehicles entering the city, the road pricing scheme also increased the peak travel period. Commuters altered their driving patterns to arrive at the restricted zone after 9:00 a.m. In response, the time for road pricing changed to 7:70 to 10:00 a.m. in August 1975. The time change caused the number of vehicles entering the CBD to decrease by 45 percent, private car usage decreased by 75 percent, and the average travel speed increased by 22 percent, from 27 km/hr (17 mi/hr) to 44 km/hr (27 mi/hr).

The long term effects indicate that there was a time period when car ridership stabilized. Not until May 1977, did the number of cars entering the restricted area increase following the introduction of the road pricing system. This can be seen in Table 2-2 which examines the change in the number of vehicles entering the restricted zone from 1975 to 1979.

While much of the reduction in traffic volume came from people switching modes of transportation or changing their travel patterns, a considerable portion also came from traffic being diverted to circumference routes. There was a substantial increase in traffic on the roads surrounding the congestion priced area during morning rush hour. This problem was relieved by altering the physical traffic management systems to give priority to vehicles on the ring road at the expense of those on the outskirts of the system.

Fourteen park-and-ride lots were installed to encourage single occupant vehicle commuters to use public transportation. However, because these facilities were not compatible with other forms of public transit or carpool service offered by private transit, (taxi drivers were not required to purchase the congestion pricing license and hence enjoyed a substantial increase in business), the park-and-ride facilities found little use. Subsequently most of the park-and-ride lots were transferred to other uses.



**Table 2-1. Vehicles Entering the Singapore Restricted Zone (1975-1979).**

Time (hrs)	Vehicle Type	Month Monitored				
		May 1975	May 1976	May 1977	May 1978	May 1979
0700-0730	Cars	5,384	5,675 (+5.4)	6,488 (+14.3)	6,723 (+3.6)	5,723 (-14.9)
	Car pools	617	509 (-17.5)	636 (+25.0)	606 (-4.7)	492 (-18.1)
	<b>Total Vehicles</b>	9,800	10,332 (+5.4)	11,489 (+11.2)	11,692 (+1.8)	10,596 (-11.9)
0730-1015 (Operating Time)	Cars	42,790	10,754 (-74.9)	10,350 (-3.8)	11,350 (+9.7)	13,181 (+16.1)
	Car pools	2,369	4,641 (+95.9)	5,337 (+15.0)	5,684 (+6.5)	5,756 (+1.3)
	<b>Total Vehicles</b>	74,014	37,587 (-49.2)	44,318 (+17.9)	47,503 (+7.2)	49,606 (+4.4)
1015-1045	Cars	NA	6,459	6,636 (+2.7)	6,326 (-4.7)	5,527 (-12.6)
	Car pools	NA	320	280 (-12.5)	289 (+3.2)	232 (-17.4)
	<b>Total Vehicles</b>	NA	13,441	13,805 (+2.7)	14,308 (+3.6)	15,179 (+6.1)

Table 2-2. Motor Vehicles Entering the Restricted Zone Before and After the Area Licensing Scheme.

Time	Motor cars			Other motor vehicles			Total all motor vehicles		
	March 75 <sup>a</sup>	June 75 1st Week	June 75 4th Week	March 75 <sup>a</sup>	June 75 1st Week	June 75 4th Week	March 75 <sup>a</sup>	June 75 1st Week	June 75 4th Week
7:00-7:30 a.m.	5,384	4,748 (-11.8%)	6,565 (+21.9%)	4,146	4,852 (+9.9%)	5,011 (+13.5%)	9,800	9,600 (-2.0%)	11,576 (+18.1%)
7:30-9:30 a.m. (Restricted Hours)	32,421	7,592 (-76.6%)	7,727 (-76.2%)	22,892	28,277 (+23.5%)	22,545 (-1.5%)	55,313	35,869 (-35.2%)	30,272 (-45.3%)
9:30-10:00 a.m.	7,059	7,109 (+0.7%)	7,479 (+5.9%)	5,716	6,909 (+20.9%)	7,561 (+32.9%)	12,183	12,586 (+9.7%)	15,040 (+17.7%)
10:00-10:30 a.m.	6,591	5,900 (-10.5%)	5,761 (-12.6%)	5,592	6,686 (+19.6%)	7,480 (+32.8%)	12,183	12,586 (+3.3%)	13,241 (+8.6%)
Highest ½ hour volume	9,241	---	---	5,759	---	---	14,973	---	---

<sup>a</sup>situation prior to road pricing being implemented.

Parentheses indicate percentage change over previous year.

Source: C-M. Seah (15).

As previously indicated, private car pooling was a success. In July 1975, car pooling accounted for 23 percent of all car trips. In November 1978, the number of trips made in car pools increased to 53 percent. One reason that car pooling was a success can be attributed to the governments encouragement of the practice by sponsoring a car management system. The car management system would electronically link up similar commuter trips for potential car pooling. However, carpoolers preferred to post notices in their own neighborhood bulletin boards, or advertise in the newspaper. A second reason for car pooling success was the General Insurance Association of Singapore announcement that insurance policies would remain valid whenever pooling occurred and no additional premiums were charged.

The World Bank (13) examined the impact of the road pricing scheme on households in the various groups affected. Sixty percent of all work trips did not pass through the licensing zone and hence were not clearly affected. Car users who did enter the restricted area had higher operating costs and reduced number of trips by 10 percent. Most non-car owning households continued as before, but a significant net travel time savings occurred. Shopping trips had a small 5 percent decrease in time travel.

The longer term impacts of road pricing, especially its effect on land use has been debated by economists. It has been argued that road pricing could force business out of areas where it was imposed. There is some evidence of this in Singapore where some office users have relocated. However, the World Bank study suggests that this may be due to a general trend towards decentralization.

The benefits of Singapore's road pricing system were also analyzed by the World Bank. Much of the benefit went to the government in terms of revenue. However, commuters enjoyed travel time savings. If time was valued at 25 to 30 percent of the wage rate (\$\$1 per hour) and treated independently of the traveler, then it is possible to estimate the value of the savings returns on an initial investment. During the first year, this amounted to a return of 15 percent. In this calculation, fuel savings and other operating costs were ignored. The net benefit would have been higher, had not the investment in park-and-ride facilities occurred.

### **United States Experiment**

In 1976, the Secretary of Transportation contacted seven urban areas in the United States about sponsoring a road pricing demonstration project modelled after the Singapore window license scheme. The road pricing demonstration project was to be funded by the Urban Mass Transportation Administration (now the Federal Transit Administration). The seven cities contacted were: Berkeley, CA, Ann Arbor MI, Madison, WI, Baltimore, MD, Atlanta, GA, Rochester, NY, Honolulu, HI, and Seattle, WA. Of the cities contacted, only Berkeley, Madison, and Honolulu, conducted a preliminary analysis. The other cities chose not to participate for various reasons.

Rochester's mayor thought that the downtown was congestion free and did not require congestion pricing. Atlanta's mayor chose not to participate due to financial problems. Baltimore's mayor chose not to participate because it was struggling to keep business from leaving downtown to suburban shopping malls. Congestion pricing would only hurt the CBD more. Seattle never responded. Berkeley and Madison completed initial studies, but halted further progress due to public opposition. The sections below will review the Berkeley and Madison cases as reported by Cheslow (16) and Spielberg (17), respectively.

### *Berkeley California*

**Background Information.** In 1976, Berkeley California had a population of 116,000 people. Because of the large amount of employment (approximately 62,000), a large amount of commute trips were generated. A planning study estimated an average of 350,000 round trips were made daily. Over 86 percent were made in cars and 7 percent were made in buses. The annual growth rate in commuter trips was about 2.7 percent. Commuter trips were about one-third of the travel in Berkeley.

Berkeley's major traffic attractors were the University of California at Berkeley and the central business district. Most commuters coming from the east use the Tunnel Road which was congested. The majority of commuters were from the neighboring city of Oakland. Parking in Berkeley was not a problem. Approximately 45,000 free of charge parking spaces were available throughout the city.

**Congestion Pricing Schemes.** To improve transportation in Berkeley, a combination of transit service improvements and road pricing were considered under different scenarios. The type of road pricing implemented was supplementary licenses displayed on the vehicle windshields. A license would have been required in order to use a vehicle in a designated time period and a designated area. The charge was \$1 per day and was to be levied each business day. Three types of area coverage were considered; the complete city, the core business area (i.e. the CBD, the University and the Slather-Gate area), and the Tunnel Road. Note that only the Tunnel Road had congestion in peak periods, not the city. The peak period was defined as 6 to 9 a.m. and 3 to 6 p.m. Road pricing was proposed to cover both peak-periods which would affect approximately 70 percent of all commuters. Transit improvements consisted of a reduction in walk and wait time for city buses by increasing the number of buses and reducing the fare to twenty-five cents.

**Estimated Impacts of Congestion Pricing.** The impact of transit improvements and road pricing was divided into all-day programs and peak period programs. An all-day program was estimated to reduce daily auto-traffic from 217,000 round trips to 170,000 round trips, a reduction of 22 percent. A city wide transit system would reduce traffic by 16 percent. A combined program would reduce traffic by 35 percent.

A peak period program with transit, and park-and-ride, would reduce auto traffic during the peak periods the same amount as an all-day program. It would not affect trips made in the off-peak.

The proportion of daily auto traffic reduced by transportation programs varied from 37 percent for an all-day program to 19 percent with a morning and afternoon peak pricing program. Both programs would reduce peak traffic by 30 percent. A core area traffic program would reduce traffic by 48 percent in the CBD area and reduce traffic by 35 percent on the Tunnel Road. The CBD area program was predicted to be the most effective because it would involve using park and ride service.

A citywide program of road pricing alone, would increase bus usage from 24,400 round trips to 45,000 round trips. Road pricing, combined with a twenty-five cent fare, would raise transit patronage to 82,000 round trips. Free park-and-ride facilities would increase transit use by 10,600 daily round trips. A citywide peak-period program would cause daily transit round trips to rise from 12,600 to 42,300. A core area program would increase daily transit round trips from 8,100 to 30,000. The Tunnel Road program would cause very little increase in transit patronage.

In terms of monetary cost, the revenues generated from the program would far outweigh the cost of maintaining the program. One drawback from the program is that it would hurt business because trip travelers would change their destinations.

Preliminary assessments showed that congestion pricing would significantly reduce traffic, enhance transit service, and generate new revenues for the localities. The project showed strong promise to alleviating congestion. However, because of local opposition, Berkeley did not accept UMTA's offer to proceed with a demonstration.

### *Madison Wisconsin*

**Background Information.** In 1970, the metropolitan area of Madison, Wisconsin, had a population of 300,000 of which two-thirds lived in the city of Madison itself. The central business district was approximately 3 miles east and west of the capital and included the University of Wisconsin. In 1962, the total number of daily person trips into the CBD were 606,000. In 1970, the daily person trips was 992,000 and forecasted to grow to 1.5 million by the year 2,000.

The transportation policy of Madison at the time was to maintain the central business district as a center for retail, government and finance. Policy discouraged private vehicle use and encouraged public transportation. Highway development was limited to projects that would not attract additional traffic into the city. City owned garages charged hourly rates which were higher for long term parking than short term parking. The amount of parking space that a new development could provide was

limited. Madison operated a public transportation bus system that had nine routes and a headway of 15 minutes.

In 1973, the average weekday daily traffic volume was greater than 90 percent of capacity on the main CBD arteries. On two of the major arterial streets, (Gorham St. and John St.) traffic exceeded the maximum capacity by 15 to 20 percent.

To improve the traffic congestion problem, four options were considered:

- 1) Improve the transit system;
- 2) Install a pricing strategy directed at vehicles operating in the city core via a parking sticker fee;
- 3) Install a pricing strategy directed at vehicles operating and entering into the city via an entry sticker fee; and/or,
- 4) Install a pricing strategy directed at vehicles anywhere in the city.

**Congestion Pricing Schemes.** The first option involved increasing bus frequency to reduce peak hour headway to 7.5 minutes and expand peak hour service to 5 hours. The estimated cost was \$5.2 million. The effect of improving service two-fold would increase ridership by only 10 percent and car pooling by 5 percent. Given such an additional cost would give such a small improvement in traffic, this option was not considered to be effective.

The second option, was a parking surcharge for all vehicles parking from 7:00 to 10:00 a.m. in the city core. The option required vehicles to display stickers in the windshield or by paying the surcharge fee to parking lot attendants. Non-work trips into the city would be largely unaffected since most of them occur after 10:00 o'clock in the morning. In fact, this would be an improvement for this group of users because the surcharge would cause more parking spots to be open for them to use which were previously occupied by peak-time commuters. Of the 21,000 cars entering the CBD during 7:00 to 10:00 a.m. time of day, 20 to 30 percent would be affected; 32 percent of all workers drove alone, 36 percent car pooled, and 32 percent used transit. A two-dollar per-day surcharge would reduce single occupied cars from 32 to 23 percent. The drawback of this operation was that the reduction in vehicle volume would remove only about 4 percent of the total CBD traffic. In addition, it was thought that some firms might reallocate outside the city and low paid workers might seek jobs outside the core and closer to home.

The third option was a core area use permit. All vehicles entering into the CBD would be required to display a vehicle use permit. Under this plan, four sub-options would be considered:

- a) \$2/day charge for drive-alone cars; no transit improvement;
- b) \$2/day charge for all cars; no transit improvements;
- c) \$2/day charge for drive-alone cars; 7.5 minute peak transit headway; park and ride lots with shuttle buses; or,
- d) \$2/day charge for all cars; 7.5-minute peak transit headway; park-and-ride lots with shuttle buses.

**Estimated Impacts.** Option (a) would have reduced auto trips by 6,709 whereas option (b) would decrease auto trips by 10,262. The daily permit revenue was calculated at \$13,846 and \$32,222 respectively and the total daily transit cost would be \$832 and \$1,515 respectively. Option (a) would reduce traffic by 23 percent and option (d) would reduce traffic by 42 percent.

The disadvantage of these options were that they would increase congestion on the South Beltline highway by 2,570 additional vehicles. The advantage was that additional parking spaces would be available for retail shoppers. Implementing the permit technique requires examining vehicles to ensure enforcement. Also, retail stores must be set up so that permits can be purchased before entry.

The fourth option was a citywide vehicle use permit, which was a transportation tax in disguise. This permit was required not only for operation in the core area, but also in the entire city. The drawback of this plan was that it lacked focus. It would have little impact on mode choice and no impact on daily transit decisions once the permit was purchased.

As with the City of Berkeley, Madison did not accept UMTA's offer to fund a congestion pricing program for reasons similar to Berkeley.

### **UMTA's (FTA) Response**

UMTA concluded that opposition was attributable to the following factors: anticipated and undesirable impacts on driver patterns, doubts about technological feasibility, legal barriers and concerns about invasion of privacy related to automatic toll collection, possible adverse impacts on the poor and businesses, and the feeling that congestion was not severe enough to warrant such a program. A review by Taylor and Hills (18) of the failed proposed UMTA demonstration project suggests that one of the main reasons for the failure was the widespread popular and political opposition, which may not always be based on a full understanding of the characteristics of objectives of the proposed system. Other objections cited were: 1) interfere with citizens' right to travel when, where and how they please; 2) harm local business interests and the city's business image; and 3) that it would discriminate against the poor.

## Hong Kong Congestion Pricing

Electronic road pricing in Hong Kong has been studied by Borins (19), Hau (20, 21), and Catling and Harbord (22). Until recently, the Hong Kong road pricing project was the only system to employ electronic road pricing and was the closest to the concept of congestion pricing.

### *Background Information*

During the 1970's and early 1980's, Hong Kong grew at an annual real GDP growth rate per capita of about 7 percent. This strong increase in income caused a corresponding increase in the demand for private cars. Traffic congestion increased dramatically because new roadway capacity was increased by only 17 percent during this time, whereas vehicle registration increased by 200 percent.

### *Congestion Pricing Schemes*

In May 1982, the Hong Kong government imposed various fees to reduce traffic. This action was based on the First Comprehensive Transport Study of 1976, which led to the White Paper on Internal Transport Policy. The White Paper explained the government's transportation policy. The policy presented three basic objectives: 1) to improve the road infra-structure; 2) expand and improve the mass transit system; and 3) to make better use of road space. The Comprehensive Transport Study showed that 75 percent of the total road space was used by only 25 percent of the total passengers. The majority of the road space was taken by private cars and taxis. The fees imposed by the government were the tripling of annual license fees on private cars to HK<sup>2</sup>\$3600, doubling of first registration taxes of private cars, and motorcycles to 70-90 percent of the import price of a vehicle and the doubling of the existing duty on gasoline to HK\$1.40 per liter. After a short evaluation period, the tax and fee increase policy was deemed to be inequitable and ineffective. The policy was abandoned, and hence, the Hong Kong government explored the use of electronic road pricing (ERP).

In November 1982, the Hong Kong Government initiated a feasibility study of electronic road pricing in Hong Kong (22). The study predicted that electronic road pricing would reduce peak-period traffic, increase off-peak travel, and decrease car ownership, all by 20 percent. The study concluded that road pricing would reduce congestion more than the electronic license plate program. However, road pricing would cost more and produce less revenue. By March 1983, the Hong Kong Government decided to begin a two-year electronic road pricing experiment. Five million dollars funded the experiment that involved the design and testing of the road pricing hardware,

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<sup>2</sup> HK denotes Hong Kong dollars.



an analysis of traffic patterns given various alternative road pricing schemes, and a policy analysis of the alternatives.

Three different zoning schemes were proposed. Scheme A involved five large zones and 130 toll sites. The charging periods were: the morning peak period (8:00 to 9:30 a.m.), the inter-peak period (9:30 a.m. to 5:00 p.m.) and the afternoon peak period (5:00 to 7:00 p.m.) and the shoulder peak periods immediately before and after the morning and afternoon peak (7:30 to 8:00 a.m. and 7:00 to 7:30 p.m.). The zones had peak charges for most of the day and shoulder charges are set at half of the peak charge. Scheme B was a simplified version of Scheme A. It did not have the shoulder charging periods and consisted of only 115 toll sites. But, tidal charging (charging on the shoulders of the peak) was introduced in the direction of the work trips made during the peak period. Scheme C consisted of 13 smaller zones and 185 toll sites. It was designed to capture short trips within the zoned areas. In all three schemes, the off-peak periods were not charged.

The system employed automatic vehicle identification technology (AVI) in which each vehicle (2,600 in total) had an electronic number plate mounted underneath it. When the vehicle passed over the toll site, an interrogator power loop embedded beneath the road surface sent out electronic signals to the moving vehicle's license plate and relayed the vehicle's identification number to a roadside computer. The data was transmitted to a central computer. The system sent a monthly bill to the motorist. Closed-circuit TV cameras automatically took pictures of vehicles with faulty or tampered identification plates.

### *Results of Congestion Pricing*

For the next four years, 1983-85, vehicle ownership for private and public use decreased dramatically. By 1985, the number of private cars decreased by 50 percent of the total vehicle fleet, with taxis making up an additional 10 percent of the fleet. Private cars and taxis made up 75 percent of the total traffic flow. Private car use declined by 10 percent even though less than 10 percent of the households had access to a private car. The number of commercial vehicles remained unchanged. Some people began to register small trucks and vans as commercial vehicles to avoid the taxes. Some of the hardest hit by the tax increases were the least affluent car owners, who tended not to drive their cars downtown to work.

Analysis of the demonstration project indicated that the system performance exceeded the minimum specifications. Studies showed found that 99.7 percent of all vehicle identification points accurately recorded the vehicle and the roadside computers were operating more than 99 percent of the time, regardless of the weather conditions. The closed circuit cameras had no difficulty identifying license numbers of vehicles not transmitting a valid identification.

The electronic road pricing program was met with considerable objection from the press, private car owners, and politicians. The program was abandoned due to public outcry and rejection by Hong Kong's district governing boards.

### **Other Experiments with Congestion Pricing**

During the 1970's, the international urban areas such as: London, Bristol, Amsterdam, Stockholm, Kuala Lumpur, and Bangkok, considered congestion pricing; however, each area abandoned the project. The predominant reason for abandonment was adverse impacts on low income groups and relatively minor expected impacts on traffic (23). Another reason for opposition was made on the grounds that it would lead to overcrowding on public transport facilities (24).

### **Lessons Learned from Past Experience**

Traffic congestion, particularly during peak periods, has been a major problem in many cities throughout the United States and elsewhere for much of the past thirty years. Research in the area of road pricing has continuously been studied in the Europe and the United States. Some of the earliest research was performed by the Road Research Laboratory in the early 1960's (18). As early as 1972, researchers and practitioners concluded that road pricing held the potential to reduce demand, that AVI technology held the most promise, but that it should be further developed. Development continued and soon became the basis for the demonstration project performed in Hong Kong, which was the first step towards a full scale implementation of electronic road-use pricing. Soon after, UMTA attempted to introduce a pricing demonstration project in the mid-1970's.

It has been suggested by Button (25) that pricing will always be met with major opposition from the motoring lobby unless there are distinctly perceived benefits from it. Furthermore, since the exact implications of pricing are uncertain, some initial experiments would be desirable, while political reality means that the introduction of any specific scheme will result in compromise over the details. Button also argues that it is essential to treat road-use pricing as a component of overall transport management and accept that it will have inevitable limitations.

Borins (19) has studied the Hong Kong experiment with congestion pricing. He believes that there are three possible hypothesis to why the Hong Kong electronic road pricing scheme failed. The first, is that the political agenda in Hong Kong was such that electronic road pricing was perceived negatively because of other political concerns at the time. A second hypothesis is that the Transport Branch of the Hong Kong Government Secretariat made tactical errors in introducing electronic road pricing; had they been more skillful, perhaps they might have been successful. The third hypothesis

is that electronic road pricing will be unpopular in any city, so that in a democratic process, it will always be voted down, either by a municipal council or by the people themselves if a referendum is held. Borins believes that the government was not able to neutralize fear of the inescapable "big brother" aspect of electronic road pricing (6).

## **PRESENT EXPERIENCE IN CONGESTION PRICING**

Hong Kong was the first to implement a congestion pricing program and has since continued their interest in the program. In addition, Singapore has continued their area licensing program. At the present however, Norway is the only other country that has initiated a road pricing program.

### **Hong Kong Continued Interest**

In 1989, the Hong Kong government tested public opinion on electronic road pricing under the guise of "area pricing." A program similar to Scheme B, discussed earlier, is under consideration. This type of congestion pricing program follows the recommendation of the Second Comprehensive Transport Study which concluded that area pricing is technically the best means of combatting congestion in selected areas (20).

In early 1992, the Government of Hong Kong began testing state-of-the-art automatic vehicle identification technology for electronic toll collection at the Aberdeen and Cross Harbour Tunnels. Since April 1992, a pilot project has been operating at the Aberdeen Tunnel and Hong Kong Island, with full commercial operation expected by April 1993. The only obstacles that exist are legislative changes that must be made to the tunnel ordinances and by-laws.

### **Singapore's Continued Operation of Area Licensing Program**

Singapore, the pioneer in road pricing, has continued their area licensing program. However, Singapore is in the process of upgrading their labor-intensive system to an electronic road pricing system. The new system is scheduled to be in operation by 1995. The initial goal is to turn the 26 manually controlled gantry points of the ALS into electronically controlled points of entry. The intention of the government is to arrive at a sophisticated electronic road pricing system. Reports indicate that the government has adopted a smart card technology (see Chapter 5 for more information about the smart card) as the basis of their new system.

## Road Pricing in Bergen and Oslo Norway

During the 1970's and 1980's, urban area road investments were limited. This was due to the lack of funds to finance construction in the cities. To alleviate this, the government considered fuel consumption taxes and toll rings.

In Bergen, to deal with the traffic, noise and air problems, a toll ring was proposed in a master plan in the early 1980's. The cost to build the system was much higher than the amount of funds allocated to Bergen by the national parliament. In Norway, the parliament is the originator of transportation policy and the source of transportation funds. If the city relied on public funds, then it would take about 30 years to implement the road system. Instead, in 1985, Bergen entered into an agreement with the government that guarantees Bergen a special grant for road construction that matches the net revenue of the toll ring. Thus, the funds available for construction doubled over the next 15 years starting in 1985. The Bergen toll system consists of six toll gates on the roads leading into the city. The gates are operated weekdays from 6:00 a.m. to 10:00 p.m. Only motorists driving to the center are charged. Two of the toll gates have four lanes and the rest have two lanes. The total average traffic is 62,000 vehicles per day in each direction. Scheduled buses are exempt from paying to enter the city.

The system works by motorists using passes which they can purchase in advance. The passes are placed on the windshield. Vehicles with a valid pass have reserved lanes and pass through without stopping. Security of the system consists of video taped recordings of the license plate at a randomly selected time period and toll gate. The recorded license plates are compared to a database containing valid license plate holders of passes. Violators are charged NOK<sup>3</sup>\$200. The system also has manually operated toll lanes for motorists who pay. These lanes have a capacity of 600-700 vehicles per hour. The toll rates are listed below in Table 2-3.

**Table 2-3. Bergen Toll Ring Charges**

		Light Vehicles	Heavy Vehicles
Pass, Annual	NOK	1,100.00	2,200.00
Pass, Semi-annual	NOK	575.00	1,150.00
Pass, Monthly	NOK	100.00	200.00
Pre-paid Ticket	NOK	4.50	9.00
Single Ticket	NOK	5.00	10.00

<sup>3</sup> NOK denotes Norwegian dollars.

The impact of the toll ring in Bergen was small. A survey of approximately 2,000 vehicles was performed by the Institute of Transport Economics in 1985 (26), and repeated in 1986 (27). The data indicated that motorists behaved differently with seasonal passes versus those without seasonal passes. Table 2-4 shows that there was a significantly lower percent change for vehicles paying per trip as opposed to vehicles paying with a seasonal pass. For vehicles paying with seasonal passes, there was not a significant percent change in commuting patterns. The total number of vehicles crossing the toll ring declined by 10 percent during the period of the toll collection. In addition, the survey found that the average level of car occupancy did not change and that there was little change in the timing of trips.

During the first year of operation, gross revenue was NOK\$55 million and costs were NOK\$9 million. This includes annualized costs for the construction of toll gates, and equipment and public relations.

**Table 2-4. Percentage Change in Number of Trips**

	Cars with Seasonal Pass	Cars Paying Per Trip
6:00 a.m. - 9:00 a.m.	-0.3	-40.8
9:00 a.m. - 5:00 p.m.	12.2	-21.1
5:00 p.m. - 10:00 a.m.	2.1	-35.2
<b>Toll Period Total</b>	<b>5.4</b>	<b>-29.8</b>

The situation in Oslo, Norway is similar to Bergen, Norway. That is, the city traffic was congested and the funds allocated by the central government were too small for effective road expansion. A toll ring for Oslo was considered because of the success in Bergen. The transportation package for the development of a toll ring and new highways and bridges was jointly funded by the government and by revenues of the toll ring system.

The Oslo toll ring consists of 18 gates located on all access roads into the city. Only motorists going into the central business district are charged. The number of lanes on the major access roads is five to six lanes, while on the smaller access roads, the number of lanes is two to three. More than 200,000 vehicles pass through the toll ring. In 1990, an all electronic control and payment system was installed. It is based on surface acoustical wave technology. It uses a passive tag which requires no batteries.

The system is used only for seasonal pass holders, but the system is capable of being used for variable charges. The original cost of the system is about NOK\$10 billion and the cost of the gates is NOK\$230 million. Annual revenues are estimated at NOK\$600 million. Operating costs are 10-12 percent of revenues.

The effects of the Oslo toll ring have yet to be studied. As of 1992, the Institute of Transport Studies has begun a comprehensive impact study of the Oslo toll ring. Preliminary estimates suggest that the decrease in traffic is less than 5 percent.

## **FUTURE CONSIDERATIONS OF CONGESTION PRICING**

At the present, there are several urban areas through the United States that are evaluating the potential of congestion pricing as a measure to reduce congestion. The state of California is currently in the process of changing state laws and local policies that effect the implementation of a congestion pricing project. This section summarizes the congestion pricing projects in Los Angeles and San Diego.

### **State Route 91**

State Route 91 in Orange County, California serves as an integral part of Southern California's transportation network and is a major commuter route between residential and employment centers in Orange, Riverside, and San Bernadino Counties. The SR 91 is the only major highway connecting Orange and Riverside Counties. Over the past 10 years, the existing 8 and 10-lane freeway has experienced a compounded traffic growth rate of 8.4 percent per year (28). The SR 91 facility currently carries 188,000 vehicles daily (average daily traffic). It has been estimated for the year 2010, the daily traffic count will reach 320,000 vehicles.

Under a unique franchise agreement between the California Department of Transportation and the California Private Transportation Corporation (CPTC), a toll expressway will be operated in the median of a 10-mile segment of SR 91. The CPTC will utilize the existing roadway plans (SR 91 is planned for reconstruction) for a dedicated HOV facility and allow a combination of toll express and HOV vehicles. Under this arrangement, it is estimated the addition of the two concurrent flow express lanes in each direction will increase the overall peak-hour capacity of the freeway by almost 50 percent.

The SR 91 express lanes will be open to HOV traffic toll-free, or at a reduced toll, while surplus capacity will be made available to non-HOV traffic at a higher toll.

The SR 91 project is expected to employ 100-percent AVI electronic toll collection technology. Therefore, conventional toll plazas are not expected to be necessary, and patrons should be able to travel the project nonstop. The SR 91 facility is planned to incorporate an extensive system of electronic toll and traffic management (ETTM) components that includes AVI. MFS Network Technologies has been selected to install the ETTM system. The SR 91 project will be one of the first all-AVI toll roads in the U.S. Significant elements of the SR 91 ETTM system include, (29):

- A video enforcement system that automatically captures a video image of violating vehicle's license plates and superimposes relevant information on the image for possible citation processing;
- A fiber optic communication network that provides the "backbone" linking all video, voice, and data systems;
- Variable message signs located significantly before the entrance to the toll lanes, advises motorists of traffic conditions ahead in time to change lanes safely;
- Vehicle detection and video surveillance coupled to a traffic management system. In-road vehicle detection placed every 1/4 mile will sense traffic conditions. Upon detection of abnormal conditions, the video surveillance system, providing video coverage of the entire roadway, will activate a corresponding set of surveillance cameras that will transmit real-time video of the area in question;
- A command and control center computing system provides for the management of revenue, traffic, maintenance, operations and customer service of the toll road; and,
- A mobile communication system is a specially designed communication system linking toll road operations to the California Highway Patrol and Caltrans.

All users of SR 91 toll lanes are expected to pass through at least two toll collection areas using the AVI electronic toll collection system identified previously. Traffic entering the toll lanes will have been provided advanced information using overhead signs of the upcoming toll lanes and other appropriate user information.

The total estimated project cost to add four express lanes to the median of the 10-mile segment of the existing SR 91 is approximately \$100 to \$110 million, including design, environmental, construction, contingencies and financing costs. Construction of the project is expected to start within this year (1993). Construction contracts specify a 36-month schedule.

## San Diego I-15 HOV Expressway

San Diego is planning a project that will allow the use of spare capacity on a high occupancy vehicle (HOV) lane by single-occupant vehicles (SOV's) upon payment of a fee. The project will be conducted jointly by the San Diego Association of Governments (SANDAG), Caltrans, FTA, and FHWA (30). The demonstration project, *The I-15 HOV Expressway Transit Development/Congestion Pricing Demonstration*, will consist of two phases. Phase one would demonstrate the implementation of low technology congestion pricing mechanisms such as the use of a pre-paid permit system to authorize the use of excess capacity on the I-15 HOV Expressway by SOV's. Phase two would demonstrate the implementation of high technology congestion pricing mechanisms such as automated high occupancy vehicle lane access through the application of Intelligent Vehicle Highway Systems (IVHS), Automatic Vehicle Identification (AVI), and Automated Toll Collection (ATC).

SANDAG's objective is to increase the overall vehicle occupancy to an average level of two persons per vehicle. According to an official at SANDAG, one option that is being considered is "what one might consider as a middle-of-the-road approach." Instead of placing the entire freeway under congestion pricing control, the operating agency would take-away two lanes and operate those as congestion priced lanes. If the motorists desired to commute in level-of-service A conditions, then they would pay the price. However, there is the option to commute in the remaining general-purpose lanes. The HOV lanes would remain, as HOV and continue to travel at no charge. Another option that is being considered is to vary the price based on the level-of-service. The lower the LOS, the higher the congestion price.

As was mentioned in the previous paragraphs, the initial phase of implementing a congestion price facility is through the use of permits. An option under consideration is to distribute different color permits for the LOS that the motorists wishes to pay for. For example, a particular color permit (premium) may allow the motorist to commute during any time of the day, peak-hours included. However, a different color permit may restrict the motorist from the peak-hours of commuting. The advantage to this approach would be the lower cost of the permit as compared to the premium permit's high cost.

Enforcement should be simple because the I-15 express lanes will only have one entry and one exit. Law enforcement personnel have stationed enforcement areas where there is room to pull over violators and give citations. And because the HOV lane has only one entry and one exit, each motorists must pass by the law enforcer.

The costs associated with SANDAG's approach to congestion pricing varies with the strategy implemented. The first phase would involve the use of permits. The costs related to this strategy would primarily be staff hours to distribute the permits and staff hours for enforcement. The second phase would be dictated by the policy formulated



through phase one. In other words, phase one will determine to what extent the public and public policy officials desire to achieve various levels of congestion, emissions, and/or energy consumption. Based on the policy developed, the technological aspects of automated vehicle identification (AVI) can be pursued. The highest cost of the system will revolve around the integration of the total system. The variable pricing scheme discussed earlier is wholly dependent on real-time data, the motorists require accurate and dependable information to the charge rate, and the computer system debiting or crediting motorists individual accounts must keep track of the current fare being charged.

## **FEDERAL PERSPECTIVE**

The Federal Highway Administration (FHWA) has taken a major step towards implementing a (possibly several) congestion pricing demonstration project(s). Recent announcements in the Federal Register dated May 29, and November 24, 1992, the FHWA stated their plans to solicit proposals from state and local governments for participation in the Congestion Pricing Pilot Program. The congestion pricing program is the result of recent legislation (Section 1012(b) of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991) that directs the Secretary of Transportation to solicit the participation of state and local governments and public authorities in congestion pricing pilot projects. Under this program, the Secretary will enter into cooperative agreements with up to five state and local governments, or other public authorities, to establish, maintain, and monitor congestion pricing pilot projects. Three of these agreements may involve the use of tolls on the interstate highway system. A maximum of \$25 million is authorized per year from 1992 through 1997 to be made available to carry out the requirements of the program.

Proposed congestion pricing projects can encompass parking pricing in conjunction with highway pricing, must involve increasing the price for the use of congested facilities and result in a net gain in revenue. The key objective is modify driver behavior through congestion charges that will promote the use of alternative travel times, alternative routes, modes, or trip patterns. However, for an urban area to gain FHWA funding for a congestion pricing project, the FHWA will give priority to proposed projects that demonstrate: 1) a comprehensive application of congestion pricing, including the use of road pricing; 2) an articulated program for addressing congestion, mobility, and related air quality and energy conservation goals; 3) extensive public and private involvement; and 4) incorporate the use of advanced electronic toll and traffic management (ETTM) technologies.

Through the congestion pricing pilot program, the FHWA is hopeful to obtain information related to the impacts of congestion pricing on travel behavior (mode use, time of travel, trip destinations, trip generations, etc., by private and commercial trips);

on traffic conditions (trip lengths, speeds, level of service); on implementation issues (technology, public acceptance, administration, operation, enforcement, legality, institutional issues, etc.); on revenues, their uses and financial plans; on different types of users and businesses; and on measures designed to mitigate possible adverse impacts and their effectiveness. These diverse information needs indicates that FHWA may fund different types of congestion pricing projects in different contexts to maximize the learning potential of the pilot program.

Contrary to the purposes of environmentalist enthusiast, the projects selected by the FHWA will reflect a clear intent to use congestion charges (direct point/time-of-travel charges varying by location and/or time) to encourage driver behavior in a manner that will promote the use of alternative times, routes, modes, or trip patterns to reduce congestion. The charges that are anticipated for pilot projects will probably have the key characteristic at targeting vehicles causing congestion, and the charges are set at levels high enough to encourage drivers to use alternative times, routes, modes or trip patterns during congested periods. The environmentalist favor congestion pricing because of the price placed on specific makes of vehicles that emit the largest percent share of harmful emissions to the ozone.

The FHWA stipulates which costs are eligible and those which are not eligible for reimbursement. The following are costs which are eligible for reimbursement:

- 1) Capital costs for installing pricing equipment (e.g. toll booths transponders, billing systems) or providing transportation alternatives to the area being priced;
- 2) Operating costs, including salaries and expenses related to the operation of the congestion pricing experiment;
- 3) Costs related to the implementation and operating of a parking pricing project;
- 4) Costs for planning, designing, monitoring and evaluating congestion pricing pilot projects; and/or,
- 5) Costs related to public relations, activities, designed to promote and provide continuing support to congestion pricing projects.

The following costs are not eligible for reimbursement:

- 1) Construction of new highways through lanes, bridges, even if those facilities were to be priced;
- 2) Complementary construction, such as construction of HOV lanes, implementation of traffic control systems or transit projects. These could be funded though other programs eligible under ISTEA 1991; and/or,
- 3) Planning studies undertaken prior to selection as a Pilot Program Participant.

The FHWA stipulates where the revenues from the congestion pricing projects may or may not be put to use. Revenues must be first applied to pilot project expenses on the facility being priced. Once those costs are covered, the revenue may be used on any project under title 23. Uses of the revenues are encouraged which will support the goals of the project, including uses which will mitigate any adverse effects where the project is implemented. Transit operating cost are not an allowable use of pilot project revenues, except when they have been included as part of the operating cost of the congestion pricing project. But transit capital costs are eligible uses of pilot project revenues.

### **Current Status of the FHWA Congestion Pricing Pilot Project(s)**

The Interagency Review Group (comprised of representatives of the FHWA, the Office of the Secretary of Transportation, the Federal Transit Administration, the Environmental Protection Agency, and the Department of Energy) evaluated all proposed congestion pricing projects that were submitted for consideration to be included in the FHWA congestion pricing pilot program. The solicitation period closed on January 25, 1993. Proposals were received for congestion pricing applications in 16 urban areas in 9 states.

The proposals were grouped into one of five categories- Full Facility Demand Pricing, High Occupancy Vehicle (HOV) Lane Pricing (HOV Buy-in), Feasibility Studies, HOV/Electronic Toll and Traffic Management (ETTM) User Toll Reductions, and Other.

The following paragraphs are taken directly from the June 16, 1993 notices of the Federal Register.

The Full Facility Demand Pricing proposals involved at least some aspect of using peak-period tolls on congestion facilities to charge vehicles for their contribution to congestion. The HOV Buy-in proposals involved a toll system that would allow single occupant vehicles (SOV's) to pay a toll to use under-utilized separated HOV lanes during congested times on the parallel general purpose lanes. Some of the proposals in this category called for converting existing HOV lanes to HOV/Express lanes, others entailed pricing on yet-to-be constructed HOV lanes. The Feasibility Study proposals were essentially designed to study congestion pricing options, with little or no commitment to implementing specific applications of congestion pricing included in the proposal. The HOV/ETTM User Toll Reduction proposals entailed reducing tolls during peak periods on existing tollways for HOV users and for users of ETTM equipment. Federal funds would be used for the installation of ETTM equipment and to compensate the toll authority for revenue losses associated with toll reductions. Other

proposals called for implementation of parking pricing with no road pricing component, and the pricing of new lanes to be added to an existing non-tolled highway.

The Interagency Review Group determined that all but one of the proposals failed to respond well to the Pilot Program criteria contained in the November 24 notice because they had little or no commitment to the implementation of road pricing projects which established a fee schedule that would influence road use choices. In addition, some proposed projects were unlikely to be implemented in time to allow evaluation information to be developed for the FHWA to report to Congress on the effectiveness of Pilot Projects prior to the expiration of the ISTEA. As a result, only the proposal submitted jointly by the California Department of Transportation and the Metropolitan Transportation Commission was selected during the initial solicitation for further negotiation of a congestion pricing pilot project.

The proposed project will raise peak-period tolls on the Oakland-San Francisco Bay Bridge to manage demand. The project will also contain significant transit enhancement, public outreach, and monitoring/evaluation elements. The Interagency Review Group believes that the Bay Area proposal, more than any other proposal received, manifests "a clear intent to use congestion charges to encourage driver behavior in a manner that will promote the use of alternative times, routes, modes, or trip patterns to reduce congestion."

In the June 16, 1993 Federal Register Notices, the FHWA states that it is extending the period of solicitation for participation in the Congestion Pricing Program for a period of 4 months from the date of that notice (therefore, until October 16, 1993). The criteria outline herein will continue to serve as the guidelines the Interagency Review Group will use to evaluate the proposals.

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CHAPTER 3

## ROAD PRICED (TOLL ROAD) FACILITIES

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This chapter of the report is focused on toll road activity because it is closely related to congestion pricing; charging a fee for use of the roadway. Although, in practice, toll roads differ from a congestion priced facility because toll roads charge the same fare 24-hours a day; toll road experience can offer much valued information in operations and financing for the development of a congestion priced facility.

### TOLL ROAD DEVELOPMENT

The practice of assessing a toll or fee for use of a highway facility is not new. Facilities such as these have existed throughout the world for many centuries. Historical evidence suggests that in 1281 the London Bridge tolled the users of the bridge and the water traffic passing beneath (31). Toll roads in the United States really began to become common facilities with the construction of the first section of the Pennsylvania Turnpike, extending between Harrisburg and Pittsburgh, in 1940. In the 1940s and 1950s, more than 3,100 miles of toll highways were built in the United States, particularly in the East (32, 5). From 1963 to 1974, another 1,240 miles of toll roads were constructed; including the 9.8 mile Dallas North Tollway. Construction of new toll roads slowed down during the next two decades. During this time, the Cimarron Turnpike in Oklahoma was opened in 1975, Dulles Toll Road in 1984, and the Sawgrass Expressway in Broward County, Florida, in 1986. Here in Texas, there has been increased activity in the construction of new toll road facilities. In 1988, 21.7 miles of the Hardy Toll Road was opened and in 1990, and 27.7 miles of the Sam Houston Tollway was opened.

Innovations in financing and toll collection technology along with a continued shifting of public funding away from new highway construction projects are moving the public toward wider acceptance of toll roads. As the toll road trend gains popularity, developers are viewing tollways as a potentially lucrative investment opportunity. The Surface Transportation Assistance Act of 1991 has increased developer interest by easing restrictions on federal funding of toll roads and giving states greater latitude to mix public and private highway construction funds. The amount of federal funding used will vary depending on the degree to which tolls can support the project. The provisions of the Act allow the use of tolls in combination with federal funds from improving existing non-interstate urban roads, which will enable cities and states to upgrade thousands of miles of highways that otherwise would continue to deteriorate. It has been predicted

the length of the 4,650-mile toll road network in the United States can be expected to double over the next 20 years (32, 5).

Robert Poole, of the Reason Foundation, attribute the increased interest in toll roads to the advancement in AVI technology and other electronic toll collection (6), while others see the more critical factors behind increased interest in tolling and congestion pricing to be congestion and air pollution. Congestion has been growing in the United States because new highway construction slowed down during the 1970s and 1980s while traffic continued to grow (5). For example, In Orange County, California, where traffic congestion is notorious, between 1972 and 1988 only four miles of freeway were built; yet during this time the population increased from 1.4 to 2.2 million (32).

Air pollution is once again a top transportation issue because the significant reductions in auto emissions in the 1970s and 1980s have not been enough to meet the federal government's standards for healthy air. Environmentalists are attracted by the potential of tolls to improve ambient air quality. Many U.S. metropolitan areas will be hard pressed to meet the national ambient air quality standards by the 1990 Clean Air Act schedule. Automobiles are a major pollution source in most cases. It is believed that technological advances can not alleviate the automobile pollution problem, and further reductions in tailpipe emissions may prove to be increasingly difficult and costly. A behavior change is required. Tolls are a means of changing motorists' behavior.

### **Types of Toll Roads**

Toll roads may be categorized by the toll collection system used. Norman Wuestefeld has extensively studied toll roads in the United States and toll road efforts for the Eurotunnel between Britain and France. Wuestefeld categorizes toll roads as ticket systems, mainline barrier system, and mainline/ramp barrier systems, and combinations thereof. In a ticket system of collection, a ticket is received upon entry and is surrendered with payment when leaving. Current examples of this type of system include the New Jersey Turnpike, Maine Turnpike, and Will Rogers Turnpike in Oklahoma.

The mainline barrier system consists of construction of barriers across the mainline at intervals of about 12 miles. In this system, toll-free travel among interchanges located between the mainline barriers is permitted. An example of the mainline barrier system was the Connecticut Turnpike.

The mainline/ramp barrier system is the most commonly used system today. Under this system, the barriers are constructed to collect tolls from all patrons that enter the system; either on an entrance ramp or exit ramp, with no toll-free travel permitted. Examples of this type of system include the Dallas North Tollway, the Houston Hardy

toll road and the Sam Houston Tollway, Illinois Tollway, Richmond Expressway System, and the Sawgrass Expressway.

### **Public Toll Road/Bridge Operators in the United States**

A list of toll road and toll bridge operators in the United States are shown in the Appendix.

### **Toll Rates**

Rates are set based on many considerations including the level of competition from tax-supported roadways in the corridor, cost of the project, nature of the patrons served, and financial requirements. Toll rates per-mile for a full-length trip by a passenger car motorists and five-axle truck operator for a representative group of toll roads were compiled by Wuestefeld and are shown in Tables 3-1 and 3-2.

### **Types of Financing**

The basic types of financing are: general obligation bonds, revenue bonds, revenue bonds supplemented by income other than that paid by users, private financing and combinations thereof. The topic of toll road financing is a very complex issue and typically will differ from any one project. Because of the complexity of this topic and the relevancy to the topic to congestion pricing, it is left to the reader to explore alternate indepth literature on the subject. Good references might include: *Toll Roads* by Norman Wuestefeld (31), and *Identification of Candidate Toll Roads in Current and Future Highway Development* by Souleyrette, Walton, and Mahmassani (33).

### **Toll Road Fare Collection**

Toll roads would not be enjoying a resurgence were it not for new technologies that address many motorist's aversion for toll collection booths. In 1988, *The Urban Transportation Monitor* conducted a nationwide survey on the public's attitude toward toll roads as a funding Source (34). The survey found that 66 percent of respondents expressed a negative or neutral opinion when offered a choice. However, when asked if they would support a toll road if a system of automatic tolls were implemented, the acceptance rate was 85 percent. This survey would tend to indicate that the public places a high value on convenience and is not opposed to a user-tax if properly administered.

**Table 3-1. Toll and Per-Mile Rates For Selected Inter-City Toll Roads**

Facility	Length (miles)	Passenger Cars		Five-Axle Trucks	
		Toll <sup>a</sup>	Per Mile Rate	Toll <sup>a</sup>	Per Mile Rate
<b>Mainline/Ramp Barrier Systems</b>					
Illinois	76.3	\$2.00	\$0.0262	\$6.25	\$0.0819
Northwest Tollway	77.1	2.40	0.0311	7.50	0.0973
Tri-State Tollway	96.3	2.70	0.0280	8.50	0.0883
East-West Tollway					
<b>New Hampshire</b>					
Central Turnpike	39.5	1.00	0.0253	2.50	0.0633
Spaulding Turnpike	22.4	0.35	0.0156	2.00	0.0893
Blue Star Turnpike	14.9	0.50	0.0336	1.25	0.0839
<b>Oklahoma</b>					
H.E. Bailey Turnpike	86.4	2.10	0.0243	6.00	0.0694
Cimarron Turnpike	59.2	1.40	0.0236	4.00	0.0676
Indian Nation Turnpike	105.2	2.50	0.0238	7.00	0.0665
Muskogee Turnpike	53.1	1.30	0.0245	3.75	0.0706
<b>Ticket Systems</b>					
New Jersey Turnpike	118.0	2.70	0.0229	9.10	0.0771
Pennsylvania Turnpike	350.0	8.70	0.0249	32.85 <sup>b</sup>	0.0939
Indian Toll Road	156.9	4.65	0.0296	11.20	0.0714
Ohio Turnpike	241.2	4.90	0.0203	19.15 <sup>b</sup>	0.0794
Maine Turnpike	100.0	2.70	0.0270	8.10	0.0810
Kansas Turnpike	231.0	7.00	0.0303	18.75	0.0812
<b>Oklahoma</b>					
Turner Turnpike	86.0	2.00	0.0233	6.50	0.0756
Will Rogers Turnpike	88.5	2.00	0.0226	6.50	0.0734

a. Full-length trip on the facility

b. The Pennsylvania Turnpike and Ohio Turnpike classifies its commercial vehicles by weight. Tolls shown for five-axle vehicles represent charges for vehicles in the 45,000 to 65,000 lb. classification.

Source: (31)



**Table 3-2. Toll and Per-Mile Passenger Car Rates For Selected Urban Toll Roads.**

Facility	Length (miles)	Toll <sup>a</sup>	Per Mile Rate
Buccaneer Trail (Florida)	15.9	0.50	0.0314
Dallas North Tollway	9.8	0.50	0.0510
Airport Expressway (Miami, Florida)	8.8 <sup>b</sup>	0.25 <sup>b</sup>	0.0284
Holland East-West Expressway (Orlando)	13.8	0.50	0.0362
Massachusetts Turnpike Extension	12.0	0.75	0.0625
Tampa South Crosstown Expressway	17.5	0.50	0.0286
New Jersey Turnpike (Interchange 9-18)	35.0	1.50	0.0429
New York State Thruway (Barrier System, NYC Area)	45.2	2.50	0.0553
Pennsylvania Turnpike (Interchange 23-30)	47.0	1.60	0.0340
Richmond Expressway	6.3	0.50	0.0794
Virginia Beach-Norfolk Expressway	12.1	0.25	0.0207
J.T. Butler Expressway	12.2	0.50	0.0410
Sawgrass Expressway (Broward County, Florida)	22.8	1.50	0.0658
Houston West-Belt Tollway (Under Construction)	27.5	2.10	0.0764
Houston Hardy Road Tollway (Under Construction)	21.7	2.00	0.0922

a. Full-length trip on the facility.

b. Round-trip toll and distance (one-way toll system).

Source: (31)

### *New Technology*

One of the key factors in the acceptance of toll roads is the promise of automatic tolls. Automated Vehicle Identification (AVI) is the most promising new technology emerging in the toll industry. Roads with electronic toll collection systems can operate without toll plazas, though on existing tollways using these systems, motorists are given a choice of traditional versus electronic lanes. A transponder located somewhere on the vehicle using the electronic system allows a reader to retrieve a vehicle identification code and relay it, along with time/date/location information, to a central computer. Violators of the automatic system are fined, but access is not denied to those not using them.

Automatic vehicle identification (AVI) is the most promising new technology emerging in the toll industry. An AVI system is designed to speed the toll collection process by having an interrogation device identify each vehicle as it approaches a toll plaza or passes a checkpoint and charging the proper toll to the user's account, thus eliminating the need for the vehicles to stop. Toll collection technology is one of the most important factors that will make congestion pricing a feasible alternative. Because of the importance of this topic, a separate chapter is devoted to the subject. See

Chapter 5 (Operational Feasibility) for more detail on automatic vehicle identification and other means of toll collection.

There are several examples of advanced toll collection in the United States. The Interagency Electronic Toll and Traffic Management (ETTM) Group representing seven toll authorities in New York, New Jersey, and Pennsylvania, [Atlantic City Expressway, New Jersey Highway Authority, New Jersey Turnpike Authority, NY State Thruway Authority, Pennsylvania Turnpike Commission, Port Authority of New York & New Jersey, Triborough Bridge & Tunnel Authority]. The Interagency ETTM Group, who together collect 37 percent (36) of all tolls in the United States, recently requested for system architecture and operating system requirements to be issued for the tri-state region, to be tested in 1993, and be fully operational by 1995 (35). The New York Thruway is the first among the Interagency Group to implement an electronic toll collection system called the *E-ZPass* system. Vehicles using the *E-ZPass* will be equipped with a small electronic device or tag that communicates vehicles and account information. Toll lanes will be equipped with readers that collect and transmit information to and from the tags. The data are then processed and appropriate toll charged to or credited against the customer's account. The *E-ZPass* is compatible with all of the toll authorities in the region, allowing motorists to use any equipped toll facility with a single tag (37).

Another recent development in interagency compatibility occurred here in Texas a few months ago. The Oklahoma Turnpike Authority and the Texas Turnpike Authority have teamed together, using similar toll tag technology, for toll collection using a single toll tag. Other examples of advanced toll collection technology use on United States toll roads are:

- As part of Virginia Department of Transportation "Fastoll" project, the DOT recently awarded MFS Network Technologies, Omaha, Nebraska, a contract to integrate toll collection including automatic vehicle identification for the Dulles Toll Road, Washington, D.C. (38).
- The Orlando-Orange County Expressway Authority in Orlando, Florida is moving forward to implement an integrated electronic toll system (38).
- The Massachusetts Port Authority (Mass Port) is testing the Intelli Tag System from Amtech Corp, Dallas, Texas on Boston's Tobin Memorial Bridge. Watching very closely is members of the New England Electronic Toll and Traffic Management (ETTM) group. The Massachusetts Turnpike Authority (Mass Pike), a member of the New England group, is looking to place electronic toll collection system on the Sumner and Callahan tunnels in Boston. According to John Judge, director of operations at Mass Pike, a top priority is compatibility with other systems in adjacent toll roads/bridges (38).

## Future Toll Road Activity

Toll road activity is most intense in California, where private development groups have franchise agreements with the California Department of Transportation (Caltrans) to construct four separate toll roads totaling 117 miles for \$2.5 billion. Each of these roads will be operated by the development group for 35 years, after which operation of and revenues from the tollways will revert to the state. The four projects will be funded by user fees collected during the 35-year franchise period and by real estate developed under 99-year ground and air rights leases on state-owned rights-of-way. The four projects are the:

- The State Route 91 express lanes project
- Santa Ana Viaduct Expressway
- San Diego Expressway
- Mid-State Tollway

According to a recent article in *Civil Engineering Magazine* (39), John Prendergast summarized the four toll roads and their current status. The four projects will feature AVI toll collection equipment and advanced traffic management systems. The SR 91 and Santa Ana River Viaduct tollways will include demand pricing, with toll rates changing several times daily depending on the level of congestion on the toll roads and approach roads. The following is a summary of his article.

The SR 91 will add four express lanes to the median of a 10-mile segment of the existing SR 91 facility in Orange and Riverside counties at a cost of \$100 to \$110 million. The franchise agreement is with the California Private Transportation Corporation (CPTC), a subsidiary of CRSS, Inc., Houston, Texas. CPTC forecasts that the express lanes will capture 30,000 vehicles per day by 1995, and 40,000 vehicles per day by year 2010. As of January 1993, the project has all required right-of-way, all environmental work has been completed, and required financing to be waiting to be finalized. Once construction begins, the project should be completed in 30 to 36 months.

The Santa Ana Viaduct Expressway is a 11-mile, 4-mile elevated toll road connecting the existing SR 57 with I-405 and SR 73 in Orange County will be constructed within the Santa Ana River channel. The estimated cost of this project is \$750 million. The franchise agreement is with the National Transportation Authority (NTA), a partnership of the Perot Group, Dallas and Greiner Engineering, Inc., Irving, Texas. As of January 1993, the project is completing the preliminary environmental work, and financing should be finalized in this current year (1993). Construction is estimated to take 36 months.

The San Diego Expressway is a 11-mile, 4-lane extension of the San Diego Expressway (SR 125) which will connect SR 54 to Otay Mesa near the Mexican border.

The estimated cost of this project is \$340 million. The franchise agreement is with California Transportation Ventures (CTV), owned equally by Parsons Brinkerhoff Development Group, Inc., San Diego; Flour Daniel, Inc., Redwood City, California; Prudential Bache Capital Funding, New York; and Transroute, a French tollroad company. As of January 1993, CTV had contracted with Caltrans to perform environmental work, which is estimated to take 18 months to complete. Construction could begin in 1996.

The Mid-State Tollway is an 85-mile beltway around San Francisco Bay area. Because this project faces several environment and engineering challenges, the project is estimated to cost \$1.2 billion, and several segments will be constructed in phases over 10 years. The franchise agreement is with the California Toll Road Company (CTRC), which includes The Parsons Corporation, Pasadena, California; Cofiroute, a French toll road company; Banque Nationale de Paris; WESTPAC Banking Corporation of Australia; and Goldman Sachs & Co., New York. As of January 1993, the CTRC was working on obtaining additional equity capital, and work was about to begin on the environmental impact study. The earliest construction date is projected in about 4 years.

A separate program to construct 3 additional toll roads will add approximately 65 miles of new road at a cost of approximately \$2.1 billion. The Transportation Corridor Agencies, a consortium made up of the Counties and the cities benefiting from the tollways, oversees the project. Engineers are the Corridor Design Management Group, Costa Mesa, California, a joint venture of HNTB, Parsons Brinkerhoff, Flour Daniel, and Church Engineering. Approximately 50 % of the money to fund the toll roads will come from developer's fees for the surrounding land, the rest will come from construction bonds, to be repaid will toll revenues. When construction is complete, the roads will be transferred to the California Department of Transportation for operation and maintenance.

The three projects will employ AVI toll collection to reduce toll plaza congestion. The goal is to have 60% of the tolls collected using this system by the year 2010. Automatic coin

machines and manual toll collection will collect the rest. The three toll roads projects are:

- Foothill Transportation Corridor
- Eastern Corridor
- San Joaquin Hills Transportation Corridor

According to Ronald Hartje (40) with Howard Needles Tammen & Bergendoff, a partner in the joint venture, the toll roads are incorporating technology that will provide the flexibility to operate each facility with a variable pricing policy. That is, making it possible to adjust the toll at different times of the day to accommodate high

peak-period traffic demand, thus making patrons to pay a premium to travel during rush hours.

The Foothill Transportation Corridor is a 30-mile, six and eight lane tollway, which will parallel Interstate 5 (I-5) and extend to connect I-5 south near the San Diego County Border. Ground was broken in November 1990 on a 7.6-mile section of the corridor, and is expected to be open within this current year (1993), with additional sections in operation in 1994 and 1996 and the entire corridor complete by the year 2000. The estimated cost of the project is \$746 million.

The Eastern Corridor is a 23-mile, three and four-lane tollway that will begin at SR 91 near the Riverside County line and run parallel to SR 55, splitting into two legs about halfway along its length, both of which connect to Interstate 5. The project is report to have begun construction in late 1991. The estimated cost to construct the Eastern Corridor is \$630 million.

The third toll road is the 15-mile, six to ten-lane San Joaquin Hills Transportation Corridor. The San Joaquin is an extension of SR 73, the Corona Del Mar Freeway, from the John Wayne Airport to San Juan Capistrano. Construction is reported to have begun in the fall 1991, with the first phase complete in 1994 and all work complete by 1995.

### **Summary of Toll Road Activity**

Toll roads have been in operation for many decades in the United States and even worldwide. In many urban areas throughout the nation, there has been widespread public acceptance of toll roads. The newly constructed toll roads are taking advantage of AVI technology to lower operating cost and alleviate congestion at the toll plazas. In several facilities, the technology is flexible to allow varying toll rates. The electronic technology used for toll collection and account transaction (debit/credit) is highly reliable. It is apparent that future toll roads will continue to employ extensive AVI and ETTM systems.

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**ECONOMIC THEORY OF CONGESTION PRICING**

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**THEORETICAL MODELS OF CONGESTION PRICING****Theory of Road Pricing**

The basic rationale behind road pricing is that each motorist does not take into consideration the costs he imposes on others and hence does not take into consideration these costs when deciding whether or not to make a car journey. These costs fall into two categories: 1) user-upon-non user costs and 2) user-upon user costs. The former involves the effects of car pollution and noise, danger, etc. The latter evolves the effects of traffic congestion. Each car trip that a driver makes imposes forms of external costs which the driver fails to take into consideration in his decision making. Drivers are only concerned with the costs that they must bear themselves, eg. gas, time cost, wear and tear on their car. They underestimate the overall or social costs of their driving on others, driver and non-driver alike.

Since the direction of this research is primarily on congestion, this review will focus on user-upon user costs. User-upon-nonuser costs is an important topic, but that is left for further research. The theory of road pricing is relatively straight forward and does not vary much from text to text. Thus, this section largely relies on Button and Pearman (12).

The basic model of the optimal road price is straight forward. Suppose that the model consists of a single road with no traffic on it. As vehicles begin to enter the road at equal intervals, traffic volume begins to increase. At low traffic volumes, there is no traffic congestion and vehicles will freely travel along the roads. This is shown in Figure 4-1. The vertical axis represents the traffic volume and the horizontal axis represents the cost of the trip. Cost is measured by the vehicle operating costs (fuel), plus the money time cost for being on the road. With low volumes of traffic,  $Q_1$ , there is no congestion. Thus, there is no user-upon user cost. Once the traffic volume increases past a critical level, cars begin to influence each others speed causing them to slow down. This forces the marginal cost of the trip to rise. It takes drivers longer to complete the trip so that vehicle costs and time costs rise.

The decision made by each motorist whether to make or not make the trip is based on whether the benefit of the trip exceeds the cost. The motorist thinks only of himself, and does not include the cost to others. Provided that benefit of the cost, measured by the demand curve exceeds the average cost of the trip, the motorist will take the trip. This is point  $Q_2$  in Figure 4-1. Beyond  $Q_2$ , the cost to the motorist exceeds

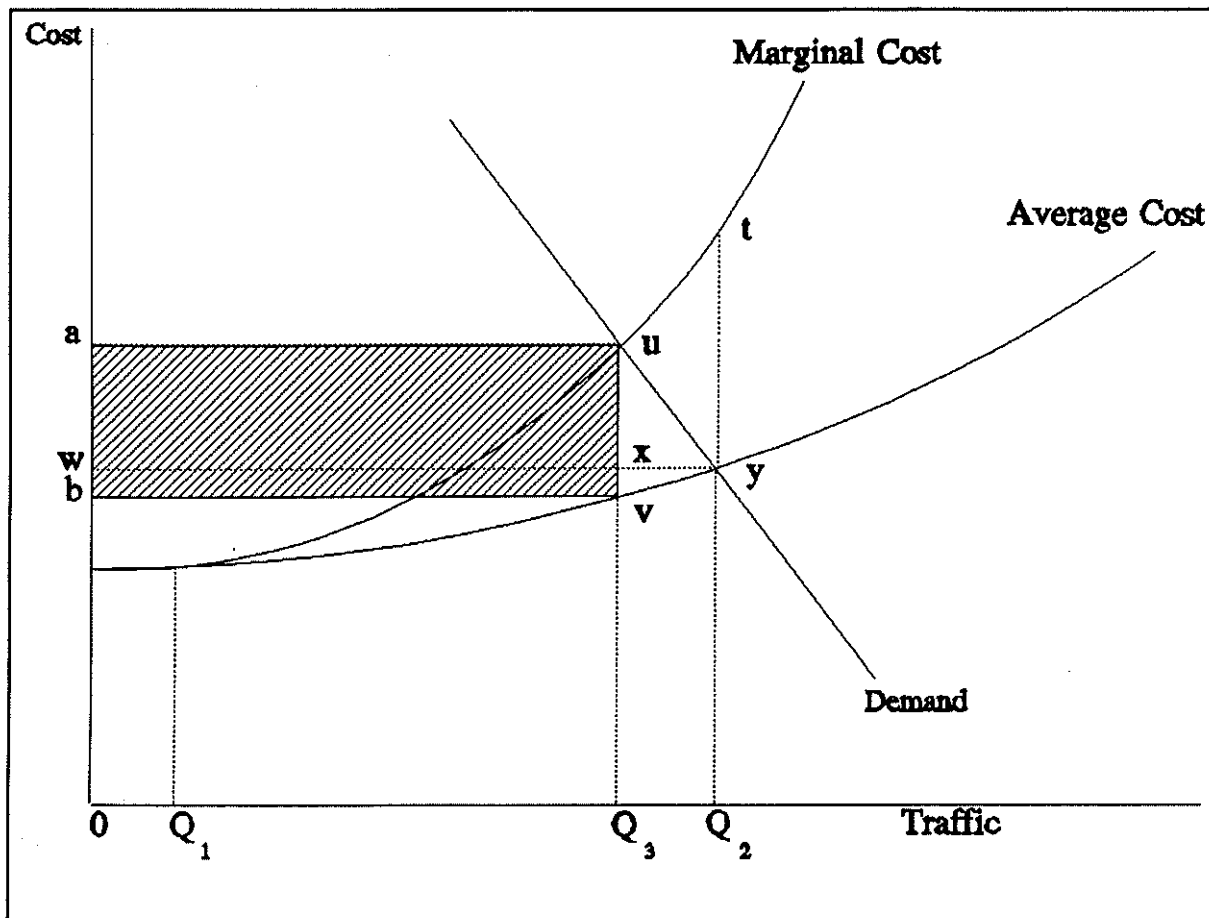


Figure 4-1. Marginal Cost of Congestion Pricing

the cost of the trip, so that the trip would not be made. At equilibrium which is represented as point  $y$ , the level of traffic would be  $Q_2$  and cost  $w$ . Note that this is not the optimal level of traffic flow, because the average cost curve  $AC$  does not take into account the marginal cost the motorist imposes on other road users. The motorist when deciding to take the trip does not take into consideration his negative externality on other drivers. For example, suppose that there are 100 cars on the road, each taking 5 minutes to travel a specified distance. In addition, suppose an additional car on the road caused each motorist to travel 5.25 minutes to complete their trip, an increase of .25 minutes. The additional motorist ignores the fact that it now takes all motorists .25 more minutes to complete the trip. The total marginal cost is 30.25 minutes of travel. The difference between the total marginal cost and average cost is the congestion cost caused by the additional car. Note that the marginal cost curve  $MC$ , which represents the social cost of using the road only begins to diverge as traffic congestion begins. This is to the right of  $Q_1$ .

At point  $Q_2$ , the marginal social cost of traffic exceeds the benefits ( $MC > 0$ ). That is, the negative externality imposed on the motorists exceeds the gains by the marginal driver. Only at point  $Q_3$  is the full marginal cost equated to the full marginal costs of using the road.

The objective of road pricing is to make motorists internalize the true cost of the use of the road by taking into consideration the marginal costs they impose on each other. In Figure 4-1, the road price is equal to  $r$ . This is the difference between marginal and average cost. This results in motorists costs at point  $a$  and traffic equilibrium at point  $Q_3$ .

The graphical analysis corresponds to a simple mathematical analysis. Suppose that there are  $q$  vehicles on the road over a period of time. Each vehicle travels  $\delta/v$  hours to travel a specified distance at a travel cost of  $c(\delta/v)$ . Let the distance be one mile so that  $\delta=1$ . Thus, the average cost to the traveller is  $c/v$  per mile and the total cost is

$$TC = (qc)/v \quad (1)$$

The marginal cost, which represents the cost of each additional vehicle is

$$MC = \frac{dTC}{dq} = \frac{c}{q} - \frac{qc}{v^2} - \frac{dv}{dq} \quad (2)$$

$$= \frac{vc - qc(dv/dq)}{v^2} \quad (3)$$

Since the motorist only takes into consideration his own cost and not that imposed by others, he will only pay the average cost  $c/v$ . The difference between the average cost and the marginal cost is the amount motorists need to be charged for them to incorporate the full cost of travel into their decision making process. Let  $r$  represent this value, where

$$r = AC - MC \quad (4)$$

$$= \frac{qc(dv/dq)}{v^2} \geq 0 \quad (5)$$

Referring to Figure 4-1, motorists enter the traffic stream up to a point where their cost of the trip equals the benefit of making the trip. This flow is excessive because traffic beyond  $Q_3$  has benefits of  $Q_3$  up to  $Q_2$ , but an overall cost of  $Q_3$  up to  $Q_2$ . There is a deadweight loss of utility. The road price  $r$  is set at where  $MC=D$ , i.e. where the marginal cost of an additional road user equals the price. Traffic flow is restrained to the point  $Q_3$ , which is where motorists incorporate the full social cost of their travel. If the flow is less than  $Q_3$ , then there is a net benefit of increasing road travel, while if the flow is greater than  $Q_3$ , then there is a net benefit of constraining road use.



At this point, several comments should be made. First, even with congestion pricing, there still is a degree of congestion on the road. The object of congestion pricing is not to remove congestion, but to internalize the external costs of highway use so that the roads are used efficiently in an economic sense. Second, road pricing is a method of improving the use of existing roads. Third, there is no mention of what is done with the revenue from congestion pricing and how it influences politicians and motorist's behavior. Fourth, the example given here to explain the concept of road pricing is over simplified, to demonstrate the concept of congestion pricing.

### **Economic Analysis of Congestion Pricing Versus other Congestion Reducing Means**

Vickery (41) analyzed congestion theory when transportation investment is used to relieve congestion on existing routes or to expand overall capacity. In doing so, he gives a powerful argument to apply congestion pricing to highways for highway expansions. His argument is based on a simple model of bottleneck congestion during a rush hour. He assumes that commuters have the same valuation of time. He also assumes that adding capacity costs \$2,000 per lane. He compares three scenarios. In the first one, he assumes that toll prices can be adjusted upwards or downwards on relatively short notice and in short increments. In the second, he assumes that a two lane highway is expanded to three lanes with no tolls. Using his numbers (see Table 4-1), he shows that a two lane bottleneck with 60 cars per minute would have congestion costs of \$4,320 per day. Expanding the highway, option 2, to a capacity of 90 cars per minute, would reduce congestion costs to \$2,400, a reduction of \$1,920, but would cost \$2,000. Two new lanes would cost \$4,000 and eliminate all of the congestion, \$4,320. Thus, the net gain would be \$320. Option 1, a variable toll would cut congestion costs by two-thirds to 1,440 and have a budget inflow of 2,880. Even if capacity expansion is worth while, the extent of capacity needed would not be so great if it were used in conjunction with variable tolls.

Vickery (41) gives additional arguments for the benefits of congestion pricing over highway investment. Congestion pricing is flexible and can be changed with relative ease. Thus it is effective in the short run and in the long run. Construction takes time and is a long run solution. When alternate routes are available, traffic is divided between them so that the total costs of travel along both routes are equalized. In addition in most congested urbanized areas there is a large amount of latent demand from trips which have been changed to a less desirable time or foregone altogether. An increase in the capacity of the bottleneck route would result in traffic being diverted from the alternate routes and from latent demand so that the conditions on the improved route quickly return to the conditions prior to the improvement. This difficulty in reducing congestion by capacity improvements is caused by underpricing the true cost of using the facilities. In addition, current techniques to evaluate highway investment does not incorporate individuals differences in the value of time or an individual's value of time at different times of the day. Instead, all individuals time is priced identically. On the other hand, congestion pricing makes it possible to exclude low value uses and

**Table 4-1. Expanding Highway Capacity vs Using an Optimal Congestion Toll**

Capacity (cars per minute)	Equivalent Number of Lanes	Duration of Queue/Toll (minutes)	Maximum Wait in Queues (minutes)	Average Toll Rate (cents)	Congestion Cost (\$/day)		
					Displaced Arrival	Waiting in Queues (= toll rev.)	Total without Pricing
50	1.67	144.00	48.00	48.00	2016	3456	5472
60	2.00	120.00	40.00	40.0	1440	2880	4320
70	2.33	102.9	34.29	34.3	1029	2469	3498
80	2.67	90.0	30.00	30.0	720	2160	2880
90	3.00	80.0	26.67	26.7	480	1920	2400
100	3.33	72.0	24.00	24.0	288	1728	2016
110	3.67	65.6	21.91	21.9	131	1571	1708
115	3.83	62.6	20.87	20.9	63	1503	1566
118	3.93	61.0	20.33	20.3	24	1464	1488
119	3.97	60.5	20.17	20.2	12	1452	1464
119.99	-4.00	60.0	20.00	20.0	0.12	1440	1440
120.01	+4.00	0	0	0	0	0	0

Source: Vickery (41), pp. 251-260.

make improvements based on uses that are sufficiently highly valued.

Newberry (42) argues that without road pricing, road improvements may yield low or even negative returns, whereas, with efficient congestion pricing this would not be the case. Consider the effects of using only road capacity expansion to relieve congestion. Suppose that capacity is doubled so that the marginal cost curve shifts from  $MC^b$  to  $MC^a$  and the average cost curve shifts from  $AC^b$  to  $AC^a$  as shown in Figure 4-2. The initial equilibrium is at point b where the number of vehicles per hour equals  $bg$  and the price of the trip is  $g$ . When average cost is lowered to  $AC^a$ , the equilibrium point becomes point d with price  $h$  and vehicles per hour  $hd$ . The apparent cost saving from the road improvement is  $gbef$ , which could be compared to the cost of the highway expansion. But with a lower average cost at  $AC^a$  traffic will increase and the new equilibrium will be point d. The benefit is actually  $gbdh$  which may be lower than the initial anticipated  $gbef$ .

If the traffic increase came from users of public transportation, the effect of a road improvement may be to raise average costs, making everyone worse off. This can be seen in Figure 4-4. Initially, the marginal cost and average cost curves are  $MC^b$  and  $AC^b$  respectively. Demand is 'demand before' and equilibrium is at point b with price

h. With a road improvement, average cost shifts to  $AC^a$  and marginal cost shifts to  $MC^a$ . The cost saving would be  $hbcf$  with no change in demand. Due to the traffic increase from users switching from public transportation to private car use, demand shifts from 'demand before' to 'demand after'. The new equilibrium is at point  $d$  with everyone being worse off, costs increase from  $h$  to  $g$ .

But with an efficient congestion charge, everyone would not be made worse off. This can be seen in Figure 4-3. Suppose the demand curve is perfectly elastic and is represented by the line  $gj$ . Without a toll charge, equilibrium is at point  $i$  where the number of vehicles per hour is  $gi$  and the price of the trip is  $g$ . With an efficient toll of  $ab$ , equilibrium is at point  $a$  with the number of vehicles per hour at  $ag$ . If road capacity is expanded, then marginal cost shifts from  $MC^b$  to  $MC^a$  and average cost shifts from  $AC^b$  to  $AC^a$ . Without a toll, point  $j$  is the new equilibrium with price  $g$  and the number of vehicles per hour  $gj$ . With an efficient toll of  $cd$ , equilibrium is at point  $c$  and the number of vehicles per hour  $cg$ . The social gain is  $acde$ . This amount can be compared to the cost of improvement. If the social gain is greater than the costs of the road investment, the expansion can be justified.

### Spacial Models of Urban Cities with Congestion

Henderson (43) studies the spacial effects of congestion and the optimal city size in a partial equilibrium model. He compares the optimum size of a city characterized by the efficient pricing of congestion and optimal investment and financing of roads to a city size under a regime of gasoline tolls and inappropriate financing of road construction. The two city sizes are compared under the assumption that individual utility levels remain unchanged because labor is exogenously set. The model is a wedge shape of a circular city. Agents travel to the central business district on a common highway. Agents make two types of trips: work trips during the peak period and recreational trips during the off-peak period. Henderson defines the optimum city size as one where residents pay a congestion toll per mile and the toll varies with the low speeds near the central business district in the peak period, and the high speeds in the nonpeak period and near the city edge in the peak period. The toll is part of transportation expenditures affecting land rents. In the equilibrium city size there is no congestion toll, but a gasoline toll that is invariant to speed and time period. In this case, the toll affects transportation expenditures and rent determination. The difference between these two cases is that the former results in a lower price for people travelling during nonpeak times and raises prices for people travelling during peak hours. Also, the gasoline tax overcharges peak users near the edge of the city where road capacity relative to traffic volume is high. Finally, it undercharges users near the central business district. Equilibrium rents increase more rapidly when going towards the center of the city. Travellers at the city's edge hence pay a higher toll and greater transportation costs which increase land rents. This makes land and hence roads more expensive. The allocation of land to roads is lower causing the speeds of travel to fall. Thus, the equilibrium city size is less than the

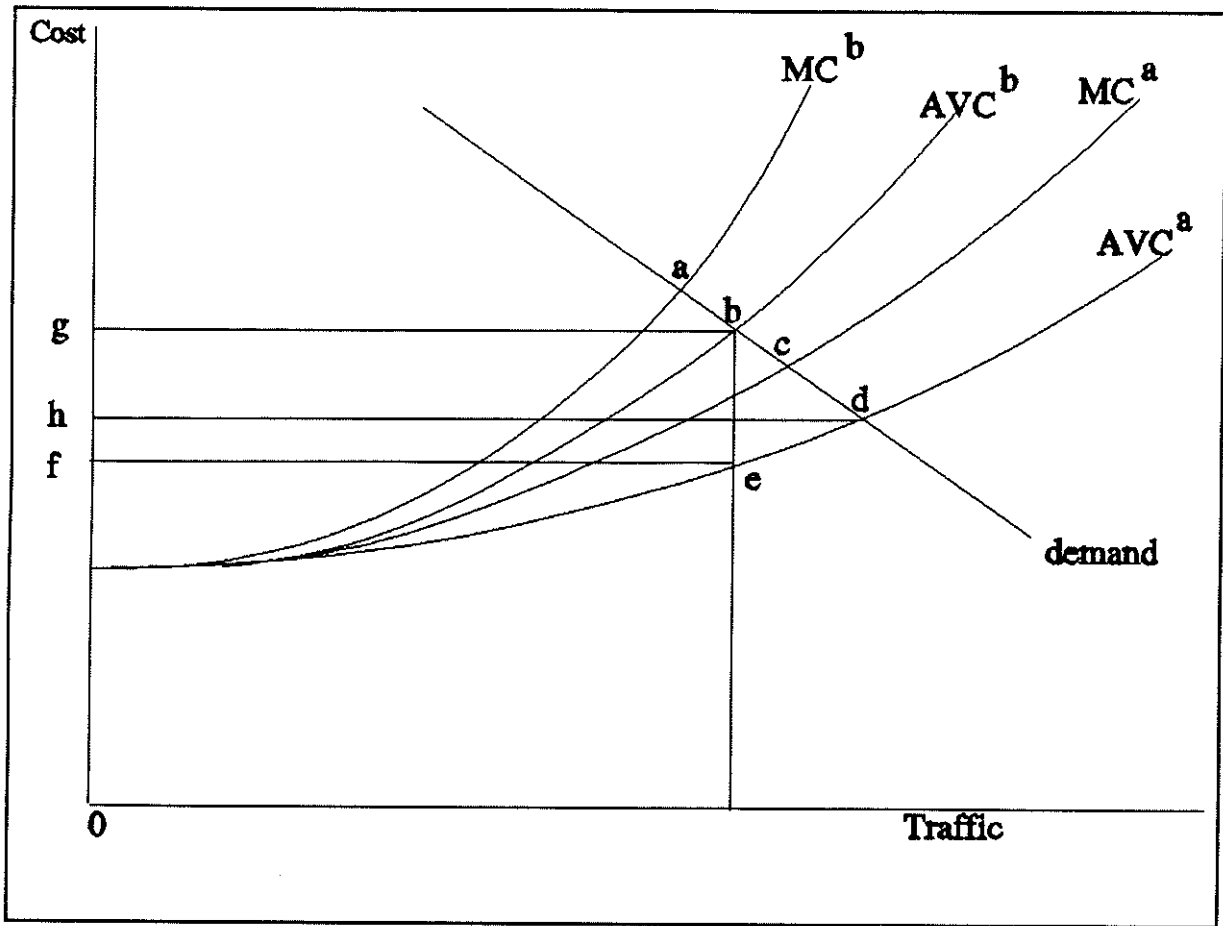


Figure 4-2. Benefit-Cost Analysis of Road Improvements

optimum city size.

Sullivan (44) analyzes congestion externalities in a general equilibrium model of land use. His work differs from previous authors e.g. Henderson (43), and Arnott and McKinnon (45) by making both the spacial distribution of labor supply and demand endogenous. Previously labor demand was assumed to be exogenous. The model consists of a monocentric city with a central business district and a residential district. The city produces an export good with capital, labor and land. The city is centered on an export node in which all export output passes. Land is allocated among three users: an export industry, a residential sector and the transportation system. Each house has a single laborer who commutes from home to work. The price of housing and labor supply varies spatially, compensating residents who incur large commuting expenses with lower housing prices and higher wages. The cost of the radial transportation system is paid by taxes. Sullivan considers two cases. First the city is closed with perfect

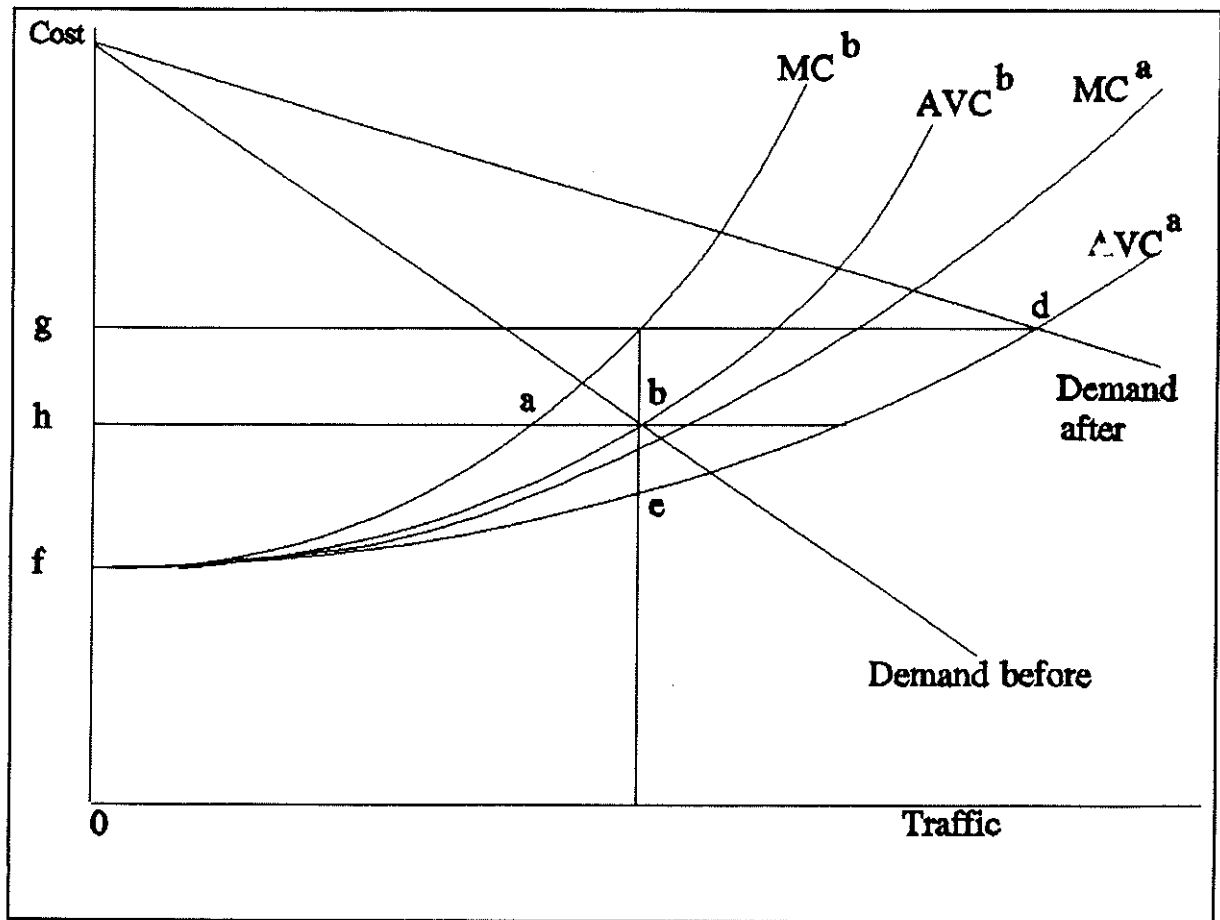


Figure 4-3. Perverse Road Improvements

immobility. That is, the population of the city is exogenous and the utility level of the residents is exogenous. Second, the city is open with perfect mobility. In this case, the city size is endogenous and utility is exogenous.

The previous literature showed that the equilibrium distribution of residences is more dispersed than the optimum distribution because congestion externalities cause transportation to be underpriced and residents to commute long distances. Congestion externalities distort the price of urban land causing the market price of land to be less than its opportunity cost. This results in roads being too wide. Also, internalization of congestion externalities generates trivial welfare gains. Sullivan's results differ from the previous results. He finds the equilibrium distribution of employment is more centralized than the optimum distribution. Internalizing the congestion externalities generates large efficiency gains. They equal 1.91% of income versus 0.068% in Arnott and MacKinnon (45). The reason for the efficiency gain is due to the demand sector

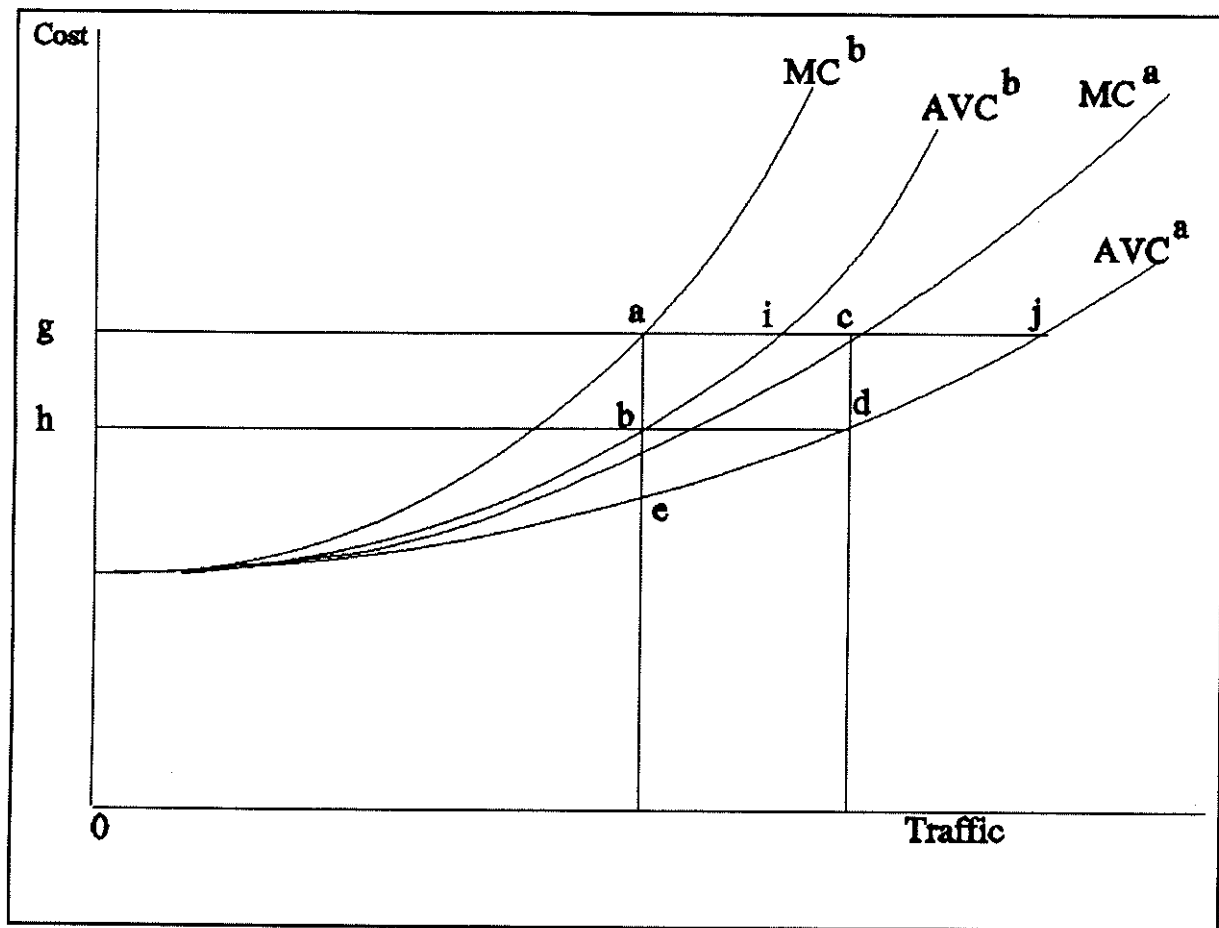


Figure 4-4. Road Improvements with Congestion Charges

being endogenous in the model. The relative price of labor rises causing output per laborer to rise. In a city with a fixed population, aggregate output rises and average production costs fall. In the open city model case, the congestion-toll policy causes the city population to increase.

Sullivan (46) extends his previous paper (44) to examine the efficiency of several second best policies. The paper focuses on the gross efficiency gains. This is the gain before administrative cost is subtracted out. Three policies are analyzed: land zoning, commuter gas taxes and modification to the radial transportation system. The zoning policy is based on two actions by the planner. First, the planner classifies the ring as either industrial or residential. Second, the planner specifies input ratios for the ring. For each industrial ring, the capital:labor, capital:land and labor:land ratios are specified. For each residential ring, the capital:land ratio is specified. Under this scheme, the planner regulates quantities of inputs, whereas under a congestion pricing

scheme, the planner regulates the prices of inputs. A unit tax on commuting is meant to represent a gasoline tax. The tax is a constant per-radial mile traveled and unlike congestion tolls, the tax does not vary spatially. The welfare gain from the land zoning scheme is \$3.38 versus a \$3.78 welfare gain from a congestion toll. The commuter gas tax has a welfare gain of \$1.15. But the transportation modification plan has a welfare loss. The relative welfare gain of each policy is dependent on the extent each policy influences the model. The way the model is set up, the only efficiency losses from congestion externalities occur in the spacial distributions of employment and residence. For this reason, congestion pricing and zoning reduce the congestion externalities. However, if the model included alternative travel modes or allowed travelers to choose the number of trips per week, model choice and trip frequency would be distorted. Zoning policy will not correct these distortions. A unit gas tax falls short of the optimal amount in the CBD, but it exceeds the optimal amount in the outlying areas. The unit tax is inefficient because congestion externalities vary spatially and the unit tax does not. Modification to the transportation system has only a minor impact on the spacial distribution because it does not influence the spacial distribution of employment and residence very much.

Kraus (47) estimates the welfare gains under different congestion pricing regimes. The three regimes are a higher gasoline tax, automatic vehicle identification and on-vehicle meters. He chooses these regimes because they are technically available for practical use. The model is a Mohring-Muth type model of household choice with exogenous rates of time valuation. The city is shaped as a wedge and is divided into three areas: central business district, residential and agriculture. The CBD comprises the center of the city, followed by residential and then agriculture. The residential zone is divided into a large number of narrow rings. The rings are indexed from 1 through  $n$ , with ring 1 closest to the CBD. The model consists of a monocentric city where workers can commute by car or bus. The work trips are made during an exogenous peak travel period. Bus service is provided at the middle of each ring. During the off-peak hours, agents make non-work auto trips. Households have identical preferences. The base equilibrium is a gasoline tax. In the AVI scheme, drivers are charged for entry into each concentric circular zone. The charge can be differentiated by time and day. In the on-vehicle metering regime, the base meters are mounted on autos. For each priced zone, there is a time rate of charge which can vary only by the time of day.

The advantage of regimes two and three is that the tolls can be varied by time and day. The paper considers two subcases: central and noncentral employment. In addition the model is further divided into two subcases where the costs of bus transportation must be met by sufficient taxation and where the fare is constrained to be positive. Only the combination of central employment and bus receipts exceeding transportation costs will be considered here. The results are shown in Table 4-2. In the first case, a gas tax regime results in a \$.87 tax and a \$2.44 headway for buses as an optimal policy. It results in a \$58.59 welfare gain per household. A one-zone AVI has an optimal charge of \$1.06 with an \$2.67 minute headway. The cordon in this case is placed at the inner boundary

**Table 4-2 Welfare Results of Gasoline, AVI and On-board Metering Systems**

	Bus head-way	Fare	Fraction commuting by auto	Ring one auto speed	Ring one bus occupancy	Welfare gain per household (\$)	Transact. costs per household (\$)	Gross benefits per household (\$)
<b>Base parameter values</b>								
Base equilibrium	2.17	0	0.241	21.14	58.61			
Gas tax regime	2.44	0	0.146	24.96	74.26	58.59		58.59
One zone AVI	2.67	0	0.103	26.13	85.44	81.86	3.78	85.64
Two zone AVI	2.69	0	0.106	26.07	85.50	81.35	5.17	86.52
Metering regime	2.70	0	0.109	26.00	85.56	85.89	0.74	86.63
Pareto optimum	2.71	0	0.111	25.97	85.76	86.77		86.77
<b>10% Reduction in S</b>								
Base equilibrium	1.94	0	0.236	19.92	58.61			
Gas tax regime	2.21	0	0.130	24.85	76.17	83.82		83.82
One zone AVI	2.45	0	0.085	26.21	88.67	115.18	3.35	118.53
Two zone AVI	2.46	0	0.090	26.10	88.46	114.81	4.63	119.44
Metering regime	2.46	0	0.093	26.04	88.21	118.93	0.66	119.59
Pareto optimum	2.46	0	0.094	26.02	88.41	119.74		119.74

Source: Kraus (47).

of any of the first 15 rings. The fraction of commuters commuting is 57% less than the base case and 29% less than the gas tax regime. The welfare gain is \$81.86. Including transportation costs, of \$3.75, the gross benefit is \$85.61. A two zone policy, with the inner cordon defined as the first 15 rings and the outer cordon of which is the inner boundary of the 42nd ring results in a daily charge of \$.084 per auto in the inner cordon and \$.34 in the outer cordon. The welfare gain is \$81.35 per household, compared with a \$81.86 under a one zone AVI. Thus, the optimal number of priced zones is one. A metering regime which begins on the inner boundary of ring 13 and extends to ring 44 which represents a meter zone extending from two miles outside the CBD to the midpoint of the residential zone has a welfare gain of \$4.03 higher than the single zone AVI regime. Thus, the metering regime gives the highest welfare gain and hence is closest to the pareto optimal welfare gain of \$86.77 per household.

### Comments on the Theoretical Soundness of Road Pricing

The debate over whether road pricing is theoretically sound or not has been largely over the issue of its distributional effects. Although road pricing may be an efficient mechanism of optimizing congestion, it may benefit the wealthy at the expense of the poor. In practice whether this will occur is difficult to determine because road



pricing affects different groups in different ways. This may involve personal value judgements, rather than pure economic analysis (48). Wealthy motorists are likely to benefit by paying the charge because they place a high marginal value on travel time savings. Middle income motorists will suffer because they cannot afford to pay the price and hence will divert to another, less preferred method of transportation. Poor public transport users will benefit from public transportation because the buses will now move more quickly and reliably on less congested streets.

Linked to the problem of the distributional affects of congestion pricing is what is to be done with the money collected from road pricing. In Figure 4-1, this is represented by rectangle *auvb*. There are several ways that the revenue could be spent, but each has serious problems (49). It may be returned directly to the motorists in the form of an income transfer. Depending upon the motorists relative elasticities, an income transfer may induce them to purchase additional road use. The size of the additional purchase will be influenced by the relative price of other goods and especially the free price of rural roads. The funds may be used to build more roads, or subsidize public transport to provide better facilities to those priced off the roads. One problem with subsidizing public transport is that if marginal cost pricing is being used, then subsidies themselves will result in deadweight welfare losses.

Cohen analyzes the distributional effects of congestion pricing in a model where congestion is caused by a bottleneck. The model is similar to Vickery (41). Motorists commute along a given route which has a bottleneck. All motorists have preferred arrival times and choose their times of departure from home to minimize their private costs of travel. Included in this cost are scheduling costs of travelling at less desirable times. A queue develops when demand exceeds the capacity of the bottleneck. An efficient policy imposes a smooth toll which eliminates the queue. Distributional effects are incorporated into the model by assuming two groups of commuters with nonidentical time values and preferences. Commuters differ in their relative and absolute values of time. Commuters in group one earn higher wages than commuters in group two. The groups are otherwise identically equal in their characteristics. Thus, the opportunity cost per person hour of commuting is higher for group one relative to the other and the individual's opportunity cost is an increasing function of the wage rate.

The model shows that when the toll is imposed that all commuters gain in net terms once the toll revenues are distributed uniformly to them in lump sum form. But that this is not the case for the individual groups. The higher wage group is generally made better off with paying tolls than before, even if they gain nothing from the redistributed toll. Low income commuters break even at best, and in some cases are made worse off by paying the tolls.

One serious objection of road pricing is from the implicit assumption that marginal social cost pricing is the correct pricing principle to apply. Marginal social cost pricing is only strictly appropriate provided that it is practiced in all other sectors of the

economy. For example, if public transportation fares exceeded their marginal cost, the marginal social cost pricing of private car traffic is likely to have little impact on traffic volume. Also, since people tend to departmentalize their consumption decisions, it may be that marginal cost pricing needs to be employed in sectors offering direct substitutes or complements to car travel.

## EMPIRICAL ESTIMATES OF CONGESTION CHARGES

### Cost Benefit Analysis in Hong Kong

Chapter 2 of this report contains the historical, financial and implementation issues surrounding road pricing in Hong Kong. This section examines the relative cost benefits of the original three schemes that were considered for Hong Kong. It also examines relative cost benefits of using an area licensing scheme in Hong Kong. The information for this analysis largely comes from Hau (11).

The net benefits of the three cases can be compared to the car restraint ownership policy and the theoretical optimal case of road pricing. The net benefits of implementing marginal cost pricing is derived from the savings in resource costs due to higher speeds and reduced operating and time costs, minus the reduced benefits of the travellers who are tolled off the road. The aggregate net benefits are calculated by adding together all time periods and all modes throughout the road network. Values of time are estimated by a logit model. The aggregate net benefits of introducing road pricing is HK\$1.25 billion annually. The simulations show that cases A, B and C achieve 59%, 70% and 74% of the net benefits of HK\$1.25 billion using the optimal pricing scheme. With the exemption of taxis, the net benefits largely accrues to public transport users in the form of increases in transit revenues. This is true for all cases. The optimal congestion cost is estimated to be HK\$10.5 in 1985. Details of the relative benefits and cost for the various schemes are shown in Table 4-3.

In 1985, the total capital cost for the system was estimated to be HK\$240 million. Half of this cost was to be used for the 210,000 electronic number plates that were to be installed at a price of HK\$460 million. Note that today, the price of a passive transponder is two-thirds of the 1985 price. Using a capital recovery factor of 0.125, the annualized capital cost is HK\$30 million and the annual operating cost is HK\$19.80 million. The annual benefit cost ratios are 14.7, 17.8, 17.8 and 24.1 for each of the three cases and the theoretical case.

Comparing electronic road pricing to the registration tax scheme imposed in 1983, electronic road pricing does relatively well. The registration tax policy had annual benefits of HK\$301 in 1985 which is about 25% of the theoretical optimum and half of Scheme A.

**Table 4-3. Results of Hong Kong Area Licensing and Electronic Road Pricing Schemes, Compared to 1991 Base (In Millions of 1985 Hong Kong Dollars)**

Option	Car ownership Restraint Measure	Area Licensing Scheme	ERP Scheme A	ERP Scheme B'	ERP Scheme C	Optimum Option
Average peak-hour charge	—	HK\$7.0	HK\$8.4	HK\$9.8	HK\$9.7	HK\$10.5
<b>Annual Benefits, B</b>						
Private Cars	-29 (-0.10)	124 (0.37)	202 (0.28)	235 (0.27)	216 (0.24)	279 (0.22)
Taxis	38 (0.13)	30 (0.09)	53 (0.07)	61 (0.07)	68 (0.07)	-21 (-0.2)
Public Transport	158 (0.52)	118 (0.35)	229 (0.41)	350 (0.40)	389 (0.42)	607 (0.49)
Goods vehicles	134 (0.45)	66 (0.19)	180 (0.25)	225 (0.26)	246 (0.27)	385 (0.31)
Benefits for All vehicles	301	338	734	871	919	1250
As a Share of the Benefits of the Theoretical Optimum	[0.24]	[0.27]	[0.59]	[0.70]	[0.74]	[1.00]
Gross Revenue Generated, R	1200	188	395	465	540	976
Annualized Capital and Operating Costs of Charging Mechanisms, C	0	10-15	49.8	49.0	51.7	> 51.7
Benefits less System Cost, NB = B - C	301	323-328	684	821	869	1200
Benefit/Cost Ratio, B/C	∞	22.5-33.8	14.7	17.8	17.8	<24.1
Revenue/Cost Ratio, R/C	∞	12.5-18.8	7.9	9.5	10.4	<18.9

**Note:**

HK\$7.8 + US\$1 and HK\$10.1 = £(1985 figures)

CPI (1990)/Cpi(1985 = 1.48 (Conversion factor using the Consumer Price Index for all items)

Figures in round parentheses are market shares.

\*ERP Scheme B is actually the Area Pricing proposal (with slight variation) simulated in Transport Department and Wilbur, Smith and Associates (1989).

Given that ERP Schemes A, B and C increase in complexity and zone-to-zone charge levels, the simulated peak-hour charges are by-products of the simulations. Benefits include the savings in travel time and operating cost of the tolled and the disbenefits of the tolled off, hence the term 'net benefits' was used in the following sources, when referring to these benefit figures. The net benefit figure used here nets out the cost of toll collection.

Source: Published by Hau (11).

The Singapore type area licensing scheme was tested and evaluated in 1985 for Hong Kong. A fee of HK\$47 was charged for vehicles crossing an entry/exit point that circles the central business district, which amounted to about HK\$20 each day in area licensing system (ALS) fees. The annual benefits amounted to HK\$338.4 million in 1985. This is approximately 27% of the theoretical optimum level of benefits and 46% of the benefits estimated by Scheme A.

The annual cost of a supplementary licensing scheme was estimated to take HK\$10-\$15 million in 1985. The annual benefit cost ratio for two separate cases (Hong Kong Island and Kowloon) under an area licensing scheme is 22.5 to 33.8. This exceeds the benefit-cost ratio of 25 for the theoretical optimal electronic road pricing system. If the benefits of time savings are ignored, and sensitivity analysis is performed, then the annual benefits for a license registration taxation scheme, ALS; and an ERP Scheme amount to HK\$18.8, HK\$56.3 and HK\$281.5 million respectively. That is, the monetary benefit-cost ratio for an ALS system rates from 3.8 to 5.6 and for ERP Scheme A, the benefit-cost ratio is 5.7.

Although ALS seems to be better than an ERP system, It has practical limitations which leads it to be ranked less than ERP. The cost per transaction is estimated to be HK7.0 to HK10.5 cents per transaction in 1985. Compared with the ERP Scheme, ALS is less costly. This is largely due to ALS's low capital requirements and recurrent costs. It has a benefit-cost ratio of 12.5 to 18.8. However, there is not a single cordon that exists to ring around the congested area of the central business district in Hong Kong which is needed for an ALS system. (But, there is one for Tsim Sha Tsui in Kowloon). Note that the ERP schemes have revenue to cost ratios of 8 to 10, whereas the theoretical optimum ERP yields a revenue-cost ratio of 19.

### **Congestion Pricing vs Revenue: The Oslo Case**

Chapter 2 of this report also contains the historical, financial and implementation issues surrounding road pricing in Oslo. Recall that the toll ring in Oslo was installed as a method to raise revenue, not as a congestion pricing scheme. This section looks at two issues studied by Larsen and Ramjerdi (50) and by Hau (11). The first is whether the system of 17 toll stations was worthwhile or not. That is, do the benefits of the system exceed the cost? Second, is it possible that a large fraction of benefits from road pricing could be achieved by imposing a toll during the peak hour only?

To estimate the benefits of the toll system, Larsen and Ramjerdi (51) use a simultaneous logit mode choice and traffic assignment model. They assume that trip timing, destination choice and location are fixed. Motorists entering the central business district do not have a feasible alternative route to bypass the toll. The trip matrices are separated into four time periods - the morning peak, the afternoon peak, the interpeak

and the offpeak. The choice of mode is private auto transportation or public transportation. The authors assume that the economic benefits of the Oslo toll system are based upon the savings in vehicle operating cost and the savings in time cost to the travelers who pay the toll minus the disbenefits to those whose trips are not undertaken. The savings in operating cost are measured by the savings in fuel consumption due to less engine idling time and stop-and-go traffic. The savings in time travel of the tolled less the welfare loss in consumer's surplus to those who are tolled off the road is shown to be less than the gross revenues of the project.

Table 4-4 and Table 4-5 show the estimates of the results. The present toll scheme uses a 24 hour flat toll throughout the year of NOK10 for light vehicles and NOK20 for heavy vehicles is non-optimal. During the peak period, the marginal external congestion cost of NOK35.60 exceeds the current 10 kroner toll. But during the interpeak and off peak periods, the current toll exceeds the marginal external cost of NOK3.80 and NOK1.40 respectively. The results in Table 4-4 show that by imposing a lower than optimal toll during the peak, positive benefits of NOK38.3 million occur. With a toll higher than the optimal one imposed during the interpeak and off-peak periods, negative benefits occur. The total annual benefits for all periods is NOK21.9 million.

Since the Oslo Toll Ring employs manual and electronic toll collection, the lane capacity is about 800 vehicles per hour. The delay caused by the stop and manual toll payment of 600,000 vehicle trips per week at 15 seconds per vehicle is taken into account. If a time value of money of NOK30 per hour and the average occupancy rate of 1.3 is assumed, then the aggregate annual delay at the toll plaza's is approximately NOK4.5 million. The estimated additional fuel cost from stop and go traffic is NOK0.4 million per year. Adding these costs to the cost of building the toll plazas of NOK96.6 million, the total net benefits are -NOK79.6 million per year. The benefit-cost ratio is 0.2. (See Table 4-5) This fails a cost benefit test. But from a revenue perspective, the adjusted annual toll revenues of NOK600 million produce a desirable 6.2 revenue-cost ratio.

The second question deals with whether or not a large fraction of benefits could be generated by imposing a toll during the peak period only. This is labeled the "Improved Scheme" in Tables 4-4 and 4-5. Larsen and Ramjerdi (51) estimate that an inbound toll rate into Oslo of about NOK29.5 would approximate the marginal external cost. Thus, the annual benefits amount to NOK95.2 million. Note that there are no benefits outside the peak period since the marginal congestion cost of traffic in these other periods is almost zero. The higher the benefits from imposing an improved 'optimal' cordon toll during the peak yields numerical benefits which are the same order as the cost of operating the present scheme. But, with the inbound peak period being the only toll, only two shifts of personal for a small period of time are needed, as compared to a round-the-clock staff for the existing situation. Thus, the cost of toll collection would be a lower amount of NOK70.0 million per year. The benefits after subtracting the cost of implementation is NOK20.3 million. The benefit-cost ratio is 1.3. Note that the toll

**Table 4-4. Estimated Benefits for Various Cordon Toll Schemes in Oslo, (in millions of 1990 Norwegian kroner)**

	Savings in Operating Cost	Savings in Travel Time	Welfare Loss of Surplus	Total Benefits
<b>Present Scheme</b>				
Peak Period	2.4	42.1	-6.3	38.3
Interpeak Period	0.2	5.0	-7.0	-1.7
Off-peak Period	0.4	5.3	-20.4	-14.7
All Periods	3.0	52.4	-33.6	21.9
<b>Improved Scheme</b>				
Peak Period	6.0	108.5	-19.4	95.2
Interpeak Period	0.0	0.0	0.0	0.0
Off-Peak Period	0.0	0.0	0.0	0.0
All Periods	6.0	108.5	-19.4	95.2
<b>Perfect Scheme</b>				
Peak Period	7.6	162.6	-19.3	150.9
Interpeak Period	0.0	0.0	0.0	0.0
Off-peak Period	0.0	0.0	0.0	0.0
All Periods	7.6	162.6	-19.3	150.9

Source: Published by Hau (11), pp.67-68.

revenue is less than one-third the revenue from the 24 hour toll scheme, but the revenue cost ratio is 2.6. The benefit-cost ratio has increased more than six times whereas the revenue cost ratio has decreased by 60%. Thus, the optimal social welfare toll does not necessarily enhance revenue. In the Oslo toll case, analyzed here, the optimal toll is two and one-half times more than the present toll, but yields two-thirds less revenue.

Instead of charging for entry into the central business district, charging for the marginal external cost that a motorist imposes on each link for a trip would represent almost a perfect road pricing system. This is labeled as the "Perfect Scheme in Tables 4-4 and 4-5. In this case, the benefits of road pricing increases by 60% from NOK85.2

**Table 4-5. Summary Results of Various Cordon Toll Schemes in Oslo, (in millions of 1990 Norwegian kroner)**

	Present Scheme	Improved Scheme	Perfect Scheme
Annual Toll Revenues, R	600.0	180.0	152.1
Annual Benefits, B	21.9	95.2	150.9
Stops at Manually-operated Tollgates	4.9	4.9	0.0
Annualized Cost of Toll Collection, C	96.6	70.0	>70.0
Benefits less System Cost, NB	-79.6	20.3	<80.9
Benefit-Cost Ratio, B/C	0.2	1.3	<2.2
Revenue-Costs Ratio, R/C	6.2	2.6	<2.2

Source: Published by Hau (11), pp.67-68.

for the single toll system to NOK150.9 million for a perfect road system. The large benefits are because of the avoided trips which would have caused high marginal external costs. Thus, the net benefits of the system increases to NOK80.9 million and the benefit cost ratio rose to 2.2. Revenues under the 'perfect' road pricing system fall from NOK180 million to NOK152.1 million and the revenue-cost ratio decreases to 2.2.

Several observations can be made regarding the relationship between toll revenue and welfare maximization. First, they may not be correlated; and in fact may move in opposite directions. The fear of government collecting high toll revenues as the system becomes perfectly priced is unjustified. Estimated benefits are just below estimated revenues, suggesting that a benefit maximizing road system is fairer than other schemes. Second, by imposing a peak period pricing program instead of a flat toll system in force at all times, there is a significant increase in benefit. Third, based on simulations, tolls for revenue financing purposes suggest that a lower toll should be used, while tolls based on congestion pricing suggests a higher toll.

## **Empirical Estimates of Energy Savings from Singapore**

In the economic literature, there is little empirical research on congestion as an energy conservation measure. A related article by Ang and Oh (52) studies the amount of energy saved in the Singapore from the Additional Registration Fee (ARF) imposed on vehicles in 1972 and also the Area Traffic Control System (ARC) installed in 1981. ARF is a tax on the open market value of the vehicle. The initial tax was 25 percent. The ATC system was implemented to coordinate the linkage of traffic signals. The ATC system resulted in a smoother traffic flow, fewer stops at traffic signals and lower fuel consumption per vehicle-km.

To estimate the effects of the ARF system on fuel savings, Ang and Oh estimate a least squares model with per capital car ownership as a function of per capita income, capital cost, running cost and total cost of car ownership for 1974-1986 on a semi-annual basis. The authors then project the car population under four different scenarios concerning the ARF rate:

- P1: 55 percent after January 1, 1974.
- P2: 100 percent after December 31, 1975.
- P3: 125 percent after February 28, 1978.
- P4: 150 percent after February 6, 1980.

In each projection, the rates prior to the date specified are assumed to be the same as those actually in effect. The projections are then compared to the actual car population to determine the change in car usage. With additional assumptions about average energy intensity for car use and average annual car milage they find that the energy savings of the various scenarios would amount from 1 percent to 8 percent. Specific values are found in Table 4-6.

## **Empirical Analysis of Road Pricing and the Optimal Toll**

Empirical studies on congestion pricing, i.e., the optimal congestion toll, can be grouped into four categories: short run, equilibrium short run, long run, and equilibrium long run. In the short run, existing capacity is taken as given. Thus, the problem is to find the optimal toll which generates the maximum net benefit for a given quantity of use. In the long run case, optimum road capacity and quantity of use are determined simultaneously when calculating the maximum net benefit of use. If the current capacity is less than the optimal capacity, then long run tolls will be less than short run tolls. A comparison of the findings of the articles reviewed here can be found in Table 4-7. The review in this section largely comes from Morrison (53).

Walters (54) was one of the first to study the magnitude of congestion tolls. His research indicates a 10-15 cents per mile toll for peak periods in congested areas and a



**Table 4-6. Estimates of Car Population and Energy Savings for Various ARF Rate Scenarios in Singapore**

Hypothetical Case	Percent Increase Projected Car Population	Percent Energy Saving in Road Transport
P1	127.5	8.0
P2	114.3	4.1
P3	108.4	2.5
P4	103.3	1.0

Source: Ang and Oh (52)

general urban fuel tax of 33 cents per gallon. In 1962, the Ministry of Transport in Great Britain produced the Smeed Report (55) which analyzes the economic aspects of road pricing. It argues that the best road pricing scheme is a system of direct road charging and that a peak period toll of 9 pence per mile (10 cents based of the exchange rates at the time) in urban areas would generate an increase in net benefits of £100-£150 million per year (\$280 - \$420 million). The report also studied, listed in decreasing desirability, were: daily licenses, a parking tax, a differential fuel tax and a poll tax on employees. In 1974, the Greater London Council (56) found that a central area license of 60 pence per auto per day (\$1.40) would reduce auto traffic entering Center London by 45 percent with net benefits of £32 million (\$75 million) per year.

Kraus, Mohring and Pinford (57) and Keeler and Small (58) analyze congestion pricing in a long run model. They argue that optimal highway capacity and hence congestion depends on the cost of adding capacity, which, in a long run analysis means that optimal tolls depend upon highway capacity cost. Kraus et. al. estimates that for a generic U.S. urban expressway ranging from 1.2 cents per mile to 2.6 cents per vehicle mile for a low capital cost expressway on the outskirts of a metropolitan area to 6.2 to 13.1 cents per vehicle mile for a high capital cost expressway adjacent to a central business district. The welfare gain would range from \$90 million to \$135 million depending on the assumptions. Keeler and Small use highway construction costs and speed flow relationships for the San Francisco Bay Area to estimate optimal congestion tolls. They find that peak period tolls range from 2.7 cents per vehicle mile for a rural-suburban freeway to a high of 34.3 cents per mile for a central city expressway. This assumes a 6 percent interest rate for the former and a 12 percent interest rate for the latter. Both assume a \$3.00 per hour value of time.

**Table 4-7. Results of Selected Studies**

Study	Application	Peak Toll*	Type <sup>b</sup>	Annual Welfare Change <sup>c</sup>
Walters (54)	generic U.S. urban expressway	10-15¢/auto-mile	SR	£100-150 million
Ministry of Transport (Smeed) (55)	urban areas in Great Britain	9 pence/auto-mile	SR	£32 million
Greater London Council (56)	Central London	60 pence/auto per day central area license	SR	\$90-1350 million for all U. S.
Kraus, Mohring, and Pinfold (57)	generic U.S. urban expressway, 1970	1.2-13.1¢/auto-mile	ELR	—
Keeler and Small (58)	San Francisco Bay Area Expressways, 1972	2.7-34.3¢/auto-mile	ELR	—
Deweese (59)	city streets in Toronto, 1973	4-38¢/auto-mile	SR	—
Viton (61)	San Francisco-Oakland Bay Bridge, 1972	15.4¢/auto-mile 24.8¢/bus-mile 33.1¢/truck-mile	ESR	—
Gomez-Ibanez and Fauth (62)	Boston, 1975	\$1.00/day downtown parking surcharge	ESR	\$23.8 million
		\$1.00/day area license, local streets only		\$20.5 million
		\$0.50/day area license, all streets and expressways		\$14.7 million
		\$0.50/vehicle existing toll surcharge		\$4.6 million
		auto-free zone		\$1.4 million

\*The range of tolls given reflects the effects of assumptions.

<sup>b</sup>SR = short run, ESR = equilibrium short run, LR = long run, ELR = equilibrium long run.

<sup>c</sup>—indicates welfare change not calculated

Source: Morrison, (53)

Deweese (59) argues that previous research, namely Mohring (60) and Smeed (55) improperly estimated the magnitude of congestion costs for two primary reasons. First, these studies calculated tolls as a function of traffic levels, but they gave limited importance to the various levels of traffic congestion. There is little empirical basis for identifying an appropriate average toll in a city over all streets and times. Second, there is little empirical basis for relating travel time to travel flow. Engineering studies used to determine the speed-flow relationship do not recognize the differences between rural

roads where relationships are predictable and urban streets where they are not, due to traffic signals, intersection spacing, etc.

As an alternative, Dewees replaces the speed-volume equations with a traffic simulation model that models the queuing of vehicles at traffic lights, the dispersion of vehicles as they move from one intersection to another and the interaction of intersecting traffic flows. The model is applied to actual Toronto road traffic on an urban street network to estimate congestion costs.

Dewees finds that the simulation results are not similar with those that would be estimated using the same traffic flows in single equation models such as Mohring and Smeed. Using Mohring's model, some of the marginal external time costs are infinite. Using Smeed's model, the costs, in general, are higher than in the simulated model's results. Table 4-8 gives the various estimates from Dewees, Mohring and Smeed's models.

Viton (61) analyzes the optimal congestion toll for the short run using an alternative approach. Viton calculates the toll using a binomial logit choice model (auto vs. bus). Also, he calculates tolls for buses and trucks because these vehicles are larger and accelerate more slowly than cars. He calculates auto tolls of 15.4 cents per mile, bus tolls of 24.8 cents per mile and truck tolls of 33.1 cents per mile during the peak period.

Gomez-Ibanez and Fauth (62) use a binomial logit model to study alternative auto restraint measures in Boston. A downtown parking surcharge of \$1.00 produced the largest annual net benefits of \$23.8 million. This amount was not very sensitive to the amount of the surcharge. A \$0.50 surcharge results in a \$19.0 million net benefit and a \$2.00 surcharge results in a \$23.2 million net benefit. A \$1.00 per day area license for local streets during peak periods yields a net benefit of \$20.5 million, whereas a license applied to all streets yields 14.7 million with a \$0.50 fee. A surcharge of existing toll facilities and a peak-period auto-free zone produced net benefits of \$4.6 million and \$1.4 million respectively.

Note that all of the studies mentioned above find that the optimal toll charges for peak period use were above the current charges. In addition, the net benefits were large. However, Borins' analysis (63) found that this result is not necessarily the case. He calculated the present discounted value of the net benefits based on a 40-year simulation of an expressway. The annualized welfare losses from non-optimal pricing range from \$15,000 for a 10 mile expressway to \$1.95 million for an expressway-subway combination. Borins' results differ from others in the literature because he starts from a point of no congestion and hence there is less gain from marginal cost pricing due to discounting over time. Since congestion occurs in the future, the discounted net benefits of adopting an efficient pricing policy are small. The papers mentioned above calculate the optimal toll and net benefits in a static framework and also assume that congestion is in the current period not the future.

**Table 4-8. Comparison of Estimated and Simulated Congestion Costs in Toronto**

Street	Speed (MPH)	Intersection Saturation		Private Avg. Cost	Marginal External time Cost (Vehicle-hours/Vehicle-mile)					
		Avg.	Max.		Smeed Equation			Mohring		
					Simulate d	Avg. v/c	Speed	Max. v/c	Avg. v/c	Max. v/c
<b>Inbound:</b>										
Leslie S.	7.38	92	159	0.136	0.38	0.68	1.05	∞	0.087	∞
Lawrence W.	17.71	68	104	0.056	0.12	0.063	0.053	∞	0.034	∞
Railside W.	15.31	57	85	0.065	0.074	0.040	0.054	0.29	0.025	0.065
Don Mills S.	11.64	80	137	0.086	0.14	0.15	0.24	∞	0.050	∞
Eglinton W.	18.32	92	107	0.055	0.14	0.68	0.046	∞	0.087	∞
Sheppard W.	22.27	42	67	0.045	0.000	0.016	0.018	0.059	0.016	0.033
Victoria Park S.	14.15	72	109	0.071	0.12	0.081	0.12	∞	0.038	∞
York Mills W.	20.91	69	81	0.048	0.005	0.067	0.025	0.16	0.035	0.033
<b>Outbound:</b>										
Leslie N.	27.90	40	72	0.036	0.001	0.014	0.028	0.081	0.015	0.038
Lawrence E.	19.38	60	96	0.052	0.017	0.040	0.036	2.0	0.027	0.11
Railside E.	17.27	53	97	0.058	0.028	0.033	0.032	3.7	0.022	0.12
Don Mills N.	16.28	47	116	0.061	0.095	0.020	0.074	∞	0.018	∞
Eglinton E.	26.92	64	76	0.037	0.0001	0.049	0.0045	0.11	0.030	0.044
Sheppard E.	23.89	45	62	0.042	0.006	0.018	0.012	0.044	0.017	0.028
Victoria Park N.	17.74	59	82	0.056	0.009	0.037	0.052	0.18	0.026	0.056
York Mills E.	19.58	45	90	0.051	0.006	0.018	0.034	0.47	0.017	0.080

Source: Dewees (59), p. 1508.

Devany and Saving (64) incorporate uncertainty into their theoretical model of highway pricing and investment in the form of random demand. As with conventional theory, (i.e. when there is no uncertainty in the model), optimal prices equal (expected) marginal cost and the sum of all congestion tolls equals capacity cost (assuming constant returns to scale in highway construction). The difference from conventional theory is that under uncertainty a positive probability of a traffic jam exists because expected traffic flow is less than capacity, where in the certainty case a traffic jam cannot occur.

Kraus (65) incorporates uncertainty into a traffic model by assuming that the demand function itself is nonstochastic, but depends upon a parameter that is unknown to highway planners who must determine the optimal toll and capacity. This results in a larger optimal capacity than would be expected for the demand. The effect of a toll varies in direction and is usually smaller in magnitude than the effect in capacity. Kraus estimates that uncertainty results in a 7.1 percent increase in optimal capacity and a 1.6

percent reduction in the optimal toll. He also estimates that the welfare loss of basing capacity and tolls on their mean uncertainty values is approximately \$220 million.

Another related area of empirical research is the specification and estimation of speed-flow curves. Typically the analysis assumes that highway capacity is infinitely divisible. Kraus (66) examines this issues by studying the effect of indivisible highway capacity on optimal tolls. He finds that for a generic US expressway, with infinitely divisible capacity, that the optimal toll would be 8.9 cents per vehicle mile. Incorporating indivisibilities results in tolls lying between 5.8 to 11.2 cents per vehicle mile. Thus, by failing to incorporate indivisibilities can result in substantial errors in calculating the optimal toll.

Broadman and Lave (67) analyze the estimation of speed-flow curves. Previous analyses based their estimates on aggregate speed-flow data. Broadman and Lave use individual vehicles as the units of analysis. This allows them to capture information that is lost due to aggregation. They find that the model fits better when the flow variable is based on six to twenty minute time intervals around the observed vehicle.

Inman (68) also focused on estimating speed-flows. He formulates a method called general congestion function (GCF) to estimate speed-flow relationships. The method assumes that the most commonly used speed-flow relationships are special cases. Assuming that GCF is correct, and comparing it to the standard quadratic approximation, he finds that the quadratic overestimates the optimal toll for low traffic volumes and underestimates tolls for high traffic volumes. He estimates that this misspecification would result in a net loss of benefits of approximately \$1 million dollars per year for the Washington DC area.

### **Congestion tolls with HOV lanes**

Most of the economic research literature on optimal congestion pricing focuses on the entire highway with uniform pricing for all of the lanes. Thus, there are not previous models and research upon which to draw from in the case of a highway system with an HOV lane. To get around this problem, this research starts with the standard optimal congestion pricing problem and adapts it to a situation where there are lanes set aside for HOV.

Given its general applicability acceptance in the economic literature, this analysis follows Keeler and Small (58) and uses there total cost curve to estimate the optimal toll and elasticity. Keeler and Small's cost curve is based on an speed-flow data collected from the San Francisco Bay area. The average cost curve is:

$$C = V (46 + (471 - 0.26X)^{-0.5}) \quad (6)$$

where X is the hourly flow of vehicles and V is the wage rate. In this analysis, X ranges from 1,200 to 2,000 and V=\$9.75.

Using equation (5), the optimal toll is:

$$r = .13VX [471 - 0.26X]^{-0.5} (46 + [471 - 0.26X]^{0.5})^{-2} \quad (7)$$

Table 4-9 shows the optimal tolls for a traffic range of 1000 vehicles per hour to 2000 vehicles per hour. The calculations assume a value of time of \$9.75 per hour. Also, the maximum traffic flow per hour is 2,000 and the base number of vehicles per hour on the HOV lane is 884.

To estimate the effect of optimally pricing and HOV lane, assume that the difference between the maximum traffic flow per hour and the flow in column two represents the additional number of drivers willing to pay the toll to use the HOV. Adding the base level to this number gives the total number of vehicles per hour in the HOV lane in column 3.

For example a toll of \$0.20 per mile has a flow of 1738.8 vehicles per hour and a residual level of 261.2. Adding 261.2 to the base level of 884 gives the total number of vehicles on the HOV lane of 1145.2.

**Table 4-9. Optimal Toll and HOV Vehicle Estimates for a Range of Vehicle Flows**

Optimal Toll	Highway Flow in Vehicles per hour with Toll	Vehicle Overflow to HOV Lane	Estimated HOV Vehicle Flow per Hour
0.04	1263.9	736.1	1620.1
0.06	1442.8	557.2	1441.2
0.08	1546.2	453.8	1337.8
0.10	1611.4	388.6	1272.6
0.12	1655.3	344.7	1228.7
0.14	1686.2	313.8	1197.8
0.16	1708.7	291.3	1175.3
0.18	1725.7	274.3	1158.3
0.20	1738.8	261.2	1145.2
0.22	1749.2	250.8	1134.8
0.24	1757.5	242.5	1126.5
0.26	1764.2	235.8	1119.8
0.28	1769.7	230.3	1114.3
0.30	1774.4	225.6	1109.6
0.32	1778.3	221.7	1105.7
0.34	1781.6	218.4	1102.4
0.36	1784.4	215.6	1099.6
0.38	1786.9	213.1	1097.1
0.40	1789.0	211.0	1095.0
0.42	1790.9	209.1	1093.1
0.44	1792.6	207.4	1091.4
0.46	1794.0	206.0	1090.0

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CHAPTER 5  
**OPERATIONAL FEASIBILITY**

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Previous attempts at implementing a congestion pricing program have been curtailed in part due to the operational barricades. The idea of requiring vehicles to stop and pay at toll plazas negated the benefit of a time savings. However, toll collection technology has advanced to a point where stopping of the vehicle is no longer required. Although technology does not make policy, technological advances can make more types of congestion pricing techniques feasible and easier to implement than ever before. Presented in this chapter are toll collection technologies and methods used by several United States toll facilities.

### TOLL COLLECTION

There are two methods to charging for roadway usage, indirect and direct (11). The indirect method involves charging for a surrogate of usage such as vehicle ownership. Other forms of indirect charging could be a fuel tax, tax on tires, and/or parking charge. Direct charging involves charging at toll sites or identifying the vehicle automatically and debiting an account.

#### **Indirect Charging Mechanisms**

Congestion is a problem that most urbanized areas experience. Therefore, most everything in the market place can be either directly or indirectly associated with transportation. The movement of people and goods is the prime objective of any transportation system. Because so much of our lives revolve around transportation, there are many possibilities to charge indirectly for congestion on the roadways. For the purpose of this report, four indirect charging mechanisms are addressed; vehicle tax, fuel tax, parking charges, and supplementary licensing.

#### *Acquisition/Purchase Tax*

As a method of charging for congestion, countries such as Korea and Hong Kong have instituted a tax on the acquisition/purchase of a vehicle, due to the severity of their traffic congestion. This type of charging mechanism is effective in reducing the overall number of vehicles in the community/country. However, as Hau points out, it is not an effective congestion management program because it affects all vehicles, urban and rural, and not just areas where high congestion occurs (11).



### *Fuel Tax*

Countries such as the United Kingdom and parts of Europe have levied a combination of a high annual entry fee and a fuel tax. This method of congestion pricing is regarded as marginally effective because the fuel tax is broad-based and not specific to the problem (i.e., unable to differentiate between peak and off-peak periods in congested and uncongested areas), therefore this method is not used very often.

### *Parking Tax*

Probably the most popular mechanisms for indirectly charging for congestion is the parking charge on "free" public space. Some cities, such as Washington, D.C. and San Francisco, institute a parking charge for side-street public parking. In theory, and ideally, for parking charges to effectively reduce congestion, they should be time-of-day and/or location-dependent charges. In other words, the farther away the parking space is from the central business area, the lower the price to park. In addition, the price to park will vary by the time of day. At present, parking rates are market-determined, with a locational monopoly element. Research has shown that effective congestion management by use of a parking tax requires the municipality to control a large fraction of both on-street and off-street parking lots (11). Empirical case studies of employer-subsidized parking show that parking subsidies induce solo driving, and decrease carpooling and public transport use (11, 69, 70).

### *Supplementary Licensing*

Supplementary licensing (also known as area licensing), is an indirect means to charge by place and time. In principle, supplementary licensing requires that traffic moving within the designated area, such as the central business district, be charged for admission during certain (peak) hours. Normally, pre-purchased stickers are displayed behind the windshield of the vehicles. The stickers represent a daily license or a monthly license and can be purchased at sales outlets such as post offices. In practice, a cordon line is established where each vehicle that passes that cordon line must possess the sticker or pay a penalty. Traffic wardens monitor each vehicle and records the license plate of vehicles without proper license permits. The most successful congestion pricing program to use supplementary licensing is the Singapore Area Licensing program. In the case of Singapore, two or three traffic wardens are required to handle one station or gantry. For ease of enforcement, stickers vary by shape and color to differentiate the days on which they are to be used. It is possible to vary charges by more than one time period or zone, by a combination of two different stickers.

Timothy Hau, at The World Bank, has studied the supplementary licensing program used in Singapore (11). In his studies, he found two primary advantages to this congestion pricing scheme. First, traffic is allowed non-stop passage into the controlled

area. And second, supplementary licensing cost are relatively low to implement. This scheme requires little capital outlay. Hau found that for supplementary licensing to be cost-effective, the number of entry and exit points must be kept to a manageable figure. Because operating costs involve only printing costs, the hiring of traffic wardens, and electricity, it is especially suitable as a short-term demonstration projects to test its feasibility in a small but congested city due to its reversible and flexible nature.

The disadvantages of this scheme are the abrupt changes in the designated zone boundary and changes in control by time of day. Hau reports that the parking charge can be set to taper off towards both the edge of the business district (or city) and the end of the rush hour (11).

### **Direct Charging Mechanisms**

The other mechanism for toll collection is direct charging. Direct charging for congestion involves charging at the place of congestion (point pricing) and/or duration pricing (continuous pricing) of congestion. Point pricing refers to the pricing of a vehicle when it passes a charging point, such as a toll site; whereas, continuous pricing involves clocking a vehicle for the time spent or distance covered between two charging points. Typically, toll-roads use off-vehicle techniques to collect fees for the use of the roadway at specific points. There are on-vehicle techniques, such as toll tags to charge vehicles for the duration of travel.

Charging vehicles for roadway usage via off-vehicle methods typically involves either a manual charging system such as tollgates or reserved lanes, or automatic scanning via automatic vehicle identification (AVI) technology, or a combination of manual and automatic scanning of vehicles. The use of tollgates (toll booths) is an established, relatively straight forward technology that is publicly accepted for toll roads, bridges, and tunnels. In addition, it is a politically palatable method of collecting tolls.

The major disadvantage to the tollgate technology for collection of user charges is the stop-and-go traffic. This results in low vehicle throughput and increased travel time by requiring vehicles to stop and pay the toll. Empirical data from existing toll roads in California, Florida and Texas indicate that about 350-500 vehicles per hour can pass through a toll lane (71, 28). Typically, six toll booths are required for each expressway lane approaching the toll facility. This problem in itself requires large land parcels to be acquired, which increases start-up capital costs. Pietrzyk (71) at the University of South Florida estimates that average running (the speed maintained once a vehicle first stops or slows down while approaching the toll lane queue through the point of being processed at the toll plaza) for a manual lane is about 2.5 mph.

## *Automatic Vehicle Identification*

The second mechanism of directly charging for congestion on an off-vehicle recording basis is automatic scanning via automatic vehicle identification (AVI). Automatic vehicle identification refers to techniques that uniquely identify vehicles as they pass specific points along a facility, without requiring any action by the driver. As with manual charging, this method of toll collection is considered to be point charging because vehicles are charged when they pass an electronic reader known as an interrogator.

AVI was first developed and tested in the late 1950's and early 1960's. It was upon the instigation of the American Association of Railroads that AVI technology was originally pioneered for the purpose of tracking railroad boxcars in the early 1960's. As early as 1963, the Port Authority of New York and New Jersey supported the development of AVI technology (72). Now, AVI technology is widely used in the rail transportation and inter-modal (shipping and trucking) transportation. The toll road industry is the newest recipient of this emerging technology. The first toll agency in the United States to use AVI technology for electronic toll collection was the Dallas North Tollway in Dallas, Texas in July 1989. Now there are many toll facilities throughout the United States, European, and Asian communities that have instigated, evaluated, and/or implemented electronic toll collection through AVI.

Currently, there are various technologies available that institute AVI. However, common to all AVI systems are three basic functional elements: a vehicle-mounted transponder (or toll tag), an adjacent reader antenna, and a master computer system for the processing and storage of data. The AVI process is relatively simple and works as follows: An antenna is placed overhead or adjacent to the roadway lane(s), such as a sign post or gantry. The antenna's reader broadcasts a radio frequency towards a transponder placed in the vehicle. The AVI tag 'modulates' the radio frequency which it receives and reflects its encrypted identification code back to the antenna which is then relayed back to the reader. The reader's function is to interpret the identification code from the signal, decrypt it and validate the code according to predefined criteria. If the security check verifies that a transponder is valid and a motorist's account is fine, an indicator light by the roadside would turn green. A yellow light may indicate that a user's account is low, and a red light would indicate that a defective or fraudulent tag is being used, at which time a video enforcement system automatically takes a picture of the offending vehicle. The reader then transmits the data to a central computer system --- composed of a system of commonly used microcomputers and a minicomputer --- which records information such as the identification code, the location, date, time, or the vehicle class code and performs off-vehicle charging either by prepayment or post-payment.

A motorist can choose to pay in advance or terms of credit. For prepayment, a user's account can be linked to a bank account and a pre-specified sum of money is

deducted periodically via electronic fund transfer. Currently in the United States and Europe, prepayment accounts can be set up by placing a prepaid cash deposit in advance, as a numbered account arrangement, thus protecting the individual's privacy. For post-payment, conventional monthly or quarterly billing statements can be automatically sent out to the user and paid in a regular straightforward manner. Currently, numerous toll-roads, turnpikes, bridges and tunnels use AVI technology to collect road user charges.

Although the AVI technology development is rapidly advancing on a daily basis due to the large number of defense related technology (hardware and software) being converted to civilian use, they typically fall into one (or more) of five types of AVI technology. The five types of AVI technology currently being developed and implemented around the world are:

- Optical and infra-red systems;
- Inductive loop systems;
- Radio frequency and microwave systems;
- Surface acoustical wave systems; and,
- Smart card systems.

Michael Peitryk, at the University of South Florida Center for Urban Transportation Research (CUTR) has studied over 30 manufacturers of AVI technology (73). The following description and comments on AVI technology are taken from his studies and research findings.

#### *Optical/Infrared Technology*

Optical/infrared technology is an optical system that employs a vehicle tag, simply a bar coded decal sticker. A laser scans continuously over the area where the tag is expected to be and the reflected signal is processed to extract the code which uniquely identifies the vehicle. Pietrzyk reports the advantages to this type of system are: 1) very simple vehicle tag (bar code imprinted on a plastic card); 2) low potential for lane-to-lane interference due to limited range; and 3) relatively fast speed compared to other optical systems that read license plates. The major disadvantage to optical systems is that they are not fully reliable especially under poor visibility or harsh weather conditions such as snow, ice or fog.

#### *Inductive Loop Technology*

Inductive Loop technology uses a loop antenna imbedded beneath the surface of the roadway to communicate with a tag mounted on the underside of the vehicle. The antenna sends out an interrogation signal and the tag responds by returning a signal that is modulated according to the data stored in the tag. Pietrzyk reports that the advantages of this type of system are: 1) potential for greater reliability due to close

proximity of loop antenna and tag; 2) very low potential for electrical interference; and 3) low potential for interference from adjacent lanes due to short coupling range. The disadvantages of an inductively coupled system are: 1) low frequency (i.e., lower maximum data rate); 2) larger and more complex vehicle tags; and 3) tag usually requires power from vehicle. There seems to be some controversy as to whether the inductive loop system is affected by outside interference. Although Pietrzyk states the inductive loop has very low potential for electrical interference, a test carried out by California' Department of Transportation (74) showed the inductive loop adversely affected by the steel-reinforcement inside the pavements. Despite the stated problems with inductive loop systems, these systems have been used for automatic bus identification in the United States, Europe and Australia (75).

### *Radio Frequency/Microwave Technology*

The radio frequency (RF) transmission (or microwave technology) are presently the most popular and widely used AVI technology. Radio frequency AVI systems employ microwave frequencies to communicate to and from the vehicle. All microwave systems have high data rates which allow multiple transmissions, thus increased reliability and security. These systems may be divided into groups categorized by the way the tag generates its microwave signal (active tag) and those in which the tag simply reflects the microwave signal that it receives (passive tag). Active tags require a power source (battery or connection to the vehicle power) while passive tags may or may not require a power source.

Microwave systems may also be divided according to the method used to store data in the tag. The codes that identify a vehicle may be stored in an integrated circuit memory or may be programmable.

In an active vehicle tag system, the transmitter at the tollbooth sends out a very short interrogation signal which triggers the circuitry in the tag. The tag responds by generating a microwave signal that is modulated with the data stored in the tag. This signal is transmitted to a receiver at the tollbooth which decodes the data and sends it to a computer for identification. Pietrzyk reports that the advantages of the active vehicle tag system are: 1) greater operating range than a passive system since the tag is not powered by the interrogating beam; 2) greater reliability than a passive system since the return signal from the vehicle is much shorter; and 3) less chance of electrical interference since the signals are stronger. The disadvantages of an active vehicle tag are: 1) greater complexity in the tag circuitry; 2) greater probability of lane to lane interference due to stronger signal; and 3) the tag must have a battery or be connected to the vehicle for its power.

In a system that employs a passive vehicle tag, the transmitter at the tollbooth must transmit a signal continuously. This signal is intercepted by the tag and reflected to a receiver at the tollbooth. The amount of reflection is varied (modulated) according

to the data stored in the tag. The received signal is decoded to recover the data, which is sent to a computer for identification. Pietrzyk reports that the advantages of a passive vehicle tag system are: 1) the tag does not require a battery; 2) the tag is less complex than the active tag; and 3) reduced chance of lane to lane interference due to the lower signal power levels. The disadvantages of a passive vehicle tag system are: 1) lower reliability than an active system; 2) greater susceptibility to electrical interference due to lower signal levels; 3) shorter operating range since the tag is powered by the interrogating beam; and 4) the overall level of microwave radiation is higher.

### *Surface Acoustical Wave Technology*

Within the system of radio frequency technology there are systems that operate at very low frequencies, commonly referred to as surface acoustic wave (SAW) technology. Surface acoustical wave (SAW) technology is similar to the RF in that it operates with a microwave frequency. However, under this system, a low power radio frequency signal from the reader is captured by the transponder antenna, which energizes a lithium crystal, setting up an acoustical wave along its surface. The surface acoustic wave (SAW) technology is widely used on AVI equipped toll roads in Norway. Pietrzyk reports the advantages of using the SAW device to store data in the vehicle tag are: 1) it is virtually impossible to duplicate the vehicle tag; and 2) the tag circuitry is much simpler. The disadvantage of using the SAW device is its limited operating range (up to 15 feet) since it is normally part of a passive system.

### *Smart Card Technology*

As mentioned previously, the integrated circuitry can possess a programmable capability (or read/write capability). This type of technology and the vehicle tag is sometimes referred to as a smart card technology. The smart card technology is the newest technology on the market. Basically, this technology is based on a two-way communication link between a 'smart' on-board unit and a roadside antenna. An on-board unit is composed of a smart card, a smart card reader and a transponder. The smart card's integrated circuit is similar to that found in the radio frequency tags. However, the smart transponder possesses a microprocessor which has both read and write capability. Hence, the smart transponder is able to maintain a transaction balance independent of a central computer and can perform simple arithmetic operations when activated, acquiring the function of an electronic purse. The prime advantage of smart card AVI technology is that it obviates the need to maintain a costly central charging system capable of handling all the separate user accounts. The chief disadvantages of smart cards are that they require complex vehicle to roadside communications and that multi-lane problems still need to be overcome entirely. The use of smart cards for AVI, despite their higher cost as compared to microwave AVI, may be integrated with the growing use of smart cards in several banking systems in Europe and the AT&T telephone communication system here in the United States.

## ADVANTAGES OF ELECTRONIC TOLL COLLECTION

The advantages of electronic toll collection as compared to manual toll collection are many. Vehicles do not have to slow down, form queues and create congestion because of the transactions cost of manual toll collection. Vehicles can travel at the desired speed, with instantaneous debiting of accounts being undertaken at reliability and accuracy levels exceeding 99.9% (76, 77, 78).

The nonstop traffic results in smooth traffic flow and high vehicle throughput of 1,200 to 2,000 vehicles per hour per lane. An AVI toll lane can process approximately three times the amount of vehicles as a manual toll lane. Additional benefits of nonstop traffic is reduced fuel consumption, risk of accidents, and polluting emissions.

The operation and maintenance of an AVI toll facility cost less than manual toll facilities. An ordinary cash ticket machine, excluding the computer linked facilities, costs approximately \$60,000. It is a mechanical device, and as such is costly to maintain. By comparison, an interrogation system comprised of three antennae, an electronic box, and computerization costs approximately \$14,000 per lane. Overall, comparison studies of existing systems indicate that the cost of installation per lane for full electronic collection is between 33 and 50 percent of the cost of a manual coin collection system (79).

The University of South Florida conducted a relative comparison of four of the technologies discussed above. Seven major technology issues were identified and used to relate the technologies. A relative comparison score of high, medium, or low was associated with the optical/infrared, inductive loop, radio frequency, and the surface acoustic wave technologies regarding each issue, with "high" being most favorable, and "low" being least favorable. Table 5-1 provides those relative comparisons.

### AVI Operating Cost

The cost of operating an AVI toll collection facility is reported to be substantially less than the alternative manned toll plazas. For example, the Oklahoma Turnpike Authority (OTA) reports a savings of \$160,000 in operating costs per year per automated toll-collection booth. To encourage motorists to use the AVI toll collection system (referred to as the PikePass) patrons receive a 30 percent discount on the cost of the toll.

**Table 5-1. Relative Comparison of ETC Technologies**

ISSUES/TECHNOLOGIES	RF/Microwave	SAW	Inductive Loop	Bar Code
Reliability	high	medium	high	low
Resistance to Duplication (security)	medium	high	medium	low
Potential for multiple read (speed vs. reliability)	high	high	low	low
Resistance to interference (lane-to-lane)	low	low	high	high
Tolerance to Environment	high	high	medium	low
Simplicity of Tag	low	medium	low	high
Health safety	high	high	high	high

### **Billing**

In general, most current billing systems connected with the AVI technology involve a prepayment method of toll collection. In Dallas, for example, motorists pay a small monthly rental fee plus a surcharge for each use of their Toll Tags. To encourage use of its AVI lanes, Oklahoma has waived the initial payment for PikePasses and offers lower toll rates to PikePass users. Motorists in both systems prepay their estimated usage charges by cash or credit card.

When the balance in their accounts becomes low, a warning light will flash as they pass through the toll gate. They replenish their accounts by making further prepayments at toll stores near or on the tollway. Oklahoma motorists may replenish their accounts automatically through regular credit card charges.

### **Toll Facility Design**

AVI technology does not require great amounts of land as required by gantry's and/or manual toll plazas. As will be discussed later, a mixture of AVI and manual toll collection would permit regular users and occasional users or commuters from out-of-town.

Integrating AVI technology into toll road design offers some unique opportunities. The most obvious is the AVI toll plaza. Currently, Orange County, California is constructing a toll facility as shown in the Figure 5-1.



The AVI toll plaza is divided into three basic areas (80):

**AVI\Coin Manual**

A typical toll plaza configuration with provisions for handling all types of transactions.

**AVI Only**

This area is reserved for patrons utilizing AVI. Signing well in advance of the toll plaza works to separate AVI traffic so that it may pass through the toll plaza area without stopping. The allowable speed will depend on the actual site conditions and provisions for escape lanes, transitions, maintenance, etc.

**HOV/AVI**

AVI may be used as an incentive to promote high-occupancy vehicle (HOV) usage. HOV lanes may be restricted to AVI and HOV only, thus increasing the overall throughput. If the HOV (or reversible/express) lanes have separate median access points, the lanes may bypass the toll plaza altogether, thus producing a toll road without toll plazas.

It is reported that the use of AVI bypass lanes offers a number of advantages, such as nonstop toll collection, reduced operating cost, increased level of service, and a potential for increased accuracy of the audit system.

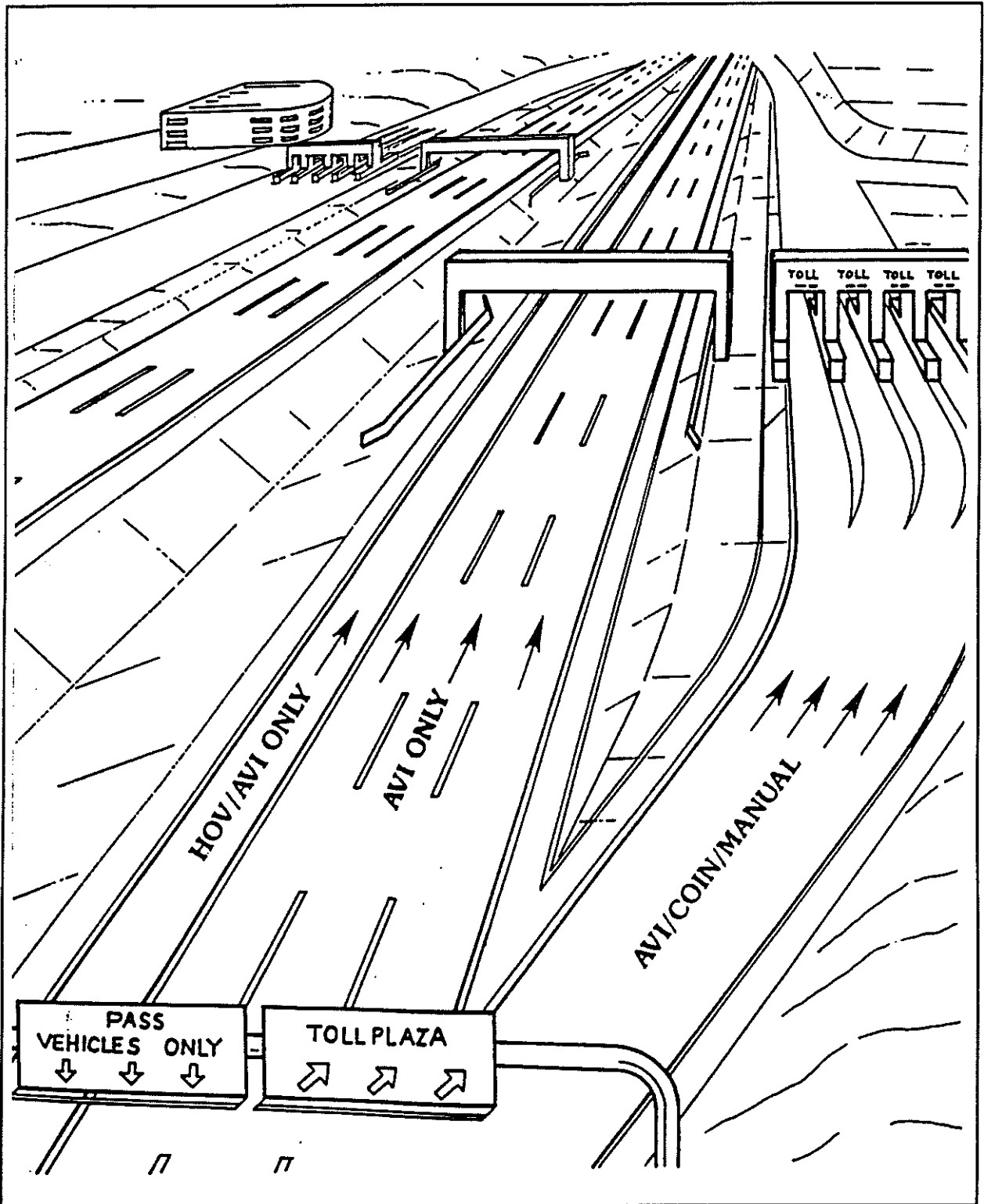


Figure 5-1. Typical Automated Toll Collection Facility

## STATE-OF-THE-ART PRACTICES FOR ROAD PRICING COLLECTION ON SELECTED TOLL FACILITIES IN THE UNITED STATES

Until recently, the Dallas North Tollway and the Crescent City Connection in New Orleans were using the latest electronic technology for automated toll collection. However, more and more toll facilities operating agencies are installing AVI technology with great success. The following section of this chapter is dedicated to describing the toll facility and the current AVI toll collection technology used.

### Dallas North Tollway

The Dallas North Tollway (DNT) was the first tollway in the United States to incorporate electronic toll collection (81). Automatic toll collection on the Dallas North Tollway became fully operational in July 1989. All 60 toll booths on the tollway are equipped with the Amtech Toll Tag system (discussed in detail below).

The Amtech Toll Tag technology was implemented in Dallas under a public/private "partnership" approach. The partnership began in 1987 to demonstrate basic performance standards. Some of the basic performance standards were:

- The system must provide the Authority and its patrons with an efficient, convenient and effective alternative means of collecting and paying tolls;
- The system must effectively interface with the Authority's existing toll collection equipment;
- The system must provide security against fraudulent transactions and demonstrate accurate and reliable billing capabilities;
- The system must provide the Authority a compatible and reliable means of collecting statistical data for auditing and accounting purposes;
- The toll tags, antennae, readers and recording system shall, read the unique identification number of the tag of 99 percent of the vehicles that properly present the tag. The system shall correctly identify 99.999 percent of the tags that it reads; and,
- The billing and recording system shall not produce multiple billings for a single tag presentation.

Under the partnership, Amtech installed the electronic toll collection system on the DNT at no cost to the Texas Turnpike Authority. Amtech provides the necessary

equipment and services to the TTA, which includes collecting tolls, managing tag distribution, and monitoring and maintaining system operation. Commuters who use the Toll Tag system are paying an additional 5 cents over and above the normal toll each time the toll is collected electronically. In addition, each commuter's account is charged a \$2 per month service charge. Amtech will continue this operation until July, 1994, at which time TTA will purchase the entire turnkey system from Amtech.

In August 1989, over 26,000 tags were in use and over 35,000 transactions are handled by AVI every day on the DNT. TTA officials report as much as 40 percent of rush hour traffic use Toll tags. Accuracy is reported to be greater than 99.98 percent. The system met all requirements, and in November 1990, the Texas Turnpike Authority reserved lanes exclusively for use by vehicles registered in the Authority's automatic toll collection system. Due to the excessive speed of vehicles passing through the nonstop AVI lane, the Authority installed speed bumps for safety concerns. Before the lanes were reserved for toll-tag vehicles only, an average daily volume of 4,600 toll-tag vehicles were recorded on the lanes. After the installation of the dedicated lanes, the volume of the toll-tag vehicles using the lane has increased to more than 15,000 per day over a period of one month (82). The Toll Tag system is presently used by over 55,000 Tollway patrons and collects over \$25 million in revenue transactions per year.

Enforcement of the electronic toll collection lanes is handled by cameras which record images of the license number and face of motorists not paying tolls as they pass through the toll-collection point. By implementing this system, the number of toll-evaders decreased from 25,000 to 500 per month (83).

### **Sam Houston and Hardy Toll Road**

In September 1992, the Harris County Toll Road Authority in Houston, Texas started electronic toll collection on the 21-mile Hardy Toll Road and the 28-mile Sam Houston Tollway. Motorists who prefer to drive without stopping can do so by setting up an escrow account with the Toll Road Authority for a rental fee of \$1 per month for the use of the tag. Sixty-nine toll lanes will provide nonstop toll collection availability. An initial order of 40,000 identification tags have been supplied by the AVI manufacture (Amtech). The project will be a joint effort with Cubic Automatic Revenue Collection Group and the Amtech Corporation.

### **Crescent City Connection Bridge**

The electronic toll collection for the Crescent City Connection Bridge in New Orleans became fully operational in January 1989. Existing tollbooths were retrofitted to AVI systems for slightly less than one million dollars (84). The annual operating cost of approximately \$100,000 includes: a maintenance contract with the AVI supplier

(Amtech), four sales clerks, and a fraction of a technician's time. It is estimated that about 30% of the average daily traffic are AVI users (60,000 vehicles). In addition, it has been estimated that the cost per AVI transaction is approximately 4 cents.

### **Oklahoma Turnpikes**

In November 1991, the Urban Transportation Monitor reported the Oklahoma Turnpike Authority's automatic toll collection system to be the largest such system in the world at more than 90,000 toll-tag equipped vehicles (84). The PikePass System covers 580 miles of turnpike. The PikePass System started on January 1, 1991 as a 470-mile, 6-turnpike system. It was later expanded with four new turnpikes representing 110 miles. To date, 160,000 tags have been issued to over 80,000 patrons. Of the 150,000+ total transactions, more than 41,000 tag transactions are registered daily (85).

In addition to the convenience of using a PikePass to pay tolls, motorists also receive a 30 percent discount over the tolls charged to paying motorists. For older toll facilities, the existing toll booth lanes have been retrofitted to allow motorist to pass through at 35 mph. The newer facilities are designed to read toll tags at highway speeds of 65+ mph (84).

The PikePass tags are passive transponders that transmit a coded radio signal when bombarded with radio energy. They have a battery that is used to keep their circuits active and ready to respond, but the battery adds no power to the transmission. Part of the circuitry of the tag is a programmable chip that contains account identification data. The system is manufactured by Amtech, and does not operate in real-time. Instead, data is downloaded at the end of the day to the central database. However, if a card is reported lost or stolen, or if the card has just been placed into service, the tag's data is transmitted immediately. The cost of the Oklahoma PikePass system was approximately \$15,000 to \$20,000 per lane. The OTA system integrated coin toll machines into the accounting system. Payback is reported to be less than two years. The Oklahoma Turnpike Authority (OTA) reports a savings of \$160,000 in operating costs per year per automated toll-collection booth.

### **Lincoln Tunnel: The Port Authority of New York and New Jersey**

Approximately 2,900 buses are equipped with roof-mounted passive tags, which are manufactured by Amtech. Only those buses equipped with ETTM tags are permitted to pass through the instrumented lanes. These lanes are used as ETTM lanes only during the morning peak hour periods in which the counterflow exclusive bus lanes are in operation. Under normal circumstances, only the bypass ETTM lane is used to process these buses. The equipped toll lane is normally staffed with a collector, but becomes available for ETTM use, if and when the bypass lane cannot be used.

Untagged or unreadable vehicles are detected by induction loops imbedded in the roadway of the lanes. These initiate the taking of short videotape sequence which can later be used to identify the questionable vehicle.

## **MOTORIST INFORMATION**

An integral element of a congestion pricing program is getting vital information to motorists. In the past, changeable message signs have been used to convey the extent of congestion to the motorist. For a congestion pricing project, the motorist will need to know the extent of congestion, available alternative routes, and the current fare associated with the alternative routes.

### **Changeable Message Signs**

Changeable message signs (CMS) are playing an increasingly important role in providing real-time motorist information. Highway CMS's are traffic control devices used for traffic warning, regulation, routing and management, and are designed to affect the behavior of motorists by providing real-time highway related information (86). Real-time information can supply the motorists of the freeway conditions downstream. If conditions are severe enough, all traffic may need to be diverted. However, recurrent congestion (which accounts for 60 percent of all congestion) can be avoided by using alternate routes if available. An alternate route could be a facility available to the public for a fare based on the extent of congestion. The CMS can relay valuable information such as the extent of congestion downstream, and the current fare on an alternative congestion priced facility.

### **HIGHWAY FACILITY CONGESTION PRICING**

Congestion pricing can involve road pricing such as a select highway facility or a particular zone such as a central business district. Congestion pricing can even involve varying the price to park within a certain area. This report has specifically address highway facility congestion pricing, although other types were mentioned. In this chapter, a discussion of highway facility congestion pricing is made. An analysis is made of congestion pricing using a HOV lane as a congestion pricing facility.

#### **General Information**

Facility pricing directly applies the concept of congestion pricing to travel corridors. As discussed in Chapter 4 (see section "congestion Tolls with HOV Lanes"), prices are charges for each vehicle trip based upon the congestion costs which that vehicles imposes on the users of a particular highway segment at a particular time of day. As discussed in Chapter 5 (general heading of Toll Collection), electronic roadside units could automatically debit the amounts owed by sending a signal to a transponder on board the vehicle. The general idea of congestion pricing is to use variable prices charged during the peak travel periods. The price would vary by the level of congestion.

Pricing points would include freeway on-ramps and off-ramps, and possibly intersections of principal arterials. Pricing points might thus occur about every one to two miles for urban freeways. If transponders were used, each time a vehicle passed a pricing point, one or more units of a "congestion price" would be debited from the owner's (owner of the transponder) account. As shown in Table 4-12 of Chapter 4, congestion fees could be from 0.03 cents to 50 cents per mile of travel, depending on the level of congestion on the facility.

All roadside pricing units could be centrally monitored, and could be capable of remote reprogramming based on travel conditions. Prices could be adjusted based upon changes in travel conditions, changes in needs for revenues, concerns about optimality, or other considerations. Careful monitoring would be necessary for record keeping to assure accuracy and to evaluate and adjust pricing programs.

It is conceivable that well over 100,000 vehicles could be involved in any actual application of corridor facility pricing in any major Texas urban metropolitan area. Therefore, a major record keeping and transponder sales operation would be required. Building a new administrative structure to deal with record keeping might add considerably to the capital costs. One potential avenue to pursue to reduce costs would associate sales of transponders with vehicle registration and registration fees.

Making certain that all vehicles which might travel in a priced corridor have transponders would require good availability of reasonable cost transponders. Even occasional users of the corridor would have to have transponders, such as business travelers, visitors, rental cars, or tourists. This requirement suggests a long lead time before any test could be implemented. A near term test could utilize a visual sticker technology, similar to Singapore's licensing scheme. However, this system would require careful monitoring by police, or other authoritative personnel, of on-ramps, etc.

Noting that one objective of congestion pricing is the altering of motorists' driving patterns, it is possible that severe impacts might occur to other facilities in the same corridor. The alternative facilities might operate at much worse service levels with a road pricing program. Therefore, the alternative facilities might require some type of control, or possibly be included in the road pricing program.

Facility pricing in a corridor might be implemented in coordination with a major corridor mobility improvement so that new and attractive choices of alternative modes or links are available when pricing starts. Improvements might include the opening of HOV lanes, a new transit line, a new toll road, or improved transit service. Complementary or compensatory improvements, such as new modal alternatives, may make road pricing more acceptable to the public, since people in the corridor may perceive that travel conditions will get better, and that the revenues from the facility road pricing project would be used to improve mobility.

The most promising options for corridor pricing are likely to involve pricing of the peak-hour vehicles travel in a corridor with new added capacity for transit, high occupancy vehicles, or general-purpose traffic. The implementation of improvements in capacity together with congestion pricing may be more acceptable to travelers than pricing of facilities in corridors where no improvements are being implemented or planned.

Corridors which may meet one or more of the above conditions include, but are not limited to :

- Planned toll road corridors
- Corridors in planning for a major reconstruction
- Other corridors served by planned transit and HOV facilities.



## ENERGY CONSUMPTION ANALYSIS

Previous sections of this chapter, and sections found in other chapters of this report, have described the potential of congestion pricing to modify motorists' behavior by altering their commute trip. Some of these modifications were: 1) encourage higher vehicle occupancy; 2) defer a trip to a different time; or 3) eliminate some trips. Any one of these modifications can reduce fuel consumption. Encouraging motorists to commute together, to leave their vehicles at home, or utilize park-and-ride lots and public transit increases the vehicle occupancy ratio and reduces the number of vehicles in the freeway traffic stream. Deferring the trip to a time experiencing lower traffic demand reduces the overall congested state of the freeway. And finally, elimination of the commute trips altogether would obviously save on fuel consumption.

### **Application of Congestion Pricing to Reduce Energy Consumption**

The following analysis makes a narrow examination of congestion pricing and the resulting change in fuel consumption. The analysis is not explicit. In other words, no one single result of congestion pricing is evaluated. The analysis takes a more general approach, which is far more realistic because limited empirical data on motorists reaction to a congestion pricing program does not exist. Therefore, the analysis examines a range of possibilities. The various scenarios examined in the analysis are most representative of a "short-term" implementation strategy. The short-term strategy would be implemented with relatively few changes to the existing freeway geometrics and operations. A long-term strategy might consist of major changes to the existing transportation facilities. The long-term strategy would probably be a large commitment and prompt a policy change before implementation. An example of a long-term congestion pricing strategy would be pricing on a major interstate freeway where every motorist that travels that freeway during the peak-period would pay a congestion-based fare.

### **Congestion Pricing Model Used for Analysis**

Congestion pricing is planned for implementation in California. State Route 91 (SR 91), also known as the Riverside Freeway, is characterized as the first congestion pricing scheme ever implemented in this nation. The SR 91 project is currently under construction and due to be completed within the next few years. The basic framework of the SR 91 project is to reconstruct the existing facility and, in addition, construct four express lanes in the median. The express lanes will be available to patrons for a fee based on the level of congestion in the general-purpose lanes. The greater the congestion, the greater the fee. The express lanes will be available at no charge to high-occupancy vehicles or public transit vehicles.

## **Application of Congestion Pricing on a Texas Highway Facility**

Beginning in 1979, the Texas Department of Transportation began implementation of a high-occupancy vehicle (HOV) lane in the I-45 North Freeway Corridor. The success of the I-45 North Freeway contraflow lane demonstration project led to development of additional HOV facilities in other Houston freeway corridors. Now, Houston is well on the way to completing the world's largest transitway system - 95.5 miles of dedicated bus and carpool lanes. Currently, close to 60 miles of barrier-separated reversible flow HOV lanes are in operation in the Houston metropolitan area.

Because there are so many miles of HOV lanes in currently or planned for operation in the Houston metropolitan area, it was appropriate to perform an analysis that used the HOV lanes for congestion pricing, similar to what is presently being attempted in California. This approach is a narrow examination of congestion pricing because only the use of an HOV lane as a congestion priced facility is considered. Other schemes of congestion pricing are not examined here.

### **Analysis of Facility Congestion Pricing**

Two scenarios involving the use of an HOV lane as a congestion priced facility are evaluated. In each scenario the traffic volume is varied on the HOV lane (i.e., requiring a fixed minimum number of passengers per vehicle). The two scenarios are:

#### *Scenario #1*

Restrict the HOV lane to vehicles with 2 or more persons per vehicle and allow congestion priced vehicles to use available capacity. The freeway mainlanes supplies the congestion priced vehicles.

#### *Scenario #2*

Restrict the HOV lane to vehicles with 3 or more persons per vehicle and allow congestion priced vehicles to use available capacity. The freeway mainlanes supplies the congestion priced vehicles.

A third scenario was considered that would have increased the capacity on the HOV facility by adding an additional lane. This scenario was later ruled inappropriate because the fuel consumption would not have differed from the first two scenarios.

In scenarios 1 and 2, the traffic that does not meet the car occupancy restrictions in the HOV lane would return to the general-purpose lanes. In other words, if the restriction of 3 or more persons per vehicle was enforced, the vehicles that did not meet

this restriction would travel in the general-purpose lanes. In any event, the vehicles added to the general-purpose lanes would not noticeably affect the peak-period travel conditions. This assumption is based on previous research by Christiansen and Morris (87) involving the impact of the HOV lane after the HOV first opened on the Katy Freeway.

### **Controlled System**

To determine the change in fuel consumption, traffic was diverted from the freeway mainlanes to the HOV lane. It is assumed that a potential market exists in the mainlane traffic to pay a "congestion charge" for use of the HOV lane to gain a better level of service. The fare charged in a congestion pricing scheme is dependent upon the level of congestion present and the impact upon congestion attributed to an additional vehicle.

As vehicles divert from the freeway mainlanes to the HOV facility, it is expected that freeway mainlane congestion would decrease and vehicle speeds would increase. However, due to latent demand (also referred to as Down's Law) the change in travel demand would not be noticed. As some vehicles divert from the freeway to the HOV lane, another vehicle would simply fill the empty space. This phenomenon has been documented in past research (87,9).

To circumvent this problem, the analysis was performed in a controlled system. This somewhat myopic approach maintains a constant flow of vehicles in the freeway mainlanes and HOV lanes. In other words, any traffic diverted from the freeway mainlanes would not be replaced by the next following vehicle just outside of the time period under consideration. For example, for the study time period of 7 to 8 a.m., a vehicle arriving at 6:59 a.m. would not be moved into the 7 to 8 a.m. time period because one vehicle was moved from the mainlanes to the HOV lane.

### **The Katy Freeway and HOV Lane**

The Katy Freeway (I-10 West) is a major east-west artery to downtown Houston and was used in the analysis as an example facility for the implementation of a congestion pricing project. Figure 6-1 illustrates the Houston area freeways, other major arterials, and the limits of the Katy Freeway included in the analysis. The Katy Freeway is a 6-lane facility that averages 185,000 vehicles per day, with approximately 16,900 vehicles during the peak hour in the peak direction. Traffic mix on the mainlanes is mostly single passenger vehicles (79 percent), with the remainder made up of 2-person (17 percent) and 3-person (4 percent) vehicle volumes. The Katy HOV lane is approximately 13 miles in length, and extends from Barker-Cypress Road to Washington Avenue. The HOV facility is a single-lane, reversible-flow, barrier-separated facility

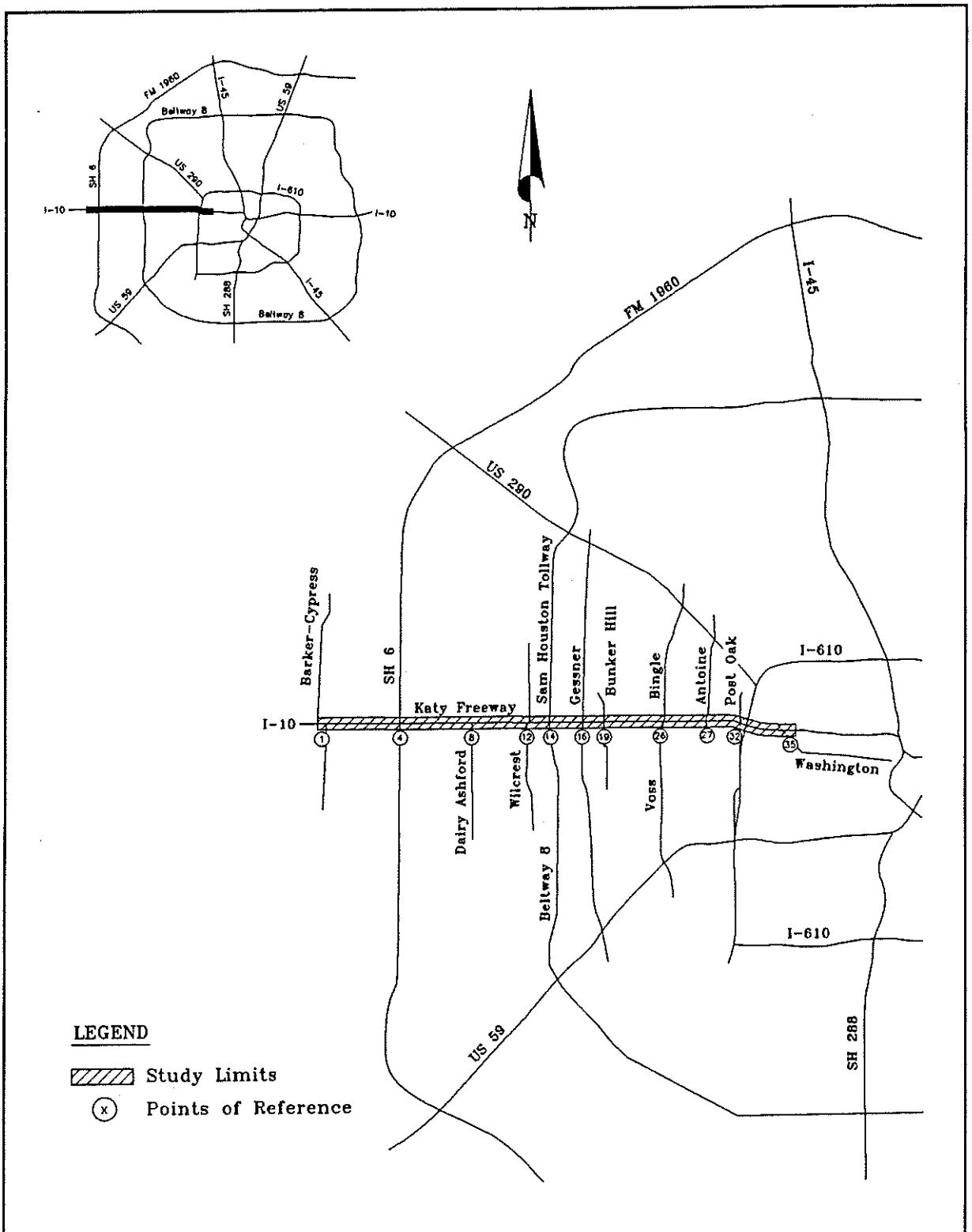


Figure 6-1 Houston Area Freeways, Major Arterials, and the Katy HOV lane.

constructed in the freeway median. The Katy HOV lane saves about eight minutes per trip and facilitates the person-movement equivalent of about two adjacent mixed-flow lanes. Direct connection ramps provide access with local streets, freeway lanes, and park-and-ride lots. Use of the facility was initially restricted to authorized buses and vanpools. However, carpools are now allowed during the peak period. The transitway traffic mix is presently composed of 93 percent carpools, 2 percent vanpools, and 5 percent buses.

## **Analysis**

The analysis of congestion pricing impacts on fuel consumption was conducted using the FREQ10 model. The FREQ10 model is a macroscopic deterministic model developed to simulate and evaluate freeway corridors. The FREQ model can evaluate priority entry (i.e., ramp control) lanes, and priority lane (i.e., one- or two-lane concurrent flow HOV lane) control on a directional freeway. In a recent FHWA report (88), the FREQ model was evaluated as one of the most informative and comprehensive simulation models, therefore, this model is appropriate for a static analysis of freeway effects due to the implementation of congestion pricing. The FREQ model produces several variables that can be used as a measures-of-effectiveness (MOE). MOEs that the FREQ model produces include vehicle-miles of travel, vehicle-hours of travel, passenger-miles of travel, passenger-hours of travel, ramp-to-ramp travel time, fuel consumption, emissions, noise, and a variety of others.

### *FREQ and Fuel Consumption*

The fuel consumption is calculated for each subsection (typically the distance from an on-ramp to the next on/off-ramp) on the mainlanes or HOV lane for each 15 minute time slice. The amount of fuel consumed is determined based on the vehicle miles travelled on the subsection during the time slice, the class of vehicle, the fuel consumption rate of the class of vehicle travelling at the average speed of the subsection, and the vehicle mix on each subsection. The three vehicle classes which are simulated are: automobiles, which include all four wheeled vehicles; gasoline-powered trucks; and diesel-powered trucks. Fuel consumption rate tables for a range of average speeds for the three vehicle classes were obtained from a Texas Metropolitan Planning Organization (MPO) and used in the model.

### *Analysis of Freeway Conditions*

To analyze the existing conditions on the Katy Freeway and HOV lane using the FREQ model, traffic volumes at each on- and off-ramp and at the beginning and end of the freeway study limits were required. This data is input into the model, then the model is calibrated using travel time data. Data from 1990 were used to model the Katy

Freeway and HOV lane existing conditions. The analysis evaluated inbound peak-direction conditions during the peak-period time of 6:00 to 9:00 a.m.

Existing conditions on the Katy Freeway mainlanes showed that the average travel speed was 43 mph over the peak-period. Travel speeds started out at the posted speed limit of 55 mph, and dropped to 33 mph within 45 minutes of simulation. As Figure 6-2 shows, the travel speed drops to a low of approximately 33 mph, then gradually increases to 55 mph by the end of the peak-period. The drop in travel speed can be attributed to an increase in traffic volume. Traffic volumes measured at Bunker Hill were 5,500 vph (1,833 vph per lane) during the peak-hour and 16,869 vehicles during the 3-hour peak-period.

Further analysis of the existing Katy Freeway conditions evaluated travel speed during the peak-hour at specific reference points along the freeway. Travel speeds were shown to be below 30 mph between State Highway 6 and Gessner, and between Bingle/Voss and Antoine. Figure 6-3 shows travel speeds on the Katy Freeway during the peak-hour for each section of freeway. This indicates that most of the corridor is experiencing congestion. Therefore, traffic congestion in the form of queuing was also evaluated in the analysis of existing conditions. The FREQ model compares the demand (traffic volume) to the available capacity by subsection and time. A queue begins to form when the demand reaches capacity for the subsection. The length of the queue is determined on the basis of speed/density relationships of the traffic stream at the subsection and upstream of the subsection. The queuing analysis in FREQ10 indicated that congested conditions began to occur at approximately 6:15 a.m. and remained until approximately 8:15 a.m. In subsequent analysis of alternative scenarios of congestion pricing, queuing will serve as the basis by which the time period of vehicle diversion will occur.

#### *Analysis of HOV Lane Conditions*

The Katy HOV lane travel speed was also evaluated during the peak period. The HOV facility is regulated by the operating agency (by changing vehicle occupancy requirements) to provide high travel speeds and reduced travel time. Travel speed on the HOV lane started out at approximately 58 mph, decreased to a low of 45 mph for a brief time, then increased back to speeds exceeding the posted speed limit of 55 mph. Figure 6-4 illustrates the HOV lane travel speed by time of day. The average travel speed over all subsections for the peak-period was 54 mph. There was evidence that some congestion does occur for a brief time between 6:15 and 6:30 a.m. at the Post Oak exit ramp (see Figure 6-1) which is a major HOV lane entrance/exit location. The congestion corresponds to the highest traffic volumes on the HOV lane. Traffic volumes during the peak-period were 1,700, 1,100, and 1,225 vph during the 6-7 a.m. time period.

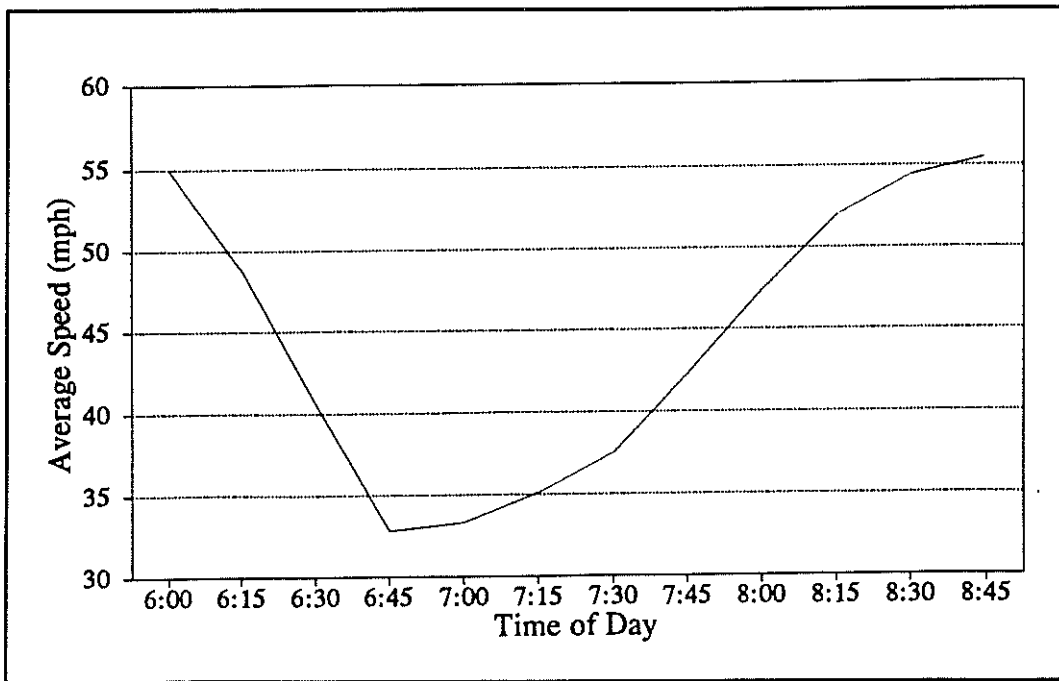


Figure 6-2 Katy Freeway Mainlane Speed.

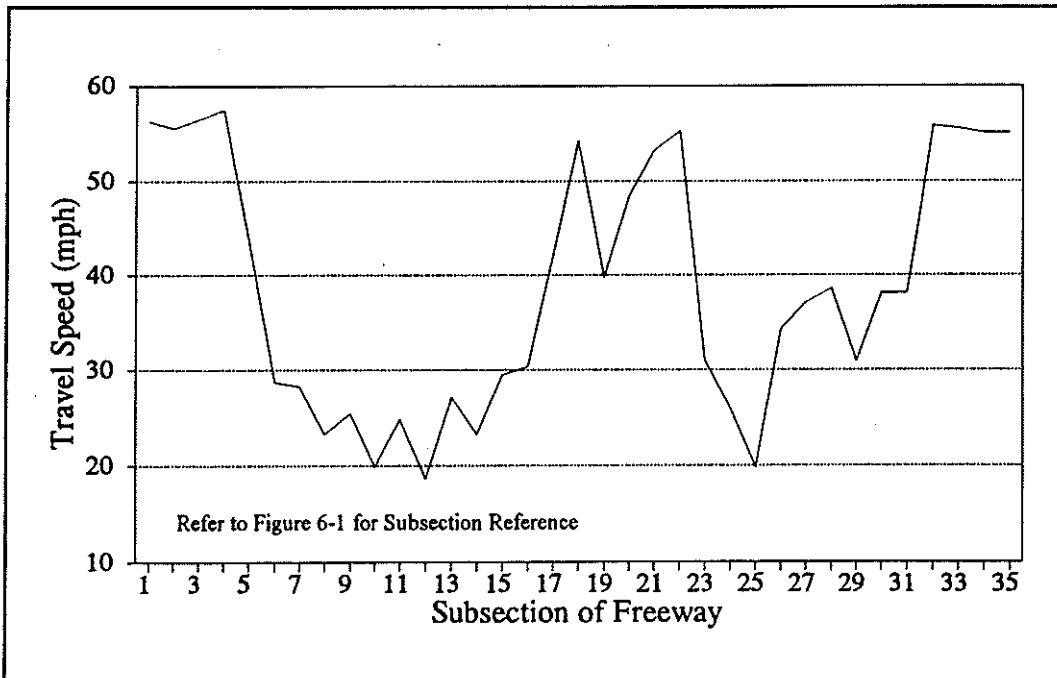


Figure 6-3 Katy Freeway Mainlane Speed by Subsection and Hour.

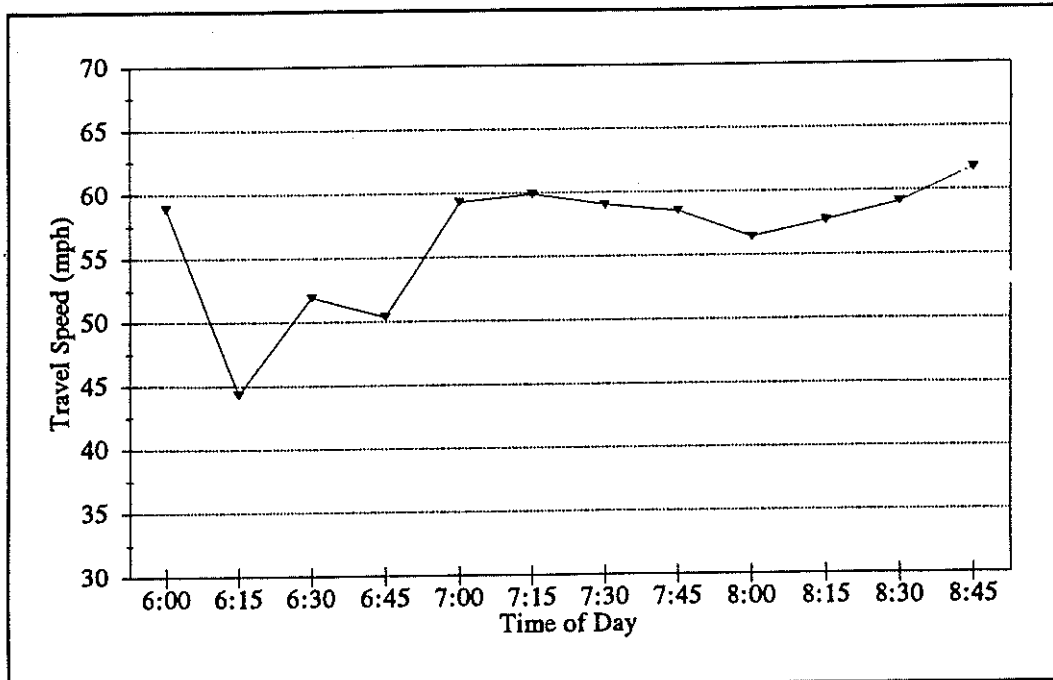


Figure 6-4 Katy Transitway Existing Condition Travel Speed.

### Analysis of Fuel Consumption

An evaluation of fuel consumption was made on the existing freeway and HOV lane during the peak-period. The analysis showed freeway vehicles consumed 16,537 gallons of fuel, whereas the vehicles in the HOV lane consumed 2,264 gallons of fuel for a total fuel consumption of 18,801 gallons. Table 6-1 provides a summary of the fuel consumption on each facility and the average travel speed on each facility.

Table 6-1. Measures of Effectiveness, HOV Lane and Freeway General-Purpose Lanes, Existing Conditions

Facility	Fuel Consumption (gallons)	Average Speed, Peak Period (mph)
HOV Lane	2,264	54
Freeway General-Purpose Lanes	16,537	43
Total	18,801	Not Applicable



## *Scenario #1*

Before the evaluation could be attempted on the Katy HOV lane, the existing traffic pattern had to be modified by removing illegal commuters. Traffic studies showed that several single occupant vehicles were using the HOV lane. Therefore, all single occupant traffic was removed from the HOV lane. The impact was small; during the first hour traffic volumes decreased by 100 vph, and 50 vph for each hour following. The reduction in traffic volumes impacted the travel speeds only slightly. From approximately 6:15 to 7:00 a.m. the traffic speeds increased approximately 10 percent and remained unchanged for the other time periods.

The remaining capacity of the HOV lane was then utilized by allowing freeway vehicles to pay a fee to use the HOV lane. The amount of traffic diverted from the freeway was determined based on the elasticity of the motorists willingness to use a congestion priced facility. The demand elasticity results are shown in Table 4-12 of Chapter 4. The economic analysis could not produce a definite traffic volume. However, it was found that a range of traffic volumes from 200 to 1,000 vehicles per hour could be diverted from the freeway traffic.

As discussed earlier, the queuing diagram of existing conditions showed that most of the congestion on the freeway occurred between 6:15 and 8:15 a.m. It is reasonable to assume that vehicles would only pay a congestion fare when conditions on the mainlanes were insufficient for their needs. Therefore, traffic was only diverted to the HOV lane during the most congested time periods- 6:30 to 8:00 a.m.

The analysis of the impacts to the freeway and HOV lane as a result of diverting traffic from the freeway to the HOV lane showed severe degradation to the HOV lane and much improvement to the freeway. The freeway showed improvement because of the closed system approach. As vehicles were diverted from the freeway to the HOV lane, those vehicles were not replaced with vehicles that would occur due to latent demand. Table 6-2 shows that at the maximum diversion of 1,000 vehicles, the freeway travel speed increased from 43 to 52 mph and the HOV lane travel speed decreased from 54 to 24 mph. In addition, Table 6-2 shows that when the freeway traffic is approximately 4,877 vph and the HOV lane traffic volume is approximately 1,800 vph, the travel speed on both facilities is approximately 47 to 48 mph. This corresponds to an approximate 400 vph diversion from the freeway to the HOV lane.

The evaluation of fuel consumption on both facilities showed an increase on the HOV lane and a decrease on the freeway. The net difference was an increase in total fuel consumption. Table 6-3 shows the fuel consumption on the freeway and HOV lane as vehicles divert from the freeway to the HOV lane.

**Table 6-2. Comparison of Travel Speeds on HOV Lane and Freeway Under Scenario #1**

Diverted Freeway Traffic Volume	Freeway		HOV Lane	
	Volume <sup>1</sup>	Speed <sup>2</sup>	Volume <sup>3</sup>	Speed <sup>4</sup>
0	5464	42.5	1400	54
200	5073	46.1	1600	51
400	4877	48	1800	47
600	4667	50	2000	42
800	4536	51	2200	26
1000	4266	52	2400	24
2000	3745	54		

<sup>1</sup> Freeway Traffic Volume taken from Bunkerhill area of Katy Freeway during the 6:30 to 7:30 am time period.

<sup>2</sup> Freeway Travel Speed corresponds to overall average speed during the peak-period (6:00 to 9:00 am).

<sup>3</sup> HOV Lane Traffic Volume taken between Gessner on-ramp and Post Oak off-ramp.

<sup>4</sup> HOV Lane Travel Speed corresponds to overall average speed during the peak-period (6:00 to 9:00 am).

**Table 6-3. Total Fuel Consumption for Scenario #1.**

Diverted Freeway Traffic Volume	Fuel Consumption (gallons) for Peak-Period (6:00 - 9:00 am)			Percent Change (%)
	Freeway	HOV Lane	Total	
0	16537	2264	18801	
200	16572	2469	19041	+1.3
400	16472	2674	19146	+1.8
600	16300	2832	19132	+1.8
800	16116	3021	19137	+1.8
1000	15803	3134	18937	+0.7

Scenario #2

The evaluation of the second scenario restricted the HOV lane to vehicles with 3 or more persons per vehicle and allowed congestion-priced vehicles to use the remaining capacity. The diversion of vehicles that did not meet the 3+ requirement significantly lowered the traffic volume on the HOV lane. As shown in Figure 6-5, traffic volumes on the HOV lane were reduced from approximately 1,700 vph to approximately 575 vph during the first hour of the peak-period.

After removing all single and double occupancy vehicles, the peak-period HOV lane travel speeds increased to an average of 61 mph. Fuel consumption on the HOV lane dropped by 65 percent to 795 gallons. The freeway travel speed and fuel consumption were unchanged at this point. Table 6-4 lists the HOV lane and freeway existing conditions under scenario #2.

It was shown earlier that most of the freeway congestion occurred between 6:30 and 8:00 a.m. This being the case, the analysis only diverted traffic from the freeway mainlanes to the HOV lane during this time period. Because traffic is only diverted from the freeway to the HOV lane between 6:30 and 8:00 a.m., the HOV lane will be under utilized during all other time periods (e.g., 8:00 to 9:00 a.m.). This approach will foster a conservative estimate of fuel usage.

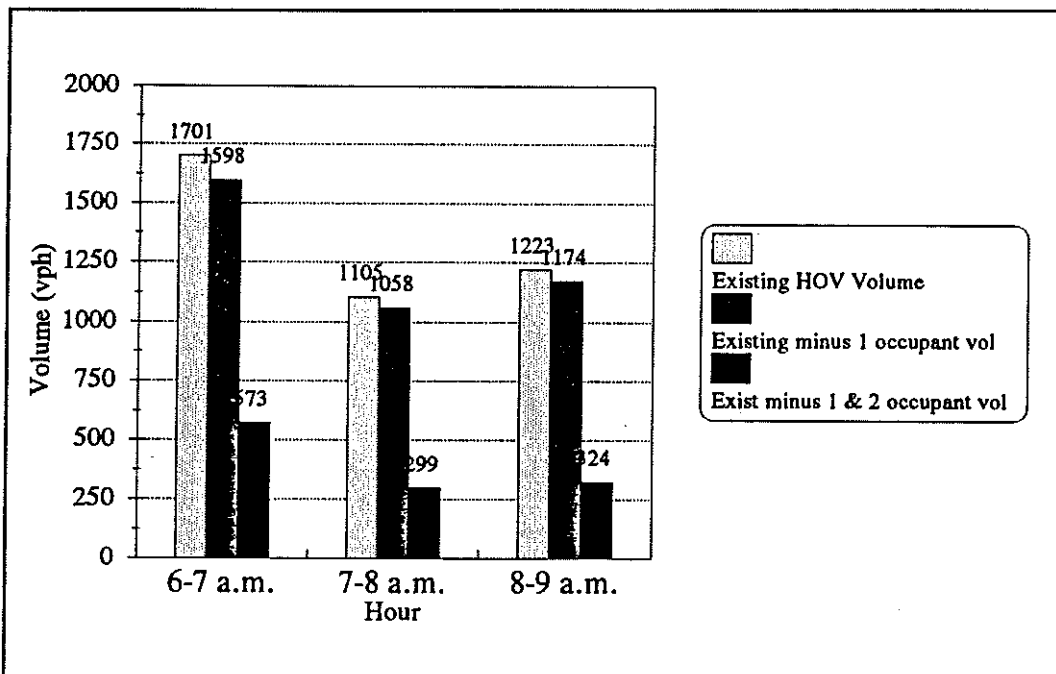


Figure 6-5 Katy HOV lane Hourly Volumes.

**Table 6-4. HOV Lane and Freeway General-Purpose Lanes, Scenario #2**

Facility	Fuel Consumption (gallons)	Average Speed, Peak Period (mph)
HOV Lane	795	61
Freeway General-Purpose Lanes	16,537	43
Total	17,332	Not Applicable

**Table 6-5. Total Fuel Consumption for Scenario #2.**

Diverted Freeway Traffic Volume	Fuel Consumption (gallons) for Peak-Period (6:00 to 9:00 am)			Percent Change (%)
	Freeway	HOV Lane	Total	
0	16537	795	17332	
200	16572	1033	17605	+1.6
400	16472	1267	17739	+2.3
600	16300	1496	17796	+2.7
800	16116	1720	17836	+2.9
1000	15803	1939	17742	+2.4

Traffic volumes of 200, 400, 600, 800, and 1,000 vph were diverted from the freeway general-purpose lanes to the HOV lane. The fuel consumption analysis showed a similar response shown in Scenario #1, an overall increase in fuel consumption. After 1,000 vph were diverted to the HOV lane, the total fuel consumption increased by 2.4 percent to 17,742 gallons. Table 6-5 shows total fuel consumption for the freeway and HOV lane after traffic was diverted.

Within Scenario #2, there exists the potential for ridesharing or carpooling. Two person carpools could be formed to share the costs and benefits of diverting to the HOV lane and paying the congestion fee. For example, if 1,000 vph were diverted from the freeway general-purpose lanes, if all those motorists joined carpools, only 500 vph would be added to the traffic on the HOV lane.

Several hypothetical scenarios were evaluated using varying percentages of carpool formation. Three scenarios evaluated were 25, 50 and 100 percent carpool formation. Table 6-6 shows the resulting traffic volume that would be diverted from the freeway lanes to the HOV lane. Using previous data on fuel consumption (Table 6-5), three tables were developed based on carpool formation. Tables 6-7, 8 and 9 show the total fuel consumption for the freeway and HOV lane for 25, 50 and 100 percent carpool formation. In addition, each table also shows the percent change in fuel consumption as related to the original conditions, i.e., no vehicles diverted from the freeway general-purpose lanes.

**Table 6-6. Potential Ride-Sharing/Carpooling Formation**

Diverted Freeway Traffic Volume	Increase in HOV Lane Traffic Following "X" Percent of Carpool Formation		
	25%	50%	100%
0	-	-	-
200	175	150	100
400	350	300	200
600	525	450	300
800	700	600	400
1000	875	750	500

**Table 6-7. Total Peak Period Fuel Consumption with 25-Percent Carpool Formation**

Diverted Freeway Traffic Volume	25% Carpool Volume	Fuel Consumption			Percent Change (%)
		Freeway	HOV	Total	
0	0	16537	795	17332	0
200	175	16572	1003	17575	+1.4
400	350	16472	1208	17680	+2.0
600	525	16300	1408	17708	+2.2
800	700	16116	1604	17720	+2.2
1000	875	15803	1796	17599	+1.5

**Table 6-8. Total Peak-Period Fuel Consumption with 50-Percent Carpool Formation**

Diverted Freeway Traffic Volume	50% Carpool Volume	Fuel Consumption			Percent Change (%)
		Freeway	HOV	Total	
200	150	16572	974	17546	+1.2
400	300	16472	1149	17621	+1.7
600	450	16300	1321	17621	+1.7
800	600	16116	1496	17612	+1.6
1000	750	15803	1653	17456	+0.7

**Table 6-9. Total Peak-Period Fuel Consumption with 100-Percent Carpool Formation**

Diverted Freeway Traffic Volume	100% Carpool Volume	Fuel Consumption			Percent Change (%)
		Freeway	HOV	Total	
200	100	16572	517	17089	-1.4
400	200	16472	1033	17505	+1.0
600	300	16300	1150	17450	+0.7
800	400	16116	1267	17383	+0.3
1000	500	15803	1380	17183	-0.9

It can be seen in Tables 6-7 and 6-8 that fuel consumption still increases as vehicles are diverted from the freeway even if 50 percent of the vehicles form carpools. However, in Table 6-9, fuel consumption is shown to be reduced in two of the diversion levels; by 1.4 percent with 200 vehicles diverting, and by 0.9 percent with 1,000 vehicles diverting.

### **Summary of Fuel Consumption Analysis**

In review of the fuel consumption data, it is apparent that the decrease in fuel consumption as a result of vehicles being diverted from a congested facility to a HOV facility operating at desirable (55 mph or higher) travel speeds is offset by the increase in fuel consumption as a result of higher operating speeds. Fuel consumption was shown to increase in Scenario #1 where vehicles are diverted from the freeway to the HOV lane under existing operating traffic volumes. In Scenario #2, several hypothetical carpool formations were evaluated. The intention here was to capture the effect of ridesharing or carpool formation. As much as one-half of the diverted freeway traffic volume was removed from the analysis. In most cases total fuel consumption rose. In only two cases did the results show a decrease in fuel consumption, ranging from about 1 percent to 1.4 percent, as compared to maintaining existing conditions (i.e., do nothing alternative).

It is worth noting that previous research involving the implementation of HOV lanes and the effect on fuel consumption have shown fuel consumption to decrease. For example, a 1975 analysis of the San Bernardino Busway in Los Angeles estimated that the HOV lane facility lowered fuel consumption by 5,400 to 6,500 gallons per day (89). In 1973, the Shirley Highway HOV lane project was estimated to reduce fuel consumption by approximately 7,400 gallons of fuel per day (90). However, these analyses are largely based on motorists changing their commute habits to a vehicle with high occupancies, such as public transit, vanpools, and carpools. For example, separate study involving the Katy Freeway and HOV lane showed that vehicle miles of travel decreased by 10 percent, and hence, fuel consumption reduced by just under 10 percent (87). Assuming similar reactions to congestion pricing, then similar reductions in fuel consumption can be expected.

In general, in order for congestion pricing to reduce energy consumption, there must be a decrease in the number of vehicle trips that more than offset the additional fuel consumption at higher speeds. Use of an HOV lane for congestion pricing generally will have little effect on the number of vehicle trips. The major impact will be vehicles switching from the more congested main lanes to the HOV lane. There may be some incentive for carpool formation, but as the analysis shows in this chapter, very high carpooling rates would be required to result in lower fuel consumption.

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CHAPTER 7

## ISSUES ASSOCIATED WITH CONGESTION PRICING

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The success of a pricing project depends on a fortuitous combination of an amenable situation; opportune timing; support of the local community, and the state and local governments; and technology adequate to the tasks at hand. Technology improvements appear to be forthcoming in the form of electronic toll collection and traffic management systems. The timing and situational matters depend on any particular project. But the success of any innovative project in the public arena still involves confronting and resolving numerous other issues that may be best termed institutional. The brief and unsuccessful experience with congestion pricing in the 1970's holds some valuable lessons for any attempts to pursue such projects.

There are myriad issues that must be addressed in order to successfully develop and implement a pricing project. These issues each need to be carefully considered in order to define their importance and how best to assess and address them. Ultimately, these issues boil down to who benefits from premium transportation services, who should pay for that service, and who is hurt or otherwise impacted by that service. In the final analysis, there must be an obviously equitable tradeoff of mitigation and compensation for disequities among the beneficiaries and those who do not benefit or are negatively impacted.

Paramount among the issues for consideration are value of time, equity, and surveillance, the latter often referred to as the "big brother" syndrome. Additional issues generally can be considered together in one of the other categories discussed below. Determining how to address those issues would be the most important decision of any pricing project.

### ECONOMIC AND SOCIAL ISSUES

#### **Value of Time**

Value of time is the crux of any congestion pricing project. How each traveler values their personal time would ultimately dictate whether they will pay the additional price of a service that saves them time. Similarly, the time value of an employer would affect their decision whether their deliveries or other shipments should incur additional cost in order to purchase that premium service. The value of time is difficult to discern because it varies both between individuals or enterprises as well as in different situations



for any particular traveler. Thus, one's time value is usually greater when there are associated monetary conditions (e.g., getting to work on time) than when shopping on weekends. And time is probably more valuable to the traveling salesman than to the private shopper enroute to the local shopping mall.

The problem faced by the technician analyzing how to price a premium transportation service is how to accurately represent the value placed on time by the market intended for that service. To be successful, a congestion or roadway pricing project must solve the riddle of obtaining this accurate estimate. That problem has been approached by employing a dynamic pricing strategy for the SR 91 demonstration in California. The dynamic pricing will change the price of using the premium service according to conditions on the competing free facility. Thus, as traffic and congestion build on the free facility, toll charges on the free-flowing premium facility will increase, and vice versa. In that situation traffic conditions will control the price, and as travelers' time values vary, so will the price. The traveler will be told the price of the premium service sufficiently in advance to permit a decision whether premium service is sufficiently important to pay that price. Obviously this will require considerable care with coordination of advertising the price that will actually be charged, and the traffic management system must be adequate to that task.

### **Traveler Equity**

The concern for equity is important from a social and political sense as well as for the economic impacts. Pricing strategies usually charge the same amount for the same premium service regardless who uses the service. Therefore, the charge may be regressive in that the more affluent or higher income travelers pay a smaller portion of their income for that service than do lower income persons. The lower income travelers usually can less afford to use premium services and, therefore, must continue enduring congestion. This is particularly sensitive if the premium service involves using public facilities in some manner, such as a private tollroad built on public land -- the situation for the SR 91 project.

The most direct solution to the equity problem would be graduated tolls based on ability to pay, but such an approach is so complicated as to be essentially unworkable. It also reduces the effectiveness of charging a price that facilitates maintaining a premium level of service. Rather than solving the equity problem directly, the more practical approach is to mitigate or otherwise compensate the aggrieved travelers, offering something that in one way or another benefits their particular group. An example might be subsidizing transit services or employer vanpooling with proceeds from a toll facility. It is quite difficult to directly mitigate aggrieved travelers because they are a disparate group coming from and going to many locations. As a result, some compensation for the general community good may be offered, such as parking or social services paid by excess revenues from the tolls on the premium facility. In addition, it

may be possible to offer subsidies to low-income commuters with something similar to the earned income credit.

## **Surveillance**

The "big brother" issue is particularly difficult to address because it is a major concern of the general public and even more so of the affected travelers. This concern is a major issue that is virtually endemic in a free society. Unfortunately, enforcement, almost by definition, is a manifestation of "big brother" because it is intended to assure that rules or laws are being obeyed. It is a concern almost any time government is a party to enforcement, and particularly private enforcement where there is no established oversight process. Enforcement tends to be better accepted when there is direct surveillance, such as toll booths or law enforcement officers, than when continuous television monitoring and recordings are used, followed by a citation in the mail. The concern about enforcement tends to be greater when it involves recording the actions of an entire group, whether individuals are violating or not, and the fear that the record so obtained may be used by other entities or for other reasons than the original enforcement. One way to mitigate this concern is by establishing an oversight audit activity that is not responsible to the audited entity and reports directly to the potentially aggrieved group or parties.

The kind of AVI system employed can facilitate enforcement. If the transponder on a user's vehicle identifies the vehicle's owner, the owner can be billed for tolls incurred, either at the end of a user period or by prepayment of tolls. Such a system can also identify violators and issue a citation, either by mail or by delivery. Not all transponders identify vehicles, however, and those that don't require televised or on-site surveillance. Even the identifying transponder system would permit vehicles without transponders to pass unless some additional surveillance is employed. Random law enforcement on-site is one possible but less effective method employed. This is an area of concern that deserves additional consideration, especially if premium service facilities are intended to be self-supporting.

## **DESIGN, OPERATIONAL AND IMPACT ISSUES**

### **Project Design Issues**

These issues relate to how a project would work; and include determining such functions as physical design; traffic handling; information gathering, processing, and display; revenue collection; and enforcement. Care in establishing these design features is critical to the financial and operational success of the project. The issues discussed here differ from the day-to-day management and operations issues discussed later,

because these issues are confronted as part of project conception and create the project that would ultimately be managed and operated. Impact issues should be considered in project design, but they are treated as a separate group here for clarity.

One important design issue is identifying the nature and extent of congestion to be relieved, that is how broad is the area or corridor affected and what are the characteristics of the congested traffic. This determination would indicate the area to consider for control with the pricing strategy. The area controlled could be the CBD, a single major facility, or several facilities in a corridor. The extent of control would depend on how wide an area would be affected by spillover of traffic from the controlled area. If the pricing strategy merely relocates congestion, it will have failed. If several thoroughfares in a corridor are to be controlled to avoid this problem, the charges must be equitable for all facilities controlled, considering the levels of diversion and congestion for each facility.

Another of the design issues is deciding the best use of existing and potentially available capacity and land in the area to be controlled. How can the existing physical situation be used or made most productive, considering the available lanes, right-of-way, and undeveloped land that could be converted for transportation use? Developed land might also be considered if using that land would better serve the needs of the larger community.

Deciding the pricing strategy is another important issue: what amount will be charged and on whom. The pricing strategy will influence both the number of vehicles using the controlled location and the occupancy of those vehicles, so it is especially important for attenuating demand. Setting the pricing strategy requires determining the capacity of the location to be controlled and deciding what level of pricing will effect adequate control so that demand does not exceed capacity. The pricing strategy will depend on the elasticity of demand, which may be established from information obtained locally or from pricing projects elsewhere.

Safety concerns are another matter to be carefully considered in developing the project operational design. These concerns require considering how to handle accidents, how to control the speed of traffic in unconstrained flow, how to keep traffic moving when flow rates become critical, and how to handle speed enforcement. It is also necessary to address handling of traffic when an accident blocks the roadway completely. If the controlled location has buses and commercial vehicles operating on it, special precautions to handle the effects of breakdowns may be necessary, particularly for handling passengers when buses must be evacuated.

It is also important to identify the kinds and locations of various support facilities, such as information collection and display devices, user detection or toll collection devices, enforcement locations, park-ride facilities if they are to be incorporated in the project, and roadside facilities such as rest areas and breakdown refuges.

Designing the facility operation must consider congestion management strategies planned or employed for other jurisdictions, particularly those in the immediate area of the project but also throughout the region or state. Different congestion management strategies would be confusing to users and may conflict with activities or intentions of other jurisdictions. The AVI system employed should also be coordinated with related local activities regionwide, statewide, and even nationally. A new charging system should be carefully considered, researched, and tested before allowing the success of a project to depend on the success of its performance.

The project design should also consider the kind(s) of electronic systems to employ, for detection, charging, and traffic management. It is particularly important that the collection/detection system be coordinated or integrated with the traffic management system in order for the pricing program to function smoothly and effectively. The technology of traffic management is progressing so rapidly due largely to the IVHS program that it is important to keep abreast of available hardware, software, and deployment strategies so as to be cognizant of new techniques that could increase the feasibility of a certain pricing strategy or in a particular location. The project design would have to confront the decision of having static or dynamic pricing and the degree to which either approach is integrated with the traffic management system.

Selection of the operating strategy should consider the experience in other locations. Among those are the demonstrations in California where citations by mail are already being employed. The successes and failures of other projects would be helpful in deciding what strategy to use in other locations.

### **Legal Issues**

Implementation of a new project would be easier if it is consistent with the existing policies, regulations and laws of the federal, state, and all affected local governments. Achieving cooperation in project development would be difficult enough without having to deal with opposition from, or changing requirements of, those entities. Nevertheless certain permissions and prohibitions of existing law, regulations, or public policy, be they local, state, or federal, may have to be changed to permit a particular financing, ownership, or operating arrangement. Any attempt to change an existing situation must be sensitive to the interests and concerns of officials of the respective jurisdictions.

Creating a new organization with authority to build, operate, charge, and enforce pricing for premium services would almost certainly require legislative approval. This may be particularly difficult if the new organization is separate from an existing tollroad authority. Tolls and special licenses have been rather commonly used in some states, but newer pricing approaches may also require special authorization. Agreements with various government entities for financing, distributing revenue, administration, and

enforcement may also have to be established in law. A particular concern may be the need to overcome the federal prohibition of tolls on facilities originally built with federal financial assistance or converting a free federal-aid road to a tollroad. Establishing authority to control support facilities, such as access, park-ride facilities, and concessions may also require legislative authorization.

Pricing projects may involve private sector participation. The legality of private sector participation in financing and operation must be resolved. If a franchise is the means to accomplish private participation, the issuer of the franchise, how to obtain the franchise, and conditions to be satisfied must be determined. The flexibility and limitations of a franchise can affect the potential for private participation. Another matter to resolve is the ability of a franchisee to issue tax-exempt bonds and the requirements so imposed.

Liability and insurability against loss are critical concerns of private operators. The nature and extent of financial responsibility and protection of a private operator would have to be resolved, considering for example applying the tort liability limitations of governments to the private operator. The nature of enforcement may require special enabling legislation, especially to authorize a private operator to exercise the police powers of government. The feasibility of incentives for private sector participation may also have to be established in law.

These are but a few of the legal and regulatory concerns that would have to be addressed for any project that involves new approaches to financing, developing, and operating a transportation pricing project. Each local situation would require careful consideration of changes needed in existing law to make a particular project feasible.

## **Financial Issues**

Financing issues are closely related to legal and regulatory matters since the novelty of pricing projects makes it likely that special legal authorization for them would be required. The key financing issues to address are, "who will pay for the project and how?"

A project fully financed by a private entity may develop more smoothly but would also be less likely to become a reality unless the private entity has a sufficient potential gain. Private financing also may offer greater latitude for innovation, but this advantage is diminished if special legislation is required to authorize the financing approach desired. By creating conditions that attract private investment, governments can realize improvements at reduced cost that they might not otherwise be able to afford. But, in so doing, the benefitting agencies must exercise care to protect the public interest. The public entity benefitting from a privately financed project should consider the conditions under which it would want or have to become involved in the project, a "bail-out."

Mixing public and private financing usually requires various legal considerations and approvals that complicate the project development process. Recent innovations in mixed and fully public or quasi-public financing may offer attractive opportunities, such as special districts, development corporations, and build-finance-operate organizations. When several financial partners are involved, be they public and/or private, the manner to distribute initial development costs, operating expenses, and revenues should be resolved prior to project commitment.

Regardless of whether public or private, the projects would probably be debt financed. It is important to assure that revenues from the pricing project would be adequate to meet debt service requirements and obtain a satisfactory interest rate. If the bonds are tax-exempt, the value of the issue would have to be limited so that it does not unduly constrain the ability of participating public entities to issue bonds for other projects and purposes. If that were the case, legislative relief might be necessary.

As recommended in the discussion of legal concerns, it may be best to exhaust all currently feasible legal financing strategies before trying to change the law to fit new public/private financing strategies.

### **Management and Operations Issues**

The management issues deal with the responsibility for organizing, building and operating the project. Organizing would require establishing the decision and activity structure for financing and for processing legal, legislative, and other policy actions. Operating activities would include maintenance, revenue collection, enforcement, and conducting other project activities day-to-day. Building of course involves construction management.

Organizing the project would require establishing relationships and mechanisms for coordinating and cooperating with the various public and private entities participating in and/or affected by the project. Agreements among the affected jurisdictions would be needed early in the project to identify responsibilities for administration, accounting, revenue distribution, enforcement, and other project activities. These coordination mechanisms would be useful to identify public policy issues of the participating jurisdictions and assure consistency of the new project with their respective goals and objectives, especially their development policies.

The functions of maintenance, enforcement, and setting or varying pricing levels would have to be assigned through the coordinating mechanisms after being established in state or local law. The management processes needed for project development and operation and the institutional concerns to be addressed in developing the organization would have to be resolved.

It is important to develop relationships among project participants and agreement on the management structure and responsibilities at the outset of the project so that conflict, controversy, and delay do not occur later.

## **Impact Issues**

Anticipating and planning to resolve potential impacts should be accomplished in project design. The nature and level of impacts would depend on the project. Impacts of a new tollroad on new location would be no different from any new highway, and impacts of new construction in existing right-of-way may well be minor but not unexpected. In either of these situations, the manner for dealing with impacts is well established. The more critical concerns for pricing projects, which are somewhat novel, are unexpected impacts and those whose magnitude may be greater than anticipated. One major expected impact of pricing projects is the equity concern discussed previously.

Other impacts would occur on businesses and other employers whose constituents and employees may have to pay to reach the business or employment location and, therefore, may be less inclined to do so. Some kind of compensation or other mitigation may be necessary for those situations. The impacts may also occur on workers, especially poorer workers, who have to pay to reach their job or a previous shopping location.

One impact especially important to local jurisdictions is the effect on land use and development. An area may be less likely to develop if there is a charge to reach that location by a toll facility or due to area pricing. That effect may be mitigated by providing some special enhancements to encourage development, particularly of a desired kind, that would offset the price disadvantage. Possible mitigations to consider might be free parking, special amenities, or even relief from development restrictions or temporary tax abatement. The project design would have to consider what those enhancements might be. A positive aspect of such an impact would be the opportunity for the jurisdiction to selectively compensate development in order to realize the kind of development desired.

Other impacts to consider include the opportunity to integrate park-and-ride facilities with the pricing-controlled facility to enhance its effectiveness. Air quality problems in non-attainment areas present another potential for positive impact. These positive impacts must be considered along with the negative because they may be important to developing project support.

Differences in impacts may arise from variations in the amount or method of pricing, the traffic to which pricing is applied, the breadth or area of coverage of the pricing, and the timing of pricing application. All of these characteristics of the pricing projects and strategies must be considered carefully to determine if there would be impacts and how to address, mitigate, or compensate them.

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## CONCLUSIONS AND RECOMMENDATIONS

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Congestion pricing is theoretically an excellent method to reduce congestion in urban areas because it forces motorists to pay for the congestion they are causing. In current practice, when a motorist enters a highway at or near capacity, the general level of congestion increases, imposing congestion costs on all the other motorists. However that single motorist only pays for his or her own costs, not the costs incurred by other motorists. This "externality" can be eliminated by charging an appropriate congestion charge. The charge would only apply to peak periods when congestion is a problem. For other times during the day, no charge would be made.

If congestion pricing is such a good idea, why hasn't it been tried very often and received intense opposition in those few attempts? One objection is the conversion of a free facility to a toll facility. The idea is that the public has already paid for the facility when it was built, but will have to pay to use it with a toll charge. Of course the toll charge is to reduce the externalities of congestion, not necessarily to generate more revenue, so the issue of what to do with the money is of prime importance. If the public can be convinced that the money will be used for beneficial purposes, such making improvements to the transportation system, and providing better public transportation services, the revenue question could be addressed. Another major source of objection are the distributional problems. Rich motorists could easily pay the congestion charge, whereas it would be a significant burden for poor motorists, especially for those commuting to work when it would be difficult or impossible to avoid the charge by traveling during non-peak periods. A way of addressing this problem would be to use part of the revenues to subsidize low income workers, by providing reduced public transit fees, subsidize employer vanpooling, or direct subsidies similar to the earned income credit.

The conclusion is that it would be feasible to implement a congestion pricing scheme, if particular attention is paid to addressing the objections and concerns of the public and government officials. A feasible place to start would be conversion of an existing HOV lane to congestion pricing, by allowing single occupancy vehicles to use the lane by paying a congestion fee tied to the amount of congestion on the main lanes, without causing congestion on the HOV lane. Conversion of an HOV lane has the obvious weakness that it would have very little effect on the overall congestion, because it would not significantly reduce the number of vehicles using the facility. However it would gauge the public acceptance of paying tolls, test the toll collection technology in this environment, and give a better idea of what level of toll is appropriate in different circumstances. Over time it could also have the beneficial effect of getting motorists



used to the idea of paying for increased travel speed, which could then be tried on the main lanes.

Several recent advances in electronic toll collection technology makes it feasible to use in a congestion pricing scheme. Vehicles equipped with toll tags can be quickly and efficiently identified, making the collection process feasible and relatively low-cost for a congestion pricing scheme. Of course the process would have to be accompanied by appropriate enforcement, along with a method for handling vehicles without toll tags, but the technology is at a point that any problems would probably be minor. Several toll facilities are already using advanced electronic toll systems with great success.

The HOV lane along the Katy Freeway in Houston was used in the study to look at the feasibility of using congestion pricing and to make estimates of the potential energy savings. Two scenarios were examined, a 2+ carpool HOV requirement, and a 3+ carpool requirement. The 3+ carpool scenario was further analyzed by assuming varying percentages of possible carpool formation rates. In both scenarios low occupancy vehicles from the main lanes could use the HOV by paying a congestion fee. In all cases, except for two traffic diversion levels with a 100 percent carpool formation rate, the fuel consumption increased with congestion pricing. The reason for this was that each scenario assumed a certain number of low-occupancy vehicles would shift from the main lanes to the HOV. The total number of vehicles would not change, except for the carpool formation cases. The higher speeds by those vehicles switching to the HOV increased fuel consumption. Keeping the total number of vehicles constant is a reasonable assumption in this case because a motorist would still have the option of using the main lanes and not paying a congestion charge, so there is little incentive for a motorist to change a trip to an off-peak period, switch to a high occupancy mode, or forego the trip altogether. To get reductions in the number of vehicles and fuel consumption would require some form of congestion pricing on the main lanes, and possibly "spillover" alternate routes.

It is recommended that a pilot demonstration project be initiated, using one of the HOV lanes in Houston as a first phase case study. The issues involved in planning and implementing a demonstration project are covered in detail in Chapter 7 of this report. The planning and implementation of a demonstration project would require a significant effort and commitment of resources. There are several issues that would have to be addressed in the project; including setting an appropriate toll; handling the equity issue, setting up an effective surveillance system that is acceptable to the public; addressing the legal and financial obstacles; making up design, operation, and maintenance plans; and anticipating and addressing potential impacts. How these issues are addressed will, to a great extent, determine the success of the project.

A demonstration project would have great potential for testing the congestion pricing concept and to demonstrate to the public the benefits of a carefully planned and executed pricing project. The major issues listed above need to be carefully considered

and addressed in order for all parties involved to view the future use of congestion pricing as an effective tool to improve the transportation system in urban areas. Ultimately, these issues come down to identifying who benefits from premium transportation services, who should pay for that service, who is hurt or otherwise impacted by that service, and how to compensate or mitigate those adverse impacts.

The transportation network provides a vital service to society for moving both people and goods. Unfortunately congestion in urban areas has imposed a tremendous cost on society by reducing the efficiency of that network. Congestion pricing gives a viable alternative to increase the efficiency of the network, providing potentially tremendous benefits to society. Given that there are few other alternatives for reducing congestion, it is time to give it a chance.

## CITED REFERENCES

1. J.A. Lindley. *Quantification of Urban Freeway Congestion and Analysis of Remedial Measures*. Report No. FHWA-RD-87-052, U.S. Department of Transportation, Washington, D.C., 1986.
2. R.W. Holder and V.G. Stover. *An Evaluation of Induced Traffic on New Highway Facilities*. Texas Transportation Institute, Research Report 167-5, March 1972.
3. H.S. Levinson. *Characteristics of Urban Transportation Demand- A Handbook for Transportation Planners*, Urban Mass Transportation Administration, Washington, D.C., April 1978.
4. A. Downs. *Stuck in Traffic, Coping with Peak-Hour Traffic Congestion*. The Brookings Institute, Washington, D.C., 1992.
5. J.A.Gomez-Ibanez. The Political Economy of Highway Tolls and Congestion Pricing, *Transportation Quarterly*, Vol 46 no 3, pp. 343-360, July 1992.
6. R. W. Poole, Jr., *Introducing Congestion Pricing on a New Toll Road*, Policy Insight Paper No. 150, The Reason Foundation, Los Angeles, California, September 1992.
7. Exploring the Role of Pricing as a Congestion Management Tool. *Search For Solutions: A Policy Discussion Series*, Number 1, Federal Highway Administration, Washington, D.C., March 1992.
8. Examining Congestion Pricing Implementation Issues. *Search For Solutions: A Policy Discussion Series*, Number 6, Federal Highway Administration, Washington, D.C., December 1992.
9. B.S. McMullen and T. Gut. HOV Lane Effectiveness in Controlling Traffic Congestion. *Transportation Quarterly*, Vol. 46, No. 3, pp. 429-434, July 1992.
10. K. Bhatt. *Congestion Pricing Potential for Reducing Traffic Congestion*.
11. T.D. Hau. *Congestion Charging Mechanisms for Roads: An Evaluation of Current Practice*. Working Paper Series 1071, The World Bank, Washington, D.C., December 1992.
12. K. Button and A. Pearman, *"Applied Transport Economics: A Practical Case Studies Approach"*, Gordon and Breach Science Publishers, New York, 1985.

13. World Bank, *Relieving Traffic Congestion: The Singapore Area License Scheme*, Staff Working Paper 281, World Bank, Washington, DC, 1978.
14. T. Toh, "Road Congestion Pricing: The Singapore Experience", *Malayan Economic Review*, Vol. 22, pp. 52-61, 1977.
15. C-M. Seah "Mass mobility and accessibility: transport planning and traffic management in Singapore", *Transport Policy and Decision Making*, Vol. 1, 1980.
16. M. Cheslow, *A Preliminary Analysis of a Road Pricing and Transit Improvement Program in Berkeley, California*, Urban Institute, Washington, DC, 1978.
17. F. Spielberg, *Transportation Improvement Programs Using Road Pricing: A Preliminary Analysis for Madison, Wisconsin*, Urban Institute, Washington, DC, April 1978.
18. I.G. Taylor and P.J. Hills, *Automated Vehicle Identification and Monitoring for Pricing Heavy Goods Vehicle Movement in London*", Research Report No. 62, University of Newcastle, Department of Civil Engineering, Transport Operations Research Group, January, 1986.
19. S. Borins, "Electronic Road Pricing: An Idea Whose Time May Never Come", *Transportation Research*, Vol. 22, pp. 37-44, 1988.
20. T. Hau, "Electronic Road Pricing: Developments in Hong Kong, 1983-1989", *Journal of Transport Economics and Policy*, 24, pp. 203-214, 1990.
21. T. Hau, "Economic Fundamentals of Road Pricing: A Diagrammatic Analysis", *World Bank Policy Research Working Paper Series*, WPS No. 1070, The World Bank, Washington, DC, December 1992.
22. J. Dawson, I. Catling, "Electronic Pricing in Hong Kong", *Transportation Research*, 20A, pp. 129-134, March 1986.
23. Unpublished notes from the University of California Transportation Center Conference on congestion Pricing Demonstration Projects, February 28 - March 1, 1991, San Diego, California.
24. T. Higgins, "Road Pricing-Should It and Might It Happen Here?", *Transportation*, 8 (2), pp. 99-113, 1979.
25. K.J. Button, "Road Pricing-An Outsider's View of American Experience", *Transport News*, 4 (1), 1984.

26. O. Larsen, "The Toll Rings in Bergen, Norway", *Transportation Research Record* 1107, 1987.
27. O. Larsen, "The Toll Rings in Bergen, Norway-The First Year of Operation", *Traffic Engineering and Control*, Vol. 29, 1988, No. 4.
28. R.L. Hartje, G.S. Pfeffer, "Private Toll Roads: SR 91 Toll Express Lanes", *ITE 1991 Compendium of Technical Papers*, Washington, DC.
29. ETTM System Selected for California's Private Toll Road", *The Urban Transportation Monitor*, Lawley Publications, February 19, 1993.
30. *Mobility TIME*, National Center for Regional Mobility, George Mason University and the Consortium for Regional Mobility, Issue 3, July 1992.
31. N.H. Wuestefeld. Toll Roads, *Transportation Quarterly*, Vol. 42, No. 1, Eno Foundation for Transportation, January 1988.
32. R.J. Hartje, Toll Roads on the March, Urban Land, 1991. *Transportation Quarterly*, Vol. 46, No. 3, Eno Transportation Foundation, Westport, Connecticut, July 1992.
33. Souleyrette, M. Walton, and H. Mahmassani. *Identification of Candidate Toll Roads in Current and Future Highway Development*, Center for Transportation Research, University of Texas, Austin, Texas.
34. Wide Spread Interest in Toll Roads, *Urban Transportation Monitor*, Vol 2, No 24, pp 8-9, Dec. 1988.
35. *Amtech Backscatter newsletter*, Vol. 1, No. 8, Dallas, Texas, 1993.
36. *Inside IVHS*, Waters Information Services, Binghamton, New York, February 3, 1992.
37. *Urban Transportation Monitor*, Lawley Publications, Burke, Virginia, September 18, 1992.
38. *Inside IVHS*, Waters Information Services, Binghamton, New York, February 15, 1993.
39. J. Predergast. Privatization Takes Its Toll, *Civil Engineering*, January 1993.
40. R.J. Hartje. Tomorrow's Toll Road, *Civil Engineering*, February 1991.

41. W.S. Vickery. "Congestion Theory and Transport Investment," *American Economic Review*, Columbia University, (59), 1969.
42. D. Newberry. "Road Damage Externalities and Road user Charges," *Econometrica*, vol. 56, pp. 295-316, 1988.
43. J. Henderson, "Congestion and Optimum City Size," *Journal of Urban Economics*," vol. 2, 1975.
44. A. Sullivan, "The General Equilibrium Effects of Congestion Externalities", *Journal of Urban Economics*, vol.13, pp. 235-255, 1983.
45. R. Arnott and J. Mackinnon, "Market and Shadow Rents with Congestion," *American Economic Review*, vol. 68, 31-55 1974.
46. A. Sullivan, "Second-Best Policies for Congestion Externalities," *Journal of Urban Economics*, vol.14, pp.105-123 1983.
47. M. Kraus, "The Welfare Gains from Pricing Road Congestion Using Automatic Vehicle Identification and On-Vehicle Meters," *Journal of Urban Economics*, vol. 25, 261-281 1989.
48. H. Richardson, "A Note on the Distributional Effects of Road Pricing," *Journal of Transport Economics and Policy*, Vol 8, pp.82-5, 1974.
49. C. Sharp, "Congestion and Welfare: An Examination of the Case for a Congestion Tax," *Economic Journal*, vol 76, pp. 806-17, 1966.
50. O. Larsen and F. Ramjerdi, "Road Pricing as a Means of Financing Investment in Transport Infrastructure, The Case of Oslo," paper presented at the 71st Annual Meeting of the Transportation Research Board, Washington, D.C., January 1992.
51. O. Larsen, F. Ramjerdi, "The Toll Rings in Norway in the Perspective of Road Pricing," paper presented at the PTRC Conference on "Practical Possibilities for a Comprehensive Transport Policy With or Without Road Pricing," London, England, pp. 1-19, December 5, 1990.
52. B. Ang and S. Oh, "Transport and Traffic Management Schemes and Energy Savings in Singapore", *Energy*, Vol. 13, pp. 141-148, 1988.
53. S. Morrison, "A Survey of Road Pricing," *Transportation Research*, vol 20A, pp.87-97, March 1986.

54. A. Walters, "Empirical Evidence on Optimum Motor Taxes for the United Kingdom," *Applied Statistics*, Vol. 10, No. 3, pp. 157-169, November 1961.
55. Ministry of Transport, *Road Pricing: The Economic and Technical Possibilities*, HMSO, London, 1964.
56. Greater London Council, *Supplementary Licensing*. Greater London Council, 1974.
57. M. Kraus, H. Mohring and T. Pinford, "the Welfare Costs of Nonoptimum Pricing and Investment Policies for Freeway Transportation," *American Economic Review*, vol. 66, pp. 532-547, 1976.
58. T. Keeler and K. Small, "Optimal Peak-Load Pricing, Investment and Service Levels on Urban Expressways," *Journal of Political Economy*, vol. 85, pp. 1-25, 1977.
59. D. Dewees, "Estimating the Time Costs of Highway Congestion," *Econometrica*, vol. 47, pp. 1499-1512, 1977.
60. H. Mohring, "The Peak Load Problem with Increasing Returns and Price Constraints," *American Economic Review*, vol. 60, pp. 693-705, 1970.
61. P. Viton, "Equilibrium Short-run-marginal-cost Pricing of a Transport Facility: The Case of The San Francisco Bay Bridge," *Journal of Transport Economic and Policy*, vol. 14, pp. 185-203, 1980.
62. J. Gomez-Ibanez and G. Fauth, "Downtown Auto Restraints Policies: the Costs and Benefits for Boston," *Journal of Transport Economics and Policy*, vol. 14, pp. 133-153, 1980.
63. S. Borins, "The Economic Effects of Non-Optimal Pricing and Investment Policies for Transportation Facilities," *Canadian Journal of Economics*, vol. 17, pp. 80-98, 1984.
64. A. DeVany and T. Saving, "Competition and Highway Pricing for Stochastic Traffic." *Journal of Business*, vol. 53, pp.45-60.
65. M. Kraus, "Highway Pricing and Capacity Choice Under Uncertain Demand," *Journal of Urban Economics*, vol. 12, 122-128, 1982.
66. M. Kraus, "Indivisibilities, Economies of Scale and Optimal Subsidy for Freeways," *Land Economics*, vol. 12, 122-128, 1982.
67. A.E. Boardman and L.B. Lave, "Highway Congestion and Congestion Tolls," *Journal of Urban Economics*, vol. 4, pp. 340-359.

68. R. Inman, "A Generalized Congestion Function for Highway Travel, " *Journal of Urban Economics*, vol. 5, pp. 21-34, 1978.
69. R.W. Willson and D.C. Shoup, "Parking Subsidies and Travel Choices: Assessing the Evidence", *Transportation*, Vol. 17, 1990, pp. 141-157.
70. D.C. Shoup and R.W. Willson, "Employer-Paid Parking: The Problem and Proposed Solutions", *Transportation Quarterly*, Vol. 46, No. 2, April 1992, pp. 169-192.
71. M.C. Pietrzyk, "Evaluation of Alternative AVI/ETTM Configurations at Toll Barriers", *ITE 1991 Compendium of Technical Papers*, Washington, DC.
72. R.S. Foote, "Prospects for Non-Stop Toll Collection Using Automatic Vehicle Identification", *Transportation Quarterly*, Vol. 35, No. 3, 1981, pp. 445-460.
73. M.C. Pietrzyk, "*Analysis of Automatic Vehicle Identification Technology and It's Potential Application on the Florida Turnpike*", Technical Memorandum 2, Center for Urban Transportation Research, October 1990.
74. P. Davies, "Testing and Appraisal of Automatic Vehicle Identification Systems", Selected Proceedings of the Fifth World Conference on Transportation Research: Transport Policy, Management & Technology Towards 2000, Yokohama, Japan, July 10-14, Vol. 11, 1989.
75. I. Catling, "*Information Technology Applications in Transport*", VNC Science Press BV, Utrecht, The Netherlands, 1987.
76. Privacy, Auditability and Computers in Electronic Toll Collection, Amtech Backscatter Newsletter, Summer 1992, Dallas, Texas.
77. R.S. Reis, D.A Carmel, and C.C. Clark. "ExpressTag - A Reliable Highway-Speed Electronic Toll Collection System". Worldwide ETTM Development conference. Proceedings of the 59th Annual meeting by International Bridge, Tunnel and Turnpike Association, 1991.
78. D.A Boss and J.W. Griffin. "Electronic Toll Collection Debuts on the Dallas North Tollway". Worldwide ETTM Development conference. Proceedings of the 59th Annual meeting by International Bridge, Tunnel and Turnpike Association, 1991.
79. D.A. Hensher. "Electronic Toll Collection." *Transportation Research*. Volume 25A, NO. 1, pp. 9-16, 1991.



80. R.J. Hartje, "Toll Roads in California", *ITE Journal*, June 1991, pp. 17-21.
81. *Backscatter*, Vol. 1, No. 8, Winter 1992-1993, Amtech's Dallas North Tollway ETTM Contract Extended.
82. *Urban Transportation Monitor*, Lawley Publications, Burke, Virginia, December 1990.
83. *Urban Transportation Monitor*, Lawley Publication, Burke, Virginia, February 1991.
84. *Urban Transportation Monitor*, Lawley Publication, Burke, Virginia, November 1991.
85. AMTECH press release dated 9/30/92. AMTECH Corporation, Dallas, Texas.
86. C.L. Dudek, "Guidelines on the Use of Changeable Message Signs", FHWA-TS-90-043, U.S. Department of Transportation, Washington, DC, May 1991.
87. D.L. Christiansen and D.E. Morris. *An Evaluation of the Houston High-Occupancy Vehicle Lane System*. Texas Transportation Institute, Research Report 1146, College Station, Texas, June 1991.
88. S. Smith, R. Worrall, D. Roden, R. Pfefer, and M. Hankey. *Application of Freeway Simulation Models to Urban Corridors*. Volume 1: Final Report. Federal Highway Administration, FHWA-RD-92-102, Washington, D.C., November 1992.
89. Crain and Associates. *San Bernardino Freeway Expressway Busway, Evaluation of Mixed Mode Operations*. Final Report. Prepared for Southern California Association of Governments, July 1978.
90. J. McQueen, D. Levinsolm, R. Waksman and G. Miller. *Evaluation of the Shirley Highway Express-Bus-On Freeway Demonstration Project*. Final Report. DOT/UMTA 7, August 1975.

**APPENDIX  
PUBLIC TOLL ROAD OPERATORS**

Operators of 28 public toll roads and/or toll bridges are listed below. This list is probably not all inclusive. The list is provided to indicate the widespread use and acceptance of road pricing.

City of Colorado Springs:	Pikes Peak Auto Highway
Connecticut Department of Transportation:	Connecticut Turnpike; Merritt Parkway; Wilbur Cross Parkway; Delaware Turnpike Administration; John F. Kennedy Memorial Parkway
California Department of Transportation:	San Francisco-Oakland Bay Bridge; Antioch Bridge; Benicia-Martinez Bridge; Carquinez Bridge; Dunbarton Bridge; Dunbarton Bridge; San Mateo-Hayward Bridge; Richmond-San Rafael Bridge; Vincent Thomas Bridge; San Diego-Coronado Bridge
Florida Department of Transportation:	East-West (Miami) Tollway; Alligator Alley (Everglades Parkway); 36th Street (Miami) Expressway; Airport Expressway (Miami); Buccaneer Trail (Ocean Highway); South Dade Expressway; South Crosstown Expressway
Florida Department of Transportation & Florida Turnpike Authority:	Florida's Turnpike
Florida Department of Transportation & Orlando-Orange County Expressway Authority:	Bee Line Expressway; East-West Expressway
Golden Gate Bridge Highway and Transportation District:	Golden Gate Bridge

Jacksonville Transportation Authority (Florida):	Jacksonville Toll Road
Illinois State Toll Authority:	Northwest Tollway; Tri-State Tollway; East-West Tollway
Indiana Department of Highways:	Indiana East-West Toll Road
Kansas Turnpike Authority:	Kansas Turnpike; 18th Street Expressway
Kentucky Turnpike Authority:	Western Kentucky Parkway; Western Kentucky Parkway Extension; Mountain Parkway; Bluegrass Parkway; Jackson Purchase Parkway; Pennyrile Parkway; Audubon Parkway; Daniel Boone Parkway; Cumberland Parkway; Green River Parkway
Maine Turnpike Authority:	Maine Turnpike
Maryland Transportation Authority:	John F. Kennedy Memorial Highway
Massachusetts Turnpike Authority:	Massachusetts Turnpike
New Hampshire Department of Public Works and Highways:	New Hampshire Turnpike; F.E. Everett Turnpike; Spaulding Turnpike
New Jersey Expressway Authority:	Atlantic City Expressway
New Jersey Highway Authority:	Garden State Parkway
New Jersey Turnpike Authority:	New Jersey Turnpike
New York State Thruway Authority:	Thomas E. Dewey Thruway (Main Line); Berkshire Section; Niagara Section;

	New England Section; Garden State Parkway Connection
Ohio Turnpike Commission:	Ohio Turnpike
Oklahoma Turnpike Authority:	Cherokee Turnpike; Creek Turnpike; Chickasaw Turnpike; John Kilpatrick Turnpike; Turner Turnpike; Will Rogers Turnpike; H.E. Bailey Turnpike; Indian Nation Turnpike; Muskogee Turnpike; Cimarron Turnpike
Pennsylvania Turnpike Commission:	Pennsylvania Turnpike; Northeastern Extension
Texas Turnpike Authority:	Dallas North Tollway; Mountain Creek Lake Bridge; Houston Ship Channel Bridge
Harris County Toll Road Authority (Texas):	Hardy Toll Road; West Belt Toll Road
Richmond Metropolitan Authority (Virginia):	Powhite Parkway; Downtown Expressway
Virginia Department of Highways and Transportation:	Richmond-Petersburg Turnpike; Norfolk-Virginia Beach Toll Road; Dulles Toll Road
West Virginia Turnpike/Toll Road Commission:	West Virginia Turnpike/Toll Road