Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-01/4009-1		

4. Title and Subtitle	5. Report Date
ASSESSING PRICING STRATEGIES AND USERS' ATTITUDES TOWARDS MANAGED LANES	January 2002
	6. Performing Organization Code
7. Author(s) Dr. Jianling Li, Dr. Shekhar Govind, Dr. James C. Williams, Dr. Siamak Ardekani, and Dr. Richard Cole	8. Performing Organization Report No. Report 4009-1
9. Performing Organization Name and Address The University of Texas at Arlington Arlington, Texas 76019	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. Research Project No. 0-4009
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P. O. Box 5080 Austin, Texas 78763-5080	13. Type of Report and Period Covered Research Report September 2000 - August 2001
	14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation (TxDOT) and the U.S. Department of Transportation, Federal Highway Administration (FHWA).
Research Project Title: Pricing Strategies for Managed Lanes

16. Abstract

The managed lane concept is being considered for major freeway projects in many metropolitan areas in the State of Texas. A key component of the managed lane concept is pricing strategy and fee charged to various types of vehicles and user groups. In spite of the useful insights provided by the existing literature on managed lane studies, little is known about the price impact on demand for managed lanes and variations among different user groups. Also overlooked are methods that can apply price elasticity information to the evaluation and selection of optimal pricing strategies. This project investigates travelers' attitudes toward the managed lane concept and develops a tool for evaluating the impacts of various pricing policies and selecting appropriate options for managed lanes in the State of Texas.

17. Key Words	18. Distribution Statement
Managed Lanes, Congestion Pricing, Toll Evaluation.	No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**	156	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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Report 4009-1
Project Number 0-4009
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Sponsored by the
Texas Department of Transportation
In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

January 2002

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ACKNOWLEDGEMENTS

The research reported herein was performed by the University of Texas at Arlington (UTA) and was sponsored by the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). Mr. Matthew E. MacGregor, P.E., and Mr. Tony B. Payberah, P.E., of the LBJ Project Office of TxDOT's Dallas District, served as the research project director and co-project director. Mr. Jay Nelson, P.E., of the TxDOT Dallas District Engineer served as the project coordinator. The authors thank them for their interest and leadership in this project.

The authors wish to thank TxDOT for its financial support and UTA for the research facilities. We would also like to thank Dr. Khali. Persad of TxDOT's Research and Technology Implementation Office, and Mr. Joey Oestrick of TxDOT's Vehicle Title and Registration Division for their support and assistance in getting data necessary for this research. Finally, we would like to express our appreciation to Ms. Key Lee of TxDOT, Mr. Chris Pourteau and Ms. Rhonda Brinkmann of TTI for their assistance in the final production of the reports.

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CHAPTER ONE: INTRODUCTION

1.1. Background

In response to concerns over traffic congestion, air quality, and resources for transportation infrastructure, governments across the world are increasingly interested in strategies that intend to maximize the utilities of transportation infrastructure. These strategies range from institutional management approaches, to market-based actions, and to intelligent transportation systems (ITS). Institutional management strategies attempt to improve access and reduce vehicle travel through institutional arrangements such as coordinating transportation and land use planning, providing ridesharing services, and managing access. Market-based measures focus on altering travel behavior through various pricing strategies. Some examples are toll, congestion pricing, motor vehicle fuel tax, differential pricing for different users, parking surcharge, mileage and emission charges, *etc.* The ITS approach includes the use of a variety of sensing, visioning, computer, and communication technologies to monitor road conditions and convey traffic information to the traveling public to maximize traffic flow. The managed lane concept combines many advantages of the foregoing strategies. A managed lane facility is designed and operated to achieve stated goals by means of managing access, user groups, pricing, and/or other criteria. It typically provides improved travel conditions to eligible users (Pricing Outreach Task Force, 2001).

A key component of the managed lane concept is the pricing strategy and fee charged to various types of vehicles and user groups. Ongoing projects around the country use a mix of fixed price per trip, time-of-day pricing, and variable pricing. A great deal of effort has been made to evaluate the ongoing pricing projects. Research so far has largely focused on the impacts of pricing projects and on the assessment of public opinions (Mastako *et al.,* 1998; Sullivan and Harake, 1998; Sullivan, 1998; Burris *et al.*, 2000; Hickman *et al.,* 2000; SANDAG, 1999; Supernak *et al.,* 1999; Ristau *et al.,* 2000; Supernak *et al.,* 2000a and 2000b). While the previous studies have provided useful insights to the impacts of congestion pricing, more studies are needed to understand the demand elasticity of managed lanes, namely, the change in the use of managed lanes such as High-Occupancy-Toll (HOT) lanes and toll facilities resulting from a unit change in an attribute such as price, controlling for other factors (Small and Winston, 1999). Also overlooked are methods that can incorporate price elasticity information to the evaluation and selection of optimal pricing strategies. This study intends to fill these gaps.

1.2. Research Objectives

The main objective of this project is to develop a tool for transportation planners and engineers and toll agencies to evaluate the impacts of various pricing policies and select appropriate options for managed lanes in the State of Texas. It studies attitudes toward the managed lane concept, analyzes variations in demand for managed lanes among different user groups, and investigates price elasticity of demand for managed lanes. In addition, it develops optimization models for the assessment of the impacts of pricing strategies on network performance, toll revenues, and air quality, and for the evaluation and selection of pricing strategies. Furthermore, it discusses the implications of the study findings and provides recommendations for the implementation of pricing projects in the State of Texas. Specifically, this research project examines the following questions:

- How would users react to the managed lane concept?
- What is users' willingness to pay for a unit of time saving?
- How do user groups differ in demand in response to the managed lane concept?
- What will be the equilibrium of travel demand and supply associated with a particular pricing policy?
- How much toll revenue will be generated with a particular pricing scheme and how will the pricing policy affect traffic flows and air quality?
- What pricing policy issues should be of concern if a toll is considered for managed lanes in Texas?

1.3. Structure of the Report

This report consists of seven chapters. Chapter Two discusses the concept of congestion pricing and describes the current status of pricing projects and research. Chapter Three outlines the framework for this research. Chapter Four explains the research methodologies applied in this study. The results of data analysis are presented in Chapter Five. Chapter Six provides guidelines and examples for using the pricing evaluation tool. The final chapter summarizes research findings and recommendations.

CHAPTER TWO: PRICING STRATEGIES AND APPLICATIONS

2.1. The Concept of Congestion Pricing

Economists have long advocated pricing as a means to allocate and maximize the utility of scarce resources. A variety of pricing strategies have been identified for transportation management. Examples are road pricing, congestion pricing, fuel tax, mileage and emission charges, and parking surcharges. While these pricing strategies share some common usage, each is also used for specific purposes. For example, road pricing in general is used for generating revenues for financing transportation investments. Fuel tax and emission charges target energy consumption and air quality concerns. Parking surcharges are mainly for parking management and recently, it has been used as a means to influence travel modes.

Congestion pricing has been considered as an efficient approach to reduce peak hour traffic congestion and to maximize the efficient use of society's economic resources, including both the capital invested in roads and the time motorists spend on commuting. Unlike regular tolls, congestion pricing incorporates market principles by charging higher prices during peak hour periods when demand for roadways is high. It is a market- or demand-based strategy designed to encourage the shift of peak period travel to off-peak periods. It assumes travel decisions are made rationally according to economic principles. Therefore, the higher the charge, the more people would be deterred from driving during peak hour periods. Besides changing the time of travel, some people may change their travel routes and modes. Some may even forego their trips. Because congestion pricing is the main concern of this project, it is the focus of discussion in this report.

Various pricing schemes have been applied in the ongoing pricing projects in the United States and other countries throughout the world. In spite of some differences, most pricing schemes are either fixed charges related to time of day, cordons, and distance, or variable charges based on traffic delay and time of day. These pricing schemes are explained below.

2.1.1. Fixed charge related to time of day

The pricing scheme of fixed charges related to time of day is a common form of congestion pricing and has been applied in many projects. Under this form of congestion pricing, different tolls are set for various periods of day, with higher tolls in peak periods and lower or zero tolls for off peak periods. In some existing toll facilities where increasing peak-period tolls is opposed, discount tolls for off-peak travel are provided to encourage motorists to shift their trips to off peak periods.

2.1.2. Cordon charging system

With the cordon charging system, charges are levied at various points around a specific area. A cordon line (or screen line) connecting these points defines the affected area. Vehicles crossing the cordon line are required to pay a toll in order to enter the area. A main purpose of this charging system is to reduce traffic congestion in an overcrowded area. The cordon-pricing concept has been applied in many places such as Singapore, and Bergen, Oslo, and Trondheim in Norway (Small, 1997).

2.1.3. Distance-based pricing

The distance-based pricing system involves charging based on distance traveled on a transportation network. Under such a system, longer-distance travelers are charged a higher price. Many regular toll roads use the distance-based pricing option. Fairness is a principle of such a charging system, meaning the more the use of a transportation facility, the more a user should pay. However, this system does not charge users based on the externality that a user imposes on others, which is usually found during peak hour periods. For this reason, the distance-based pricing system is used or proposed to be used in conjunction with the fixed charges related to time of day and/or cordon systems to purposely control the use of a transportation facility. Sometimes, a minimum distance-based surcharge is imposed with other pricing systems to discourage the interruption by short-distance trips on toll lane traffic.

2.1.4. *Variable charges*

Variable charges based on traffic delay and time of day have become possible as advanced toll collection and information technologies become available. Under such a system, tolls are automatically set at regular intervals (e.g. every 2 minutes) based on traffic delay on the toll lanes and a predetermined traffic flow objective, such as to maintain a minimum speed of 50 miles per hour. The toll information is displayed on message boards along the roadside to inform motorists about traffic condition and toll changes.

In recent years, some of the above mentioned pricing schemes have been used in conjunction with some forms of privilege for high-occupancy-vehicles to encourage carpooling. Such applications are known as the High-Occupancy-Toll (HOT) lane projects.

2.1.5. *Discussion*

The cordon charging system is useful for managing traffic congestion in an area and is easy to operate. The other charging systems are often used in a corridor or on a specific transportation facility. Previous research suggests that delay- and time-based charging systems can have the greatest impact on network speed and hence on congestion among all the charging systems. A distance-based charging system has similar or fewer impacts on travel than delay- and time-based charging. The effect of a cordon system is relatively small. In addition, a cordon charging system has been criticized as being inflexible, unfair to those making short trips across the cordons, and likely to generate adverse impacts outside the cordons (Oldridge, 1990; Smith, et al., 1994; May and Milne, 2000). However, a hybrid approach, which combines two or more pricing schemes, can overcome the disadvantages of individual pricing systems and have larger effect than one pricing system.

Congestion pricing can be applied to various transportation facilities. Currently, the Value Pricing Pilot Program under the Transportation Equity Act for the 21st Century (TEA21) has supported projects in four broad categories including higher peak period prices on existing toll facilities, conversion of High-Occupancy-Vehicle (HOV) lanes to

High-Occupancy-Toll (HOT) lanes, pricing of new capacity/new HOT lanes, and pricing of parking and converting fix costs of driving to variable costs (DeCorla-Souza, 2001).

Many congestion pricing projects offer motorists the choice of traveling on free or toll, namely the managed lane, facilities. The pricing system applied to the managed lanes is also known as value pricing, which is a system of fees or tolls paid by drivers to gain access to dedicated road facilities providing a superior level of service compared to the competitive free facilities.

2.2. Current Status Of Pricing Projects And Research

A number of pricing projects and research have been completed in cities and regions across the world and in the U.S. Tables 2.1 and 2.2 summarize the current status of the worldwide and U.S. pricing projects respectively. Small (1997) provided a good description of the worldwide experience with congestion pricing. In this section, we focus on the pricing projects and research in the U.S.

Table 2.1.
Pricing Projects and Studies in The World

Country	Location	Status	Pricing Systems
Singapore	Singapore	Implemented (1975)	Cordon, time-based, city center
France	Autoroute A1	Implemented (1992)	Time-based + distance-based, corridor
Norway	Bergen	Implemented (1986)	Cordon, fixed toll, City center
	Oslo	Implemented (1990)	Cordon, fixed toll, City center
	Trondheim	Implemented (1991)	Cordon, time-based, City center
Hong Kong	Hong Kong	Trial	Cordon, time-based, City center
England	Cambridge	Proposal, research	Dynamic pricing, distance-based, City center
Sweden	Stockholm	Research	Cordon, time-based, City center
Germany	Stuttgart	Research experiment (1994-1995)	Cordon, Time-based, City center
Netherland	Randstad	Research (1995)	Opinion survey
England	London	Research	Cordon, time-based, City center
South Korea	Seoul	Research	Congestion pricing on existing toll road
Canada	Toronto	Implemented	Time-, distance-based

Sources: Small, 1997. Additional information was collected by the authors from various sources.

Table 2.2.
Status of Congestion Pricing Projects and Studies in The U.S.

States	Locations	Project Types	Status	Notes
Arizona	Phoenix freeways	2	Research	Study, no implementation
California	SR 91, Orange Co.	3	In operation	Monitoring and evaluation on going
	Bay Bridge	1	Plan	Overturned
	I-15, San Diego	2	Adopted	Planning for I-15 HOV ext. is underway
	SR 101, Sonoma Co.	3	Research	Exploration, part of the Bay Bridge study
	Los Angeles	2	Research	Feasibility study, recommend HOT lanes on SR91, SR57, & SR14
	I-680, Alameda Co.	2	Research	Feasibility study, nearly completed
Colorado	I-25, Denver	2	Legislative issue	Feasibility study, nearly completed
	Boulder	2	Research	Pre-project study completed, plan for demo upheld.
Florida	Florida Turnpike	1	Planning	Feasibility study
	Lee County	1	Adopted	Shoulder period toll discount
Maine	Maine Turnpike	1	Field Trials	Two series of trials of discounted tolls were conducted in 1995 & 1996.
Maryland	State Hwy Adm. Corridors & Maryland Transport Authority facilities	2	Proposed research	Initial statewide feasibility study completed. New HOT lane project proposed.
Minnesota	Minneapolis/Saint Paul Region	4	Research	Demo on hold (98); approval for demonstration secured
New Jersey	N.J. Turnpike toll facilities	1	Adopted	Proposal to monitor & study effects
	Port Authority toll facility	1	Adopted	Proposal to monitor & study effects

Table 2.2. (continued)

States	Locations	Project Types	Status	Notes
New York	Tappan Zee Bridge	1	Research/ Adopted	Congestion pricing on commercial vehicles adopted
Oregon	Portland	4	Research	Pre-project study of congestion pricing
Pennsylvania	Turnpike	1	Research	Proposal for feasibility study, effect on commercial and passenger vehicles
Texas	I-10, Houston	2	Adopted	Some evaluation studies
	I-10, Houston	2	MIS	Extension of QuickRide HOV lane
	I-45/US 290/US 59	2	Research	Feasibility study begun
	I-635/LBJ, Dallas	3	Research	Feasibility study completed
Washington	Seattle	4	Research	Feasibility study of Parking & cash-out; pre-project studies have been completed; proposed implementation project
Wisconsin	I-94, Hampton Roads		Future research	

Notes: Project type 1: Higher peak-hour tolls on existing toll facilities.
Project type 2: Conversion of HOV lanes to HOT lanes.
Project type 3: Tolling on new capacity.
Project type 4: Mix of pricing or other transportation pricing applications

Sources: Compiled by the authors from various sources.

As seen from Table 2.2, four pricing projects have been implemented in the U.S., most notably the Express Lane Value Pricing project on the State Route 91 (SR91) in Orange County, California, the Dynamic Pricing project in San Diego, California, the Variable Bridge Tolls in Lee County, Florida, and the QuickRide pricing project in Houston, Texas. In addition, the New Jersey Turnpike and New York/New Jersey Port Authority have recently implemented new toll schedule with higher peak-period tolls. Furthermore, a number of cities and regions throughout the country are in various stages of implementing pricing projects or are considering the concept. According to the Federal Highway Administration, twenty-one proposals from fourteen states have been submitted for federal funds for study or implementation of congestion pricing (FHWA, 2001). In the following, we briefly describe the ongoing pricing projects in the U.S. and review existing research on the evaluation of these pricing projects.

2.2.1. Project descriptions

The SR91 Express Lane pricing project is a privately financed, barrier-separated toll facility in the median of a heavily congested freeway connecting Anaheim and Riverside County. It opened in December 1995. Only users with electronic toll collection (ETC) tags are allowed to use the facility.

The San Diego Dynamic Pricing project, located on I-15, is a HOT lane facility that allows Single-Occupancy-Vehicles (SOVs) to pay a toll to use the reserved HOV lanes. The project started in December 1996 and consists of two phases with different pricing schemes. It has entered the second phase since March 1998. The San Diego I-15 project is managed by the San Diego Association of Governments in cooperation with the California Department of Transportation (Caltrans) and the Federal Highway Administration (FHWA).

The QuickRide program in Houston, Texas, is also a HOT lane facility that began in January 1998. However, the one-way reversible HOT lane is restricted to vehicles with two or more occupants. Vehicles with three or more people can travel on the lane for free. Vehicles with two occupants are allowed to use the restricted HOT lane with a fee during peak periods. Single occupant vehicles are not eligible for using the lane. The program is sponsored jointly by the Metropolitan Transit Authority of Harris County (METRO) and the Texas Department of Transportation.

The Variable Bridge Tolls in Lee County of Florida is a pricing project that applies value pricing on two existing toll bridges – the Cape Coral and Midpoint Memorial Bridge. The project was implemented by Lee County in cooperation with the Florida Department of Transportation and FHWA in August 1998 (Berg *et al.*, 1999).

New Jersey Turnpike Authority Commissioners approved an increase in peak hour tolls in early 2000. The peak hour tolls were set to increase 20 percent for cash-paying motorists in January 2001, and 8 percent for vehicles with an E-Z pass traveling during weekends or peak hours (7 – 9 AM and 5 – 7 PM) by May 2001.

2.2.2. *Pricing policies*

Most of the ongoing pricing projects in the United States use fixed charges related to time of day. For example, the SR91 Express Lanes in southern California adopts a pricing schedule that charges higher tolls during peak hour periods than in other periods. Prices in different time periods of a day are preset. Users enter the facility with full knowledge of toll that they will pay. Figures 2.1A and 2.1B show the eastbound and westbound toll schedules of SR91 Express Lanes effective on January 2, 2001.

Figure 2.1A.
Eastbound Toll Schedule, SR91, CA (Jan. 2001)

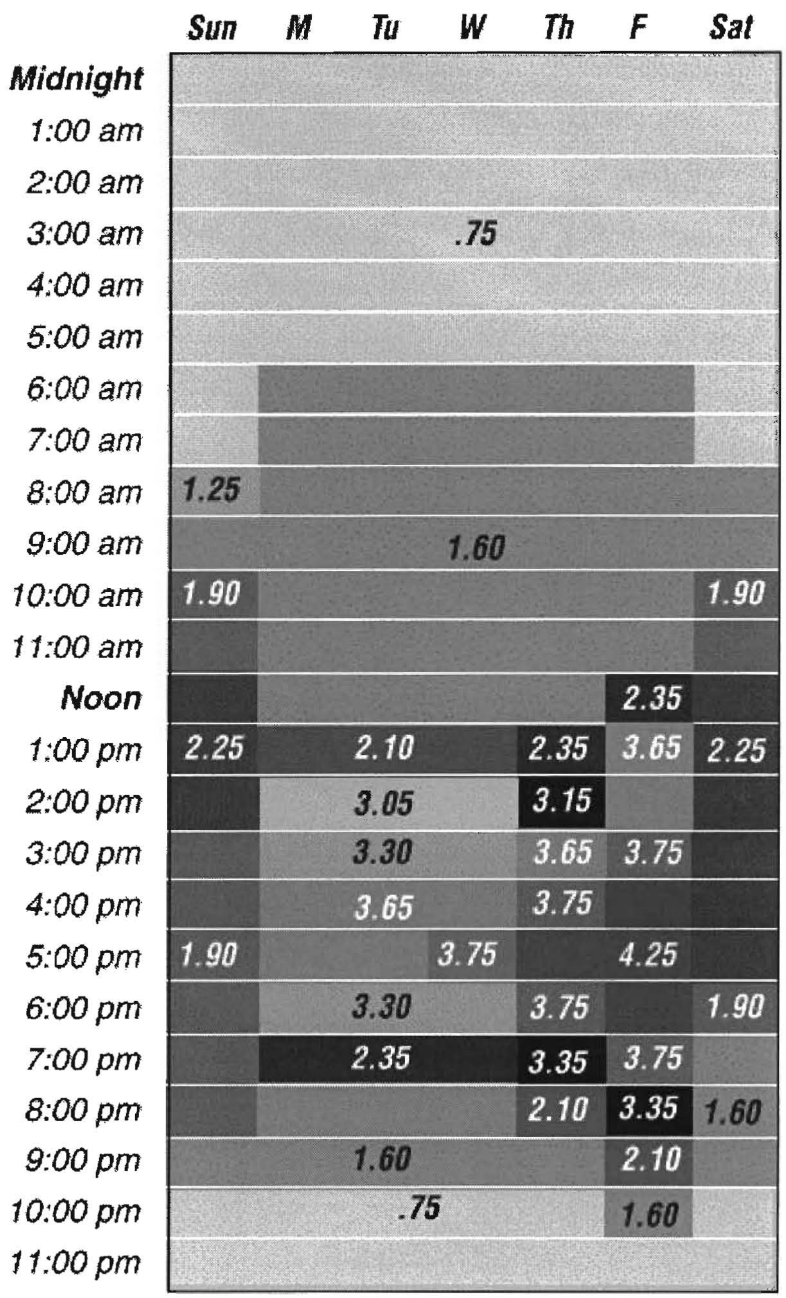
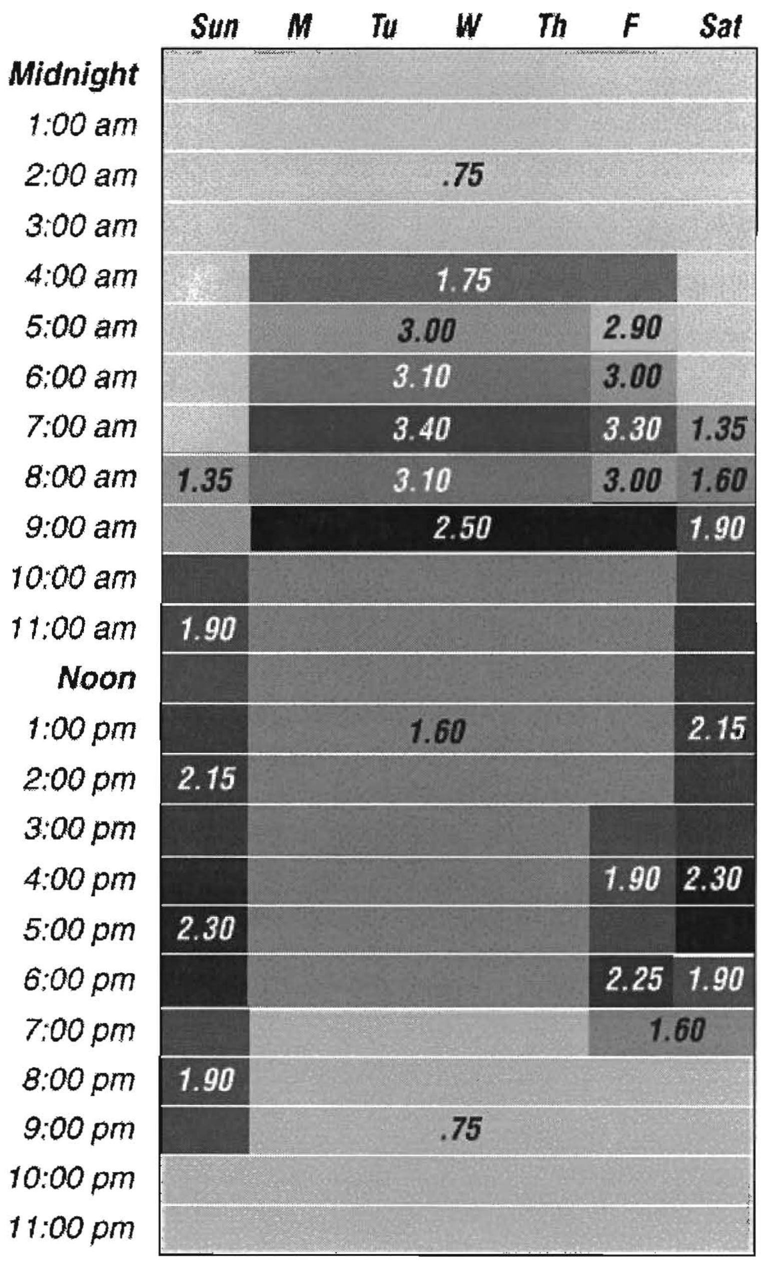


Figure 2.1B.
Westbound Toll Schedule, SR91, CA (Jan. 2001)

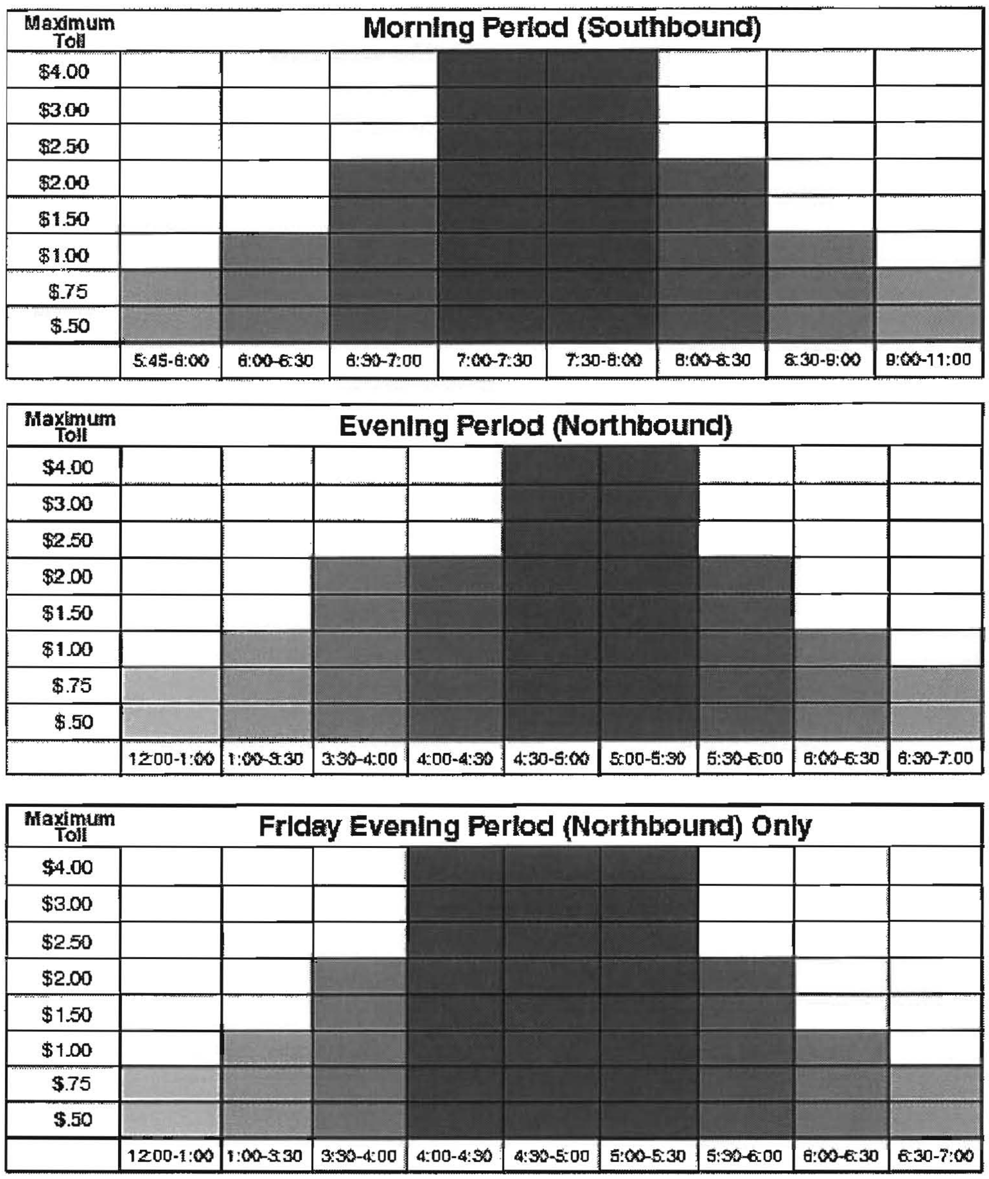


In the case of Lee County project in Florida, a 50 percent discount for traveling outside the heavy peak hour periods was provided to users who pay their toll electronically.[1] The cost for using the QuickRide managed lane in Houston is $2 per vehicle per trip.

The San Diego I-15 project, which also started with a flat monthly fee for unlimited use of the HOV lanes, is the only one that adopts a dynamic variable charge scheme based on level of congestion and time of day in the United States so far. For example, based on the level of congestion, tolls in general vary from $0.50 to $4.00 for each trip during peak periods (7:00 ~ 8:00AM and 4:30 ~ 5:30PM). The toll can go up to $8 per trip if traffic congestion exceeds the level maintained by the normal range of tolls. The lowest toll in off-peak periods ranges from $0.50 to $0.75 (see Figure 2.2).

[1] The heavy peak hour periods are defined as 7:00 AM ~ 9:00 AM and 4:00PM ~ 6:30 PM.

Figure 2.2.
Toll Schedule, I-15, CA (June 30, 2000)



2.2.3. Synthesis Of Research On Existing Pricing Projects In The U.S.

Research on the ongoing pricing projects has explored issues such as impacts of the pricing projects on traffic conditions (Sullivan and Harake, 1998; Sullivan, 1998; Shin and Hickman, 1999; Supernak *et al., 1*999; SANDAG, 1999; and Burris *et al.*, 2000); on vehicle occupancy rate (Chu and Fielding, 1994; Mastako *et al.,* 1998; and Parkany, 1999); on commercial vehicle travel (Vilain and Wolfrom, 2000), and on local housing choice and business (Supernak *et al.*, 2000a and 2000b). The research has generated a number of main findings on travel behavior and traffic congestion:[2]

- Pricing projects affect users' time of travel. For example, a survey of bridge users by the Lee County project study in May 1999 found that among the 7.9 percent of all respondents who acknowledged that they were affected by the congestion pricing project, the off-peak toll discount attracted more than 84 percent of eligible users to change their travel time during the time of the study (Burris, 2001). A study of the FasTrak users' common transactions before and after the pricing change in San Diego I-15 on August 31, 1998, also indicated that pricing reduction in the off-peak periods did cause about 0.4 to 2.5 percent shift in time of travel from peak periods to off-peak shoulders (SANDAG, 1999).
- There were some shifts in travel mode. The SR91 study found a greater than 40 percent jump in the number of peak period HOVs carrying 3 or more people (HOV3+) during the first three months after the SR91 toll lanes opened. However, it also found a significant increase in number of SOVs changing from HOV2s, since HOV2s were paying the same as SOVs (Sullivan, 2000). The effect on travel mode is also observed in other congestion pricing projects. According to the Phase II Year Two Overall Report written by the I-15 project evaluation team, the average daily carpool volumes on the I-15 express lanes, after adjusting for possible monthly effects, were higher in 1998 under the dynamic pricing system than in 1997 with the fixed monthly payment system (SANDAG, 2000). A study of demand for the QuickRide program in Houston found that by allowing two-person carpools to use the HOV lane with a $2 toll, there was a significant shift in carpools and travel on peak periods. For example, according to data from a mail-back survey in mid-1998, about 25 percent of the QuickRide trips on a given day were previously SOV trips on the main lanes. The improvement of traffic flow also attracted more trips to the HOV lane during the

[2] For pricing impacts on commercial travel, housing choice, and business, please refer to related literature.

peak period (Hickman, et al., 2000). However, the research on the Lee County project found no significant change in travel mode (Burris, Feb. 2000).

- Some projects found a shift in travel route after the implementation of pricing strategies. For example, a study on the Lee County project found that about 9 percent of those who changed their behavior due to the pricing policy changed their route of travel (Burris, Jan. 2001). The study of SR 91 shows a more complex picture on route change. For example, the study found that shortly after the express lanes opened in late 1995, some travelers who previously used parallel arterials returned to the SR91, probably due to the improved traffic condition on the freeway. A rough estimation suggests that about 20 percent of total SR91 traffic increase in the first year after the opening of the Express Lanes may have been traffic from parallel streets. However, traffic on the parallel arterials increased again during 1998, when freeway congestion increased (Sullivan, 2000).
- While the experience of the existing pricing projects indicates that congestion pricing has improved throughput on freeways, overall traffic conditions on the travel corridor changed little due to the induced traffic. According to the Final Report on the SR91 Evaluation Study released in December 2000, the Express Lanes attracted about 13 percent of the total SR91 average daily traffic. The toll facility initially reduced peak period traffic delays on the free lanes from 20 to 40 minutes to less than 10 minutes. However, severe congestion on the free lanes has returned, though the delays have not yet reached the level of congestion before the Express Lanes were opened. In the case of San Diego, overall daily traffic volumes changes on the I-15 main lanes were mixed, with ups and downs from Fall 1996 through Fall 1998 (SANDAG, 2000).
- A handful of studies investigate demand for managed lanes. Li (2001) examined the factors influencing travelers' decision to use managed lanes based on survey data of SR91 users. She found that trip purpose, income, vehicle occupancy, and age are primary explanations of decisions in using managed lanes. Such decisions are also related to the level of traffic congestion on freeways. Some of her findings were confirmed by Ghosh's study. Using data from the San Diego I-15

pricing project, Ghosh (2001) estimated the joint decision to use managed lanes in the morning and afternoon commute. The study suggested that commuters tend to use the managed lanes when toll is higher, since the toll rises according to the level of congestion. In addition, the estimated value of time for the morning commute was higher than that for the afternoon commute.

- Previous research has investigated the elasticities of various transportation costs, including fuel price, parking fee, tolls, mileage and emission charges, and combinations of the prices. Most of the studies were based on model simulations. Toll elasticity is found to be in the range of -0.1 to -4.0, meaning that a 10 percent increase in toll price would cause a 1 to 40 percent decrease in travel demand for toll lanes (Harvey, 1994; Hirschman, et al. 1995; Mekky, 1999). The elasticity of vehicle operating costs, including fuel, parking fees, and road tolls, is found to be in the range of –0.3 to –3.2 (Button, 1993; De Borger, et al., 1997; Small & Winston, 1999). The price elasticity varies by trip type and over time. Urban commuting trips are less elastic than urban shopping trips. Similarly, the price sensitivity of motor vehicle use increases over time, namely vehicle use is less elastic in response to price change in the short run. However, motorists are more sensitive to price change in the long run as they are able to find alternative ways of travel for certain trips.

The pilot projects provide opportunities for empirical study of price elasticity for managed lanes. Table 2.3 summarizes the empirical findings of price elasticity for managed lanes. For instance, using data from SR91 Express Lanes, Delhgren (1999) found that the correlation between toll price, measured as dollars per minute travel time saved, and traffic volume for the express lanes was about -0.02 ~ -0.16, though the finding was only confirmed from data on the eastbound of SR91. The study was based on hourly data at Imperial East and Gypsum Canyon East of SR91 for a period of two weeks in one month for two years. A more recent study on SR91 Express Lanes shows a higher price elasticity of -0.70 ~ -1.00 (Sullivan, 2000). A study of the Lee County Pricing project shows that price elasticity ranges from –0.03 to –0.36 (Burris, 2001). In the study, price elasticity was calculated by dividing percent change in traffic volume by percent change in toll cost between the year prior to variable pricing and the year after variable pricing was implemented.

Table 2.3.
Price Elasticity Estimates

	Price Elasticity Est.	Methodology
Transportation Research*	-0.10 ~ -4.00	Various methods
Lee County, FL**		% change in traffic during discount periods divided by % change in toll cost
• Midpoint Bridge	-0.05 ~ -0.36	
• Cape Coral Bridge	-0.03 ~ -0.20	
SR 91, CA		
• 6-hour peak-periods ***	-0.70 ~ -0.80	Conditional logit models for route choice***
• 1-hour peak-period ***	-0.90 ~ -1.00	
• Avg. hourly for 2 weeks ****	-0.02 ~ -0.16	Linear regression****

Sources:
* Victoria Transport Policy Institute, 2001.
** Burris, 2001.
*** Sullivan, 2000.
**** Dalhgren, 1999.

2.2.4. FAIR Lanes: Emerging Concept In Congestion Pricing Studies

Review of all pricing projects in the U.S. found that currently, congestion pricing has been implemented in either new capacities, or HOT lanes converted from HOV lanes, or on existing toll facilities. There is no conversion of existing free lanes to managed lanes due to public resistance. As a result, a new concept has been proposed to manage traffic congestion where converting free lanes to managed lanes is the only option. This concept is known as the "Fast and Intertwined Regular (FAIR)" lanes. This concept involves separating congested freeway lanes into two sections: fast lanes and regular lanes. The fast lanes would be electronically tolled express lanes, where tolls are set in real time to control traffic in the free-flow maximum. The regular lanes would continue to be free with constricted flow as at present, but drivers would be compensated with credits for giving up their right to free use of the fast lanes. Motorists can use the credits to travel on the fast lanes for free.

2.2.5. *Implementation Issues*

Previous studies suggest that political and institutional issues are important for implementing managed lanes. A number of recommendations have been provided for overcoming the political and institutional barriers based on the experience with congestion pricing (FHWA, 1997). These recommendations include:

1. Determine the goals to be achieved through congestion pricing. As mentioned above, congestion pricing can be applied to manage travel demand, raise revenues for transportation investments, and address environmental and energy impacts. Different pricing policies have different impacts. Transportation agencies should determine the priority of goals to be achieved prior to the selection of pricing strategies for the managed lanes.
2. Assess pricing strategies in the context of other alternatives. All possible market-based strategies that may have potential for achieving the determined goals should be examined and presented to stakeholders.
3. Develop a reliable technology plan. The plan should address issues such as privacy, costs, and reliability related to the operation of managed lanes.
4. Focus on revenue uses and equity impacts. A main challenge to the implementation of congestion pricing is opposition from groups who consider themselves worse off once pricing is established. Users generally accept congestion pricing on a single lane that was not previously available if other lanes are free. Where all previously free lanes are tolled, there is often strong opposition because the toll is perceived as double taxation and hardship on less affluent people. Hence, compensation for adversely affected groups, such as directing toll revenues to improve transit services or traffic conditions, is necessary to address equity issue.
5. Outreach to key opinion groups. An outreach effort is important to gain support from and involvement of citizens, elected officials, and institutional leaders in the process of planning and implementing managed lanes. In addition, a marketing and media strategy should be carefully designed and an

incremental approach should be adopted in order to insure the success of project implementation.

In summary, this chapter introduces the congestion pricing concept and various pricing strategies. In addition, it recapitulates the findings from previous studies on managed lanes. The concept of price elasticity can be applied to the development of a toll estimation model, as seen in the following chapter. Empirical lessons from existing pricing projects provide useful insight for planning and implementing managed lanes. Transportation professionals and agencies can benefit from empirical lessons by avoiding the problems that existing projects had and incorporating the successful approaches and recommendations to the planning and implementation of managed lanes.

CHAPTER THREE: STUDY FRAMEWORK

3.1. Assumptions

As seen in the previous chapter, evaluation of pricing strategies is a core component of planning and implementing managed lanes. To assist the evaluation, we developed an analytical framework for studying the price elasticity of demand for a given managed lane facility and the impacts of pricing. A dynamic approach is applied to the development of the framework. Major assumptions include:

- Travelers are informed of traffic conditions and toll at the time of travel.
- Travelers make rational travel decisions based on cost and benefits of travel options.
- Travel cost includes travel time and toll.
- Demand for managed lanes fluctuates with changes in travel cost and traffic conditions.
- Equilibrium can be reached when travel costs for using the managed and regular lanes are the same.
- Some travelers would not use the managed lanes regardless of price.

3.2. Conceptual Framework

Based on these assumptions, we developed a conceptual framework for modeling price elasticity of demand for managed lanes and the impacts of price on traffic conditions, toll revenue, and vehicle emissions. The model framework begins by comparing travel times over a toll-travel and a free-travel facility.

Consider a particular O-D pair along a travel corridor served by two facilities: toll lanes and general purpose (GP) lanes. Total number of Origin-Destination (O-D) travelers (N_{TOTAL}) in a particular time period is assumed to be constant. For all variables, the subscripts T and G represent toll lanes and GP lanes, respectively. P denotes price. Greece letters represent functions. Other variables are:

- For toll Lanes: (q_T = flow, u_T = speed, T_T = travel time between the O-D pair, N_T = number of toll lane users).
- For GP lanes: (q_G = flow, u_G = speed, T_G = travel time, N_G = number of GP lane users)

Demand for toll lane usage is a function of the price (P) charged and the travel-time savings ($T_G - T_T = \Delta T$):

$$N_T = \alpha(P, \Delta T) \tag{1}$$

Users are sensitive to price in its own right; e.g., certain users may choose not to pay above a certain amount regardless of the time savings (See Figure 3.1). That is:

$$N_T = \beta(P) \tag{2}$$

Further, travel-time savings ΔT can be expressed as a function of the number of users on the toll Lane facility, as expressed in Equation (3).

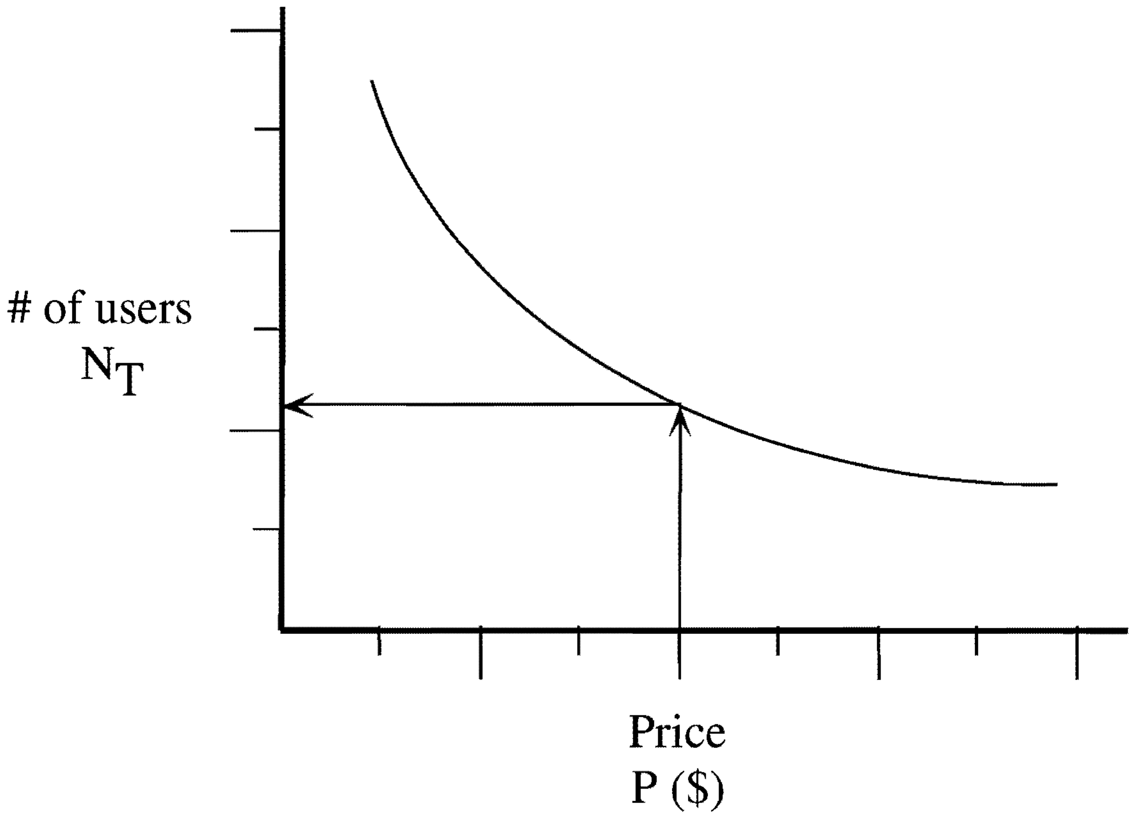
$$\Delta T = \gamma(N_T) \tag{3}$$

Figure 3.1.

Number of Users Versus Price

(Empirical Function)

(for a fixed O-D, user strata, and ΔT)



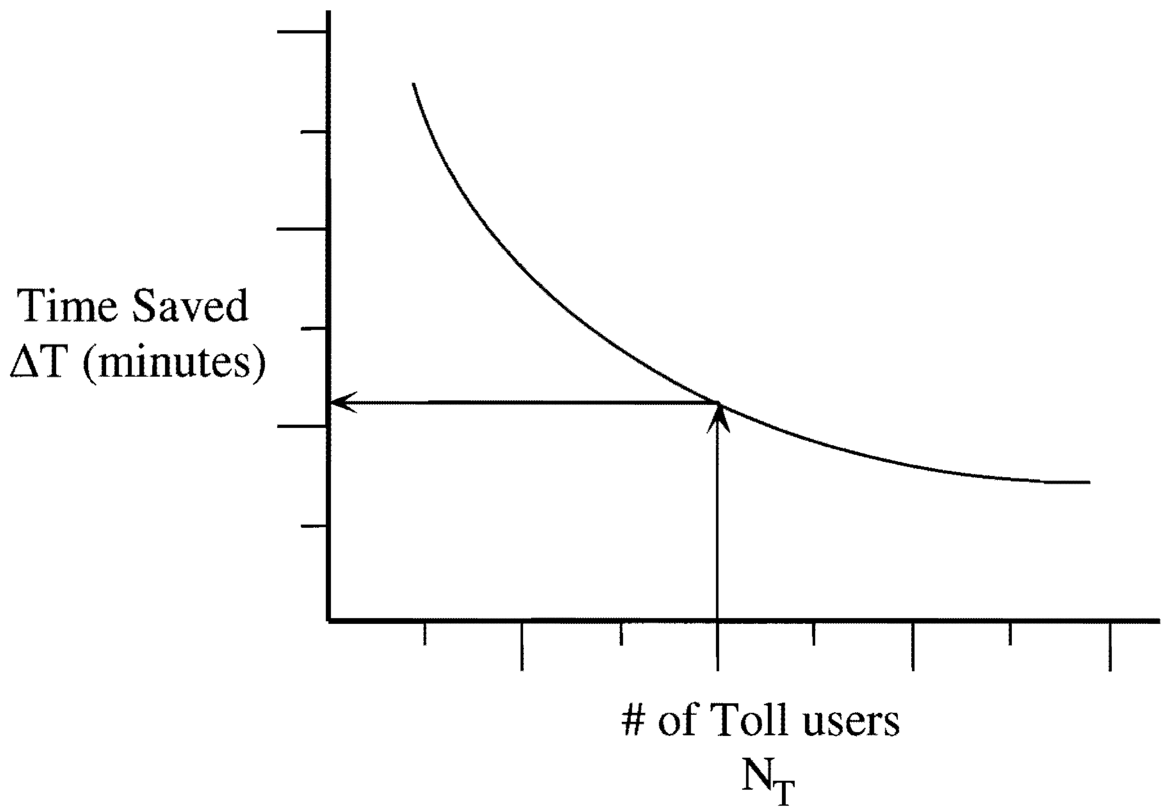
For example, on the toll lanes, the more users, the slower the speeds, and the longer the travel time. Conversely, on the GP lanes, the fewer users, the faster the speeds, and the shorter the travel time. Hence, the savings in travel time for using the toll lanes decline (See Figure 3.2).

Figure 3.2.

Time Savings from Number of Toll Users

(Derived function)

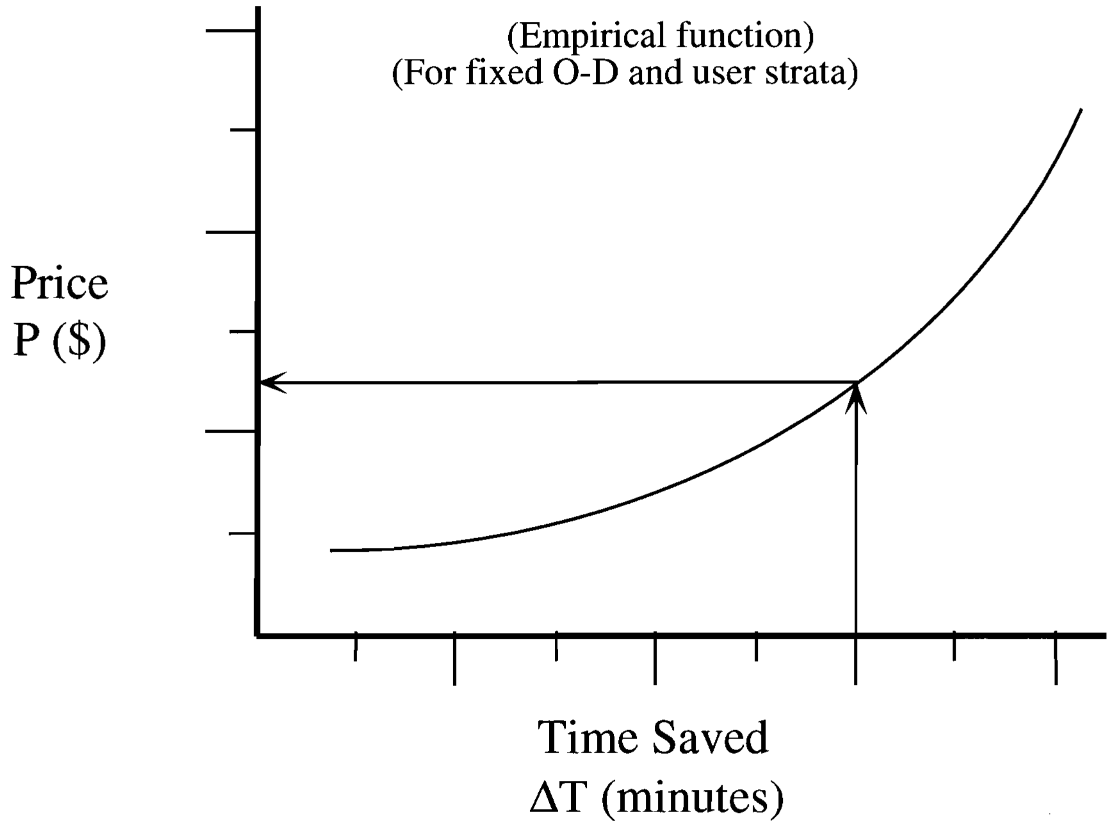
(Total Demand = Constant)



For a particular user stratum, the price a user is willing to pay is a function of the travel-time savings. E.g., for a travel-time savings of only a few minutes, certain users may not be willing to pay any amount; conversely, time savings of an hour could have many users paying substantial amounts (See Figure 3.3.). The relationship between price and time savings can be described by Equation (4).

$$P = \lambda(\Delta T) \tag{4}$$

Figure 3.3.
Price from Time Saved



Thus each of the three variables in the Price Elasticity of Demand Model Equation (1) can be expressed as a function of one of the other two remaining variables. Equations (2) and (4) can be derived from the survey data. To derive Equation (3), normalize the units of flow (for unit time, lane, etc.) to match the units of number of users (per unit time):

$$N_T = q_T$$
$$N_G = q_G \quad (5)$$

The total number of users will be:

$$N_{TOTAL} = N_T + N_G = q_T + q_G \quad (6)$$

where:

$$q = k\,u \quad (7)$$

As indicated before, q and u represent flow and speed, respectively. k is concentration (or density). Speed, flow, and concentration are the three fundamental characteristics of traffic stream. The q-k-u relationships for both facilities can be determined by well-established methodologies (Figures 3.4, 3.5, and 3.6).

Figure 3.4.
Flow and Density

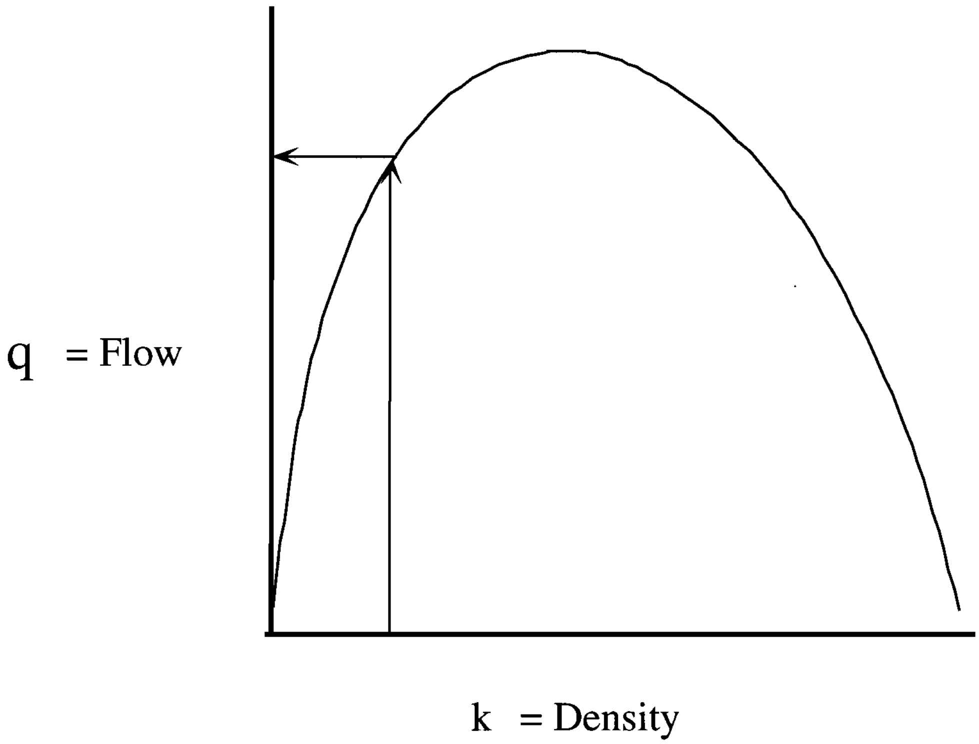


Figure 3.5.
Speed and Flow

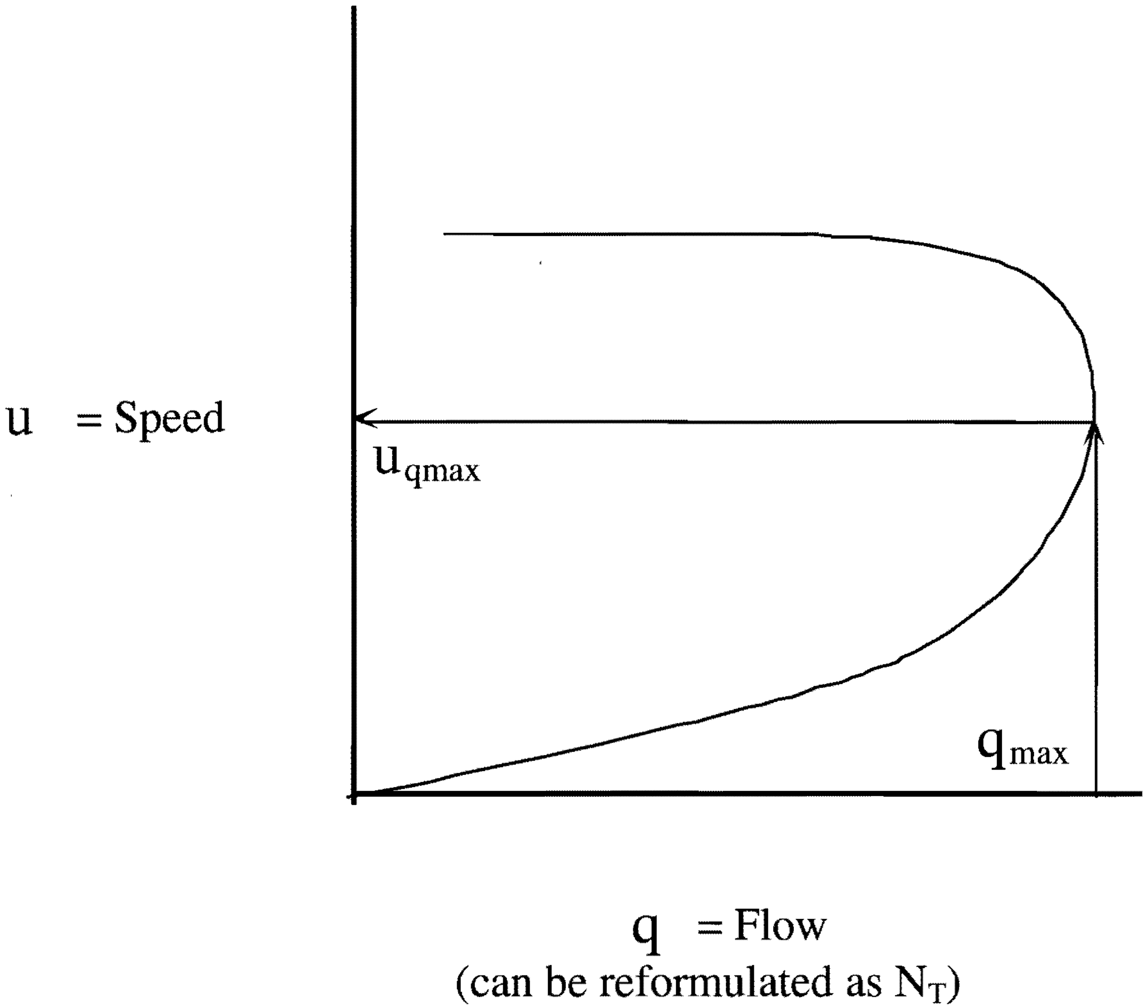
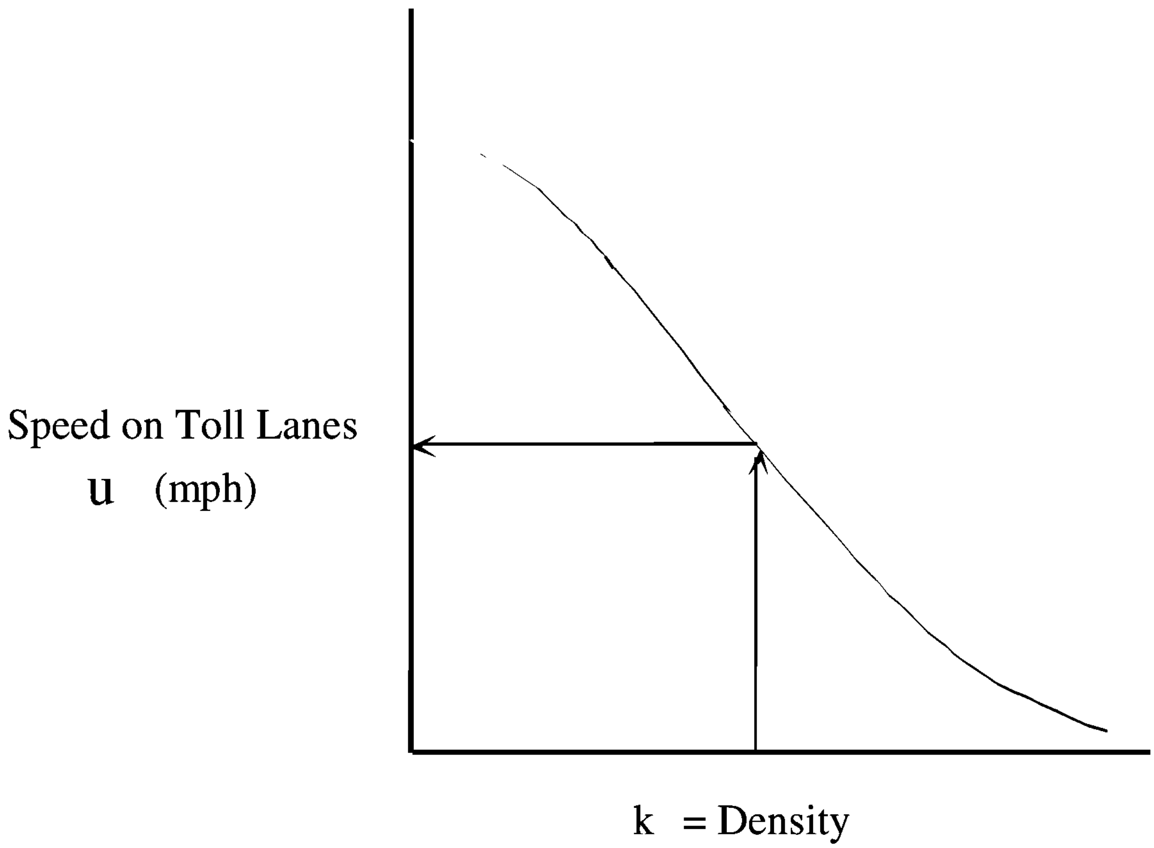


Figure 3.6.
Speed and Density



Starting with a current value of q_T, we can estimate q_G from the relation:

$$N_{TOTAL} = q_T + q_G = \text{constant} \tag{8}$$

From q_T and q_G, we can estimate u_T and u_G respectively from the *q-u* function for the toll lanes and GP lanes. The travel times on each of the two facilities can now be estimated:

$$u_T = \mu(q_T) \tag{9}$$

$$u_G = \nu(q_G) \tag{10}$$

$$T_T = \psi(u_T) = \psi(\mu(q_T)) = \psi(\mu(N_T)) \tag{11}$$

$$T_G = \Phi(u_G) = \Phi(\nu(q_G)) = \Phi(\nu(N_G)) \tag{12}$$

The difference in travel times between the two facilities can now be calculated.

$$\Delta T = T_G - T_T \tag{12}$$

Since N_{TOTAL} = constant, we have derived a function as in Equation 3 (Figure 3.2)

$$\Delta T = \psi(\mu(N_T)) - \Phi(\nu(N_{TOTAL} - N_T)) = \gamma(N_T) \tag{13}$$

CHAPTER FOUR: DATA AND METHODOLOGY

In order to develop the models outlined in the previous chapter, travelers' price-elasticity with respect to the travel-time savings between the toll and general purpose (GP) lanes must be determined. A generalized time saving vs. price relationship has to be constructed for the users of the toll and GP lanes. Data needed to generate the function can be obtained from a survey of travelers prior to implementation of managed lanes or field observation of changes in demand after implementation and subsequent price changes. Furthermore, the *q-k-u* curves (flow-density-speed functions) for the facilities are derived by empirical means. In this chapter, we first discuss the data needs for this study, then describe methods used for data collection for this study. Following the discussions of the data, we report how the survey was conducted. Finally, the analytical approach applied in this study is presented.

4.1. Data Needs

Information on factors influencing travel decisions is necessary in order to develop the models outlined in the previous chapter. These data include the following categories:

- Travelers' trip characteristics and available options
- Travelers' attitude toward the managed lane concept
- Travelers' characteristics
- Design configuration of freeway or travel corridor where managed lanes will be implemented
- Traffic patterns on the freeway or travel corridor

Travel characteristics include trip purpose, origin and destination of trip, trip length, time and duration of travel, and travel mode. Research has found that demand elasticity is related to travel characteristics due to different time values and constraints of various trips. In general, work trips and special trips made under certain time constraints such as medical emergency trips, or trips to catch airplanes, meetings, and appointments, etc., are less elastic than social or recreation trips. In addition, travel options, such as the availability of public transit, taxi, carpool, and parking, and cost of parking at the trip origin and destination will affect demand elasticity.

Attitude information is needed to understand travelers' willingness to pay and their reactions to price, including changes in travel mode, travel time, travel destination, and the frequency of travel.

Travelers' characteristics refer to demographic and socioeconomic status of travelers. A main component of pricing study is the value of time. It affects travelers' decision on whether to use the managed lanes and the price that they are willing to pay. However, the time value varies from one traveler to another. It is associated with travelers' demographic and socioeconomic status.

The design configuration of the freeway or travel corridor where managed lanes will be implemented is important, since the capacity and operational characteristics, such as the number of general purpose and managed lanes, speed limit, and where and how managed lanes can be accessed, determine the traffic flow on the freeway for a given travel demand.

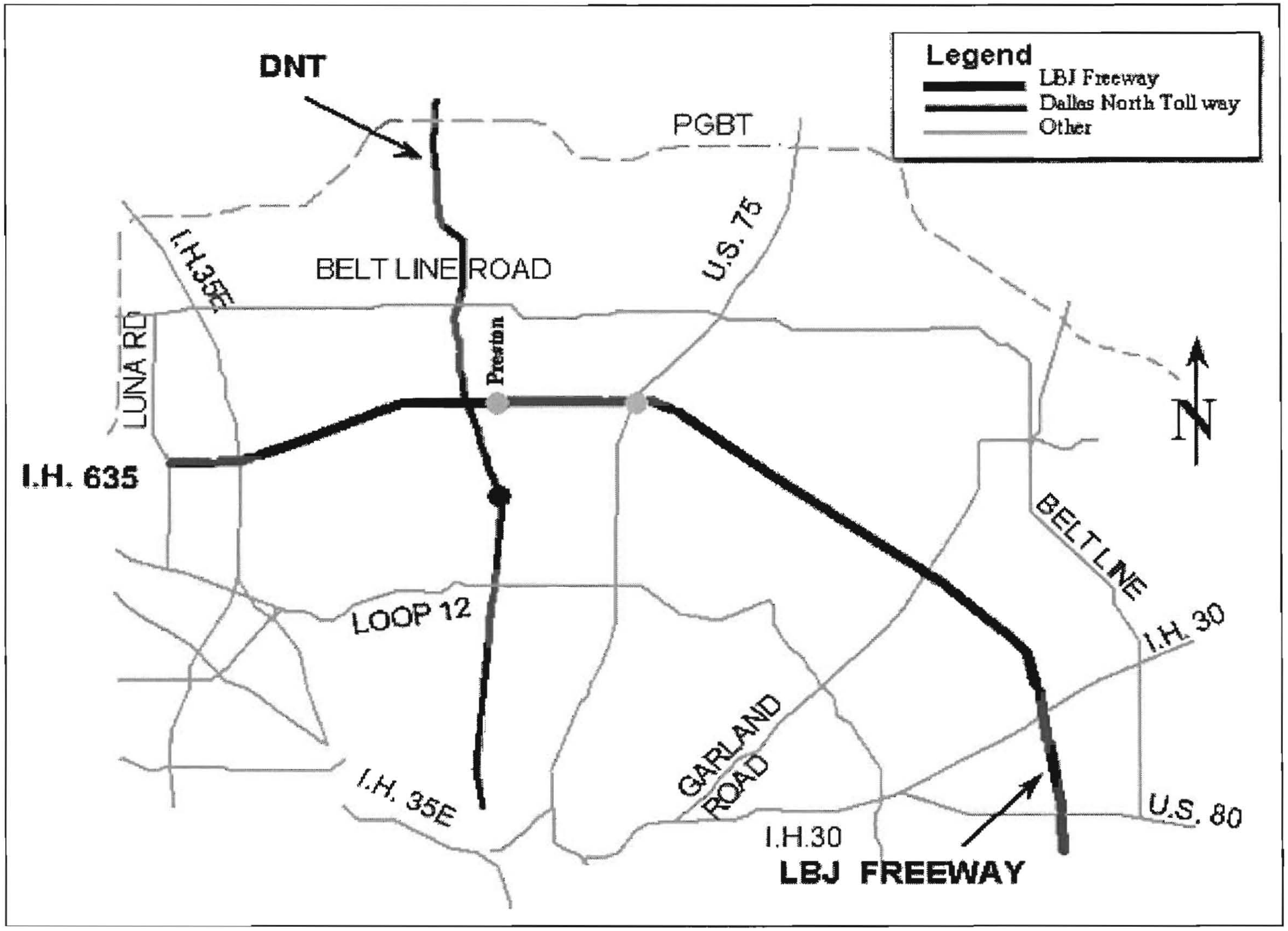
Information on the temporal pattern of traffic conditions is used for setting the price structure. Demand for managed lanes is high when the time savings realized by using managed lanes is great. The temporal traffic pattern includes the distribution of traffic volume, speed, and density over time of day. Time savings by using the managed lanes are higher when difference in traffic condition between the managed lanes and the general purpose lanes is greater.

4.2. Data Collection Methods

The spatial and temporal distribution of travel patterns and travelers' characteristics can be obtained through field observation and survey. For the purpose of this project, we selected the Lyndon B. Johnson Freeway (LBJ) and the Dallas North Tollway (DNT) in Dallas, Texas, as our case studies. The locations of the two travel corridors are shown in Figure 4.1. The two facilities are selected because of their specific geographic locations and operational characteristics. Both LBJ and DNT are located in the metroplex where traffic congestion and air quality issues have become top priorities on the planning agenda and the concept of managed lanes is being considered as a management tool. A study of travelers' response to the managed lane concept and differences in price sensitivity among various user groups in the two locations provide timely and useful information for planning and implementing pricing policies in the area. It will also have direct implications for the planning and implementation of managed lanes in other areas of Texas and the country.

Figure 4.1.

Locations of LBJ and DNT Corridors



Surveys of travelers in the two locations are also necessary for analyzing differences in price elasticity under different circumstances. Currently, all lanes on LBJ are free general purpose lanes. The LBJ users have not been exposed to a user charge (toll). However, DNT is a pure toll facility with no adjacent non-tolled freeway lanes. Users on DNT must pay a fixed charge based on distance regardless of time of day and vehicle occupancy. Due to these distinctions, travelers may have different reactions to the managed lane concept and pricing associated with their implementation.

A stated preference method was used to collect data on travelers' response to managed lanes and their willingness to pay for the time savings resulting from using managed lanes. The survey consisted of questions on trip characteristics, traveler's reactions to the managed lane concept, and their willingness to pay for the time savings resulting from using managed lanes, as well as travelers' characteristics. Survey participants were asked about their regular travel patterns on the freeways. They were then introduced to the managed lane concept and asked how they would like to travel if managed lanes were implemented. The survey instruments for LBJ and DNT are included in Appendix A.

It should be pointed out that while the stated preference survey is a common and perhaps one of the best methods to collect data for price elasticity studies under the circumstance where users have no experience with managed lanes, it can only provide information on perceived time savings and willingness to pay. The users' attitude towards managed lanes also depends on benefits that users perceive. However, the perceived time saving and willingness to pay differ from actual time saving and market price that users will pay after the implementation of managed lanes. Therefore, price elasticity of demand derived from the survey data may not be accurate. True price elasticity will have to be examined through price experiments once the managed lanes are in operation. Nevertheless, stated preference data does provide information that can be used for setting initial pricing policies for new managed lanes.

4.3. Survey Administration

The surveys were administrated over a four-month period. Survey participants were first recruited, and then contacted for telephone interviews. A number of steps were taken to recruit survey participants. These steps include:

- **Collect vehicle license numbers.** Vehicle license numbers of the LBJ and DNT travelers were taken in various locations of the two travel corridors during different time periods, including morning peak (7:00 AM ~ 9:00 AM), mid-day off peak (12:00 noon ~2:00 PM), and afternoon peak (4:00 PM ~6:00 PM) on Monday, Wednesday, Friday, and Saturday. For the mid-day off peak period, vehicle license numbers were collected by cruising along the study corridors in both directions. Due to heavy congestion during peak periods, the license numbers were collected at selected entrance and exit ramps along the corridors in both directions.
- **Match addresses with vehicle license numbers.** After collecting and recording vehicle licenses, the information was sent to the Motor Vehicle Division of the Texas Department of Transportation for address matching. Information on vehicle ownership, and type and make of vehicles were returned with owners' mailing addresses. Unmatched records and those with duplicate ownership were removed from the database.
- **Obtain telephone numbers.** The vehicle license database does not contain telephone numbers. In order to procure telephone numbers for the survey, a telephone matching was performed.
- **Select survey samples.** At this step, duplicate telephone numbers were removed from the database. In addition, we excluded phone numbers that were clearly businesses based on the vehicle owner's name and were further than 80 miles from Dallas. This means that all numbers with area codes 214, 469, 817, and 972 were kept. In addition, all numbers with area codes 254, 903, and 940 were individually examined and those more than 80 miles from the Dallas Central Business District were excluded. All telephone numbers with other area codes were eliminated from our final sample pool for telephone survey.

About 11,100 license numbers were collected initially in February, 2001 through field observation. The number of cases was reduced to 8,916 after address matching, and further reduced to 4,628 after telephone matching. In order to secure the size of sample pool needed for the telephone survey, an additional 6,372 vehicle licenses were collected in March and processed as described above. The second data collection effort produced over 2,000 additional telephone numbers. After removing ineligible telephones, a total of 4,836 cases were available for telephone survey, which was about 28 percent of the licenses originally collected.

The telephone surveys were conducted by the Survey Research Center of the University of North Texas. 802 individuals participated in the surveys. The response rate was about 17 percent. Table 4.1 summarizes sample cases available at different stages of the data collection process.

Table 4.1.
Results of Survey Sample Data Collection

	Time	Collected #	Address Matching		Telephone Matching		Samples For Survey		Respondents	
			#	%	#	%*	#	%*	#	%*
DNT (1st)	AM Peak	2,119	1,743	82	869	50 (41)	518	60 (24)	113	22 (5)
	OFF Peak	1,873	1,603	86	853	53 (46)	574	67 (31)	93	16 (5)
	PM Peak	1,601	1,259	79	647	52 (40)	399	62 (25)	82	21 (5)
LBJ (1st)	AM Peak	1,106	896	81	457	51 (41)	352	77 (32)	119	34 (11)
	OFF Peak	2,488	2,004	81	1,090	54 (44)	729	67 (29)	100	14 (4)
	PM Peak	1,913	1,411	74	712	50 (37)	443	62 (23)	100	23 (5)
TOTAL	**1st**	**11,100**	**8,916**	**80**	**4628**	**52 (42)**	**3,015**	**65 (27)**	**607**	**20 (6)**
DNT (2nd)	PM Peak	1,701	1,362	80	589	43 (35)	500	85 (29)	112	22 (7)
LBJ (2nd)	AM Peak	2,623	2,167	83	932	43 (36)	797	86 (30)	33	4 (1)
	PM Peak	2,048	1,600	78	621	39 (30)	524	84 (26)	50	11 (3)
TOTAL	**2nd**	**6,372**	**5,029**	**79**	**2,142**	**43 (34)**	**1,821**	**85 (29)**	**195**	**11 (3)**

Note: * Numbers in parentheses are percent of total vehicle licenses originally collected from the travel corridors. Numbers without parentheses are percent of numbers in preceding columns.

4.4. Analytical Approach

Various methods were used to analyze the survey data. First, descriptive statistics of the survey sample population were calculated. Second, travelers' responses to the managed lane concept were analyzed. Finally, price elasticity and optimization models were derived. The procedures for deriving model parameters are:

- Empirically derive the price elasticity of travel demand; i.e., derive a functional relationship between the maximum price, and the number of users willing to pay.

- Empirically derive the price elasticity of travel-time savings; i.e., derive a functional relationship between the price a user is willing to pay for a corresponding savings in time.

- Construct the *q-k-u* curves for the toll and general purpose facilities. The *q-k-u* curves can be constructed with field data. In this study, we used the Greenburg model to describe the *q-k-u* relationship.
- Optimize flow on toll lanes. The maximum demand for toll lanes can be expressed as:

$$\max \{ N_T \} = \max \{ \alpha(P, \Delta T) \}$$

An iterative procedure was used to arrive at the optimal value of variables. Specific steps are:

Step 1: From the speed-flow function for the facility, determine the speed $u_{q\max}$ at $q_{\max}$ (as shown in Figure 3.5).

Step 2: Compare current speed, u_T to $u_{q\max}$

Step 3: If $u_T > u_{q\max}$ then, to attract more users, set P to new price (reduced price) $P_{New} = P_{Current} - \delta P$

Step 4: Get new N_T (number of users) for new price P_{New} from the price and demand function, as shown in Figure 3.1,

Step 5: For the new N_T, calculate the new travel-time differential ΔT from Figure 3.2.

Step 6: With the new ΔT, use Figure 3.3 to calculate a new current price, $P_{Current}$.

Step 7: For $P_{Current}$, the new current price from Step 6, use Figure 3.1 to get a new N_T

Step 8: Use Figure 3.5 to calculate the new u_T from N_T.

Step 9: If $u_T > u_{q\max}$, GOTO Step 3.

Step 10: If $u_T = u_{q\max}$, use Figure 3.5 to calculate *k*, then use equation (7) to derive the optimal flow q_T on toll lanes, namely the maximum demand N_T for toll lanes.

- Calculate emission indexes. CO, HC, and NOx indexes are non-dimensional numbers for the purpose of comparison between different pricing models. The emission indexes can be calculated based on speeds on general purpose lanes and managed lanes of the studied corridor. An Environmental Protection Agency (EPA) model formulated in the 1980s was used in this study, since no new model was recommended by EPA at the time when the toll model was developed. The EPA model has a limit on speed range from 10 mph to 60 mph.

CHAPTER FIVE: RESULTS OF DATA ANALYSIS

In this chapter, we present the results of survey data analysis. First, we describe the demographic and socioeconomic profile of survey participants. We then analyze the travel patterns of survey participants. Travelers' attitude towards managed lanes is examined after the descriptions of travelers' characteristics and travel patterns. Finally, we investigate travelers' perceived time saving and willingness to pay for using managed lanes, and derive the demand elasticity model.

5.1. Travelers' Characteristics

The sample for the survey includes 802 individuals. About half of the survey participants were recruited from travelers on LBJ and the other half were from DNT users. Information on travelers' characteristics includes age, gender, race, household size, number of workers in a household, number of drivers in a household, as well as number of preschool and/or elementary school children in a household. The survey also collected information on household income and vehicle ownership. The demographic and socioeconomic characteristics of the survey participants are presented in Figure 5.1 and Tables 5.1 and 5.2, respectively. Data indicates that about 57 to 59 percent of the survey respondents are female. The age distribution is fairly even, especially in the age groups of 31 to 65. The survey respondents in the age group of 65 and over accounted only about 6 and 7 percent of the DNT and LBJ users respectively.

Figure 5.1.
Gender Composition

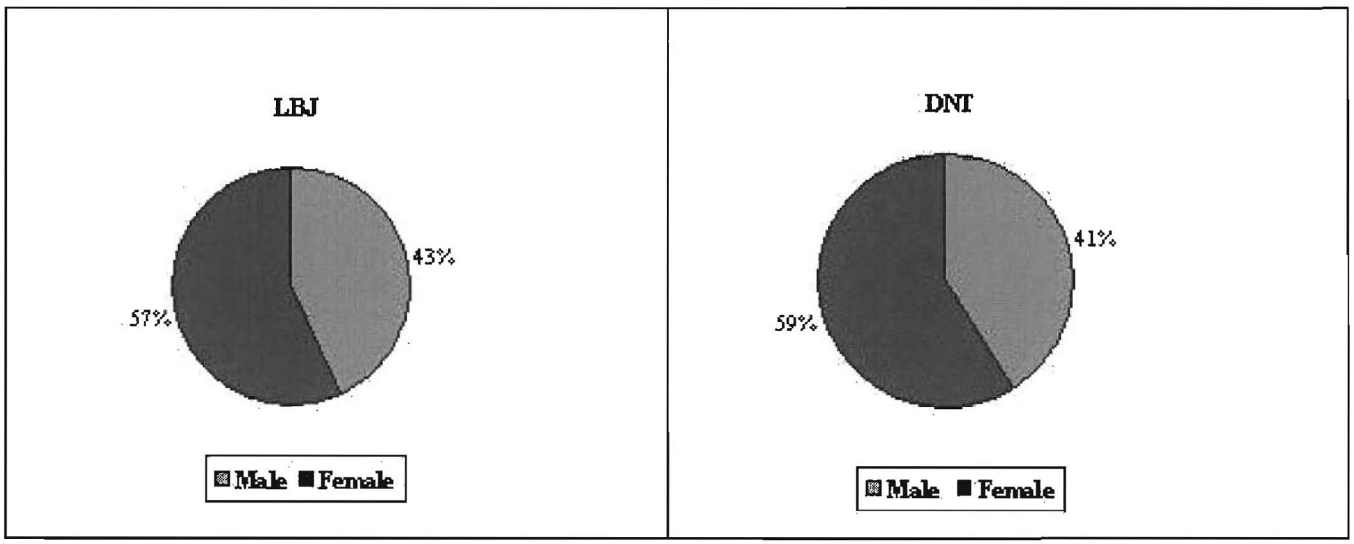


Table 5.1
Demographic Characteristics of LBJ and DNT Users

	LBJ		DNT	
	N	%	N	%
Age Groups				
19-30	67	17.5	50	13.2
31-40	95	24.9	92	24.2
41-50	98	25.7	116	30.5
51-65	95	24.8	99	26
65+	27	7.1	23	6.1
Total	382	100	380	100
Mean	43.84820		44.9684	
Mode	36.00000		38.0000	
STD	13.60110		12.4534	
# People Per Household				
1.00	44	11.00	52	13.0
2.00	123	30.60	130	32.8
3.00	86	21.40	85	21.4
4.00	90	22.40	82	20.7
5.00	38	9.50	43	10.8
6.00	7	1.70	4	1.0
7.00	8	2.00	0	0
8.00	2	0.50	1	0.3
10.00	1	0.20	0	0
Total	399	100	397	100
Mean	3.0627		2.8766	
Mode	2.0000		2.0000	
STD	1.4436		1.2782	
# Young Children Per Household				
0.00	246	65.1	268	71.3
1.00	62	16.40	52	13.80
2.00	50	13.20	40	10.60
3.00	14	3.70	15	4.00
4.00	6	1.60	1	0.30
Total	402	100.00	400	100.00
Mean	0.6032		0.4814	
Mode	0.0000		0.0000	
STD	0.9587		0.8577	
# Workers Per Household				
0.00	24	6.00	10	2.5
1.00	115	28.60	144	36.00
2.00	198	49.30	200	50.60
3.00	43	10.70	31	7.80
4.00	12	3.00	6	1.50
5.00	7	1.70	3	0.80
6.00			1	0.30
Total	402	100.00	400	100.00

Table 5.1 (continued)

	LBJ		DNT	
	N	%	N	%
Mean	1.812		1.7266	
Mode	2.0000		2.0000	
STD	0.939		0.8005	
# Drivers Per Household				
0.00	1	0.20	1	0.3
1.00	48	11.90	57	14.30
2.00	254	63.20	249	62.40
3.00	70	17.40	66	16.50
4.00	22	5.50	18	4.50
5.00	5	1.20	7	1.80
6.00	1	0.20	1	0.30
Total	402	100.00	400	100.00
Mean	2.207		2.1704	
Mode	2.0000		2.0000	
STD	0.7966		0.8182	
Race/Ethnicity				
White	295	73.38	315	78.75
Hispanic	38	9.45	13	3.25
Black	23	5.72	32	8.00
Asian	26	6.47	8	2.00
Other	13	3.23	19	4.75
Missing	7	1.74	13	3.25
Total	402	100.00	400	100.00

Most of the survey participants were in two- to four-person households. These people make up over 70 percent of the total samples. About one-third of the survey respondents were in two-person households. The majority of survey respondents did not have preschool or elementary school children in their households. About half of the survey respondents had two workers in their households. The average number of drivers per household was 2.2 for LBJ and DNT users, and over 60 percent of the survey respondents were in two-driver households. The majority of survey respondents were white.

The average household size of LBJ users was slightly greater than that of DNT users, while the average age of LBJ users was about one year younger than that of DNT users. In addition, the percentage of households without preschool or elementary school children of DNT users was about 6 percent higher than that of LBJ users.

Table 5.2.
Socioeconomic Characteristics of LBJ and DNT Users

	LBJ		DNT	
	N	%	N	%
Annual Household Income				
Group 1: <15K	8	2.60	9	2.90
Group 2: 15K-25K	5	1.60	4	1.30
Group 3: 25K-50K	47	15.20	36	11.50
Group 4: 50K-75K	84	27.10	59	18.80
Group 5: 75K-100K	61	19.70	66	21.10
Group 6: 100K-125K	49	15.80	53	16.90
Group 7: 125K+	56	18.10	86	27.50
Total	402	100.00	400	100.00
Mean	4.7935		5.147	
Mode	4.0000		7.0000	
STD	1.5103		1.5743	
# Vehicles Per Household				
0.00	1	0.2		
1.00	47	11.80	53	13.40
2.00	218	54.60	212	53.40
3.00	83	20.80	97	24.40
4.00	38	9.50	21	5.30
5.00	7	1.80	10	2.50
6.00	4	1.00	2	0.50
7.00			2	0.50
8.00	1	0.30		
Total	402	100.00	400	100.00
Mean	2.3835		2.3375	
Mode	2.0000		2.0000	
STD	0.9903		0.9545	

Household income of the survey respondents was fairly high. Over 80 percent of survey respondents reported household income of $50,000 or more. Less than 5 percent stated having household income of $25,000 or less. The mean of annual household income of LBJ users was 4.79, indicating the average annual household income was in the income group 4 with income range between $50,000 and $75,000. About 18 percent of LBJ survey respondents reported household income of $125,000 or more. The average household income of DNT users was in the range of $75,000 to $100,000. About 27.5

percent of total DNT survey respondents reported household income of $125,000 or more. Average vehicle ownership of LBJ survey participants was 2.38 vehicles per household, similar to the 2.34 vehicles per household of DNT users. Over 50 percent of the survey participants were in 2-car households.

In summary, the sample consists of more female than male respondents. The majority of survey participants were white, middle age, and in households with relatively high income and two workers. Most survey participants owned two vehicles and had no preschool or elementary school children.

5.2. Travel Patterns of Survey Participants

Travel patterns of survey participants include trip type, frequency of using the selected travel corridors, travel mode, travel distance, and time of travel on the corridors. Among the 802 respondents, about 9 percent said that they travel on the corridor only for work trips, another 50 percent indicated that they use the corridor only for non-work trips, and 41 percent responded that they use the corridor for both work and non-work trips. Table 5.3 shows the responses to the use of LBJ and DNT corridors. As seen in the table, a higher percent of DNT respondents used the corridor for work trips than that of LBJ respondents did. In comparison, more LBJ users reported that they used the corridor only for non-work trips than DNT users did.

Table 5.3
Use of Travel Corridors

	LBJ		DNT	
	N	%	N	%
Work Only	28	7	46	11.5
Non-Work Only	216	53.7	186	46.5
Both	158	39.3	168	42.0
Total	402	100	400	100

Survey participants were also asked how often they use the corridors. Table 5.4 shows that most people used the travel corridors 5 days per week for work trips, and only 1 day per week for non-work trips.

Table 5.4
Frequency of Using Travel Corridors

	LBJ		DNT	
	N	%	N	%
Work Trips:				
1/week	3	1.62	13	6.13
2/week	7	3.78	13	6.13
3/week	11	5.95	16	7.55
4/week	13	7.03	14	6.60
5/week	125	67.57	134	63.21
6/week	14	7.57	12	5.66
7/week	11	5.95	10	4.72
Sub-Total	185	100.00	212	100.00
Non-Work Trips:				
1/week	193	52.88	157	44.73
2/week	64	17.53	61	17.38
3/week	32	8.77	29	8.26
4/week	23	6.30	27	7.69
5/week	13	3.56	27	7.69
6/week	10	2.74	8	2.28
7+/week	30	8.22	42	11.97
Sub-Total	365	100.00	351	100.00

Note: Data does not include cases with missing value.

Like many large metropolitan areas in the U.S., the rate of driving alone was high in the two corridors. For example, when asked how they travel for work trips, 75 percent of DNT and 79 percent of LBJ users said they drove alone. Among those carpoolers, most commuted with their family members. As seen in Table 5.5, family carpools in DNT count for about 72 percent of total HOVs, higher than 63 percent in LBJ. Non-family carpools count for only 7 ~ 7.5 percent of total trips.

Table 5.5
Travel Mode of Work Trips

	LBJ		DNT	
Vehicle Occupancy	N	%	N	%
SOV	147	79	160	74.8
HOV2	26	14	34	15.9
HOV3	10	5.4	14	6.5
HOV4	3	1.6	4	1.9
HOV5	0	0	2	0.9
Total	186		214	
# Family Member in HOVs				
0	14	36.8	15	27.8
1	15	39.5	28	51.9
2	7	18.4	8	14.8
3	2	5.3	2	3.7
4	0	0	1	1.9

The survey asked the entry and exit locations of travelers on the travel corridors. Based on the responses, the distance traveled by survey participants on the corridors was calculated. Table 5.6 shows information on travel distance of LBJ and DNT users for both work and non-work trips. As indicated in the table, the average travel distance of work trips was 6.5 miles for LBJ users and 7.6 miles for DNT users. The distance traveled by LBJ and DNT users ranged between less than a mile to more than 22 miles. While there is a difference in average travel distance between users of the two corridors, the average travel distances of work and non-work trips in each corridor are almost identical.

Table 5.6
Travel Distance of LBJ and DNT Users*

	LBJ (Miles)		DNT (Miles)	
	Work Trips	**Non-Work Trips**	**Work Trips**	**Non-Work Trips**
Mean	6.4775	6.4627	7.6245	7.3868
Mode	7.96	7.96	6.27, 10.06**	6.27
Std. Deviation	4.3513	4.2559	4.2598	4.497
Minimum	0.83	0.31	0.65	0.87
Maximum	19.08	19.08	19.85	22.31
N	109	199	137	216

* Exclude cases with missing value. ** Multiple modes.

Table 5.7 summarizes when survey respondents normally travel on the corridor for work and non-work trips. As seen from the table, trips to work are concentrated in the morning peak period from 6 ~ 9 AM. For example, about 89 percent of total LBJ work trips and 85 percent of total DNT work trips occurred during this period. In comparison, non-work trips were spread throughout the day, with more taking place during mid-day and early evening than other periods.

Table 5.7.
Time of Travel of LBJ and DNT Users

Time	LBJ				DNT			
	Work		Non-Work		Work		Non-Work	
	N	%	N	%	N	%	N	%
1 ~ 6	4	2.0	9	2.41	12	6.52	6	1.69
6 ~7	29	14.5	7	1.87	18	9.78	3	0.85
7 ~8	70	35.0	10	2.67	66	35.87	16	4.52
8 ~9	57	28.5	15	4.01	61	33.15	9	2.54
9 ~ 10	22	11.0	21	5.61	11	5.98	19	5.37
10 ~11	6	3.0	65	17.38	3	1.63	52	14.69
11 ~12	2	1.0	21	5.61	1	0.54	23	6.50
12 ~13	3	1.5	54	14.44	2	1.09	41	11.58
13 ~14	0	0.0	19	5.08	0	0.00	17	4.80
14 ~15	0	0.0	16	4.28	0	0.00	16	4.52
15 ~16	1	0.5	8	2.14	1	0.54	5	1.41
16 ~17	1	0.5	18	4.81	3	1.09	14	3.95
17 ~18	1	0.5	13	3.48	1	0.54	13	3.67
18 ~19	1	0.5	26	6.95	4	2.17	27	7.63
19 ~20	1	0.5	24	6.42	1	0.54	24	6.78
20 ~21		0.0	11	2.94		0.00	5	1.41
21 ~22		0.0	3	0.80		0.00	1	0.28
22 ~23		0.0	0	0.00		0.00	0	0.00
23 ~24		0.0	1	0.27		0.00	1	0.28
24 ~1		0.0	1	0.27		0.00		0.00
Missing	2	1.0	32	8.56		0.00	62	17.51
Total	200	100.0	374	100.0	184	100.0	354	100.0

5.3. Attitudes Toward the Managed Lane Concept

Travelers' attitudes toward the managed lane concept were surveyed with a stated preference method. In the survey, the concept of managed lanes was first introduced to survey participants. They were then asked if they would be interested in using the managed lanes if implemented. The DNT users were not asked this question since toll facilities already exist on DNT. Those who expressed interest in using managed lanes were further asked how they would use the managed lanes. The results are presented below.

5.3.1. Interest in using managed lanes

There is a significant interest in using managed lanes. As seen in Table 5.8, among those who indicated using LBJ for work trips, about 54 percent said they would be very likely or somewhat likely to use the managed lanes if implemented. The response rate for non-work trips was about 51 percent, slightly lower than that of work trips.

Table 5.8.
Attitudes Toward Using Managed Lanes

Location	LBJ	DNT
Interested in Using Managed Lanes		
Work Trips		
Yes	54.1%	N/A
No	45.9%	N/A
Non-Work Trips		
Yes	50.5%	N/A
No	49.5%	N/A
Interest in Carpooling to Use Managed Lanes		
Work Trips		
Yes	29.3%	21.5%
No	70.7%	78.5%
Non-Work Trips		
Yes	40.8%	34.0%
No	49.2%	66.0%
Interest in Driving Alone Using Managed Lanes		
Work Trips		
Yes	80.8%	46.3%
No	19.2%	53.4%
Non-Work Trips		
Yes	66.1%	N/A
No	33.9%	N/A

5.3.2. *Interest in carpooling to use managed lanes*

When asked whether they would be willing to carpool in order to use the managed lanes for free or at a reduced fare, only about 29 percent of LBJ work trip respondents said that they would be very or somewhat likely to carpool for work trips. The answers to the same question from DNT users are similar to LBJ users with only 22 percent saying that they would be very or somewhat likely to carpool.

In both corridors, the percentage of non-work trips willing to carpool is higher than that of work trips. About 41 percent of LBJ non-work trip users indicated that they would be likely to carpool in order to use the toll lane for free or at a reduced fare, as compared to 29 percent of work trips. The answer from DNT users was 34 percent, as compared to 22 percent of work trips in the corridor. This suggests that it is easier to carpool for non-work trips than work trips.

A comparison of DNT and LBJ found that the percentage of users who are willing to carpool in order to use managed lanes for free or at a reduced fare is lower on DNT than LBJ, both for work and non-work trips. This may be due to the higher income of DNT users and their experience with toll.

5.3.3. *Interest in driving alone using managed lanes*

Overall interest in driving alone using managed lanes is high. For example, about 81 percent of LBJ travelers indicated that they would be very or somewhat likely to pay a toll in order to drive alone on managed lanes for their work trips. Although the percent for non-work trips is not as high as the percentage of work trips, it still accounts for about 66 percent.

In general, a higher fraction of LBJ survey respondents indicated that they would drive alone using managed lanes than DNT users. Only about 44 percent of the DNT work trip users indicated a willingness to pay a higher toll in order to travel alone on managed lanes. The sharp contrast between answers from DNT and LBJ users implies that a certain proportion of DNT users are unwilling to pay more than what they are paying now.

5.4. Variations Among User Groups

In this section, we examine the variation in attitude towards using the managed lanes among different user groups in addition to the variation between work and non-work trips. User groups in this study are defined on the basis of gender, income, and age. We first analyze the differences in attitudes toward using managed lanes among LBJ users, and then focus on variations of interest in carpooling and driving alone using managed lanes for work trips by user groups respectively.

5.4.1. Variation in using managed lanes

Tables 5.9 to 5.11 display LBJ users' responses to the use of managed lanes by gender, age, and income groups respectively. Data indicate that there is no significant difference between men and women in their attitudes towards using managed lanes for work and non-work trips. The proportion of women who intend to use the managed lanes for work trips is slightly higher than that of men, while a higher proportion of men than women said that they would use managed lanes for non-work trips.

Table 5.9
LBJ Users' Attitude Towards Using Managed Lanes by Gender

	Work		Non-Work	
	Yes	No	Yes	No
Female	54.9%	45.1%	49.8%	50.2%
Male	53.2%	46.8%	51.6%	48.4%
Total	54.1%	45.9%	50.5%	49.5%

Work and non-work trips share the same pattern of variation in using managed lanes among age groups. As seen in Table 5.10, users in the age group of 31 to 40 would be most likely to use managed lanes, followed by those in the age range of 41 to 50. Users in the oldest age group would be the least likely to use managed lanes.

Table 5.10
LBJ Users' Attitude Towards Using Managed Lanes by Age Group

Age Groups	Work		Non-Work	
	Yes	No	Yes	No
19 ~ 30	50.0%	50.0%	51.6%	48.4%
31 ~ 40	63.5%	36.5%	57.5%	42.5%
41 ~ 50	56.8%	43.2%	54.3%	45.7%
51+	42.6%	57.4%	41.2%	58.8%
Total	53.7%	46.3%	50.3%	49.7%

Note: age groups of 51 ~64 and 65+ were combined due to too few cases in the categories.

Table 5.11 shows that there are some variations in attitude towards using managed lanes for work trips among difference income groups. But the data do not show a linear pattern of intent to use managed lanes related to income. For example, the lowest income groups (less than 25K) would be the most likely to use managed lanes for work trips, followed by those with income between 75K and 125K. Most users in the 50K-75K income group said they would not use the managed lanes for their work trips, resulting in the lowest proportion of intent for use of managed lanes among all the income groups. Only 56.7 percent of users in the highest income group said they would use the managed lanes for their work trips.

LBJ users' attitude towards using managed lanes for non-work trips is somewhat related to income. Table 5.11 shows that low income groups are the least likely to use managed lanes for non-work trips. High income groups in general are more likely to use managed lanes, except the group with household income of 125K and over.

Table 5.11
LBJ Users' Attitude Towards Using Managed Lanes by Income Group

Income Groups	Work		Non-Work	
	Yes	No	Yes	No
< 25K	80.0%	20.0%	16.7%	83.3%
25K-50K	52.4%	47.6%	44.4%	55.6%
50K-75K	40.4%	59.6%	52.1%	47.9%
75K-100K	69.0%	31.0%	54.4%	45.6%
100K-125K	63.6%	36.4%	66.7%	33.3%
125K+	56.7%	43.3%	53.7%	46.3%
Total	56.0%	44.0%	53.2%	46.8%

5.4.2. Variations in carpool formation to use managed lanes

Tables 5.12 to 5.14 display variations in carpool formation to use managed lanes. Data show that there is little difference between men and women in attitudes toward carpooling to use managed lanes for work trips. However, more men indicated that they would like to carpool using managed lanes for non-work trip than women. The difference between men and women in attitudes toward carpooling to use managed lanes for non-work trips was 8 percent on LBJ and 5 percent on DNT (Table 5.12).

Table 5.12
Interest in Carpool Using Managed Lanes by Gender

	LBJ				DNT			
	Work		Non-Work		Work		Non-Work	
	Yes	No	Yes	No	Yes	No	Yes	No
Female	29%	71%	38%	62%	21%	79%	31%	69%
Male	30%	60%	46%	54%	22%	78%	36%	64%
Total	29%	71%	41%	59%	22%	78%	34%	66%

There are some differences among age groups in attitudes toward use of carpool in managed lanes (Table 5.13). In general, more people in younger groups than in older groups indicated intent to carpool to use managed lanes. For example, about 39 percent of LBJ users in the age group of 31 to 40 showed that they would like to carpool to use managed lanes, followed by the age group of 19 to 30. The oldest age group (50+) showed the lowest tendency to carpool to use managed lanes for work trips. Among DNT users, the youngest age group displayed the highest likelihood to carpool to use managed lanes for work trips. Both LBJ and DNT users show a negative relationship between age and tendency to carpool to use managed lanes for non-work trips, that is, the youngest age group has the highest percentage of intent to carpool to use managed lanes for non-work trips. The percentage decreases as age increases.

Table 5.13
Interest in Carpool Using Managed Lanes by Age Group

Age Groups	LBJ				DNT			
	Work		Non-Work		Work		Non-Work	
	Yes	No	Yes	No	Yes	No	Yes	No
19 ~ 30	33%	67%	59%	41%	38%	62%	53%	47%
31 ~ 40	39%	61%	39%	61%	19%	81%	46%	54%
41 ~ 50	32%	68%	46%	54%	18%	82%	28%	72%
51+	15%	85%	26%	74%	22%	78%	22%	78%
Total	31%	69%	41%	59%	22%	78%	34%	66%

Note: age groups of 51 ~64 and 65+ were combined due to too few cases in the categories.

As seen in Table 5.14, most LBJ users in the lowest income group (annual household income less than 25K) indicated that they would like to carpool in order to use managed lanes for free or at a reduced toll, for both work and non-work trips. This finding at least partially explains why users in the lowest income group are most likely to use managed lanes for work trips and least likely to use managed lanes for non-work trips. In contrary, most users in the highest income group (125K+) indicated that they would not like to carpool using managed lanes. The responses of DNT users were similar to those of LBJ users.

Table 5.14
Interest in Carpool Using Managed Lanes by Income Group

Income Groups	LBJ				DNT			
	Work		Non-Work		Work		Non-Work	
	Yes	No	Yes	No	Yes	No	Yes	No
< 25K	88%	12%	100%	0%	37%	63%	78%	22%
25K-50K	18%	82%	35%	65%	5%	95%	23%	77%
50K-75K	21%	79%	47%	53%	27%	73%	44%	56%
75K-100K	30%	70%	40%	60%	21%	79%	39%	61%
100K-125K	43%	57%	40%	60%	26%	74%	29%	71%
125K+	13%	88%	31%	69%	26%	74%	26%	74%
Total	30%	70%	40%	60%	23%	77%	34%	66%

5.4.3. Variations in driving alone using managed lanes

Variations in attitudes toward driving alone using managed lanes for work trips among different user groups are presented in Tables 5.15 to 5.17. The results of gender difference are shown in Table 5.15. About 82 percent of male LBJ travelers indicated that they would drive alone using managed lanes if implemented, about 2 percent higher than that of their female counterparts. However, the gender difference is not significant. Data from DNT shows similar results, namely male travelers are more likely to drive alone and pay a higher toll in order to use managed lanes for work trips than women. The gender difference among DNT travelers in attitudes toward driving alone using managed lanes is greater than that among LBJ travelers. Nevertheless, both genders of DNT users are less likely to use managed lanes than their LBJ counterparts.

Table 5.15
Users' Attitudes Toward Driving Alone Using Managed Lanes by Gender (Work Trips)

	LBJ		DNT	
	Yes	No	Yes	No
Female	79.6%	20.4%	38.3%	61.7%
Male	82.0%	18.0%	55.2%	44.8%
Total	80.8%	19.2%	46.3%	53.7%

In terms of age difference, both LBJ and DNT travelers share a similar pattern in their intent to drive alone using managed lanes for work trips (Table 5.16). More users in older age groups are inclined to drive alone using managed lanes than those in younger age groups. The 41-50 age group is most likely to drive alone using managed lanes (92 percent), followed by the oldest age group (90 percent). The pattern of variation in driving alone using managed lanes among age groups shown in Table 5.16 is slightly different from that in using managed lanes in general among age groups as shown in Table 5.10, in which the 31-40 age group has the highest propensity for using managed lanes for work trips while the oldest group has the lowest.

Table 5.16
Users' Attitudes Toward Driving Alone Using Managed Lanes by Age Group (Work Trips)

Age Groups	LBJ		DNT	
	Yes	No	Yes	No
19 ~ 30	66.7%	33.3%	40.0%	60.0%
31 ~ 40	72.7%	27.3%	52.1%	47.9%
41 ~ 50	92.0%	8.0%	58.9%	41.1%
51+	90.0%	10.0%	40.3%	59.7%
Total	80.6%	19.4%	48.7%	51.3%

Users' attitudes toward driving alone using managed lanes among income groups are shown in Table 5.17. For LBJ, the intent to drive alone using managed lanes is the lowest for the 50K – 75K income group. However, all income groups have relatively high rate of intent to drive alone using managed lanes. Data also show that the LBJ users in all income categories are more likely to drive alone using managed lanes than the DNT users in the respective income groups.

Data from DNT show that there is less variation in attitudes toward driving alone using managed lanes among income groups. Except the lowest income group, the rate of intent to drive alone using managed lanes ranges from 42 percent to 58 percent of respondents. Unlike LBJ users, the highest rates occur in the 50K-75K and 125K+ income groups. Data also show that tendency of driving alone using managed lanes in general increases as income rises.

Table 5.17
Users' Attitudes Toward Driving Alone
Using Managed Lanes by Income Group (Work Trips)

Income Groups	LBJ		DNT	
	Yes	No	Yes	No
< 25K	75.0%	25.0%	14.3%	85.7%
25K-50K	90.9%	9.1%	42.1%	57.9%
50K-75K	63.2%	36.8%	56.7%	43.3%
75K-100K	80.0%	20.0%	44.8%	55.2%
100K-125K	85.7%	14.3%	51.7%	48.3%
125K+	100.0%	0%	58.1%	41.9%
Total	82.0%	18.0%	50.3%	49.7%

5.5. Tendency for mode change

The survey results also suggest that users may change their travel modes on managed lanes in two ways. Some current SOV users stated that they would be willing to carpool in order to use managed lanes for free or at a reduced toll, while some current HOV users revealed that they would be likely to pay a toll and drive alone. Some users indicated that they would be willing to do both, i.e. carpool and drive alone. But in general, current SOV users appear to be more willing to drive alone and pay a toll for using managed lanes than HOV users do. On the other hand, current HOV users are more likely to carpool to use managed lanes than SOV users are. These tendencies can be seen in Tables 5.18 and 5.19. For example, among those LBJ users who indicated that they would be likely to use the managed lanes for work trips, about 83 percent of current SOV users said that they would be willing to pay a toll and drive alone, as compared to 73 percent of the current HOV users. Only about 21 percent of the current SOV users stated that they would carpool in order to use the managed lanes for free or at a reduced toll, as compared to 59 percent of current HOV users. Table 5.19 shows similar tendencies for DNT users.

Table 5.18
Tendency for Mode Change for Using Managed Lanes
(LBJ, Work Trips)

Mode for Using ML	Carpool		SOV and Pay Toll	
	Yes	No	Yes	No
Current Mode: SOV	21%	79%	83%	17%
HOV	59%	41%	73%	27%

Note: Cases with missing values are not included.

Table 5.19
Tendency for Mode Change for Using Managed Lanes
(DNT, Work Trips)

Mode for Using ML	Carpool		SOV and Pay Toll	
	Yes	No	Yes	No
Current Mode: SOV	14 %	86%	47%	53%
HOV	44%	56%	43%	57%

Note: Cases with missing values are not included.

5.6. Value of Time Savings

Tables 5.20 and 5.21 show the perceived time savings and willingness to pay for LBJ and DNT users for work and non-work trips. Survey participants who indicated that they would be willing to pay in order to drive alone on the managed lanes were asked how much time they would save if they could travel at a speed of at least 60 miles per hour and the maximum amount they would be willing to pay for the perceived time savings. The responses for work trips range from 1 to 60 minutes saved for LBJ and zero to 60 minutes for DNT users. The maximum that respondents would be willing to pay for the time savings is $5 for LBJ users and $10 for DNT users.

Table 5.20
Perceived Time Savings and Willingness to Pay
(Work Trips)

	LBJ		DNT	
	Time Saving (Minutes)	Willing to Pay ($)	Time Saving (Minutes)	Willing to Pay ($)
Mean	18.25	0.81	14.80	1.39
Minimum	1	0	0	0
Maximum	60	5	60	10
Std. Deviation	12.54	0.7939	11.04	1.8044
N	80	80	94	94

Table 5.21
Perceived Time Savings and Willingness to Pay
(Non-Work Trips)

	LBJ		DNT	
	Time Saving (Minutes)	Willing to Pay ($)	Time Saving (Minutes)	Willing to Pay ($)
Mean	16.89	0.85	13.73	1.39
Minimum	1	0	0	0
Maximum	60	9	45	10
Std. Deviation	10.21	1.0019	8.01	.8569
N	114	110	306	306

The results of the time savings and willingness to pay questions for non-work trips are similar to those for work trips, except the maximum amount that LBJ users would be willing to pay for non-work trips is $9 instead of $5 as for work trips, and the maximum time saving perceived by DNT users for non-work trips is 45 minutes instead of 60 minutes as for work trips.

The differences in time savings and willingness to pay between work and non-work trips are not significant. For example, the average time saving perceived by LBJ users is 18.25 minutes for work trips and 16.89 minutes for non-work trips. The average willingness to pay of LBJ users is $0.81 for work trips and $0.85 for non-work trips. The difference in time savings between work and non-work trips for DNT users is only about 1 minute and the average willingness to pay for work trips are identical to that for non-work trips. Interestingly, we found that while the average time savings perceived by LBJ users is higher than DNT users, the average willingness to pay of LBJ users is lower than that of DNT users. This may be explained by the travel conditions on the corridors and users' experience with tolls. DNT is less congested than LBJ, and therefore DNT users perceive less time savings. In addition, DNT users already pay tolls based on travel distance. Their experience with tolls may contribute to their willingness to pay.

Survey data also reveals that the average value of time for DNT users is higher than that of LBJ users. For instance, the average value of time for LBJ users was about $3.02/hour. According to estimates in the literature, travel time is valued at 41 percent of the average wage rate (Small & Winston, 1999). This $3.0/hour value of time is equivalent to about $7.36/hour average wage rate, which is considerably lower than the average wage rate of $18.89/hour (in 1999 dollars) in the Dallas region[3]. The average time value of DNT users was $6.07/hour. This value of time is equivalent to $14.82/hour, which is close to, but still lower than the average wage rate in this region. Interestingly, the survey data reveals that the time value of non-work trips in both corridors is higher than the time value of work trips.

[3] The number was derived from the latest information on average annual pay at the time this report was written. The information was obtained from the Dallas Information Office, Bureau of Labor Statistics.

We compared the means of time savings and willingness to pay, both for work and non-work trips, by gender, but found no significant differences between men and women. We did not compare differences in time savings and willingness to pay by age groups and income groups, since there are too few cases to produce meaningful information.

5.7. Aggregate Price Elasticity Functions

5.7.1. The price and time-savings function

The aggregate price and time-savings function is derived through several steps.

First, the means and standard deviations of price and time-saving in each 5-minute interval are calculated. Second, cases with values that are outside the range of 2 standard deviations from the mean value in each time interval are excluded from the database. Finally, the data is aggregated into 5-minute intervals and a regression function is derived. Figures 5.2 and 5.3 are the plots of time savings and willingness to pay for LBJ and DNT survey participants respectively.

Based on data obtained from the surveys, price and time-savings functions can be derived for LBJ and DNT, respectively. The results of a linear regression function are shown in Table 5.22.

Table 5.22
Regression Estimates of Willingness To Pay

	Intercept	Time Savings	Model R^2	Significance
LBJ	.425	.0257	.765	.004
DNT	.552	.0101	.874	.001

These results indicate that willingness to pay for managed lanes is very inelastic with respect to time-savings. While the base amount that DNT users are willing to pay is higher than that of LBJ users, the incremental price that DNT users are willing to pay for additional time saving is less than that of the LBJ users. This finding implies that DNT users are less sensitive than LBJ users in willingness to pay for an additional unit of time savings.

Figure 5.2.
Aggregate Time Savings and Willingness to Pay of LBJ Users

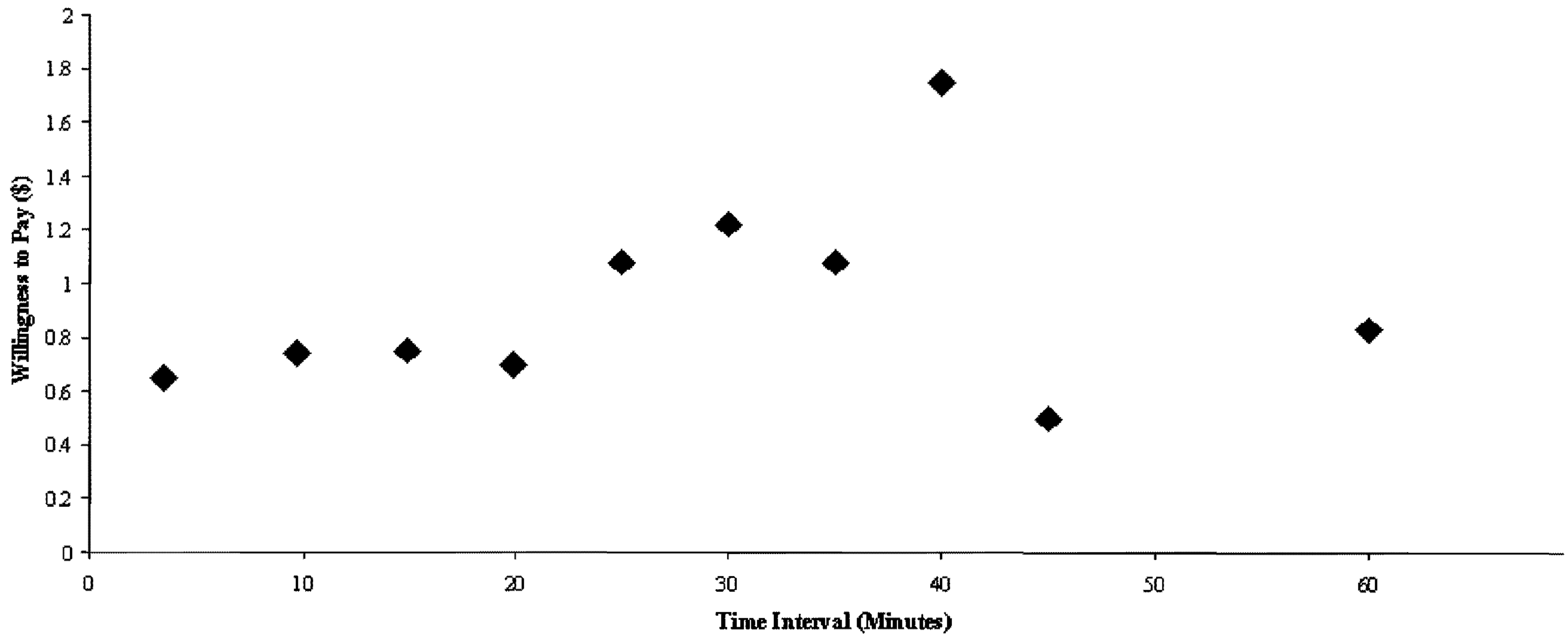
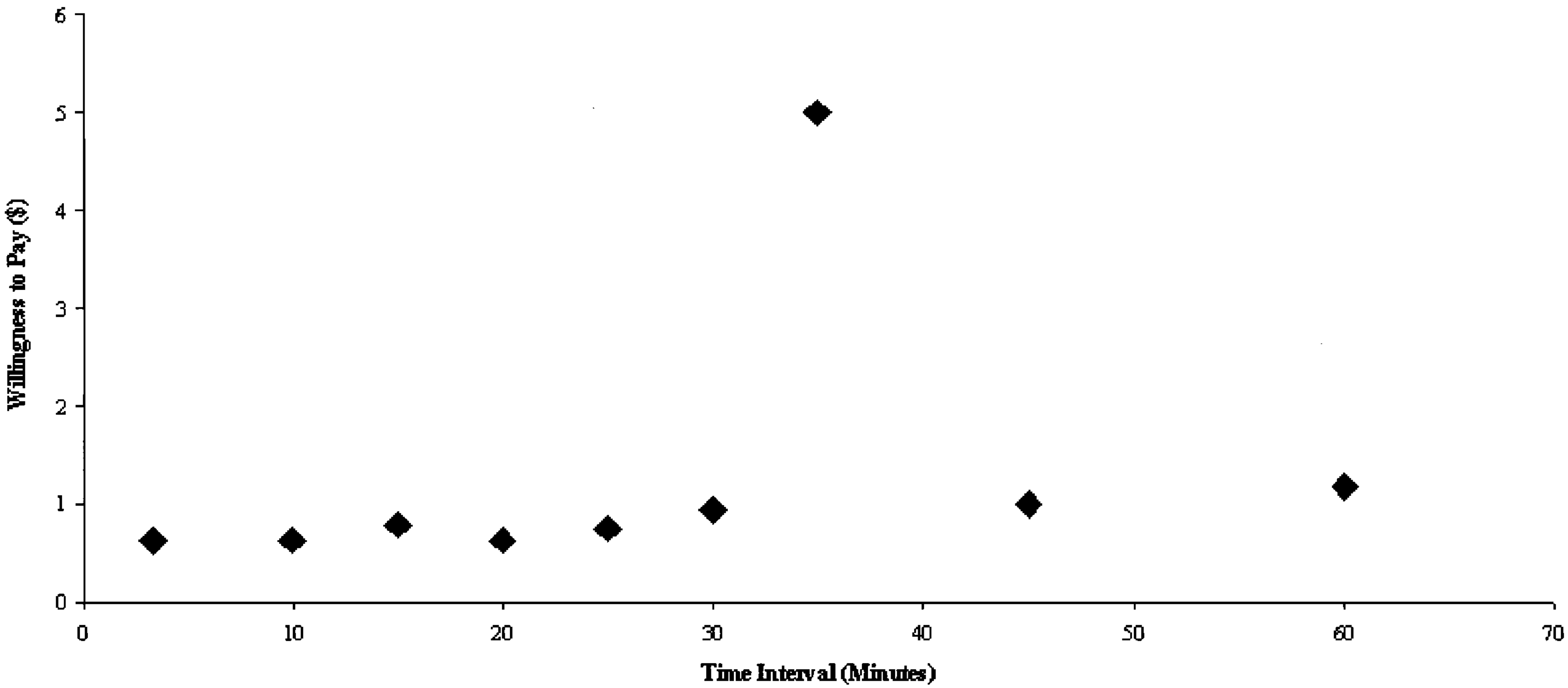


Figure 5.3.
Aggregate Time Savings and Willingness to Pay of DNT Users



5.7.2. The price and demand function

The price and demand function is derived from a logistic function for choice between two options. The logistic function is expressed as the following:

$$f_1 = e^{u1} / (e^{u1} + e^{u2}) \qquad (5.1)$$

Where

f_1 = probability of choosing option #1.

U_1 = utility function of option #1.

U_2= utility function of option #2.

In this application, the concern is the shift between the managed lanes and the GP lanes at the aggregate level and price is the utility factor influencing the decision of choice between the managed lanes and the GP lanes. The utility function for the managed and GP lanes can be expressed in terms of price as $U_1 = \alpha P_1$ and $U_2 = \beta P_2$, where P_1 and P_2 are the prices for using the managed and GP lanes, and α and β are model parameters respectively. Equation 5.1 can then be re-written as:

$$f_1 = e^{\alpha P1} / (e^{\alpha P1} + e^{\beta P2}) \qquad (5.2)$$

Where f_1 is the probability of drivers choosing the managed lanes. Since there is no charge for using the GP lanes ($P_2 = 0$), Equation 5.2 can be further simplified, namely:

$$f_1 = 1 / (1 + e^{-\alpha p1}) \qquad (5.3)$$

and $$f_2 = 1 - f_1 = 1 / (1 + e^{\alpha p1}) \qquad (5.4)$$

where f_2 is the probability of drivers choosing the GP lanes.

Thus the parameter α can be derived with aggregate data on the fraction of drivers using the GP lanes (f_2) and price for using the managed lanes (P_1). Figures 5.4 and 5.5 show the relationship between price and the fraction using the GP lanes generated from the survey data of LBJ and DNT users.

Figure 5.4. Relationship Between Price and Demand of LBJ

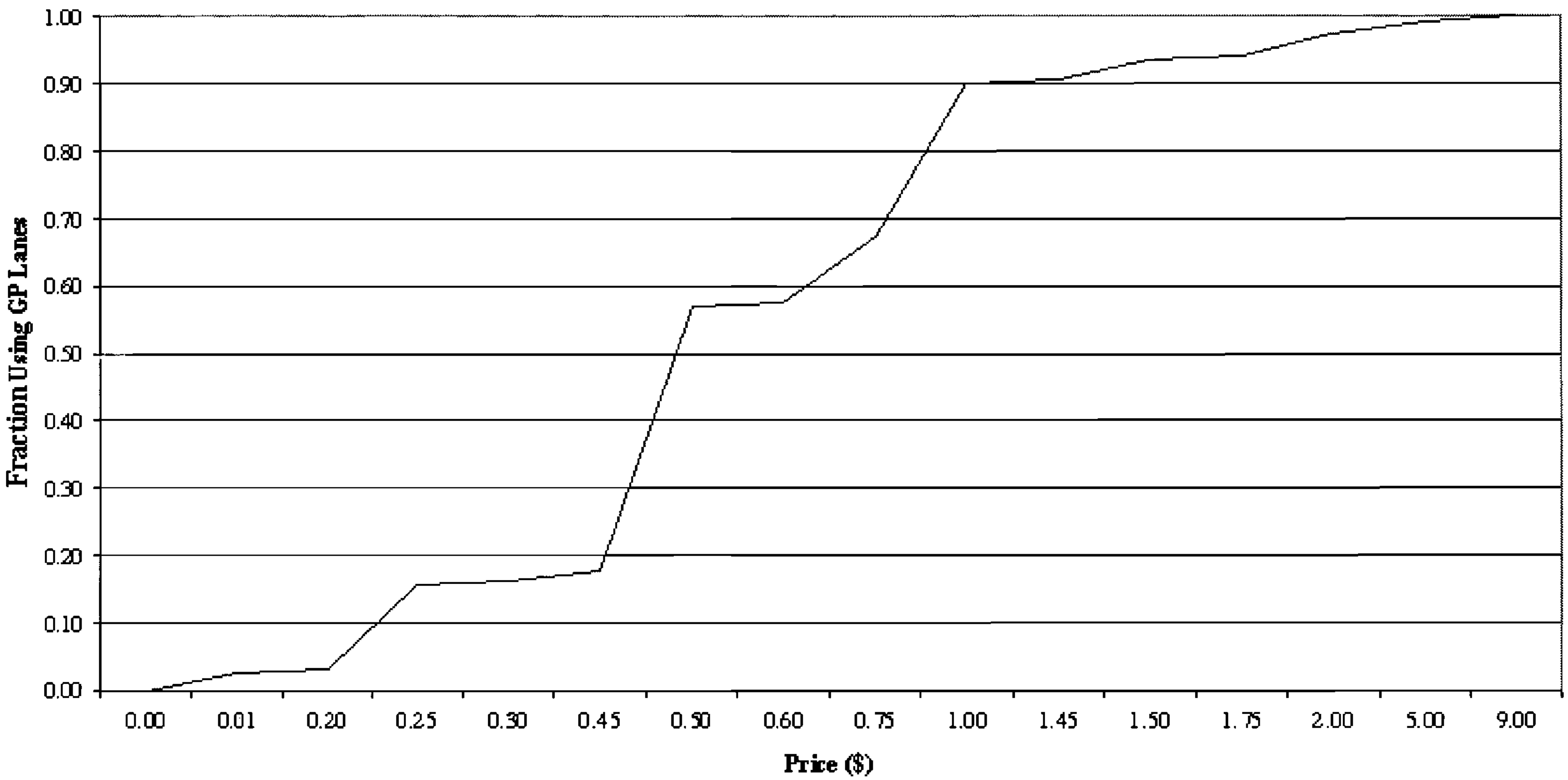
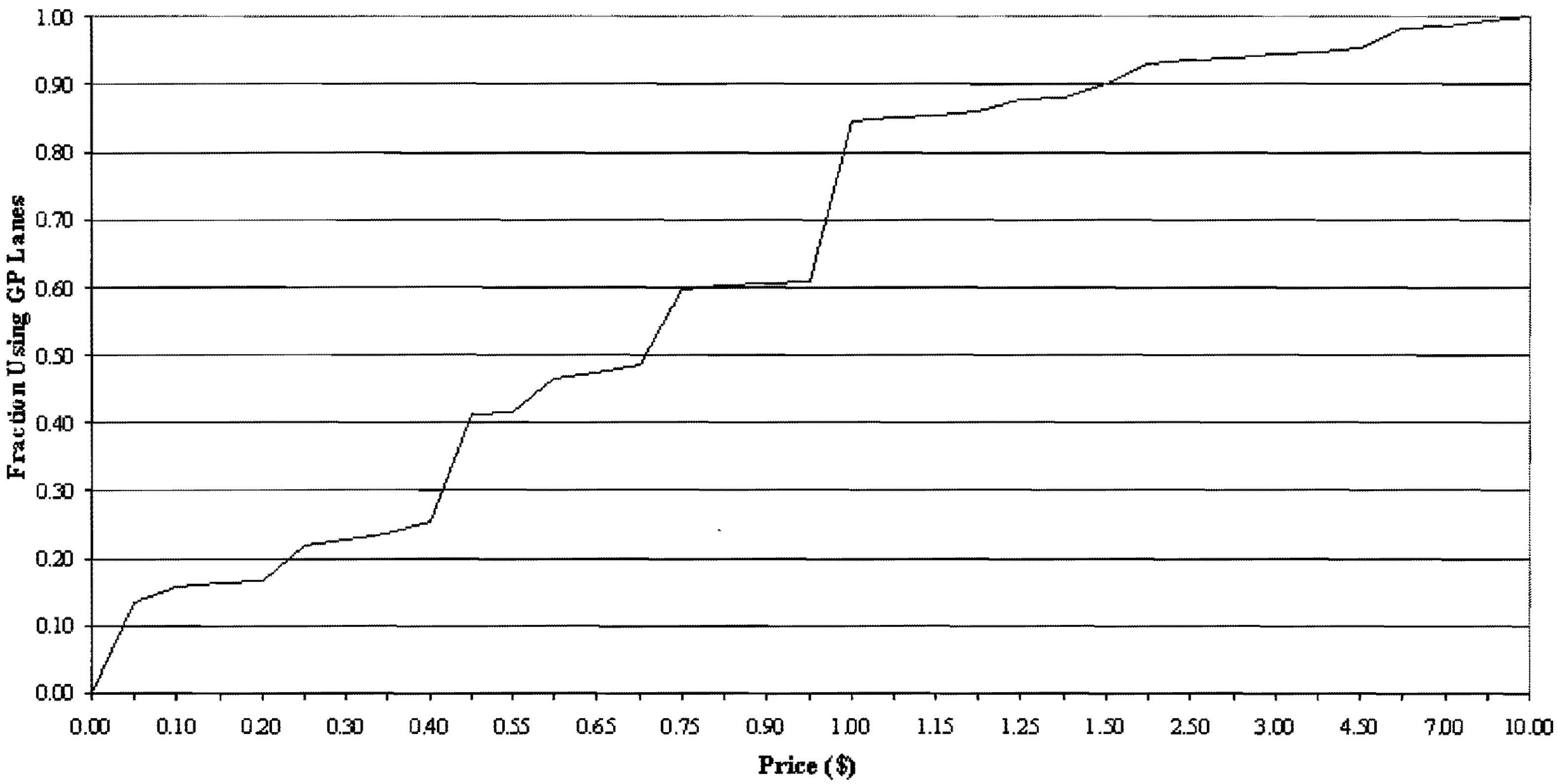


Figure 5.5. Relationship Between Price and Demand of DNT



CHAPTER SIX: IMPLEMENTATION OF THE TOLL EVALUATION MODEL

This chapter briefly describes the model developed for evaluation of pricing strategies for managed lanes. In addition, it provides examples for using the model. Detailed instructions on application of the model are provided in the User Guide To Toll Evaluation Model V1.0 (TEM1) in Appendix B.

6.1. The Toll Evaluation Model

The toll evaluation model is built in a MS Excel Workbook. It consists of four worksheets including:

- Toll Model,
- Price Elasticity,
- Speed-Flow, and
- Fuel, CO, HC, NOx.

The Toll Model sheet is the cornerstone of TEM1. This is the sheet where the user can select different toll pricing strategies and analyze their effects on flow, speed, travel time, delay, revenue, and environmental impacts. The Price Elasticity sheet provides a tool for modeling price elasticity of demand for managed lanes in two steps: price that a traveler is willing to pay for different levels of time savings to be realized by traveling on managed lanes, and proportion of users shifted to the general purpose (GP) lanes at a given price. The Speed-Flow sheet presents models describing the speed-flow-concentration relationships for the study corridor. The last sheet, Fuel, CO, HC, NOx, provides information on fuel consumption rate and CO, HC, and NOx emission rates at different speeds. Users can access to each of these worksheets through the sheet tabs near the bottom of the workbook window (see Figure 6.1).

Figure 6.1.
The Sheet Tabs

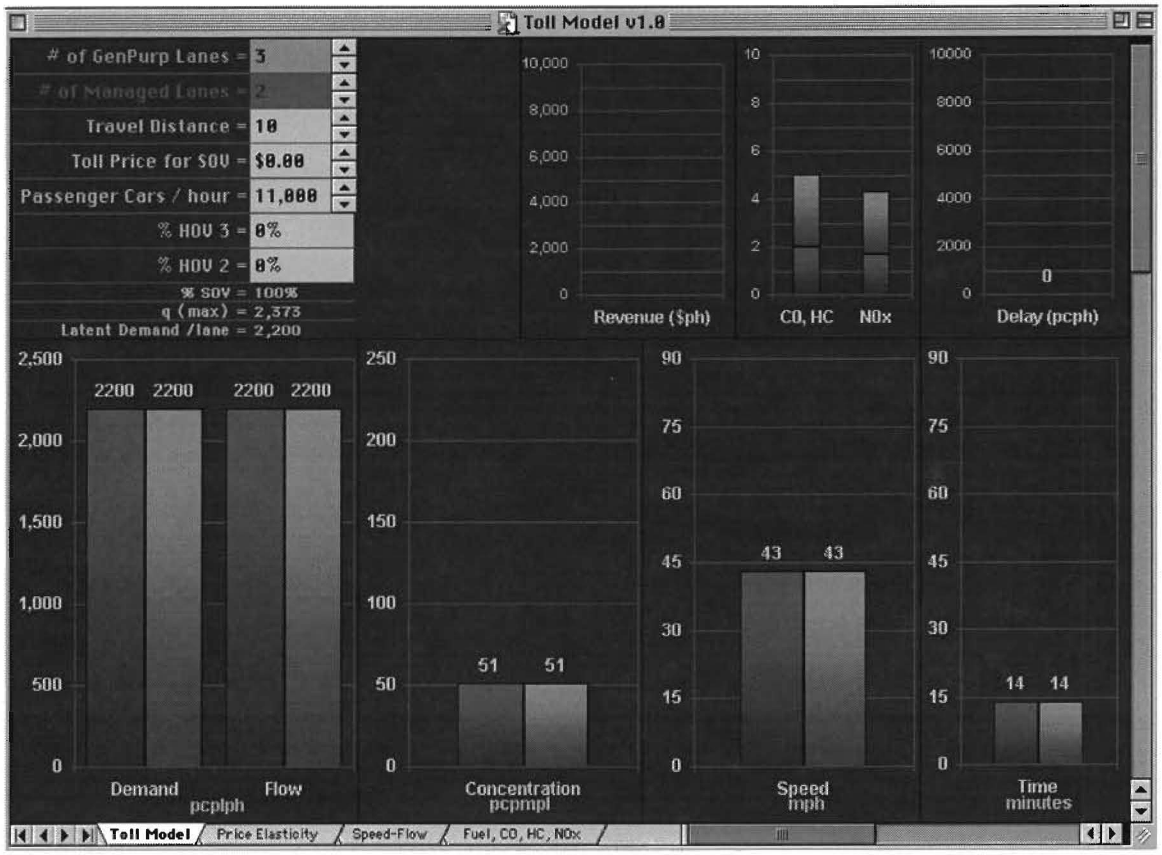
For each of the first three worksheets, a number of valid inputs are required from the model user. The input variables required for each worksheet are described below.

6.1.1. Input variables required for the Toll Model sheet

The Toll Model sheet is shown in Figure 6.2. As seen in the figure, the following inputs are required from the model user:

1. **Number of General Purpose (GP) Lanes:** The number of GP lanes (non-tolled) in one direction. Permissible values are in the range of 1 to 10 lanes.
2. **Number of Managed Lanes:** The number of managed (HOV/T) lanes with free access for HOV users and tolled access for SOV users, in each direction. Permissible values are in the range of 1 to 5 lanes.
3. **Travel Distance:** The average travel distance of users on the study corridor. Permissible values are in the range of 1 to 50 miles.
4. **Toll Price for SOV:** Toll price charged to SOV users for access to the managed lanes. Permissible values are in the range of $0 to $20. The model interprets the price of $0 as free access on the managed lanes for all users (HOV and SOV).
5. **Passenger Cars / hour:** The directional peak hour volume in passenger cars per hour (pcph). This will be the total directional volume of both the GP and managed lanes. Permissible values are in the range of 4,000 to 35,000 pcph.
6. **% HOV 3:** Percent of vehicles that are HOV 3 and above. The minimum and maximum numbers for this variable are 0% and 5%.
7. **% HOV 2:** Percent of vehicles that are HOV 2. The minimum and maximum numbers for this variable are 0% and 10%.

Figure 6.2.
The Toll Model Sheet



The inputs for variables #1, #2, and #4 are determined by individual project design and pricing policy. The inputs for variables #3, #5, #6, and #7 will have to be obtained through field observation.

6.1.2. Input variables required for the Price Elasticity sheet

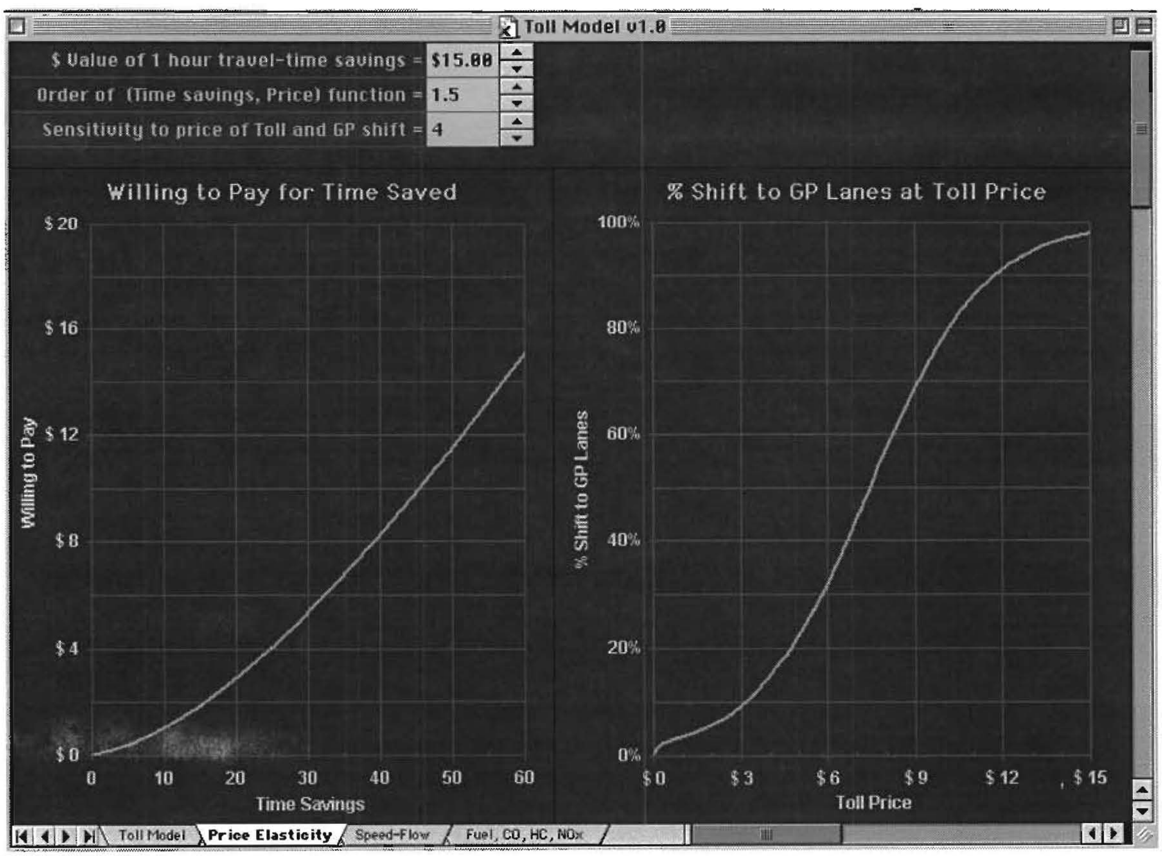
Three input variables are required for the Price Elasticity sheet (Figure 6.3). They are:

1. **$ Value of 1 Hour Travel-Time Savings:** This is the price that a commuter is willing to pay for one hour of travel-time savings. The value of this variable is in the range of $2 to $20.
2. **Order of (Time Savings, Price) Function:** This variable is the order of the polynomial curve used to represents the Willingness to Pay (price) as a

function of Travel-Time Savings, as shown in Figure 3.3 and Equation (4) in Chapter 3 and on left side of Figure 6.3. A value of 1 indicates a linear relationship between Willingness to Pay (price) and Travel-Time Savings. A value other than 1 signifies a nonlinear relationship between the two variables. In this model, the value of this variable is set to be in the range of 1 and 3.

3. **Sensitivity to Price of Toll and GP Shift:** This is a measure of change in the log of the odds ratio of the managed lane flow to the GP lane flow for every one unit change in toll price. This is the parameter α in Equation (5.4) in Chapter 5. The value of this variable will define the sensitivity of travelers to changes in the toll and delineate the shape of the price and demand curve shown on the right side of the Price Elasticity sheet (Figure 6.3). The values of this parameter range between 1 and 10.

Figure 6.3.
The Price Elasticity Sheet



The effects of the order of the Time-Saving and Willingness-to-Pay function and the measure of price sensitivity are shown in Figures 6.4 and 6.5. The input values of the three variables can be generated from survey data of the travelers in the study corridor.

Figure 6.4.
The Effects of Low Input Values on The Price Elasticity Sheet

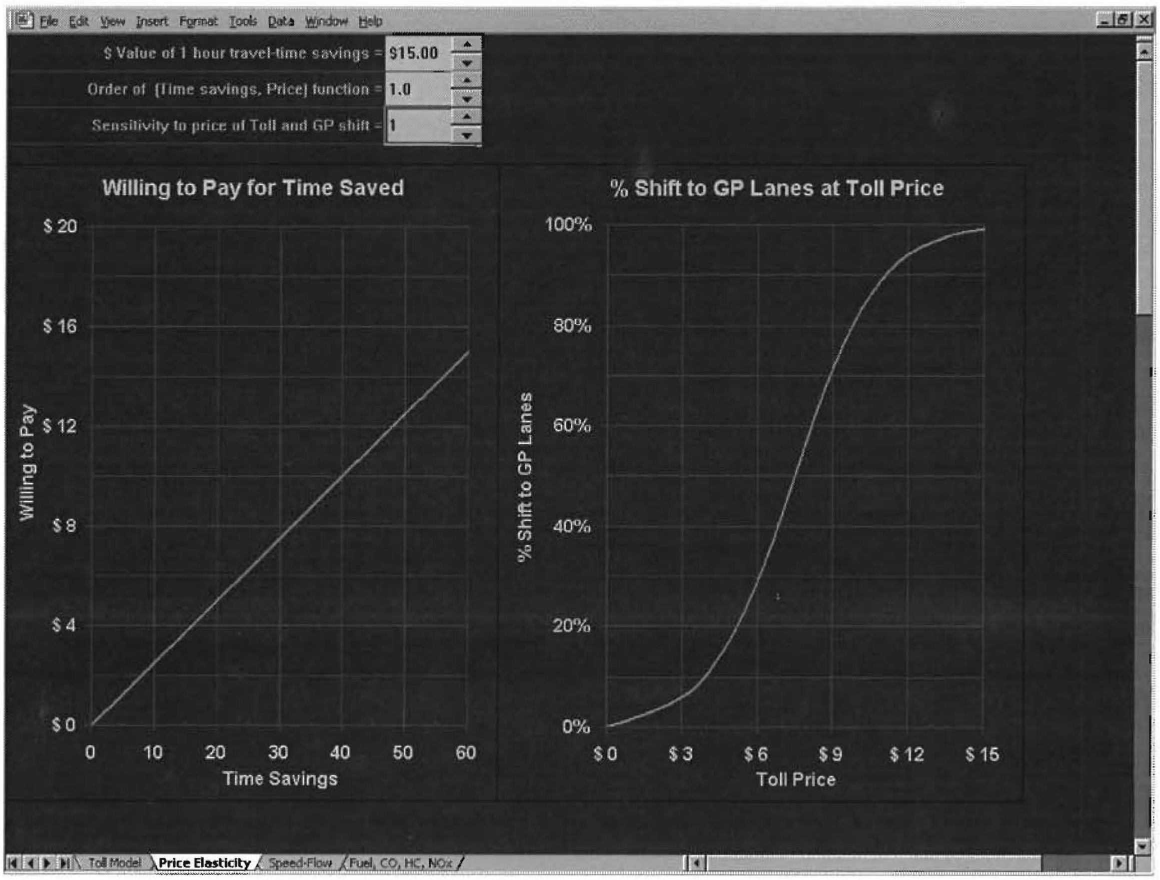
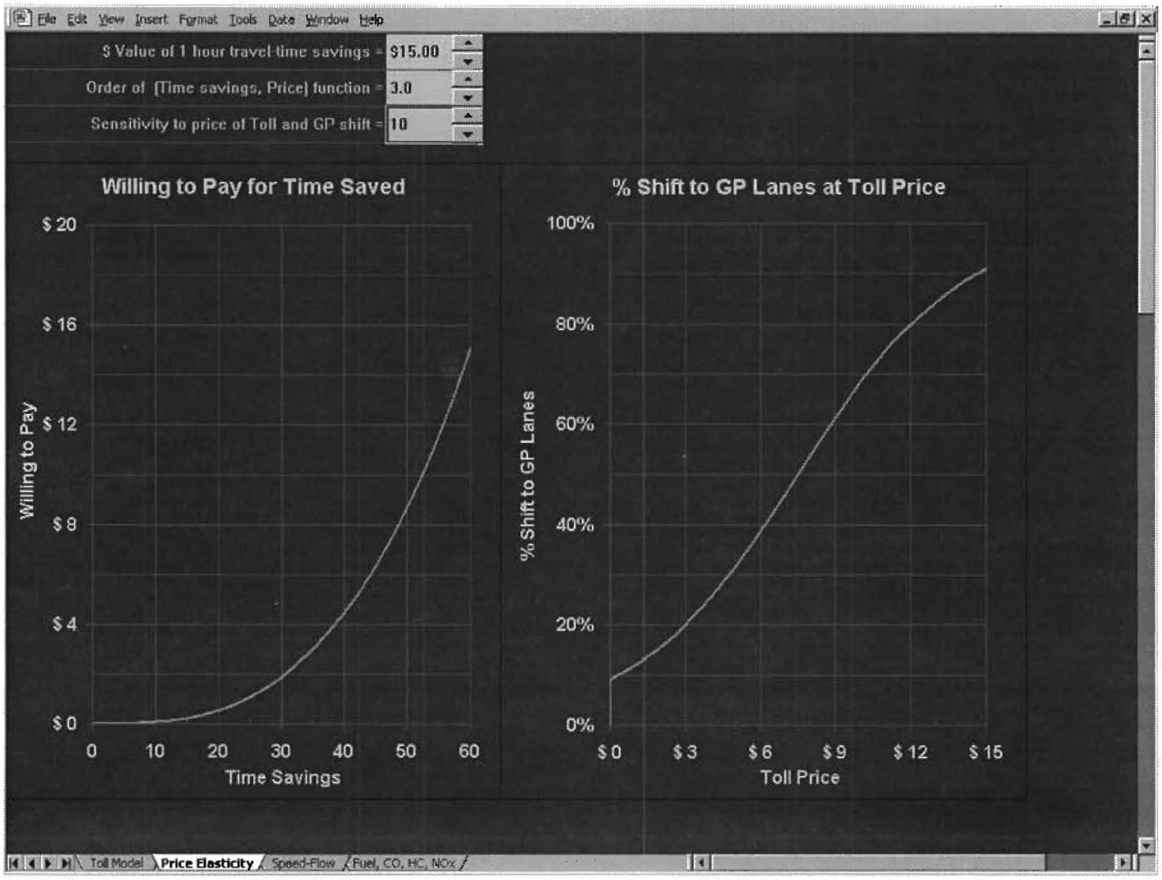


Figure 6.5.
The Effects of High Input Values on The Price Elasticity Sheet



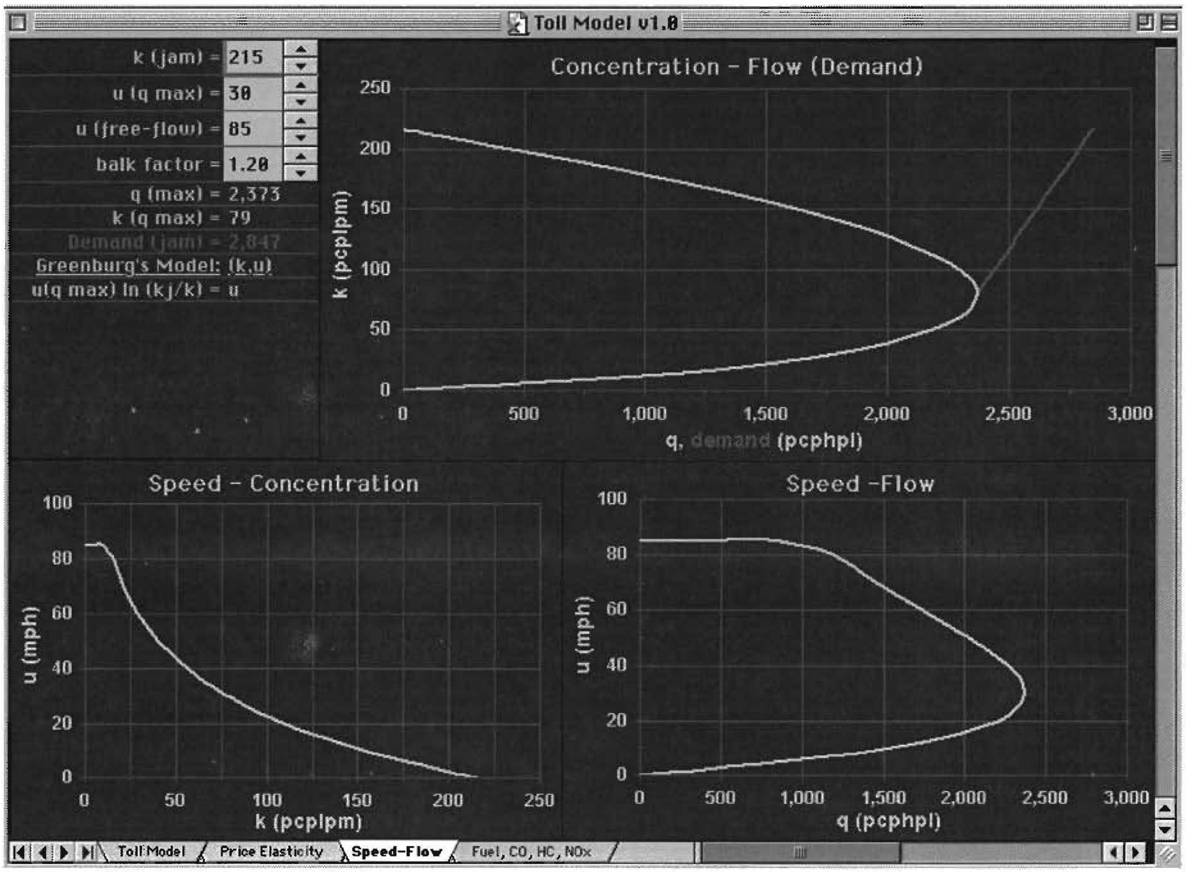
6.1.3. Input variables required for the Speed-Flow sheet

Four input variables are required for the Speed-Flow sheet, as seen in Figure 6.6. These variables are:

1. **k (jam):** The jam concentration for the GP and managed lanes, expressed as passenger cars per lane per mile. Permissible values are in the range of 200 to 240 pcplpm.
2. **u (q max):** The speed at which maximum flow rate occurs, measured in miles per hour. Permissible values are in the range of 20 to 50 mph.
3. **u (free flow):** The free flow speed of the lanes, also measured in miles per hour. Permissible values are in the range of 55 to 85 mph.

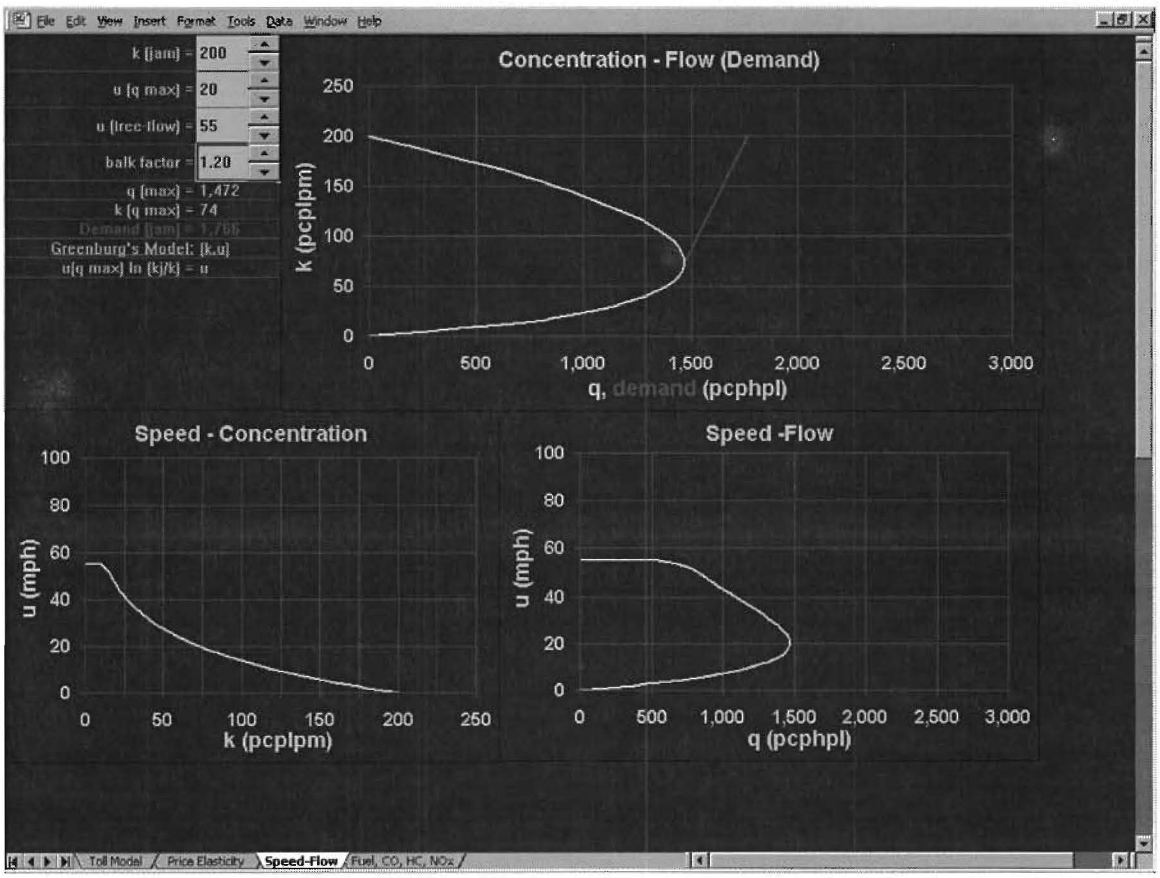
4. **Balk Factor:** A multiplier that determines the demand level at which commuters balk at joining a queue. This factor, when multiplied by the demand at capacity (maximum flow), will give the level of demand that would result in jam concentrations. The valid inputs for this variable are values between 1.2 and 1.5.

Figure 6.6.
The Speed-Flow Sheet



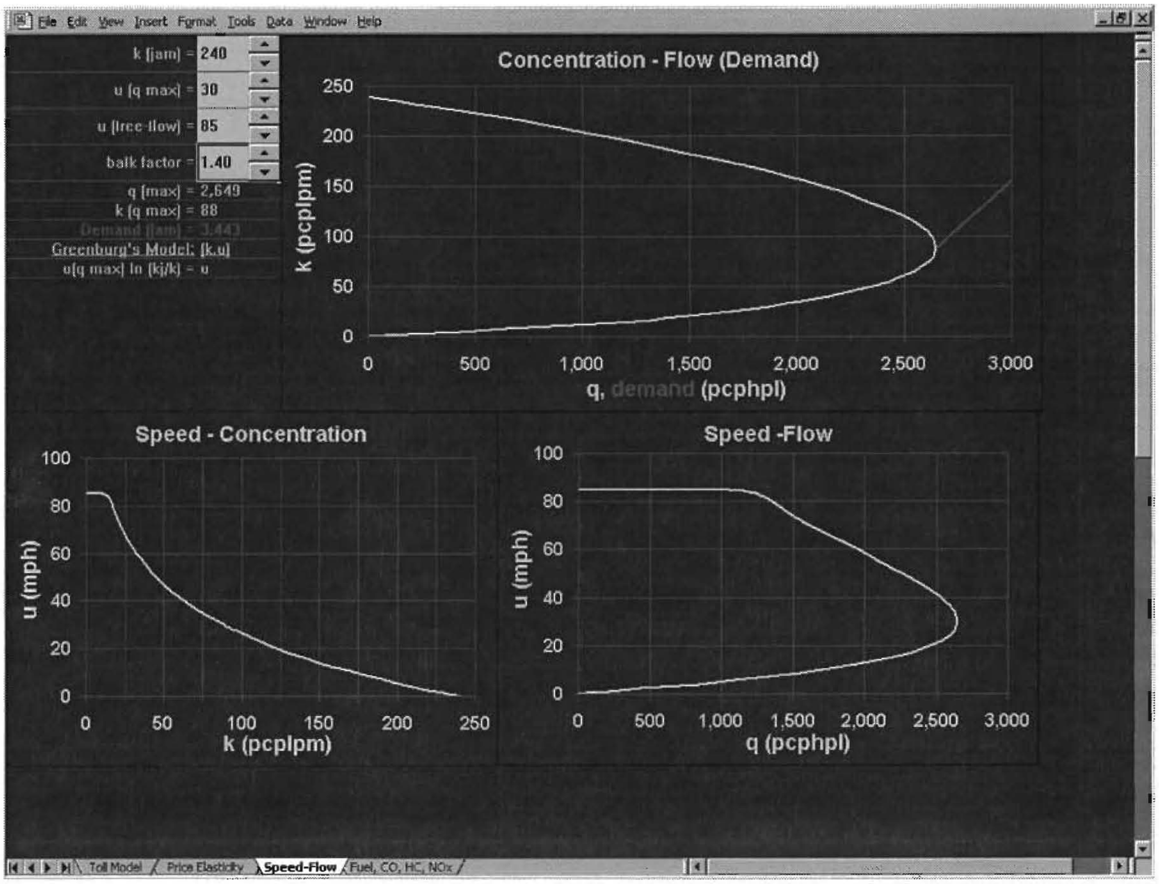
The effects of low and high input values on the Speed-Flow sheet are shown in Figures 6.7 and 6.8. The values of the above variables can be calibrated from local traffic count data. In the absence of pertinent local data, the values of 220 pcplpm, 30 mph, 75 mph, and 1.2 are recommended for the k (jam), u (q max), u (free flow), and the balk factor, respectively.[4]

Figure 6.7.
The Effects of Low Input Values on The Speed-Flow Sheet



[4] See the User Guide in Appendix B and consult the current Highway Capacity Manual for details about these variables.

Figure 6.8.
The Effects of High Input Values on The Speed-Flow Sheet



Once the above inputs are provided, the model user can observe the impacts of pricing on toll revenue, traffic conditions (including flow, speed, travel time, and delay) on both the GP and managed lanes, as well as on emission.

6.2. Applications of the Toll Evaluation Model

In this section, we provide a few examples on how to use the toll evaluation model to search for optimal pricing strategies that can achieve different objectives. These examples include:

- Determine toll to ensure a minimum speed on managed lanes.
- Determine toll to ensure a minimum speed on the GP lanes.

- Determine toll to ensure flow on the GP lanes is maximized.
- Determine toll to ensure flow rate on managed lanes is at or below x% of capacity.
- Determine a toll to maximize revenue.

6.2.1. A hypothetical scenario

In order to demonstrate the use of the model for selecting toll to meet the above objectives, a scenario is assumed as the following:

A 10 mile long corridor is served by 4 GP lanes and 2 HOV/T lanes on each direction. The peak hour directional volume is 12,500 passenger cars with 1% HOV3+, 5% HOV2, and 94% SOV. Consumer behavior studies have determined that the time value of travelers in this corridor is $ 12.00 for one hour of travel-time savings, and the Time Savings vs. Price Willing to Pay function is best modeled using an order (power) of 1.8. The sensitivity to toll and % shift to the GP lanes is assumed to be 5. Traffic flow studies have determined that the speed-concentration-flow functions best represent local driving conditions when k(jam) = 220 pcplpm, and u(q max) =30 mph, and u(free flow) = 75 mph. The balk factor value of 1.2 is assumed.

Enter these input variables in various worksheets in the model:

Speed Flow sheet:

k (jam) = 220 pcplpm

u (q max) = 30 mph

u (free flow) = 75 mph

Balk Factor = 1.2

Price Elasticity sheet:

$ Value of 1 hour Travel-Time Savings = $12.00

Order of (Time Savings, Price) Function = 1.8

Sensitivity to Price of Toll and GP Shift = 5

Toll Model Sheet:

Number of General Purpose Lanes = 4

Number of Managed Lanes = 2

Travel Distance = 10 miles

Passenger Cars / hour = 12,500 pc

% HOV3+ = 1%

% HOV 2 = 5%

6.2.2. Application Demonstrations

Objective #1: Determine toll price to ensure a minimum speed of 60 mph on managed lanes.

Application steps:

- Start with a value of Toll Price for SOV = $0.00 in the Toll Model sheet. This implies that there is no toll and all lanes are free lanes. The total volume of vehicles is distributed evenly over all possible lanes. The speed of traffic flow on all lanes is calculated to be 50 mph.
- Adjust toll. When toll for SOV on HOV/T lanes is raised to $1.00, all HOVs (those previously on the GP lanes) shift to managed lanes. However, many SOVs shift from managed lanes to the GP lanes. As a result, the speed on managed lanes has increased to 53 mph, while the speed on the GP lanes has dropped to 47 mph. When toll is raised to $2.00, more SOV from managed lanes shift to the GP lanes. The speed on the former is now 55 mph and the latter is 44 mph. At a toll of $3.00, the speed on managed lanes is 58 mph and the speed on the GP lanes reduces to 40 mph. As toll is raised to $4.00, the speed on managed lanes is 63 mph, and drops to 25 mph on the GP lanes. In addition, the delay, calculated by subtracting capacity from demand, on the GP lanes is 369 pcph because the demand for the GP lanes is more than its total capacity.
- Find the toll that ensures a minimum speed of 60 mph on managed lanes: Reduce toll to $3.75. At this price, one can observe that the delay variable becomes 41 mph and that the speed on managed lanes is 62 mph. Therefore a toll between $3.00 and $3.75 will result in a speed within a couple of mph of 60 (±2) for managed lanes. Any price within this range could be ideal for implementation. Further decisions for establishing an exact price point may be made by comparing

the environmental impacts (CO, HC, and NOx Index) for different toll prices within this range (e.g., at $3.00, $3.25, $3.50, and $3.75).

Objective #2: Determine toll price to ensure a minimum speed of 45 mph on the GP lanes.

Application steps:

- Start with a value of Toll Price for SOV = $0.00 on the Toll Model sheet. The speed of traffic flow on all lanes is 50 mph.

- Adjust toll. At $1.50, the speed on the GP lanes is 46 mph, and at $2.00, it drops to 44 mph. Therefore a toll between the $1.50 and $2.00 will be required to meet the objective of 45 mph speed on the GP lanes.

Objective #3: Determine toll to ensure the flow on the GP lanes is maximized, namely the flow is close to (but less than) 2428 pcplph {= q (max), the capacity}.

Application steps:

- Start with a value of Toll Price for SOV = $0.00 on the Toll Model sheet. This implies that there is no toll and all lanes are free access lanes. The total volume of vehicles is distributed uniformly over all lanes. The traffic flow on all lanes is calculated to be 2083 pcplph.
- Adjust toll. When toll for SOV on HOV/T lanes is raised to $3.50, the demand for managed lane has decreased to 1770 pcplph, while the demand for the GP lanes has increased to 2397 pcplph, which is slightly less than its maximum capacity of 2428 pcplph. If the toll is any higher, demand for the GP lanes becomes more than its capacity, introducing delays. Hence a toll of $3.50 will ensure a maximum flow rate on the GP lanes.

Objective #4: Determine a toll to ensure the flow on managed lanes is at or below 65% of capacity, namely the flow on managed lanes is less than 1578 pcplph.

Application steps:

- Start with a value of Toll Price for SOV = \$0.00 on the Toll Model sheet.
- Adjust toll. Gradually raise the toll. When toll is raised to \$4.75, the flow on managed lanes is 1534 pcplph, which fulfills the given objective. The user can also observe that at this price, traffic flow on the GP lanes exceeds the maximum capacity and causes delay. The CO and HC environmental index is higher than 7. The user should determine if such an objective is justified.

Objective #5: Determine a toll to maximize toll revenue without causing delays.

Application steps:

- Start with a value of Toll Price for SOV = \$0.00 on the Toll Model sheet.
- Adjust toll. Gradually raise the toll. When toll is raised to \$3.50, the toll revenue reaches to \$9,763 without causing delay. Any toll that is higher than that will result in delay. At this point, traffic demand and flow on the GP lanes are also less than the maximum rates. Therefore, a toll of \$3.50 satisfies the given objective.

6.2.3. Summary

As demonstrated above, the tool can be used to find a toll that realizes different objectives. The results from the above demonstrations also indicate that some objectives are in conflict with each other. For example, maximizing toll revenue may be realized at the expense of sacrificing environmental benefits and utility of transportation facilities, as shown in Example #4. Finally, the demonstrations also show that the tool can be used to search for a toll that optimizes a number of objectives. As seen from the above results, a toll of \$3.50 will satisfy objectives #1, #3, and #5 and maintain relatively low CO, HC, and NOx emissions.

CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS

This report describes the tasks accomplished in the project including:

1. Review of the literature on existing congestion pricing projects and studies;
2. Develop conceptual models and survey instruments;
3. Conduct survey;
4. Analyze survey data; and
5. Develop a tool for the evaluation of pricing strategies.

Instructions for using the evaluation tool are provided in Chapter Six and a separate guidebook, included as Appendix B. In this chapter, we summarize the findings of the literature search and survey data analysis, and discuss implementation issues and future research directions.

7.1. Lessons Learned from Existing Pricing Projects

The literature search has resulted in a number of observations:

1. Congestion pricing is gaining momentum under the sponsorship of ISTEA and TEA21. So far, four congestion-pricing projects have been implemented and project monitoring and evaluation of these projects are underway. Toll agencies in New York and New Jersey have just started implementing congestion pricing on their toll facilities. In addition, many states are in the process of exploring the feasibility of congestion pricing.
2. Current congestion pricing projects have been implemented on new capacity, existing toll roads, and existing HOV lanes.
3. Studies are underway to explore the FAIR (Fast and Intertwined Regular) lane concept for implementing congestion pricing in locations where new capacity cannot be built and converting existing general-purpose lanes is necessary.
4. Congestion pricing schemes include variable charges; fixed charges related to time of day, cordons, and distance; and combination of both.

5. Evaluation of successful projects has found that congestion pricing has had positive impacts on traffic throughput and on travel behavior, including time of travel, mode change, and travel route selection to a certain extent. Effect on overall traffic conditions is mixed, due to induced travel demand.
6. Empirical studies provide limited information on price elasticity of demand for managed lanes. Research estimates that price elasticity ranges from –0.03 to –0.36 for Lee County, Florida, and from –0.02 to –1.00 for SR91, California.
7. Previous studies suggest lessons on goal setting, pricing policy evaluation, equity consideration, and marketing approaches for overcoming political and institutional barriers for the implementation of managed lanes.

7.2. Survey Administration and Key Findings of Data Analysis

Travelers on LBJ and DNT were recruited and surveyed for information about their attitudes towards managed lanes and sensitivity to price. A number of steps were taken in the recruitment process including vehicle license recording, address matching, telephone matching, and data cleaning. About 17,500 vehicle licenses were recorded by observers on the two study corridors. However, less than 30 percent of the recorded licenses were included in the sample pool for telephone survey. Eight hundred and two individuals participated in the survey.

A stated preference method was used to survey travelers' attitudes towards managed lanes. Based on data collected from the surveys, we analyzed attitudes toward the managed lane concept and variations in attitudes toward using managed lanes among different user groups, as well as tendency for mode change. In addition, we studied price elasticity of demand for managed lanes, and developed a tool for assessing the impacts of pricing strategies on network performance, toll revenues, and air quality, and for the evaluation and selection of pricing strategies. Analysis of the survey data has resulted in a number of key findings:

1. *Demographic characteristics of survey participants*: The gender composition and age distribution of survey participants are fairly even. The majority of survey participants are white and in households with 2 ~ 4 people. Over half of the survey participants are in 2-car and 2-worker households. The demographic and

socioeconomic characteristics of LBJ users are similar to those of DNT users except income. Over 65 percent of DNT users are in households with income over $75K, as compared to 53 percent of LBJ users.

2. *Current travel patterns*: Most participants use the studied corridors for both work and non-work trips or for non-work trips only. Between 75 to 79 percent of survey participants drive alone. Among HOV users, over 60 percent carpooled with family members. Average travel distance was about 6.5 miles on LBJ and 7.5 miles on DNT.

3. *Attitude towards using managed lanes*: Over 50 percent of survey participants indicated that they would be very or somewhat likely to use managed lanes if implemented. Interest in driving alone using managed lanes is higher than that of carpooling using managed lanes. In addition, work trips have greater tendency to use managed lanes than non-work trips. Participants would also be less likely to carpool and more likely to pay and drive alone on managed lanes for work trips than non-work trips.

4. *Variations in attitude towards using managed lanes*: Attitude towards using managed lanes among LBJ users is complex. Overall, gender difference in attitude towards using manage lanes is not significant. However, the survey data do show that users in the middle age groups indicated that they would be more likely to use managed lanes than those in younger and older age groups. The proportion of interest in using managed lanes for work trips is higher in low- and high-income groups than in middle-income groups. Interest in using managed lanes for non-work trips becomes higher as income increases. Further investigations of tendencies for driving alone and carpooling using managed lanes provide some explanations on variations in attitude towards using managed lanes among different age and income groups. As seen from Chapter Five, middle-age and low-income groups are more likely to carpool to use managed lanes, while interest in driving alone using managed lanes is positively related to income.

5. *Possible impact on mode change*: Survey data indicated that most SOV users would continue driving alone on managed lanes, and most current HOV users would

remain carpooling using managed lanes as well. Few SOV users would change to HOV in order to use managed lanes for free or at a reduced fare, and *vice versa*.

6. *Value of travel time saving*: The data show that the value of travel time savings for LBJ and DNT users are fairly low, about $3/hour and $6/hour respectively. However, it is interesting to note that, on average, LBJ users perceive more time savings from using managed lanes than DNT users, but their average willingness to pay for the time savings is lower than that of DNT users

7. *Price elasticity of demand*: Data show that the demand for managed lanes is inelastic to price for both LBJ and DNT users. The basic price that LBJ users are willing to pay is lower than that of DNT users. However, the incremental price, that is, the willingness to pay for an additional unit of travel time saving, on LBJ is higher than that for DNT users.

The application demonstrations of the tool developed in this research show that the tool can be used to select a toll that realizes different objectives, such as ensuring a minimum speed on the managed lanes or the general purpose lanes, maximizing traffic flows or toll revenues, as well as minimizing environmental impacts. The results of the demonstrations also indicate that some objectives are in conflict with each other. For example, maximizing toll revenue may be realized at the expense of sacrificing environmental benefits and utility of transportation facilities. Finally, the demonstrations also prove the tool can be used to search for a toll price that optimizes a number of objectives.

7.3. Implications and Recommendations

The above research findings have a number of implications. First, there is considerable public acceptance of the managed lane concept. This can be seen from data on the likelihood of using managed lanes. A high level of public acceptance provides a good opportunity for implementing managed lanes.

Second, unless there are dramatic changes in pricing and traffic congestion, it is not likely that the managed lane option would affect the travel mode of LBJ and DNT users. Managed lanes may have only limited impact on carpooling if incentives (e.g. price and travel time saving) for carpooling are not high enough, since most who expressed willingness to carpool are current carpoolers. In fact, it may be easier to pay a toll, especially with a toll tag, than to form carpool if toll is low.

Third, most of the low-income users may benefit from the implementation of managed lanes, as most of users in the low-income group indicated willingness to carpool in order to use managed lanes for free or at a reduced toll.

In addition, the difference in perceived time savings and willingness to pay between LBJ and DNT survey respondents implies that experience with toll may be an important factor in explaining willingness to pay for time savings, though income may play a role as well.

Moreover, the operational agencies of managed lanes may need to pay more attention to pricing during peak hours, because pricing policy may have more impact on peak hour travel demand for managed lanes and therefore on traffic congestion as a high proportion of users indicated interest in using managed lanes for work trips.

Furthermore, toll agencies and transportation authorities must set the priorities of goals and objectives when developing pricing policies, as some of the objectives of implementing managed lanes may be in conflict with each other.

Finally, our experience with survey data collection suggests that the preparation of survey sample pool should take into account unexpected factors, such as weather condition, traffic condition, and data availability. More samples may be needed in the initial data collection stage in order to provide sufficient samples for survey.

It should be pointed out that while the stated preference method is a good way for investigating travelers' potential reaction to managed lanes before implementation, the method can only provide perceived information on time savings and willingness to pay. There will be a gap between real and perceived time savings. In addition, there is a difference between willingness to pay and market price. The true price elasticity of demand for managed lanes, as widely suggested, has to be studied with empirical data through field observation after the implementation of managed lanes.

This research leads to a number of recommendations for model implementation and future research direction:

1. Investigate the political and institutional issues of implementing managed lanes. The focus of this research is to develop a technical tool for evaluation of pricing policies. As learned from the literature search, political and institutional factors play a vital role in the success of a project. In addition, public involvement, funding, marketing, legislative, and operational issues are crucial for managed lane planning and implementation as well. More research is required to investigate these issues.
2. Continue the current research to improve the toll evaluation model developed in this study. As shown in Chapter Six, the tool has the ability to search for a pricing policy that maximizes toll revenues or vehicular flow over a toll facility. It is also possible to maximize simultaneously both the revenues and the flows. However, due to time and data constraints, the research has not fully investigated the relationship between price and HOV, e.g. price impacts on mode change and impact of HOV on travel demand for managed lanes. In addition, the tool does not provide an option of evaluating impacts of pricing HOVs. Furthermore, there is a need to fine-tune the shape of the price and demand curve. Therefore, future research should continue to improve the model with feedbacks from field tests of the model. New research also needs to find new emission information.
3. Provide training for using the evaluation tool developed in this study. While researchers of this study have made an exceptional effort to explain the model and potential applications in this report and the guidebook, it will be necessary to provide training in using the model in order to insure the correct use of the model. The model requires inputs from the user. If the user does not supply correct information, the model could provide misleading results.

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APPENDIX A

SURVEY QUESTIONNAIRES

SURVEY QUESTIONNAIRE FOR LBJ USERS

Hello:
My name is XXX. I am with the University of Texas at Arlington. We are conducting a study on the use of LBJ Freeway for the Texas Department of Transportation. This survey will take less than 10 minutes. Would you be willing to participate?

Yes (Continue the survey)
No ("Thanks for your time." Stop)

Thank you.

Travel Information:

1. Do you use LBJ for your trip to work?
   1. Yes (Go to question 2)
   2. No (Go to question 26A)

2. How many days per week do you use LBJ for your trip to work?

3. How many people, excluding yourself, are usually in your car as you take LBJ to work?
   (If the answer is 0, go to question 5. Otherwise go to question 4)

4. How many carpoolers are your family members?

5. What time of day do you normally enter LBJ on your way to work?

6. Where do you normally enter LBJ on your way to work?
   1. West of Stemmons Freeway
   2. Stemmons Freeway (I-35E)
   3. Denton Drive
   4. Josey Lane
   5. Webb Chapel Road
   6. Marsh Lane
   7. Midway Road
   8. Welch Road
   9. Dallas North Tollway
   10. Dallas Parkway
   11. Inwood Road
   12. Montfort Drive
   13. Preston Road
   14. Hillcrest Road
   15. Park Central
   16. Coit Road
   17. North Central Expressway (US 75)

18. TI / Floyd
19. Greenville Avenue
20. Forest Lane
21. Audelia Road
22. Skillman Street
23. Miller Road
24. Plano Road
25. Kingsley Road
26. Jupiter Road
27. Garland Road
28. Shiloh Road
29. Northwest Highway
30. Ferguson Road
31. Saturn Road
32. Centerville Road
33. La Prada Drive
34. Oates Drive
35. Galloway Avenue
36. I – 30
37. South of I – 30
38. Other

7. Where do you normally exit LBJ freeway on your way to work?
   1. West of Stemmons Freeway
   2. Stemmons Freeway (I 35E)
   3. Denton Drive
   4. Josey Lane
   5. Webb Chapel Road
   6. Marsh Lane
   7. Midway Road
   8. Welch Road
   9. Dallas North Tollway
   10. Dallas Parkway
   11. Inwood Road
   12. Montfort Drive
   13. Preston Road
   14. Hillcrest Road
   15. Park Central
   16. Coit Road
   17. North Central Expressway (US 75)
   18. TI / Floyd
   19. Greenville Avenue
   20. Forest Lane
   21. Audelia Road
   22. Skillman Street
   23. Miller Road

24. Plano Road
25. Kingsley Road
26. Jupiter Road
27. Garland Road
28. Shiloh Road
29. Northwest Highway
30. Ferguson Road
31. Saturn Road
32. Centerville Road
33. La Prada Drive
34. Oates Drive
35. Galloway Avenue
36. I – 30
37. South of I – 30
38. Other

8. Besides LBJ, do you also use Dallas North Tollway or George Bush Turnpike for your trip to work?
   1. Yes
   2. No

Toll for work trips:

The Texas Department of Transportation is considering adding new lanes on LBJ Freeway, which would function as high occupancy toll lanes. Vehicles with two or more people could travel on these lanes for free or at a reduced toll. One-person vehicles would pay higher tolls during peak periods than off-peak periods, if they chose to use the new lanes.

If you were provided with such options,

9. Would you use the new lanes for your work trips?
   1. Yes (Go to question 10)
   2. No (Go to question 16)

10. Why would you use the new lanes (check all that apply)?
    1. Time saving
    2. More reliable travel time
    3. Safer
    4. Comfort
    5. Other (please specify)

11. Would you be willing to carpool in order to use the new lanes for free or at a reduced toll for your work trips?

1. Yes
2. No

12. Would you be willing to pay a toll in order to drive alone in the new lanes for your work trips?
    1. Yes
    2. No (Go to question 16)

13. How much time do you believe you could save if you were able to drive at 60 miles per hour to go to work in the new lanes?

14. What is the maximum amount you would be willing to pay for the time saving?

15. How many times per week would you use the new lanes?

16. Would you use routes other than LBJ for your work trips?
    1. Yes
    2. No

17. Is public transportation available for your work commute?
    1. Yes
    2. No (Go to question 19)

18. Would you use public transportation for your work trips?
    1. Yes
    2. No

19. Does your employer subsidize the cost of using public transportation?
    1. Yes
    2. No (Go to question 21)

20. How much does your employer subsidize the cost of using public transportation?

21. Do you have the option of adjusting your departure and arrival time for you work trip?
    1. Yes
    2. No

22. Would you alter your commuting schedule to off-peak in order to pay a reduced toll on LBJ for your work trip?
    1. Yes
    2. No

Parking At Work:

23. What is the cost of parking at your place of employment?

24. How much does your employer subsidize the cost of parking at your place of employment?

25. How much does your employer subsidize carpools? **(Go to question 26B)**

Non-Work Trips:

26A. Do you use LBJ for non-work trips?
1. Yes (Go to question 27)
2. No ("Thank you very much." Stop)

26B. Do you use LBJ for non-work trips?
1. Yes
2. No (Go to question 42)

27. What are the purposes of your non-work trips on LBJ (check all that apply)?
    1. Shopping
    2. Recreation
    3. School
    4. Airport
    5. Visit family/friends
    6. Child care
    7. Other (please specify)

28. About how frequently do you use LBJ for these trips?
    1. Daily
    2. 5 times per week
    3. 4 times per week
    4. 3 times per week
    5. 2 times per week
    6. Once per week
    7. Other

29. What time of day do you normally enter LBJ for these trips?

30. Where do you normally enter LBJ for these trips?
    1. West of Stemmons Freeway
    2. Stemmons Freeway (I-35E)

3. Denton Drive
4. Josey Lane
5. Webb Chapel Road
6. Marsh Lane
7. Midway Road
8. Welch Road
9. Dallas North Tollway
10. Dallas Parkway
11. Inwood Road
12. Montfort Drive
13. Preston Road
14. Hillcrest Road
15. Park Central
16. Coit Road
17. North Central Expressway (US 75)
18. TI / Floyd
19. Greenville Avenue
20. Forest Lane
21. Audelia Road
22. Skillman Street
23. Miller Road
24. Plano Road
25. Kingsley Road
26. Jupiter Road
27. Garland Road
28. Shiloh Road
29. Northwest Highway
30. Ferguson Road
31. Saturn Road
32. Centerville Road
33. La Prada Drive
34. Oates Drive
35. Galloway Avenue
36. I – 30
37. South of I – 30
38. Other

31. Where do you normally exit LBJ freeway for these trips?
    1. West of Stemmons Freeway
    2. Stemmons Freeway (I - 35E)
    3. Denton Drive
    4. Josey Lane
    5. Webb Chapel Road
    6. Marsh Lane
    7. Midway Road
    8. Welch Road

9. Dallas North Tollway
10. Dallas Parkway
11. Inwood Road
12. Montfort Drive
13. Preston Road
14. Hillcrest Road
15. Park Central
16. Coit Road
17. North Central Expressway (US 75)
18. TI / Floyd
19. Greenville Avenue
20. Forest Lane
21. Audelia Road
22. Skillman Street
23. Miller Road
24. Plano Road
25. Kingsley Road
26. Jupiter Road
27. Garland Road
28. Shiloh Road
29. Northwest Highway
30. Ferguson Road
31. Saturn Road
32. Centerville Road
33. La Prada Drive
34. Oates Drive
35. Galloway Avenue
36. I – 30
37. South of I – 30
38. Other

32. Would you use the new lanes for your non-work trips?
    1. Yes
    2. No (Go to question 39)

33. Why would you use the new lanes for your non-work trips (check all that apply)?
    1. Time saving
    2. More reliable travel time
    3. Safer
    4. Comfort
    5. Other (please specify)

34. Would you be willing to carpool in order to use the new lanes for free or at a reduced fee for these non-work trips?
    1. Yes
    2. No

35. Would you be willing to pay a toll in order to drive alone in the new lanes for your non-work trips?
    1. Yes
    2. No (Go to question 39)

36. How much time do you believe you could save if you were able to travel at 60 miles per hour on the new lanes for a non-work trip?

37. What is the most you would be willing to pay for this time saving?

38. How many times per week would you use the new lanes for your non-work trips?

39. Would you use routes other than LBJ for your non-work trips?
    1. Yes
    2. No

40. Is public transportation available for your non-work trips?
    1. Yes
    2. No

41. Would you use public transportation for your non-work trips?
    1. Yes
    2. No

Household Information:

42. How many people (including yourself) are in your household?

43. What is your estimated total household annual income?
    1. Under $15,000
    2. $15,000-$24,999
    3. $25,000-$49,999
    4. $50,000-$74,999
    5. $75,000-$99,999
    6. $100,000-$124,999
    7. $125,000 and over

44. How many children living in your household are in preschool and/or elementary school?

45. How many workers are in your household?

46. How many people in your household are licensed drivers?

47. How many vehicles are in your household?

General Information:

48. What is the year of your birth?

49. How do you define your race/ethnicity?
    1. White
    2. Hispanic
    3. Black
    4. Asian
    5. Other

50. Gender (fill in by interviewer)
    1. Male
    2. Female

SURVEY QUESTIONNAIRE FOR DNT USERS

Hello:
My name is XXX. I am with the University of Texas at Arlington. We are conducting a study on the use of LBJ Freeway for the Texas Department of Transportation. We would like to get the opinion of people that are already using a toll road. This survey will take less than 10 minutes. Would you be willing to participate?

Yes (Continue the survey)
No ("Thanks for your time." Stop)

Thank you.

Travel Information:

1. Do you use the Dallas North Tollway (DNT) for your trip to work?
   1. Yes
   2. No (Go to question 27A)

2. How many days per week do you use the DNT for your trip to work?

3. How many people, excluding yourself, are usually in your car as you take the DNT to work?
   (If the answer is 0, go to question 5. Otherwise go to question 4)

4. How many carpoolers are your family members?

5. What time of day do you normally enter the DNT on your way to work?

6. Where do you normally enter DNT on your way to work?
   1. SH 121
   2. Spring Creek Parkway
   3. Wind Haven Parkway
   4. Parker Road
   5. Park Blvd
   6. Plano Parkway
   7. State Highway 190 (President George Bush Turnpike)
   8. Frankford Road
   9. Trinity Mills Road
   10. Keller Springs Road
   11. Arapaho Road
   12. Belt Line Road
   13. Spring Valley Road
   14. LBJ Freeway (I-635)
   15. Inwood
   16. Harvest Hill

17. Forest Lane
18. Royal Lane
19. Walnut Hill Lane
20. North West Highway (Loop 12)
21. Lovers Lane
22. Mockingbird Lane
23. Lemmon Avenue
24. Wycliff Avenue
25. Oak Lawn Avenue
26. Cedar Springs Road
27. I-35E (Stemmons Freeway)
28. Downtown Dallas

7. Where do you normally exit DNT freeway on you way to work?
    1. SH 121
    2. Spring Creek Parkway
    3. Wind Haven Parkway
    4. Parker Road
    5. Park Blvd
    6. Plano Parkway
    7. State Highway 190 (President George Bush Turnpike)
    8. Frankford Road
    9. Trinity Mills Road
    10. Keller Springs Road
    11. Arapaho Road
    12. Belt Line Road
    13. Spring Valley Road
    14. LBJ Freeway (I-635)
    15. Inwood
    16. Harvest Hill
    17. Forest Lane
    18. Royal Lane
    19. Walnut Hill Lane
    20. North West Highway(Loop 12)
    21. Lovers Lane
    22. Mockingbird Lane
    23. Lemmon Avenue
    24. Wycliff Avenue
    25. Oak Lawn Avenue
    26. Cedar Springs Road
    27. I-35E (Stemmons Freeway)
    28. Downtown Dallas

8. Under current traffic condition, approximately how many minutes per trip do you save by using DNT instead of taking alternative routes?

9. Besides DNT, do you also use LBJ or President George Bush Turnpike for your trip to work?
   1. Yes
   2. No

Toll for work trips:

It is believed that charging different rates by time of day might improve traffic flow and reduce travel time on toll roads. This idea would have a lower toll for off-peak travel and a higher toll for the peak period, and it could also allow vehicles with 2 or more people to travel on toll roads for free or at a reduced toll. Under this idea, travelers could save anywhere between 5 to 25 minutes per trip depending on their point of entry and exit to a typical toll road.

If you were to travel on such a toll road on a regular basis,

10. Would you be willing to carpool in order to use the toll road for free or at a reduced toll for your work trips?
    1. Yes
    2. No
    3. Maybe

11. Would you use routes other than the toll road for your work trips?
    1. Yes
    2. No
    3. Maybe

12. Would you use bus or rail for your work trips?
    1. Yes
    2. No
    3. Maybe

13. Would you be willing to pay a higher toll in order to drive alone during peak-hour period for your work trips?
   1. Yes
   2. No (Go to question 17)

14. How much time do you believe you could save if you could travel at 60 miles per hour on the toll road instead of taking alternative routes?

15. What is the maximum amount you would be willing to pay for this time saving?

16. How many times per week would you use the toll road at such a cost?

17. Is public transportation available for your work commute?
   1. Yes
   2. No

18. Does your employer subsidize the cost of using public transportation in any forms?
   1. Yes
   2. No (Go to question 20)

19. How much does your employer subsidize using public transportation?

20. Do you have the option of adjusting your departure and arrival time for you work trip?
   1. Yes
   2. No (Go to question 22)

21. Would you alter your commuting schedule to off-peak in order to pay a reduced toll on the toll lane for your work trip?
   1. Yes
   2. No (Go to question 24)

22. How much would you be willing to pay to travel on the toll road during off-peak period?

23. With such a cost, how many times per week would you travel on the toll road during off-peak period?

Parking At Work:

24. What is the cost of parking at your place of employment?

25. How much does your employer subsidize the cost of parking at your place of employment?

26. How much does your employer subsidize carpools? (Go to question 27B)

Non-Work Trips:

27A. Do you use the DNT for non-work trips (shopping for example)?
1. Yes (Go to question 28)
2. No ("Thank you very much for your time." Stop)

27B. Do you use the DNT for non-work trips (shopping for example)?
1. Yes
2. No (Go to question 39)

29. What are the purposes of your non-work trips on the DNT (check all that apply)?
1. Shopping
2. Recreation
3. School
4. Airport
5. Visit family/friends
6. Child care
7. Other (please specify)

29. About how frequently do you use the DNT for these trips?
1. Daily
2. 5 times per week
3. 4 times per week
4. 3 times per week
5. 2 times per week
6. Once per week
7. Other

30. What time of day do you normally enter the DNT for these trips?

31. Where do you normally enter the DNT for these trips?
   1. SH 121
   2. Spring Creek Parkway
   3. Wind Haven Parkway
   4. Parker Road
   5. Park Blvd
   6. Plano Parkway
   7. State Highway 190 (President George Bush Turnpike)
   8. Frankford Road
   9. Trinity Mills Road
   10. Keller Springs Road
   11. Arapaho Road
   12. Belt Line Road
   13. Spring Valley Road
   14. LBJ Freeway (I-635)
   15. Inwood
   16. Harvest Hill
   17. Forest Lane
   18. Royal Lane
   19. Walnut Hill Lane
   20. North West Highway (Loop 12)
   21. Lovers Lane
   22. Mockingbird Lane
   23. Lemmon Avenue
   24. Wycliff Avenue
   25. Oak Lawn Avenue
   26. Cedar Springs Road
   27. I-35E (Stemmons Freeway)
   28. Downtown Dallas

32. Where do you normally exit the DNT for these trips?
   1. SH 121
   2. Spring Creek Parkway
   3. Wind Haven Parkway
   4. Parker Road
   5. Park Blvd
   6. Plano Parkway
   7. State Highway 190 (President George Bush Turnpike)
   8. Frankford Road
   9. Trinity Mills Road
   10. Keller Springs Road
   11. Arapaho Road
   12. Belt Line Road
   13. Spring Valley Road
   14. LBJ Freeway (I-635)

15. Inwood
16. Harvest Hill
17. Forest Lane
18. Royal Lane
19. Walnut Hill Lane
20. North West Highway (Loop 12)
21. Lovers Lane
22. Mockingbird Lane
23. Lemmon Avenue
24. Wycliff Avenue
25. Oak Lawn Avenue
26. Cedar Springs Road
27. I-35E (Stemmons Freeway)
28. Downtown Dallas

33. Why do you use DNT for your work or non-work trips (check all that apply)?
    1. Most direct way
    2. Quickest way/Time saving
    3. No alternative way (if this is checked, go to question 35)
    4. More reliable travel time
    5. Safer
    6. Comfort
    7. Other (please specify)

34. Do you have alternative route for your non-work trips?

35. Would you be willing to carpool in order to use the toll road for free or at a reduced price for these non-work trips?
    1. Yes
    2. No

36. How much time do you believe you could save if you were able to travel at 60 miles per hour for a non-work trip on the toll road instead of taking alternative routes?

37. What is the most you would be willing to pay for this time saving?

38. How many times per week would you use the toll road for non-work trips at such a cost?

Household Information:

39. How many people (including yourself) are in your household?

40. What is your estimated total household annual income?
    1. Under $15,000
    2. $15,000-$24,999
    3. $25,000-$49,999
    4. $50,000-$74,999
    5. $75,000-$99,999
    6. $100,000-$124,999
    7. $125,000 and over

41. How many children living in your household are in preschool and/or elementary school?

42. How many workers are in your household?

43. How many people in your household are licensed drivers?

44. How many vehicles are in your household?

General Information:

45. What is the year of your birth?

46. How do you define your race/ethnicity?
    1. White
    2. Hispanic
    3. Black
    4. Asian
    5. Other

47. Gender (fill in by interviewer)
    1. Male
    2. Female

APPENDIX B

USER GUIDE TO TOLL EVALUATION MODEL V1.0

User Guide to Toll Evaluation Model v1.0

TEM-1

by

Shekhar Govind

Developed at

The University of Texas at Arlington

for

Texas Department of Transportation

Contents

Foreword

Toll Evaluation Model v1.0 (TEM-1) models the flow patterns on Managed (HOV/T) lanes and General Purpose (free-access) lanes along a corridor. TEM-1 provides pricing strategies to optimize delay, flow, speed, and revenue, for any corridor served by both HOV/T and free-access lanes. TEM-1 is designed as an Excel Workbook with 4 sheets, each sheet modeling one of the following: Toll Model, Price Elasticity, Speed-Flow, and Fuel, CO, HC, and NOx.

This user guide for TEM-1 is organized into 2 Chapters. Chapter I covers the usage of TEM-1 and the interpretation of results obtained from it. Chapter II provides examples of how TEM-1 may be used to for pricing strategies to optimize, speed, flow, and revenue for Managed lanes.

CHAPTER I

1.1 Introduction

When the TEM-1 workbook is opened as a document in MS Excel, the bottom bar of the TEM-1 window provides tab buttons to navigate through each of the 4 sheets:

- Toll Model
- Price Elasticity
- Speed-Flow
- Fuel, CO, HC, NOx

See Figure 1. Among the 4 buttons, one will be highlighted and in front of the other three. This is the sheet the viewer is currently observing. E.g., In Figure 1, Toll Model is the front, indicating that the Toll Model sheet is on screen.

Figure 1

For the TEM-1 to perform properly, a few variables found in the first three sheets listed above (Toll Model, Price Elasticity, and Speed-Flow) require a valid input from the user. Numbers outside of the range of permissible values that have been provided will produce erroneous results.

1.2 Toll Model Sheet

The Toll Model sheet (Figure 2) is the cornerstone of TEM-1. This is the sheet where the user can try out different toll pricing strategies and analyze their effects on flow, speed, travel time, delay, revenue, and environmental impacts.

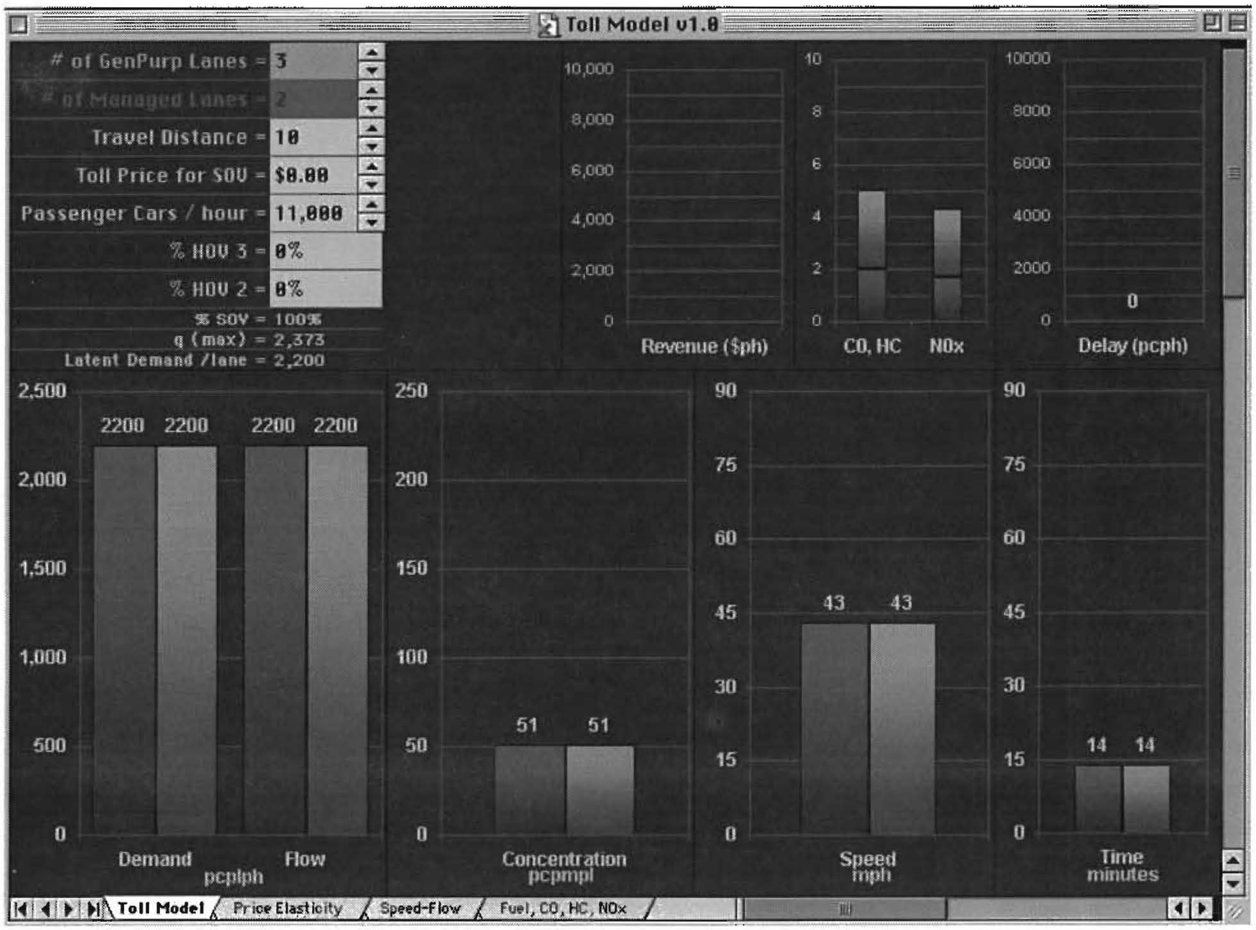

Figure 2

1.2.1 Input Variables

Number of General Purpose lanes: The number of General Purpose (free access) lanes in each direction. Range of permissible values = {1, 10} lanes

Number of Managed Lanes: The number of managed (HOV/T) lanes with free access for HOV users and tolled access for SOV users, in each direction. Range of permissible values = {1, 5} lanes

Travel Distance: The average distance traveled by commuters along a corridor. It is required to establish the travel time experienced by users of the two facilities. Range of permissible values = {1, 50} miles

Toll Price for SOV: Toll price charged to SOV users for access to the managed lanes. The model interprets price = $0 as free access on the Managed lanes for all users (HOV and SOV). Range of permissible values = {0, 20} $

Passenger Cars / hour: The directional peak hour volume in passenger cars / hour. This will be the total directional volume of both the general purpose lanes and the managed lanes. Range of permissible values = {4,000, 35,000} pcph

% HOV 3: Percent of vehicles which are HOV 3 and above. The model does not distinguish between HOV 3 and HOV 3+. For most places, a value of 5% may be considered to be an optimistic estimate for this variable. Range of permissible values = {0, 5} %

% HOV 2: Percent of vehicles which are HOV 2. Nationally, the average for the total % of HOV commuters is typically below 15%. Range of permissible values = {0, 10} %

1.2.2 Results

The other variables and bar charts on this sheet provide information used to analyze the effects of the pricing strategy being studied.

User Equilibrium: The price at which SOV users on the General Purpose lanes will begin to shift to Managed lanes because the travel time savings is worth the toll price being charged.

q (max): The maximum flow rate per lane possible on the study facility (i.e., the maximum capacity per lane). The variable value is obtained from the Speed-Flow sheet. This value should be compared with the Latent Demand / Lane.

Latent Demand / Lane: The directional peak hour demand (Passenger Cars / hour) divided by the sum of (Number of General Purpose lanes) and (Number of Managed Lanes.) This variable represents the lane volume if all lanes were General Purpose lanes and the traffic was evenly distributed among the lanes.

Caution: **If {User Equilibrium > Toll Price for SOV} , TEM-1 will not function properly.**

Caution: **If {q (max) < Latent Demand / Lane} , capacity has to be increased to avoid chronic delays. Unless capacity is increased, TEM-1 will not function properly.**

1.2.3 Interpreting the Bar-Charts

Green bars represent the situation for General Purpose lanes.

Pink bars represent the situation for Managed lanes.

Revenue ($ph): The revenue collected in $ per hour by collecting a toll from SOV users for access to the Managed lanes. HOV2 and HOV3 are not charged any toll.

CO, HC, and NOx Index: The emissions index is a non-dimensional number from the Fuel, CO, HC, NOx sheet. These values are derived only for the purpose of comparison between different pricing models. The green and pink bars represent the relative adverse environmental impacts from General Purpose Lanes and Managed Lanes respectively (shorter bars are better, longer bars are worse). These results have been derived from an EPA model formulated in the 1980s for a range of speed that extends only between 10 mph and 60 mph. The results, therefore, should be interpreted with care, and only in the context of TEM-1.

Delay: The total delay in vehicles per hour along the study corridor expressed as passenger cars per hour (pcph). This variable has a nonzero value when the demand for General Purpose lanes is greater than its capacity. When the demand is less than the capacity, Delay = 0.

Demand and Flow: The demand for, and the resulting flow on General Purpose lanes and Managed lanes expressed in passenger cars per lane per hour (pcphpl).

Concentration: The number of vehicles present in unit length of the facility expressed in passenger cars per mile per lane (pcpmpl). Concentrations are calculated in the Speed-Flow sheet.

Speed: The speed of the vehicles on General Purpose lanes and Managed lanes expressed in miles per hour (mph). Speeds are calculated in the Speed-Flow sheet.

Time: The time taken by the vehicles to cover the Travel Distance on General Purpose lanes and Managed lanes in minutes.

1.3 Price Elasticity Sheet

The Price Elasticity sheet (Figure 3) provides the model for the price a commuter is willing to pay for different levels of time savings realized by travelling on Managed lanes.

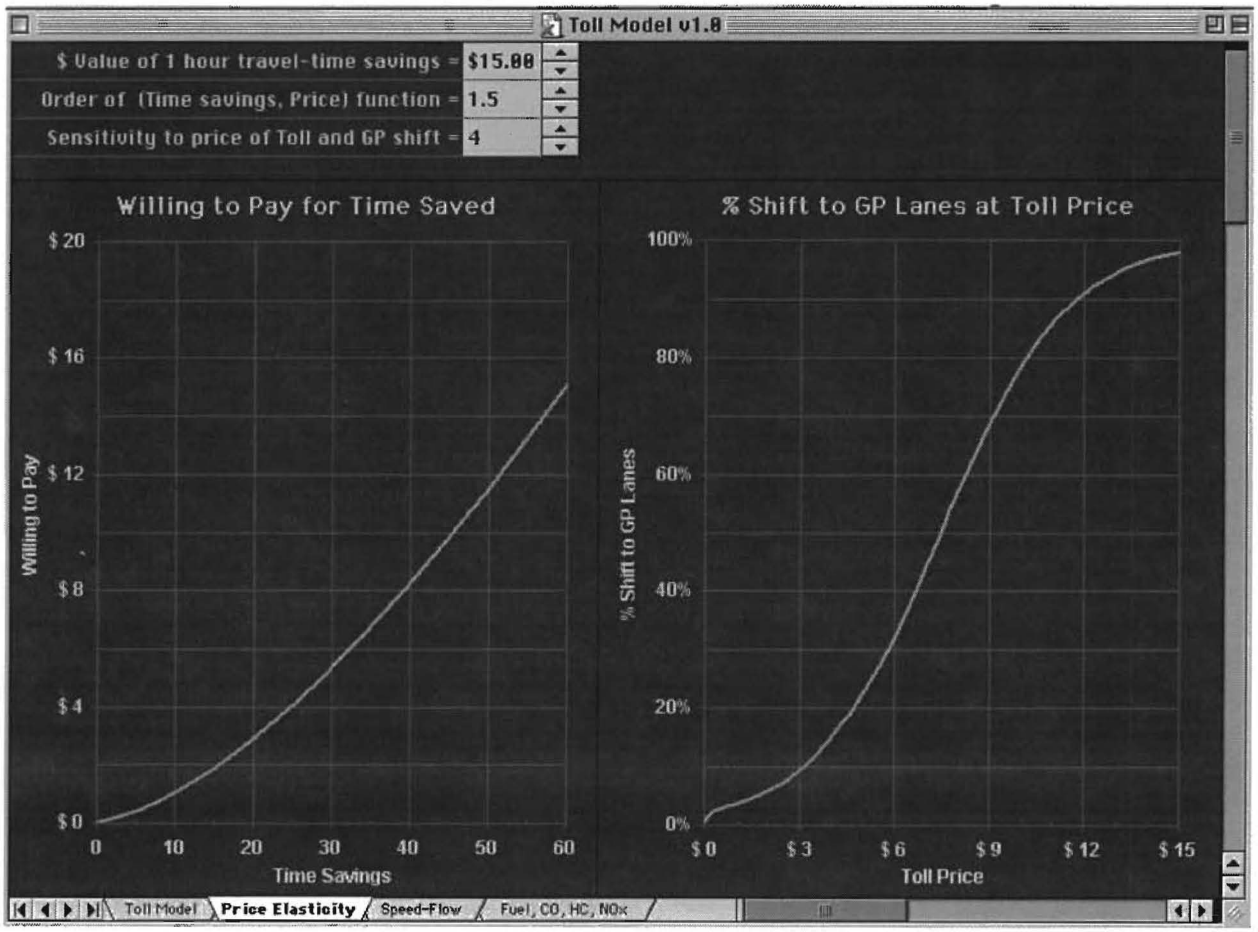

Figure 3

1.3.1 Input Variables

$ Value of 1 hour Travel-Time Savings: The price a commuter is willing to pay to get 1 hour of travel-time savings. Previous research suggests that the value of this variable is about 40% of the hourly wage of the commuter. This value is the maximum value used to render the plot Willing to Pay for Time Saved. Range of permissible values = {2.00, 20.00} $

Order of (Time Savings, Price) Function: This variable is order of the polynomial curve used to represent the Willingness to Pay (price) as a function of the Travel-Time Savings. A value of 1.0 makes the plot in Willing to Pay for

Time Saved a linear plot. In the absence of pertinent local data, a value of 2.0 is recommended. Range of permissible values = {1.0, 3.0}

Sensitivity to Price of Toll and GP Shift: The value of this variable will define the sensitivity of users to price – i.e., the % of users who shift to free lanes even at the smallest price increase. The % Shift to General Purpose lanes is represented here as a logistic function of the Toll Price. I.e., At a given level of Tool Price, a certain percentage of users will shift to traveling on the General Purpose lanes rather than travel on the tolled Managed lane. This behavior is modeled as a logistic 'S'-shaped curve. In the absence of pertinent local data, a value between 3 and 7 is recommended. Range of permissible values = {1, 10}

1.3.2 Calibration

Calibration of this model has been made as simple as possible without loosing any of the complexities which makes it a powerful tool. Only 3 input variables are required. The variable $ Value of 1 hour Travel-Time Savings is the price a commuter is willing to pay to get 1 hour of travel-time savings. While a baseline price can be established by local surveys, there is ample evidence to suggest that this price is under-reported by consumers. The best way to establish the price points for transportation behavior along a certain corridor is to alter toll prices and monitor and analyze the behavior of "transportation consumers".

The variable **Order of (Time Savings, Price) Function** can be established by fitting a power function to the price of travel time savings discussed above. Data for most localities would likely be best fit with the power (order) in the range of 1.5 to 2.0 If "T" is the Time Savings, "P" the Price, and "F" the Order (power) of Function, the relationship is given by $P = T^F$

The variable **Sensitivity to Price of Toll and GP Shift** does not require much calibration since it is derived from a logistic function. Using a logistic curve simplifies the calibration process because the midpoint has already been fixed by the price of 1 hour of travel time savings. Since the logistic curve is symmetric about its midpoint, the only calibration required is to match consumer behavior at the extremes of the scale. A value close to 1 should be used if the transportation consumer has a low sensitivity to price at the two extremes of the scale, and a high sensitivity to price in the mid-range. A value close to 10 should be used if the sensitivity to price is practically linear over the entire price range. If local consumer data is not available, a value close to 5 is most likely a good input value.

1.4 Speed Flow Sheet

The speed-flow relationships for both General Purpose and Managed lanes (Figure 4) is formulated using Greenburg's Model that relates speed (u) to concentration (k) by:

$$u = u(q \max) \ln \frac{k_{jam}}{k}$$

where:

u = speed

k = concentration

k(jam) = Jam concentration

u(q max) = speed at maximum flow rate

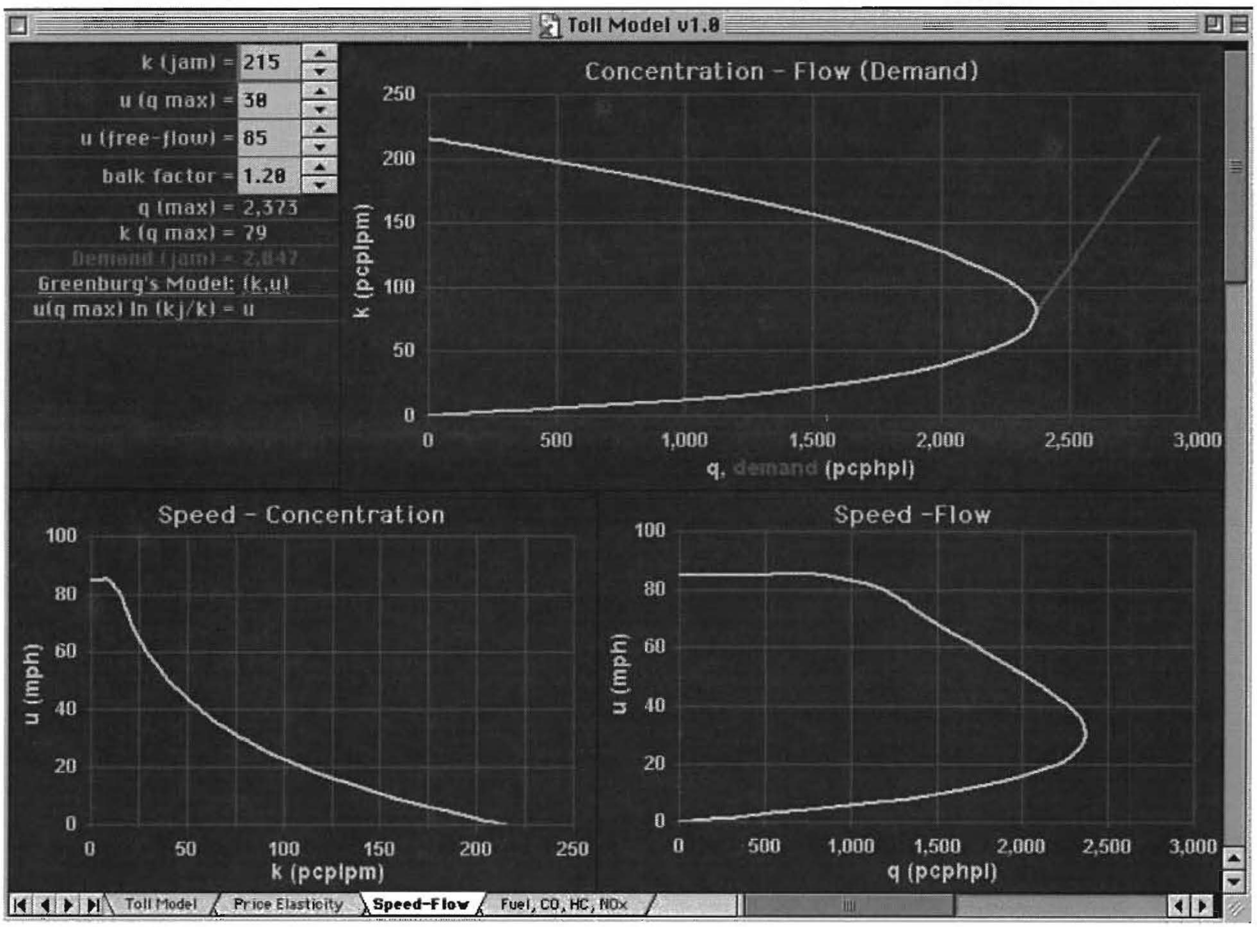

Figure 4

1.4.1 Input Variables

k (jam): The jam concentration for the General Purpose and Managed lanes, expressed as passenger cars/lane/mile. Required for Greenburg's Model.

In the absence of local data, a value of 220 pcplpm is recommended. Range of permissible values = {200, 240} pcplpm

u (q max): The speed at which maximum flow rate occurs. Required for Greenburg's Model. In the absence of local data, a value of 30 mph is recommended. Range of permissible values = {20, 50} mph

u (free flow): The free flow speed of the lanes. Although this variable is not required for the standard formulation of Greenburg's equation, it is used to prevent the speed function from exponentiation at low concentration values. It acts as the maximum Speed value and represents the 'Y' intercept on the Speed-Concentration plot. In the absence of pertinent local data, it is recommended that the value of this variable be set at 75 mph. Range of permissible values = {55, 85} mph

Balk Factor: This factor when multiplied by the demand at capacity (q max) will give the level of demand which would result in jam concentrations. The use of this variable is required to calculate the flow and concentration on a lane when the demand for the lane exceeds its capacity. For example, if the demand for a lane is xx% greater than its capacity, what would be the resulting flow and concentration? Since the Highway Capacity Manual does not address this type of question, the Balk Factor (BF) is utilized to calculate flow and concentration for values of demand greater than capacity. The concentration is assumed to vary linearly with demand between the points ({q max}, k{q max}) and ({BF * q max}, k{jam}). A lower Balk Factor would result in the jam concentration being reached fairly quickly once the demand exceeded capacity. A higher Balk Factor would require higher values of demand (in excess of capacity) to reach jam concentration. In the absence of pertinent local data, a value of 1.20 is recommended. Range of permissible values = {1.1, 1.5}

1.4.2 Interpreting the Plots:

The Greenburg Model is plotted as the Speed–Concentration curve. The functional relation:

$$q = k\,u$$

is used for the other 2 (Speed–Flow, and Concentration–Flow) plots. When recommended values (provided above) are used for the variables on this sheet, the Speed-Concentration-Flow functions provide values that are similar to those recommended by the Highway Capacity Manual. The balk factor is a multiplier which determines the demand level at which commuters balk at joining a queue. This can likely happen when there is jam concentration. This relationship is represented by the pink line in the Concentration–Flow curve, and is used to determine the concentration (and flow) when demand exceeds capacity.

This Speed-Flow sheet is used to calculate the flow, concentration, speed and travel time on the General Purpose lanes and Managed lanes. These values are displayed in the Toll Model sheet as separate bar charts for each of the 2 types of lanes.

1.4.3 Calibration

For TEM-1 to accurately predict transportation consumer behavior, the Greenburg Model needs to be properly calibrated to better reflect local driving habits (e.g., speed-headway distribution) and driving conditions (e.g., highway geometrics). It is strongly recommended that local data for speed-concentration-flow be collected and analyzed, and the Greenburg Model inputs k(jam), u(q max), and u(free flow) modified to reflect driver behavior along the study corridor.

1.5 Fuel, CO, HC, NOx Sheet

The last sheet, Fuel, CO, HC, NOx, does not require any inputs from the user, and is simply provided for informational purposes. As mentioned earlier, this is a plot of the EPA model for the rate of consumption of Fuel, and the rate of emissions of CO, HC, and NOx at different speeds. This is used to calculate the nondimensional Emissions Index shown in the Toll Model sheet (Figure 5).

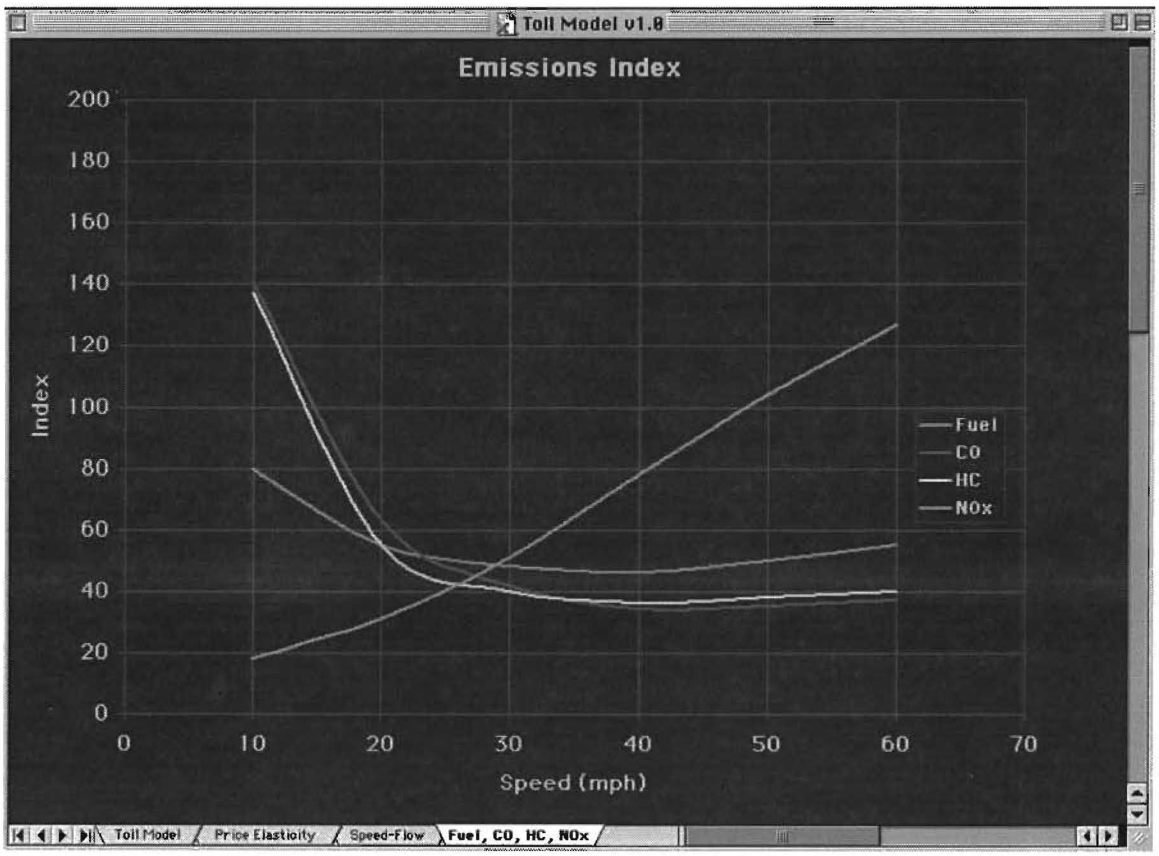

Figure 5

CHAPTER II

2.1 Optimal Pricing Strategies

A few examples of how to use the TEM-1 application to optimize different objective functions are presented here. The examples cover optimization of the toll price for the following objectives:

- Determine Toll Price to ensure that speed on Managed lanes does not drop below a given minimum speed.
- Determine Toll Price to ensure that speed on General Purpose lanes does not drop below a given minimum speed.
- Determine Toll Price to ensure flow on General Purpose lane is maximized.
- Determine Toll Price to ensure flow rate on Managed lanes is at or below x% of capacity
- Determine a Toll Price to maximize revenue.

2.2 Corridor Scenarios and Objective Functions for Speed

A 10 mile long corridor is served by 4 General Purpose lanes and 2 Managed HOV/T lanes. The peak hour directional volume is 12,500 passenger cars with 1% HOV 3, 5% HOV 2, and 94% SOV. Consumer behavior studies have determined that the commuters in this corridor put a value of $ 12.00 for 1 hour of travel-time savings, and the Time Savings vs. Price Willing to Pay function is best modeled using an order (power) of 1.8. No calibrations are available for the sensitivity to price of Toll and %General Purpose shift, and this is assumed to be 5. Traffic flow studies have determined that the Speed-Concentration-Flow functions best represent local driving conditions when k(jam) = 220 pcplpm, and u(q max) =30 mph, and u(free flow) = 75 mph. No balk factor data is available for this community and a value of 1.2 is assumed. Enter the following variable values in the various sheets:

Speed Flow sheet:

k (jam) = 220 pcplpm
u (q max) = 30 mph
u (free flow) = 75 mph
Balk Factor = 1.2

Price Elasticity sheet:

$ Value of 1 hour Travel-Time Savings = $12.00
Order of (Time Savings, Price) Function = 1.8
Sensitivity to Price of Toll and GP Shift = 5

Toll Model Sheet:

Number of General Purpose lanes = 4

Number of Managed Lanes = 2

Travel Distance = 10 miles

Passenger Cars / hour = 12,500 pc

% HOV 3 = 1%

% HOV 2 = 5%

2.2.1 Objective Function Example 1

Determine Toll Price to ensure that speed on Managed lanes does not drop below a given minimum speed of 60 mph. A pricing strategy is required to ensure that the speed of vehicles on the Managed lanes is at or above 60 mph.

Solution:

Start with a value of Toll Price for SOV = $0.00 This implies that there are no tolls, and all lanes are free access lanes. The total volume of vehicles is distributed uniformly over all possible lanes (flow = 2083 pcphpl). The speed of traffic flow on all lanes is calculated to be 50 mph.

When Toll Price for SOVs on the Managed lanes is raised to $1.00, all HOVs (including those previously on General Purpose lanes) shift to Managed lanes. However, many more SOVs (from among those previously on Managed lanes) shift to General Purpose lanes. This leads to 2001 pcphpl on the Managed lanes, and 2124 pcphpl on the General Purpose lanes. As a result, the speed on Managed lanes has increased to 53 mph, while the speed on the General Purpose lane has dropped to 48 mph.

When the Toll Price is raised to $2.00, more SOVs from Managed lanes shift to General Purpose lanes - the speed on the former is now 55 mph and the latter is 47 mph. At a Toll Price of $3.00, the speed on Managed lanes is 58 mph and General Purpose lanes has reduced to 45 mph. At $3.30 the speed on Managed lanes is 60 mph, and General Purpose lanes has dropped to 44 mph. So $3.30 is the minimum price which will ensure a speed of at least 60 mph on the Managed lanes.

Now we should also establish the maximum price that can be charged without creating delays on the General Purpose lanes. Delays are created when the demand is greater than the capacity of the facility. This could happen if the Toll Price is so high that many SOVs shift to the General Purpose lane, thereby creating a demand greater than its capacity. At a Toll Price of $6.00, we find that the Delay variable has a value of 707 pcph (i.e., the total demand for the General Purpose lanes exceeds its total capacity by

707 passenger cars per hour). By reducing the Toll Price to $5.30, we can bring the Delay variable to 0.

This example has established that a Toll Price between $3.30 and $5.30 should be considered for meeting the desired minimum speed of 60 mph on Managed lanes. If the Toll Price is below $3.30, the speed on Managed lanes would be below 60 mph. If the Toll Price is above $5.30, the demand for General Purpose lanes would exceed its capacity and introduce delays. Any price within this range this range could be implemented.

Further decisions for establishing a more exact Toll Price may be made by either considering the Revenue variable or comparing the environmental impacts (CO, HC, and NOx Index) for different Toll Prices within the $3.30 to $5.30 range. For example, within this given range, we find that for a Toll Price of $4.90, the Revenue variable is maximized at $ 11,025 per hour. This results in Managed lane speed = 70 mph, and General Purpose lane speed = 37 mph , with Delay = 0. In addition to meeting the speed objective for Managed lanes, a Toll Price = $4.90 maximizes revenues and does not introduce delays on the General Purpose lanes.

2.2.2 Objective Function Example 2

Determine toll price to ensure that speed on General Purpose lanes does not drop below a 45 mph minimum speed. A pricing strategy is required to ensure that the speed of vehicles on the General Purpose lanes is at least 45 mph.

Solution:

The initial discussions from the previous example is also valid here. Start with a value of Toll Price for SOV = $0.00 The speed of traffic flow on all lanes is 50 mph. At $1.00, the speed on General Purpose lanes is 48 mph, at $2.00 it is 47 mph, and at $3.00 it is 45 mph. Therefore a Toll Price between $0.00 and $3.00 will meet the objective of 45 mph or higher speed on the General Purpose lanes. Within this range ($0.00 to $3.00), $3.00 is also the Toll Price at which Revenue is maximized ($8,785 per hour).

2.3 Corridor Scenarios and Objective Functions for Flow

A 15 mile long corridor is served by 3 General Purpose lanes and 1 Managed HOV/T lane. The peak hour directional volume is 7,500 passenger cars with 1% HOV 3, 3% HOV 2, and 96% SOV. Consumer behavior studies have determined that the commuters in this corridor put a value of $ 16.00 for 1 hour of travel-time savings, and the Time Savings vs. Price Willing to Pay function is best modeled using an order (power) of 1.7. No calibrations are available for the sensitivity to price of Toll and

%General Purpose shift, and this is assumed to be 5. Traffic flow studies have determined that the Speed-Concentration-Flow functions are best represent local driving conditions when k(jam) = 210 pcplpm, and u(q max) =31 mph, and u(free flow) = 75 mph. No balk factor data is available for this community and a value of 1.2 is assumed. Enter the following variable values in the various sheets:

Speed Flow sheet:

k (jam) = 210 pcplpm
u (q max) = 31 mph
u (free flow) = 75 mph
Balk Factor = 1.2

Price Elasticity sheet:

$ Value of 1 hour Travel-Time Savings = $16.00
Order of (Time Savings, Price) Function = 1.7
Sensitivity to Price of Toll and GP Shift = 5

Toll Model sheet:

Number of General Purpose lanes = 3
Number of Managed Lanes = 1
Travel Distance = 15 miles
Passenger Cars / hour = 9,000 pc
% HOV 3 = 1%
% HOV 2 = 3%

2.3.1 Objective Function Example 3

Determine Toll Price to ensure the flow on General Purpose lane flow is maximized. A pricing strategy is required to ensure that the demand for vehicles on General Purpose lanes is close to (but less than) 2395 pcphpl {= q (max), the capacity}.

Solution:

Start with a value of Toll Price for SOV = $0.00 This implies that there are no tolls and all lanes are free access lanes. The total volume of vehicles is distributed uniformly over all possible lanes. The traffic flow on all lanes is calculated to be 2250 pcphpl.

When Toll Price for SOVs on the Managed HOV/T lane is raised to $1.00, the demand for the Managed lane has decreased to 2171 pcphpl, while the demand for General Purpose lanes has increased to 2276 pcphpl. As we continue to increase the Toll Price to ($2, $3, $4), we observe the flow on General Purpose lanes to slowly increase towards the theoretical capacity of 2395 pcphpl. At a Toll Price of $5.00, the demand for

General purpose lanes is 2382 pcphpl (still below capacity, i.e., zero Delay), while at \$6.00, the demand is 2433 pcphpl (now above capacity, with a Delay of 177 pcph). The desired Toll Price is between \$5.00 and \$6.00

At a Toll Price of \$5.30, the demand for General Purpose lanes is 2395 pcphpl, which equal to its capacity of 2395 pcphpl. If the Toll Price is higher than \$5.30, demand for General Purpose lanes becomes more than its capacity, introducing some Delays. Hence a Toll Price between \$5.00 and \$5.30 will ensure a maximum flow rate on the General Purpose lanes. At the Toll Price of \$5.30, the speed on the Managed lane is 60 mph, and the speed on the General Purpose lanes is 31 mph.

2.3.2 Objective Function Example 4

Determine toll price to ensure flow rate on Managed lanes is at or below 85% of capacity: A pricing strategy is required to ensure that the flow on Managed lanes is less than 2036 pcphpl (= 0.85 capacity).

Solution:

A value of Toll Price for SOV = \$3.40 results in a flow of 2036 pcphpl on the Managed lane. When the Toll Price is greater than \$5.25, Delays are introduced in the General Purpose lanes. Hence a Toll Price greater than \$3.40 but less than \$5.30 will fulfill the given criterion.

2.4 Corridor Scenarios and Objective Function for Revenue

A 5 mile long corridor is served by 2 General Purpose lanes and 2 HOV/T lanes. The peak hour directional volume is 7,500 passenger cars with 5% HOV 3, 10% HOV 2, and 85% SOV. Consumer behavior studies have determined that the commuters in this corridor put a value of \$ 6.00 for 1 hour of travel-time savings, and the Time Savings vs. Price Willing to Pay function is best modeled using an order (power) of 1.5. No calibrations are available for the sensitivity to price of Toll and %General Purpose shift, and this is assumed to be 5. Traffic flow studies have determined that the Speed-Concentration-Flow functions are best represent local driving conditions when k(jam) = 220 pcplpm, and u(q max) =30 mph, and u(free flow) = 70 mph. No balk factor data is available for this community and a value of 1.2 is assumed. Enter the following variable values in the various sheets:

Speed Flow sheet:

k (jam) = 220 pcplpm

u (q max) = 30 mph

u (free flow) = 70 mph

Balk Factor = 1.2

Price Elasticity sheet:

$ Value of 1 hour Travel-Time Savings = $6.00

Order of (Time Savings, Price) Function = 1.5

Sensitivity to Price of Toll and GP Shift = 5

Toll Model sheet:

Number of General Purpose lanes = 2

Number of Managed Lanes = 2

Travel Distance = 5 miles

Passenger Cars / hour = 7,500 pc

% HOV 3 = 5%

% HOV 2 = 10%

2.4.1 Objective Function Example 5

Determine a Toll Price to Maximize revenue: A pricing strategy is required to ensure Revenue is maximized from the toll for SOVs in Managed lanes without causing delays.

Solution:

When the Toll Price is set to a value greater than $2.70, it results in Delays on the General Purpose lanes. Therefore, the Toll Price has to be equal to or less than $2.70. Checking different values less than $2.70, we find that if the Toll Price for SOV is set to $2.45, the Revenues are maximized at $4,235 per hour. Revenues decrease both above and below this price. Therefore, a Toll Price of $2.45 would be recommended to maximize revenue.