Alternative Tolling Schemes for the San Jose Lagoon Bridge

by

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B.S., Civil Engineering
University of California at Berkeley, 1990

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Abstract

The San Jose Lagoon Bridge in Puerto Rico is the first privatized toll facility built in the United States in over 40 years and will serve as a model for future privatization projects. This thesis explores the effects of different tolling schemes on revenues and users of the San Jose Lagoon Bridge. A model is constructed using the best available data for the bridge and the San Juan area. This model is then used to predict demand on the bridge under four different tolling schemes. The first tolling scheme is a flat-rate toll charged throughout the day, the second scheme has different peak and off-peak tolls, the third scheme has different toll rates for the a.m. peak, interpeak, p.m. peak, and off-peak periods, while the fourth scheme changes toll every hour. The results of the study show that if revenue maximization is the goal, then a lower flat-rate toll could be charged. If rate of return regulation for the private firm and optimal use by the public are the goals, then a much lower toll rate is found to be appropriate. A model for congestion management purposes is also developed as well as a model that uses price discrimination to differentiate between different trip purposes. The results of the analysis show that significant increases in revenue can be achieved using price discrimination.

Thesis Supervisor: Professor David H. Bernstein
Title: Assistant Professor of Civil and Environmental Engineering
Thanks To:

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Chapter 1

Introduction

Budgetary constraints and tax revolts have put a strain on government resources to construct and maintain the transportation infrastructure necessary to sustain mobility in the United States. Consequently, the interest in the use of private capital to construct transportation improvements has increased dramatically in recent years. The passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991 has addressed this growing interest by authorizing use of federal highway funds to construct privatized facilities.

The innovative use of private capital to finance public works projects has raised many interesting questions. How should private firms be regulated by the government to insure that excessive profits aren't being made? Who benefits and who pays when a private toll facility is built? The future of privatized toll roads in the United States is uncertain at this time. The projects currently being developed have encountered many obstacles and will serve as prototypes by which the merits of privatization can be measured. However, they must be evaluated as prototypes, taking into account factors unique to the first-time, experimental nature of prototype projects in general.
Puerto Rico has taken a lead role in using privatization to finance transportation improvements. The demand for transportation in Puerto Rico coupled with a lack of funds available to construct improvements has forced the government to use privatization to finance their projects. The first such privatized project in Puerto Rico is the San Jose Lagoon Bridge. This is the only privately owned and operated facility built in the post-Interstate era in the United States. The lessons learned from the experiences of the San Jose Lagoon Bridge will help projects in the future address issues unique to privatized projects.

This chapter motivates the research through a discussion of demand for transportation in Puerto Rico as well as a discussion of the lack of available funds to construct improvements. Then, a brief description of the bridge project is given and the main research objectives are outlined. The chapter concludes by laying out the structure of the remainder of the thesis.

1.1 Demand for Transportation in Puerto Rico

The growth in Puerto Rico's economy and population has created a need for an efficient transportation network to serve its business and citizens. Puerto Rico's economy has been growing at a fast pace and has raised the standard of living of its people. This growth in the economy has resulted in an increase in demand for transportation not only by business but by the citizens as well. Population growth has been accompanied by an increase in auto ownership which has further strained the transportation network of Puerto Rico.
1.1.1 Economic Development

The future of Puerto Rico's economic growth depends largely on the investment in transportation that it makes today. The Puerto Rico Highway and Transportation Authority (PRHTA) has been aggressively pursuing expansion of its transportation infrastructure to keep up with the increased demand that the growing economy is placing on existing facilities. Since 1980, the gross product has more than doubled from $11 billion to over $23.6 billion. Although this growth has leveled off recently, the overall trend remains up as shown in Figure 1.1.

Figure 1.1: Gross Product of Puerto Rico

![Gross Product of Puerto Rico](image)

Source: Statistical Abstract [1993]

Much of Puerto Rico's economic growth can be attributed to the growth in the manufacturing sector of the economy. In 1992, the manufacturing sector accounted for over 55% of the gross domestic product. According to a Department of Labor and Human Resources household survey, the manufacturing sector employed 155,000 workers, or 16.8% of total employment in fiscal 1991 (Bond Prospectus [1992]). The
main recipient of manufactured goods is the mainland United States. Many mainland companies have located manufacturing plants in Puerto Rico since the average hourly manufacturing wage in Puerto Rico is only approximately 53% of the average mainland United States rate (Bond Prospectus [1992]). Some of the largest employers include General Electric, Johnson and Johnson, and Westinghouse Electric. Puerto Rico’s manufacturing gross product has increased by 78% since 1984 (as shown in Figure 1.2) while the total gross product has increased by only 67% over the same period.

Figure 1.2: Manufacturing Gross Product

![Pie Chart]

Source: Statistical Abstract [1993]

In addition to manufacturing, a growing sector of the economy is the tourism industry. In 1991, tourism accounted for 6.3% of the island’s gross product with tourist expenditures reaching $1.4 billion, an increase of 51% over 1987 expenditures. In fact, the total number of visitors reached 3,517,425 in 1991, a figure almost equivalent to the entire population of Puerto Rico (Bond Prospectus [1992]).
1.1.2 Population and Auto Ownership Growth

According to the U.S. Bureau of the Census, the population of Puerto Rico in 1990 was 3,522,000, representing a 9.9% increase over 1980 levels. Over the same period, the number of vehicle registrations skyrocketed by 56.9% to 1,321,627 (Highway Statistics [1980,1990]). The huge increase in vehicle registrations may be due to the rise in average compensation which increased from $9,563 in 1980 to $15,351 in 1990 in nominal dollars, a 60.5% increase. In addition, the unemployment rate showed a modest decline from 17.0% in 1980 to 14.2% in 1990. However, by 1992, this figure increased to 16.5% (Statistical Abstract [1993]).

The growth in vehicle ownership has consequently led to an increase in number of vehicle miles traveled (VMT) as shown in Figure 1.3.

Figure 1.3: Vehicle Miles Traveled

1.2 Coping with Demand in Puerto Rico

An analysis of various key statistics published in the Federal Highway Administration's publication *Highway Statistics* provides a good insight into how the PRHTA is dealing with the demands that the economy and population is placing on the transportation infrastructure. In order to accommodate increased demand, the PRHTA has steadily increased the amount of highway mileage available as shown in Figure 1.4.

![Figure 1.4: Total Highway Mileage](image)


The increase in highway mileage did not come without expense, however. Over the same period, capital outlay has increased dramatically as shown in Figure 1.5.

The large increase in capital outlay was offset somewhat by an increase in total receipts (as shown in Figure 1.6), partially due to revenue from user fees such as gas taxes. A majority of the increase in total receipts, however, is due to an increase in the number of bonds issued by the PRHTA.
Figure 1.5: Capital Outlays


Figure 1.6: Total Receipts


That portion of total receipts from federal funding has remained relatively stable over this period due to apportionment based on formulas. The Fiscal Year 1993 apportionment is expected to be $88.47 million. However, this apportionment is
decreased by $6.5 million because of the minimum drinking age penalty resulting in a net allocation of $81.98 million (Parker [1992a]). The Minimum Drinking Age Penalty is 10% of the apportionment provided under the Surface Transportation Program, the National Highway System, and the Interstate Maintenance Program. Total federal funding for Puerto Rico is shown in Figure 1.7.

Figure 1.7: Total Federal Funding

![Bar graph showing total federal funding from 1980 to 1992.]


As mentioned earlier, since federal funds have remained relatively constant over this period, the PRHTA has issued bonds to supplement their income to construct transportation improvements (see Figure 1.8). Between 1980 and 1991, the PRHTA had issued bonds in relatively modest amounts.

However, in 1992, an unprecedented $612 million worth of bonds were issued by the PRHTA. This may have been a good move by the PRHTA due to a favorable interest rate environment but the issue also places great pressure on the PRHTA to keep up with debt service payments and maintain an adequate debt coverage ratio.
Puerto Rico's aggressive issuance of debt has resulted in over a billion dollars in bonds outstanding as shown in Figure 1.9.

Figure 1.8: Proceeds From Bonds


Figure 1.9: Bonds Outstanding

The interest payments on these bonds must be made and an adequate debt service coverage ratio must be maintained in order to retain a favorable credit rating. These ratings will be used to grade bonds issued in the future and a favorable credit rating would result in lower interest payments for future bond issues. Therefore, the PRHTA has looked to the use of private capital to further develop its transportation network without placing an additional strain on its own finances.

1.3 The San Jose Lagoon Bridge Project

The demands placed on Puerto Rico's transportation infrastructure has far exceeded the resources available to accommodate the needs of its economy and its people. Consequently, the government has looked at alternative ways to finance transportation improvements. One method being implemented is privatization. The government has currently authorized the privatization of two new facilities, the San Jose Lagoon Toll Bridge and the PR 66 Toll Road. Privatization of highways has gained greater exposure in recent years and the lessons learned from these facilities will help ease the implementation of future privatization projects.

The San Jose Lagoon Bridge project is the first of two highway projects identified by the Puerto Rico Highway and Transportation Authority for development through privatization. The second project, the PR 66 Toll Road, will connect San Juan with Fajardo and will begin construction after the San Jose Lagoon Bridge. The bridge is approximately 2.1 miles long and connects Luis Munoz Marin International Airport near PR 26 with the Municipality of Carolina to the south near PR 181. The bridge has two lanes in each direction and has a toll plaza with 10 toll booths at the south end.

On March 27, 1992, the Concession Agreement was signed by Autopistas de Puerto Rico (APR), a consortium consisting of Dragados y Construcciones (the largest construction conglomerate in Spain), Rexach Construction Company (the largest general
contractor in the Commonwealth), and Supra and Company (a special partnership). Under the terms of the Concession Agreement, APR will operate the toll road under the Build Transfer Operate (BTO) scheme for 35 years until the year 2026. The BTO scheme transfers liability from APR to the PRHTA during operation of the bridge. However, APR is still liable for any events that occur during construction.

1.3.1 Financing

While the San Jose Lagoon Bridge is touted as a privatization project, the government still plays a vital role not only in regulation, but also in financing the $126 million project. Before 1986, states were able to issue government-backed debt and loan the proceeds to private developers. However, the law permitting this type of financing was repealed as part of the 1986 Tax Reform Act, except in Puerto Rico. The Commonwealth of Puerto Rico is unlike states in that it is a separate tax jurisdiction and can issue tax-free government-backed revenue bonds for private projects. These bonds carry a significantly lower interest rate than bonds issued by corporations because they are tax-free and guaranteed by the PRHTA. The PRHTA issued $117 million worth of special facility revenue bonds in 1992 and lent the proceeds to APR. APR financed the remaining $9.4 million and agreed to a guaranteed maximum price of $83 million for constructing the bridge. This price is based on an overhead and profit fee equal to 14.42% of the aggregate construction costs. In order to make the bonds more palatable to investors, as part of the Concession Agreement, it is the PRHTA's responsibility to secure all rights-of-way and obtain the necessary permits to complete the project.
1.3.2 Termination Option

A unique provision in the Concession Agreement gives APR the right to terminate the contract if traffic levels do not meet certain criteria. If any of the following occur on a cumulative basis for six month periods, APR may be released from its obligation to operate the toll road and transfer ownership of the bridge to the PRHTA:

- during the first 3 years of operation, traffic levels are less than 80% of forecast;
- during the fourth through sixth years, traffic levels are less than 85% of forecast;
- during the seventh and eight years, traffic levels are less than 90% of forecast; or
- during the ninth year until termination, traffic levels are less than 100% of forecast.

Furthermore, if the contract is terminated, the PRHTA will have to pay APR a rate of return of 12.5% on any capital contributed up to that point for the development, design, construction and operation of the bridge.

1.3.3 Traffic Studies

In order for APR to receive financing for the project, Vollmer Associates was hired to perform a traffic analysis to determine whether or not toll revenues would cover debt payments. In addition, as part of the San Juan Regional Transportation Plan study, Barton Aschman Associates performed a traffic study that included the San Jose Lagoon Bridge. Table 1.1 summarizes the results of both studies for the year 2010.
Table 1.1: Forecasted Traffic in 2010 for the San Jose Lagoon Bridge

<table>
<thead>
<tr>
<th>Study Author</th>
<th>Forecasted Bridge Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vollmer Associates (VA)</td>
<td>29,300</td>
</tr>
<tr>
<td>Barton Aschman (BAA)</td>
<td>45,900</td>
</tr>
</tbody>
</table>

Sources: Bond Prospectus (1992) and San Juan Regional Transportation Plan (1993)

The two estimates differ significantly from one another due to the different methodologies used to derive their estimates. Vollmer Associates based their figure on travel time and distance savings while BAA used a complex trip generation model for the entire San Juan Region to achieve their estimate. Both studies took into account the toll in each direction for passenger cars and the availability of alternate free routes. However, for passenger cars, Vollmer Associates used a toll rate of $2.80 while BAA used a toll rate of only $1.50. Debt service is projected to be $18.24 million in 2010 dollars while projected revenues are expected to be $29.3 million using the Vollmer forecast and $25.1 million using the BAA forecast. Even with the more conservative estimate, traffic is estimated to be sufficient to cover debt payments and provide a profit for the private firm.

However, if traffic levels do not meet the criteria outlined under the termination option, a tremendous burden will be placed on the PRHTA to not only pay APR, but also keep up with debt service payments which range from a low of $7.4 million in early years to a high of $21.5 million in the year 2013 (Bond Prospectus [1992]). The PRHTA has many other projects to manage including the Tren Urbano rail project and must be prepared financially to deal with this prospect of termination. If a need for funds arises, then methods outlined in the next chapter could be used to raise revenues.
In addition, the bridge itself may be a source of revenues. The focus of the fourth chapter is determining the effects of alternative tolling schemes on the San Jose Lagoon Bridge on both traffic and revenues.

1.4 Thesis Objectives and Outline

Puerto Rico faces many challenges in the future regarding financing its transportation improvements. There are two main objectives of this research:

1) To assess various methods that can be used to finance Puerto Rico's transportation improvements.

2) To look at alternative tolling schemes for the San Jose Lagoon Bridge and their effects on both revenues and the users.

Chapter 2 examines several methods currently being used to raise revenues as well as other financing strategies. First, conventional methods are discussed and the applicability to Puerto Rico is addressed. Then, congestion pricing is discussed as a method of not only raising revenues, but managing congestion as well. The use of road pricing allows the development of privatization and the following section examines the various obstacles, advantages, and disadvantages of privatization. The final section summarizes the various financing policies discussed in the chapter.

Chapter 3 outlines the development of the model that will be used to determine the effects of different toll rates on the San Jose Lagoon Bridge. Various previous studies were used to develop the model. First, calculations from Vollmer Associates are presented and used to construct a basic demand model for the area. Then, data from Barton Aschman Associates are used to disaggregate demand into distinct market
segments with unique travel trip-times. The next section discusses the price sensitivities of these different market segments and how they react to changes in tolls.

Chapter 4 presents the results from the model. The effects of different scenarios on both revenue and users are discussed and summarized. First the objective of revenue maximization is examined. The second objective is to maximize use by the public using a rate of return constraint. Then, the possible use of congestion pricing is addressed. The fourth section examines price discrimination as a way of maximizing revenues and discusses possible implementation strategies. Conclusions and recommendations are then discussed in Chapter 5.
Chapter 2

The Economics and Politics of Highway Projects

The significant capital investment required to build highways is always an issue of political debate when considering a new project. The methods used to raise revenues to pay for transportation improvements must be analyzed both from a financial and political perspective. These matters can be addressed by answering the questions; how much revenue will this measure raise and who will be affected? In addition, the effects of the new project on the environment and the economy are also key points that must be addressed before a project is approved.

This chapter first identifies various methods that can be used to raise revenues and their political implications. Then, the effects of congestion are discussed and the use of congestion pricing is examined as a possible solution. The third section discusses public/private partnerships as a way of leveraging public funds to finance transportation improvements. A comprehensive assessment of privatization efforts is discussed in this section including a summary of the relative advantages and disadvantages of privatization. Finally, the fourth section sums up the arguments for and against each method.
2.1 Financing Highway Projects

There are a variety of methods that governments can use to raise revenues, each having different effects. These methods may be used individually or in combination depending on how much revenue is needed and the possible effects of each policy. Some of the most common policies include:

- raising fuel taxes
- raising vehicle registration fees
- raising parking fees
- tolling facilities
- public/private partnerships

A breakdown of current (1992) revenue sources gives a good indication of what policies the PRHTA might want to pursue in the event of a revenue short-fall. The sources of revenue are summarized in Table 2.1.

Table 2.1: Revenue Sources for the PRHTA

<table>
<thead>
<tr>
<th>Revenue Source</th>
<th>% of Total Receipts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor Fuel Taxes</td>
<td>35.62%</td>
</tr>
<tr>
<td>Motor-Vehicle and Carrier Taxes</td>
<td>15.73%</td>
</tr>
<tr>
<td>Toll Receipts</td>
<td>15.93%</td>
</tr>
<tr>
<td>Federal Funding</td>
<td>17.96%</td>
</tr>
<tr>
<td>Interagency Payments</td>
<td>0.50%</td>
</tr>
<tr>
<td>Miscellaneous Receipts</td>
<td>14.26%</td>
</tr>
</tbody>
</table>

Source: Highway Statistics [1992]
2.1.1 Fuel Taxes

Raising fuel taxes is perhaps the easiest method to increase revenues for transportation purposes. No special facilities are needed to collect the revenues and the revenue stream is fairly constant from year to year. Gasoline taxes are also used widely as a source of revenue because the user is directly charged depending on how much fuel is consumed. However, raising fuel taxes is very controversial politically. Arguments against raising fuel taxes include the effect that it has on a region's economy (ITE [1989]). Fuel is one of the most important resources needed for industrialized areas and an increase in the fuel tax could have an adverse effect on competitiveness with other regions which may result in lost jobs. Legislation is usually required to adopt a gas tax increase and the debate surrounding the advantages and disadvantages may cause significant delay in implementation or defeat in legislation. For example, an issue in the 1992 election for President of the U.S. was the magnitude of raising the fuel tax in the future. Even a small proposed increase caused much political debate even though the U.S. has one of the lowest gas taxes in the world as shown in Table 2.2.

Table 2.2: Gas Taxes in Perspective

<table>
<thead>
<tr>
<th>Country</th>
<th>Tax per Gallon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Italy</td>
<td>$3.56</td>
</tr>
<tr>
<td>France</td>
<td>$2.80</td>
</tr>
<tr>
<td>Germany</td>
<td>$2.59</td>
</tr>
<tr>
<td>Britain</td>
<td>$2.21</td>
</tr>
<tr>
<td>Japan</td>
<td>$1.63</td>
</tr>
<tr>
<td>United States (average)</td>
<td>$0.34</td>
</tr>
</tbody>
</table>

Source: Parker [1992b]
A fuel tax increase may also be warranted just to keep the revenue stream constant because improvements in gasoline mileage may cause a decrease in revenues even with increased vehicle miles traveled (Felgner [1988]).

Gasoline taxes are the most important revenue source for the PRHTA. In 1992, revenues related to motor fuel taxes amounted to $147.6 million and made up 35.6% of its revenues excluding revenue from bond issues (Highway Statistics [1992]). Puerto Rico has not raised its gas tax rate since 1976. The rate of 16 cents per gallon charged by the Commonwealth is less than half the average rate charged by the mainland states (Parker [1992b]). However, to qualify this statement, it must be noted that Puerto Rico's per capita income is much lower than the states'. Gasoline usage in Puerto Rico is rising and in 1992 amounted to 961,755,000 gallons (see Figure 2.1).

Figure 2.1: Total Gasoline Usage in Puerto Rico

<table>
<thead>
<tr>
<th>Year</th>
<th>Gallons (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>700,000</td>
</tr>
<tr>
<td>1981</td>
<td>700,000</td>
</tr>
<tr>
<td>1982</td>
<td>700,000</td>
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<td>1991</td>
<td>700,000</td>
</tr>
<tr>
<td>1992</td>
<td>1,000,000</td>
</tr>
</tbody>
</table>

Source: Highway Statistics [1992]

Gasoline use in Puerto Rico has been increasing steadily over the past decade with a slight decrease in usage in 1991. As noted earlier, fuel is one of the most important inputs for a growing economy and the effects of an increase in the fuel tax could possibly
disrupt business. However, from a broader perspective, if a moderate increase is imposed and used to construct or repair transportation infrastructure, the Commonwealth may ultimately benefit from such an increase.

In order for gasoline tax increases to become politically acceptable, users must be aware of the transportation improvements that will be funded by such measures and the potential benefit they may ultimately have on the individual (ITE [1989]).

2.1.2 Vehicle Registration Fees

Vehicle registration fees can be collected based on either vehicle weight, vehicle class, or miles traveled. An advantage of using vehicle registration fees as a source of revenue is that it is a stable source of income, much like fuel taxes. However, fees do not generate revenues that are proportional to damage inflicted to the road and highway use unless the weight of the vehicle and the mileage driven are taken into consideration. Collecting this type of data can be labor intensive and may increase evasion. The structure of rate increases should be considered carefully, taking into account the goals of the government. For example, the structure of Indonesia's registration fee in 1985 turned out to actually be detrimental to their highway system (Kennedy School of Government [1986]).

The registration fee in Indonesia was based on vehicle price and class of vehicle. Higher rates were charged to passenger cars while lower rates were charged to pickups and trucks. This scheme was first instituted in hopes of promoting use of pickups and trucks in building the economy. However, by 1986, 50-100 small manufacturers were creating passenger vehicles by fitting light pickup chassis with passenger van bodies. Because these vans were based on a pickup chassis, they were classified for tax purposes as trucks and thereby escaped the heavier duties and taxes applied to passenger sedans.
The result was a high growth rate in trucks and buses which consequently increased infrastructure needs by causing more damage to pavements and increasing congestion.

Vehicle registrations have been increasing in Puerto Rico and in 1992, there were 1,595,328 vehicles registered. Table 2.3 breaks down these vehicles by class.

Table 2.3: Vehicle Registrations in Puerto Rico

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Number of vehicles registered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automobiles</td>
<td>1,380,213</td>
</tr>
<tr>
<td>Trucks</td>
<td>212,028</td>
</tr>
<tr>
<td>Buses</td>
<td>3,087</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,595,328</strong></td>
</tr>
</tbody>
</table>

Source: Highway Statistics [1992]

The PRHTA currently receives $15 per vehicle in annual registration fees generating approximately $24 million per year (Parker [1992b]). A $1 increase in vehicle registration fees would increase revenues by approximately $1.6 million assuming no decrease in number of registrations. Growth in the three different classes of vehicles is shown in Figures 2.2, 2.3 and 2.4.

The number of automobile registrations saw a sharp rise in the mid 1980's but has recently leveled off (see Figure 2.2). However, as shown earlier, the number of vehicle miles traveled has actually increased in recent years. This means that automobile use is increasing in terms of vehicle miles traveled per registered vehicle. Truck registrations have also experienced a similar pattern in registration growth as shown in Figure 2.3.
The number of bus registrations, on the other hand, has experienced a sharp increase in recent years as shown in Figure 2.4.
There was a huge jump in bus registrations between 1988 and 1989. Bus and truck registrations should be treated separately from automobile registrations depending on the goals of the government. Trucks are used mainly for business applications while buses are a more efficient means of transporting people than automobiles.

2.1.3 Parking Taxes, Fees, Fines

Growth of the United States economy has resulted in a labor force expansion that has increased the number of workers and the number of work-trip commuters in metropolitan areas. In addition, the growth of the economy has increased the standard of living of individuals which has resulted in an increase in vehicle availability. With a higher standard of living and an increase in vehicle availability, a large portion of the work force has decided to live in suburban areas, away from the hustle and bustle of the big cities. Consequently, demand for parking spaces in central business districts has increased.
With a limited supply available to accommodate demand, parking taxes could be imposed up to the point where demand equals supply, which would result in an increase in parking revenue. The advantages of regulating parking rates is not limited to the potential revenue gained. Regulating parking rates can also indirectly alter driver behavior and control much of the auto use during peak hours. People who have to travel into the city will have four choices:

- make the trip and pay the higher parking rate;
- make the trip at a later time;
- make the trip using another mode (e.g. bus); or
- not make the trip at all.

Higher income individuals are more likely to be able to afford the higher parking rate while lower income individuals are more likely to make the trip using another mode or not at all. Therein lies one of the major disadvantages of using parking rates to either raise revenues or control traffic. Equity concerns are not the only problem related to raising parking rates. Business may also be affected by less traffic in their area and these costs may outweigh the benefits of parking rate increases from a societal perspective. Those whose time is valuable are the first to attempt to buy their goods in less congested suburban centers, while those whose time is least valuable tend to shop in congested areas (Fixler [1987]). This means that business in congested areas would not be able to attract higher income individuals who may be more likely to buy products or acquire services.

The excess demand for parking spaces in San Juan during peak hours may serve as a possible revenue source for the PRHTA. A study completed by Barton Aschman Associates (BAA) in February 1992 found that only 58 % of this demand was being met by available parking spaces during peak hours (Econometrica [1992a]). This suggests that
parking in the area is currently underpriced and there is potential to raise prices to increase revenue.

The Department of Consumer Affairs is responsible for establishing parking rates in Puerto Rico. In order to increase revenue, parking rates could be set at higher levels during peak hours and lower levels during off-peak hours. In addition, all-day parking could be differentiated from short-term parking in order to offset any adverse effects parking regulation might have on local businesses. With more short-term parking available, shopping trips would not be as suppressed and businesses would not be as badly affected. By discouraging all-day parking, commuters would be forced to use public transit or carpool.

Peak period pricing would not only increase revenue, but would ensure optimal use of the facility by the public as well. However, proper regulation would be required to make sure private operators do not receive windfall profits from a parking rate increase.

As with toll rate increases, the effects of parking rate increases are difficult to determine. With the addition of the Tren Urbano rail system, demand may decrease for parking in the central business district or become more elastic and a rate increase may result in under-utilization of parking facilities. On the other hand, increased use of transit may spur more auto use as highways become less congested and demand for parking spaces may remain the same.

2.1.4 Toll Roads

Tolling of roads is the most direct form of charging the user. Vehicles can be charged not only based on the costs that they impose on maintenance of the facility, but also the costs they impose on other vehicles by adding to congestion. A toll schedule can be set up so that vehicles are charged based on size, weight, number of axles, and distance traveled to recoup the costs of the damage that the vehicle inflicts on the road. Similarly,
a toll schedule that changes over the course of the day can be used in an effort to spread
demand more evenly between peak and off-peak hours. Existing facilities would be used
more efficiently and capital improvements could be delayed. A particularly interesting
tolling scheme is the "HOV Buy-in" where a single occupancy vehicle may "buy into" an
existing carpool lane. In addition, other innovative tolling schemes such as head-of-the-
line privileges may be used to raise revenues or alter driver behavior.

2.1.4.1 Traditional Tolling

The use of toll financing enables governments to construct or repair facilities that
otherwise would take longer to finance through conventional tax sources alone
(Wuestefeld [1988]). Governments finance toll facilities by issuing bonds that use toll
revenues to cover debt service. The large up-front capital cost of construction is
effectively amortized over long periods of time and this type of financing makes
construction of new facilities more manageable for the government. Users benefit by
being able to use a facility sooner than if it was financed through taxes but would also
have to pay a toll. Since bond issues are based on toll revenues, traffic flows are the key
variable that determine whether or not a facility can be financed through tolls and
consequently, makes traffic forecasting a critical issue.

The history of traffic levels on existing roads makes tolling of existing facilities a
less risky proposition than tolling a new road. These traffic levels could be adjusted to
reflect the elasticity of using the facility with respect to the new toll rate in order to
forecast demand. However, implementation of tolls on existing facilities would be much
more difficult politically than on a new facility because users would not be used to paying
for something that they had received for free in the past. However, a Roper Organization
poll found that only 12% of the population oppose tolls in any form as long as they
perceive a benefit such as quicker, safer trips on a road that's quickly built and in better repair (Felgner [1988]).

Tolling is not without disadvantages, however. The drawbacks to tolling include the increased cost of constructing and operating a toll facility and the political obstacles that tolling faces. A 1983 study found that the cost of toll collection averaged about 18% of gross toll revenues compared to 1% of gross revenues for collection of motor-fuel taxes (Wuestefeld [1988]). However, with the use of Automatic Vehicle Identification (AVI), these costs may be reduced significantly in the future (Gomez-Ibanez [1992]). Users may perceive a toll as a form of double taxation since they already pay gas taxes (Felgner [1988]). In addition, tolling has distributional effects and opponents argue that it is unfair to poorer users. Literature on the distributional effects of road pricing shows that where there is a high rate of vehicle ownership it would be regressive because costs would fall most heavily upon lower-income drivers who would be forced to change from road to public transit (Borins [1988]). Tolls are more likely to be regressive if they replace a highly progressive tax or enable government to provide a program that benefits mainly the rich, and to be progressive in the opposite cases (Small [1983]). Though, with tolls, users are usually able to choose between the tolled route and an alternate free route which may, however, be more circuitous or congested (Felgner [1988]).

Toll rates in Puerto Rico were raised for the first time in almost 20 years of operation in 1991-92, and has increased revenues by about $18 million per year to approximately $60 million (Parker [1992b]). An analysis by Econometrica, a Puerto Rico economic consulting firm, showed that traffic volumes did not change significantly from previous levels before the toll increase, suggesting that demand for the toll roads is fairly inelastic (Econometrica [1992b]). The study further projects the additional revenues that can be achieved by raising rates further in 2002-2003. Should the PRHTA need additional revenues in the interim, an increase in toll rates should be considered. The elasticities calculated by Econometrica range from -0.013 to -0.280 with an average elasticity of
about -0.11. This means than a 10% increase in the toll rate would result in only a 1.1% decrease in traffic. Many toll facilities require that any revenues received by the toll road through tolls must be used exclusively for the toll road. If this is the case in Puerto Rico, then legislation must be passed to allow use of these revenues for other purposes if funds are needed to finance other transportation improvements.

2.1.4.2 HOV Buy-in

Tolling of facilities is desirable because it gives the government more control over traffic levels. For example, high-occupancy vehicle (HOV) lanes can be introduced as part of a toll road and be charged a lesser rate or no toll at all in order to encourage carpooling. An example of such a scheme is the San Francisco Bay Bridge. During the hours of 6 a.m. to 9 a.m. and 3 p.m. to 6 p.m., vehicles with three persons or more are allowed to use special HOV lanes at the toll plaza and avoid paying the $1.00 toll. During the morning peak hours, informal carpools have been set up at parking lots all over the East Bay where commuters can hitch a ride with other commuters headed toward San Francisco to the west for free because the time and toll saved at the toll plaza makes it worthwhile for the driver of the vehicle. The encouragement of higher vehicle occupancy rates is desirable but from an efficiency standpoint, the HOV lanes are being under utilized.

A possible solution to the inefficiencies associated with HOV lanes is to let single occupancy vehicles (SOV) or non-HOV vehicles pay an extra toll to use the HOV lane (Bernstein [1991]). A toll rate could be set just high enough so that the HOV lane does not become congested. This type of scheme would be most effective if a dedicated HOV lane existed for the length of the toll facility. For example, such a scheme may not be as effective on the San Francisco Bay Bridge, where time savings are limited to the toll plaza.
and not on the bridge itself. Furthermore, electronic toll collection should be used to minimize queuing delays at toll plazas.

This "HOV buy-in" scheme is being developed for the State Route-91 (SR-91) median lanes in Orange County, California. This privately built road will help alleviate growing congestion on a 10 mile section of SR-91 by providing four additional lanes (two lanes in each direction) within the median. Initially, vehicles with two or more persons will be able to use the facility for free while SOVs will have to pay a toll. If such a scheme results in congestion on the new facility, vehicles with two persons (HOV-2s) will have to pay a toll as well. However, as part of the agreement between the government and the private developer, HOV-3s will always be able to use the facility for free. This project will use electronic toll collection and tolls will be varied during the day depending on the level of congestion on the road.

2.1.4.3 Other Tolling Schemes

In addition to the "HOV Buy-in" scheme, other tolling schemes could be used to either maximize revenue or alter driver behavior. For example, a "head-of-the-line" tolling scheme would allow drivers with monthly passes to use a special electronic toll collection lane at the toll plaza to pay their toll (Bernstein [1994]). These drivers would be charged more than other users for this privilege but ultimately may benefit through decreased travel times.

Another possible tolling scheme related to "head-of-the-line" privileges is charging a different toll at each toll booth. For example, if there are three toll booths, booth #1 could charge $1, booth #2 could charge $2, and booth #3 could charge $3. This type of scheme creates an equilibrium where only those willing to pay a higher toll to decrease travel time will use booth #3. Those with medium value of time would use booth #2 and the rest would use booth #1.
In addition to these revenue raising schemes, driver behavior may be altered through tolling. Transportation planners have tried encouraging carpooling by providing measures such as dedicated HOV lanes and free use of toll facilities. However, a recent survey revealed that the average number of passengers per automobile in the U.S. dropped from 1.3 in 1980 to 1.1 in 1990 (PWF [1991]). A federal highway official, commenting on the failure of state and federal efforts to increase occupancy per vehicle, noted, "At least it can't get much worse."

One way of altering driver behavior would be to charge a toll that depends on the number of occupants in a vehicle. For example, if 4 or more people are in the vehicle, there would be no toll. If 3 people were in the vehicle, then the toll would be $2 and if 2 people were in the vehicle, the toll would be $4. Finally, if only one person were in the vehicle, then the toll would be $6. This type of scheme may be difficult to implement but may be feasible in the future with the use of surveillance cameras and electronic toll collection.

2.2 Congestion and Social Welfare

Congestion on freeways affects the quality of life for everyone. The added delays of a commute trip or the added cost that delays incur on shipping costs decreases the efficiency of the entire economy. In addition, the stress and frustration of spending nonproductive hours stuck in traffic takes an added toll. In a recent nationwide survey, 80% of those polled said they considered traffic congestion a major problem in their cities (Drummond [1991]). This section first identifies the problem, then discusses possible solutions to congestion and their effects on social welfare.
2.2.1 The Congestion Problem

Congestion on freeways results in lost productivity for the American workforce. Americans lose more than 2 billion hours a year to traffic delays and, by the year 2005, that figure could increase to almost 7 billion hours if steps are not taken to mitigate the situation. This translates into a yearly cost of $34 billion according to one estimate (Drummond [1991]). These delays not only affect work trips, but trips related to distribution of goods as well. The American Association of State Highway and Transportation Officials estimates that truck delays alone add $7.6 billion a year to the cost of goods that Americans buy (Drummond [1991]).

A majority of these delays occur during peak hours. The percentage of peak hour travel on urban interstates that occurred under congested conditions reached 70 % in 1989, up from 41 % in 1975 (Sussman [1992]). This trend of increased congestion is expected to continue in the future. According to a study by the Federal Highway Administration, delays on urban freeways are expected to increase by a whopping 360% between 1985 and 2005 in central cities and by 433% in outlying areas (ITE [1989]).

2.2.2 Congestion Mitigation

Governments have tried using three fundamental ways of dealing with both an increased demand for, and a limited supply of transportation. The traditional approach to solving urban transportation problems in the face of increased demand is to increase the supply of transportation facilities. This includes constructing new highways as well as expanding old ones. The second option is to promote transit use. This policy has been relatively unsuccessful to date, but as conditions worsen, may become more effective in the future. The third option is transportation demand management. There are a number of methods that use highway demand management to decrease the number of vehicles on
the road but many are strongly opposed by the public and have a difficult time being approved for implementation. The following sections briefly describe some of the methods currently being used to deal with congestion.

2.2.2.1 Increasing Supply

Over the past 20 years or so, the number of new projects authorized for construction has been limited due to a number of factors. For example, between 1979 and 1989, the total number of miles of road in urban areas has increased only 9% while the number of vehicle miles traveled has increased 38% (Highway Statistics [1979 and 1989]).

The decrease in new construction can be attributed to the increase in cost associated with highway construction coupled with budgetary constraints of local governments. Using 1977 as the base year (i.e., 1977=100), construction costs have increased from 142.6 in 1979 to 184.2 in 1989 (Highway Statistics [1979 and 1989]). With the future of new road construction in question, transportation planners have promoted the use of transit as an alternative to driving.

2.2.2.2 Promoting Transit Use

Once commuters try using transit, they may find the cost of using transit favorable over using autos. For example, there was a noticeable gain in ridership on the Bay Area Rapid Transit (BART) system from the 1989 Loma Prieta earthquake which closed the Bay Bridge. During this period, when the bridge was closed for repairs, ridership jumped from 219,000 to 357,000 passengers a day (BART [1992]). Many of the riders chose to continue using BART service even after the bridge was reopened. This suggests that there is potential to increase transit ridership if commuters just try the service for a few weeks.
Before any actions are taken to promote use of transit, the reasons for the unpopularity of transit must be assessed. In order to make transit cost-efficient and serve more people, many stops must be made to pick-up and drop-off passengers. This constant acceleration and deceleration greatly affects travel times. For example, in 1985, the average worktrip travel time in New York City by transit took 46 minutes. However, the same trip took only 26 minutes by automobile (JAPA [1991]). There are, however, methods of decreasing travel times of transit in order to make transit travel times more competitive with those of the automobile. These methods include express bus service, use of dedicated bus lanes, and increasing frequency. In addition to making transit use more attractive, policies that make auto use less attractive should be used as well to maximize the effects.

2.2.2.3 Transportation Demand Management

With a limited amount of supply available to accommodate an ever increasing demand, transportation demand management techniques are used to optimize usage of existing facilities. Some strategies that hold promise and are currently in use in some cities include alternative work hours, ridesharing, growth management, and auto restricted zones. Alternative work hours and ridesharing are categorized as "market based" policies whereas mandates by the government to control congestion such as growth management and auto restricted zones are categorized as "command and control" policies (Searching for Solutions [1992]). For most facilities, the problem of limited supply becomes apparent only during peak hours and therefore this period should be the focus of any new policy.

Many employers now implement policies such as flex-time and compressed work weeks in order to spread demand more evenly during peak periods. Flex-time allows workers to choose a time that is most convenient for them to travel and thereby effectively creates an equilibrium where only those commuters willing to face congestion during the
peak time use the facility. Compressed work weeks effectively reduces the number of worktrips made, by having employees work more hours per day but fewer days per month.

In addition to reducing the number of trips made, increasing the number of people per auto helps reduce congestion as well. Ride sharing is a policy used by governments to maximize the number of persons using a facility rather than maximizing the number of vehicles using a facility. Many freeways around the United States have HOV lanes that require vehicles to have a specified minimum number of persons in the vehicle to use the lane. These HOV lanes usually have less traffic than other lanes and therefore can travel at higher speeds.

These "market based" policies of alternative work hours and ridesharing may be used in conjunction with "command and control" policies to reduce congestion further. Proponents of "market-based" strategies consider them to be more efficient ways of achieving clean air objectives, whereas proponents of uniform "command and control" standards consider this approach more politically acceptable and more equitable than "market based" strategies (Searching for Solutions [1992]).

Growth management is a form of "command and control" policy used by government to regulate development in regional areas. Before any new development can occur, studies must be done to assess the impact of such development on infrastructure. If the development is deemed to make existing conditions worse, then the project may be denied the necessary permits to proceed.

Another form of government regulation is auto-restricted zones. Land use policies could be geared to make it relatively easier to access facilities by transit than auto. For example, if parking availability is limited, then transit might be the only convenient means of access to a given destination.

A very successful program has been in place in Singapore since 1975. When this Area Licensing Scheme first went into effect, the number of private cars entering the downtown during the morning rush hours dropped from 4500 to about 1500 (ITE Journal
This type of congestion pricing has been advocated for years and has gained a renewed interest due to rising congestion and developments in electronic toll collection (Bernstein and Muller [1993b]). In addition, integrating the use of new technology such as driver information systems with congestion pricing has further contributed to the renewed interest in congestion pricing (El Sanhouri and Bernstein [1994]).

2.2.2.4 Congestion Pricing

Congestion pricing is a way of allocating scarce resources (freeway capacity) in an efficient economic manner. By charging a toll, only those people who are willing to pay the price of the toll will use the facility. In this way, the toll could be set in such a manner as to maximize throughput and decrease congestion. In addition, air quality concerns can be addressed since vehicles in stop-and-go conditions produce several times more pollutants per mile than when they are traveling smoothly at cruising speeds (Poole [1988]). However, such user charges may be difficult to implement due to political opposition and equity concerns but may be easier to implement relative to increasing transit use.

Because people have shown a reluctance to use mass transit, a more successful approach may be to charge them for use of congested roads. Congestion pricing encourages changes in the following characteristics of travel behavior:

- departure times
- mode choice
- destination
- route choice
- carpooling
- whether or not to make the trip at all
A recent congestion pricing symposium outlined some of the key issues that need to be addressed before congestion pricing can be implemented (Searching for Solutions [1992]). Symposium participants selected the problem of selling the concept of congestion pricing to the public as the most critical issue to be addressed in implementing congestion pricing projects. Using congestion pricing revenues to compensate those who may be adversely affected by its implementation was seen as a possible solution to this problem. The government has encouraged the development of congestion pricing by authorizing the Congestion Pricing Pilot Program of five demonstration projects intended to provide real-world tests of congestion pricing concepts that will help others learn more about problems of design, implementation, and operation of congestion pricing projects. The Federal share of funding for congestion pricing projects is 80%. The incentives apply to both public and privately owned facilities, and the tolls may be continued indefinitely.

Concerns about the perceived adverse effects of congestion pricing on local business and low-income groups have prevented its enactment in the United States. Layard (1977) performed an analysis of the distributional effects of congestion pricing. He concluded that the use of congestion pricing may be regressive as it discourages journeys with low travel time values and encourages those with high travel time values. Past attempts at implementing pricing strategies have not succeeded because too little emphasis was placed on generating local support and because congestion levels were not viewed as sufficiently unacceptable. Symposium participants concluded that a congestion pricing plan must include a comprehensive package of revenue use to enhance transit or other mobility alternatives. Further, the public must perceive that a congestion problem exists, must be made aware that auto travel is currently subsidized, and must be convinced that it is receiving a benefit from congestion pricing (Searching for Solutions [1992]).

The efficient use of potential congestion pricing revenues is key to the implementation of any congestion pricing strategy. In the absence of any redistribution of toll revenue, low income groups lose more than high income groups, because the higher
value of time savings by high income individuals more than compensates for their greater
likelihood of using autos (Morrison [1986]). Careful consideration must be given to who
wins and who loses when congestion pricing is implemented. Suggested winners include
current operators and users of HOV lanes, road users who are willing to pay the higher
price for spending less time in traffic, businesses that rely on deliveries, and the major
recipients of activities funded with congestion pricing revenues. The losers might include
those who cannot afford to pay the increased tolls, drivers on unpriced roads that get
additional traffic from those avoiding congestion tolls, and perhaps businesses in the
vicinity of the priced roads (Gomez-Ibanez [1992]). However, studies have been
performed which show that it may be possible to implement congestion pricing schemes
that significantly improve social welfare without significantly increasing user-costs
(Bernstein and Muller [1993a]).

Before any steps are taken to implement congestion pricing, past experiences, both
in the U.S. and abroad, should be examined to guide today's projects. In the 1970's,
UMTA attempted to implement areawide congestion pricing by using windshield stickers
similar to those used in Singapore. Estimates indicated that daily charges of $2 to $3
levied for entrance to the downtown area, would result in a 35 % decrease in congestion.
However, because of strong local opposition, the projects never progressed beyond the
planning phase. The issues that defeated the project were the impact on low-income
commuters, the concept of "freedom of the road," legal and enforcement issues, and
possible adverse effects on business (Searching for Solutions [1992]).

Road Pricing schemes have been considered for introduction in various cities
around the world. In London, congestion pricing was first considered by the Smeed
Committee in the early 1960's. As the committee studied the possibilities of congestion
pricing, they developed a set of principles that still offer practical guidelines for congestion
pricing projects. The Smeed Principles state (Searching for Solutions [1992]):
1. Charges should be closely related to the amount of road use.

2. Prices should be variable to some extent for different roads (or areas) and for different classes of vehicle at different times of the day, week, or year.

3. Prices should be stable and easily determined by road users before they embark on a journey.

4. Payment in advance should be possible, but credit facilities may be permissible under certain conditions.

5. The impact of the system on individual road users should be accepted as fair.

6. The method should be simple for road users to understand.

7. Any equipment used should be highly reliable.

8. The system should be reasonably free from the possibility of fraud and evasion, both deliberate and unintentional.

9. The system should be capable of application throughout the country, if necessary, and to a vehicle population of more than 30 million.

The only true urban road pricing system in operation is the area licensing scheme (ALS) that was introduced in Singapore in 1975. Some of the key impacts on mode split are summarized in Table 2.4.

Table 2.4: Effects of ALS on Singapore Mode Split

<table>
<thead>
<tr>
<th>Mode</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus</td>
<td>35.9%</td>
<td>43.9%</td>
</tr>
<tr>
<td>Auto</td>
<td>32.8%</td>
<td>28.2%</td>
</tr>
<tr>
<td>Taxi</td>
<td>1.0%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Legal carpools</td>
<td>6.4%</td>
<td>12.6%</td>
</tr>
</tbody>
</table>

The amount of bus use increased by 22.3% over previous levels while the number of legal carpools almost doubled. Hong Kong also experimented with the notion of congestion pricing in the mid 1980's.

In 1985, Hong Kong was experiencing tremendous growth both in population and vehicle use. This resulted in severe congestion during peak hours which hampered the mobility of Hong Kong's citizens. Instead of increasing vehicle registration fees, the government decided to implement congestion pricing as a more equitable way to control congestion. This policy allowed more people the opportunity to own a car while at the same time, penalizing those who use facilities during peak hours. In the end, however, traffic levels were deemed not as congested as forecasted earlier and the project was canceled (Dawson [1986]).

2.3 Public and Private Roles in Highway Projects

With governments facing severe budgetary constraints, participation by the private sector is seen as a way of leveraging resources to accommodate the needs of the public. The degree of private involvement ranges from simple contracting out to full privatization of highways. This section discusses various ways the private sector can be involved in financing transportation improvements.

2.3.1 Public/Private Partnerships

A variety of methods are currently being used to charge those in the private sector who benefit from public improvements a fee to help defray the cost to the government of providing the improvement. These methods include the following public-private policies (ITE [1989]):
• **Assessment Districts**
  A special tax levy on all property owners in a district for an improvement which benefits primarily those specific owners, and which is approved by a majority of the property owners.

• **Special Districts**
  An assessment district with a governing body separate from the local government.

• **Tax Increment Financing**
  Increases of tax revenues that are realized as a result of new development in a specified area are earmarked by financing public improvements in that area.

• **Development Agreements**
  Private/public agreement on specific development based on private agreement to pay for itemized elements of traffic improvements, in return for a public commitment to and assistance in removing as many impediments and delays in administrative actions as possible.

• **Development or Impact Fees**
  Established to compensate the community for extra costs for public facilities that the development will cause.

• **Infrastructure Bank**
  A pool of federal grants, proceeds from state bond issues, state appropriations and perhaps some private capital to form revolving loan accounts as seed money for traffic and road improvements.

The policies outlined above are currently being used by local governments in the U.S. to help pay for needed improvements. For example, Ft. Collins, Colorado, requires developers to provide all streets internal to the owner's project, and in addition pay a street
oversizing fee for collector and arterial streets, set to recover the cost above that of a local street. The major limitation to these policies is that funding must be tied to projects directly related to those contributing the funds (Institute of Transportation Engineers [1989]). However, this helps ease the burden on local governments by freeing up resources that can be used on other projects.

2.3.2 Privatization

As mentioned in Chapter 1, faced with an increased demand for transportation, especially in the San Juan area, the government of Puerto Rico must determine how it will finance future expansion of its transportation network. One method that the government has pursued is privatization.

In 1990, the Puerto Rico Highway and Transportation Authority (PRHTA) identified the San Jose Lagoon bridge as one of two projects that might be suitable for private design, construction, operation, and maintenance. Through notices published in newspapers, the PRHTA requested interested parties to submit their qualifications for the realization of the project.

On August 23, 1990, the Legislature of Puerto Rico established the Board of Awards which was authorized to ratify contracts enabling private funding of projects. The official justification for this legislation was that:

"The Legislature found and declared that it was essential for the economic and social development of the Commonwealth to maintain an efficient ground transportation system; that present and future needs of the Commonwealth for highway systems would require substantial additional investments, and alternative funding sources should be developed to augment or supplement available public sources of revenue; that privately funded projects whereby private entities obtain
concession agreements to prepare the final design and to build, operate, maintain and manage, with private funds, all or a portion of public ground transportation facilities will allow for joint venture of private and public entities to take advantage of private sector efficiencies and allow for rapid formation of capital for funding purposes, subject to continued compliance with applicable Commonwealth and federal laws, offer the traveling public alternate route selections in project areas and will more quickly reduce congestion..."(Concession Agreement [1992])

The use of privatization to finance public works projects has received much more attention in recent years in the United States due to a lack of available funding and a rise in congestion. The following sections discuss some of the issues that have been raised as a result of the resurgence of privatization.

2.3.2.1 The Trend Toward Privatization

The privatization of public services in the United States has been expanding at an increasing rate. A national survey conducted in 1982 revealed that over 60 types of public services were already being contracted to the private sector. For example, the survey found that over 40% of commercial solid waste collection was done by private firms (Kemp [1991]). By 1993, privatization had spread throughout the nation even more. The Energy Department had announced plans to privatize its uranium enrichment program over the next two years and newly elected Los Angeles Mayor Richard Riordan had pledged to sell Los Angeles International Airport (Financial World [1993]).

According to a 1992 study by the accounting firm Deloitte & Touche, nearly half of the nation's largest cities have increased the number of services they contract out every year by a factor of 10 since 1988. The factors that influence a state's decision to privatize were determined by a 1989 survey by Deloitte & Touche as shown in Table 2.5.
Table 2.5: Reasons for Privatization

<table>
<thead>
<tr>
<th>Reason</th>
<th>% of States</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxpayer revolt</td>
<td>11%</td>
</tr>
<tr>
<td>Loss of Key Staff</td>
<td>16%</td>
</tr>
<tr>
<td>Bond Issue Failure</td>
<td>16%</td>
</tr>
<tr>
<td>Labor Difficulties</td>
<td>26%</td>
</tr>
<tr>
<td>Rapid Population Growth</td>
<td>32%</td>
</tr>
<tr>
<td>Credit Limit Reached</td>
<td>32%</td>
</tr>
<tr>
<td>Budget Cutbacks</td>
<td>58%</td>
</tr>
<tr>
<td>Demand for New Services</td>
<td>69%</td>
</tr>
</tbody>
</table>

Source: Financial World [1993]

This trend toward privatization includes the development of privatized toll roads. There are currently seven such projects under development, four in California, one in Virginia, and two in Puerto Rico. These projects have paved the way for future projects by overcoming legal hurdles and other obstacles. The debate over the advantages and disadvantages of the privatization of toll roads has also been raised as a result of these projects but no definitive conclusions have been reached. The future of privatized toll roads in the United States will largely depend on the success (or failure) of the projects currently being developed. Several papers have been written on these issues and the following sections give brief summaries of their assessments. First, factors influencing the development of privatized toll roads will be discussed. Then, the possible obstacles they face will be summarized. Finally, the relative advantages and disadvantages will be assessed.
2.3.2.2 Factors Influencing the Development of Privatized Toll Roads

The development of privatized toll roads has primarily resulted from a combination of an increasing need for infrastructure improvements and a decreasing availability of public funds to construct these improvements (Drummond [1991]). With an economy that has shifted toward service, the importance of transporting goods by freeway efficiently has increased dramatically in recent years. The need for infrastructure improvements is mostly due to a maturing roadway system and an increase in congestion because the effective price to use freeways is zero (Beesley and Hensher [1990]). In addition, the interstates were originally intended to be throughways, but some have become major commuter highways which has resulted in significant wear and tear on many highways (Drummond [1991]). Furthermore, motor-vehicle registrations are consistently growing at a faster rate year after year than that of the general population. For example, between 1979 and 1989, the number of motor-vehicle registrations increased 17% while the total population in the United States increased by only 13% (Highway Statistics [1979 and 1989]).

With more cars on the road, more miles are being traveled and consequently, infrastructure is suffering. The number of vehicle miles traveled in the United States between 1979 and 1989 has increased 38% while the number of miles of road classified as "deteriorated" has increased 132% over the same period. In addition to the extra wear and tear caused by the increase in vehicle miles traveled, many of today's roads are reaching their original design life and are in dire need of maintenance. To make matters worse, the cost of operating and maintaining these roads has increased dramatically in recent years. For example, using 1977 as a base year (i.e., 1977 = 100), operating and maintenance costs have increased from 118.2 in 1979 to 219.1 in 1989, an increase of over 85% (Highway Statistics [1979 and 1989]). If these trends continue unabated, the mobility of the people in the U.S. will suffer and so too will the nation's economy.
As mentioned earlier, the amount of construction of highways has not kept up with the growth in vehicle miles traveled. States are limited by voters in the amount of tax and debt they can issue. Furthermore, government workers typically have higher overhead costs than workers in private firms. Moreover, an analysis of state budgets shows that highway revenues and expenditures are receiving a smaller share of total state resources (Walton [1990]). Another important factor that has contributed to the decrease in the development of infrastructure is a concern for the environment (Fixler [1987]).

2.3.2.3 Obstacles to Privatization

Privatization of toll roads faces many obstacles, both in terms of government regulation and political opposition. State governments must first pass enabling legislation to allow privatization of roads. Such legislation has already been passed in states such as Arizona, Florida, Virginia and California, and is under consideration in many other states as well. Once this legislation is passed, privatized toll roads are still subject to government scrutiny. Possible federal regulation may come from the following policies (Walton [1990]):

1) National Environmental Policy Act
2) Clean Air Act
3) Uniform Relocation Assistance and Real Estate Acquisitions Policy Act
4) Federal Water Pollution Control Act
5) Davis Bacon Act
6) Title 23 of the Federal Aid Highway Program
The implications of the first four acts are related to environmental and equity concerns and would apply to any infrastructure improvement, public or private. However, private firms have had a more difficult time clearing environmental hurdles than governments because of the first-time nature of these projects. For example, The Toll Road Corporation of Virginia (TRCV), developer of the privatized Dulles Toll Road Extension, spent most of 1991 securing required environmental permits from the U.S. Army Corps of Engineers, gaining necessary land use permits from Loudoun County, and assembling the rights-of-way. The environmental and land use permits required some design changes, which added another $10 million to construction costs. The right-of-way assembly was time consuming because several smaller landowners, whom TRCV had thought would donate rights-of-way, wanted to be paid. In the end, TRCV had to persuade Loudoun County to threaten to exercise eminent domain on its behalf so that the land prices demanded were more manageable (Kennedy School of Government [1993]).

By contrast, the concession agreement for the San Jose Lagoon Bridge gave the responsibility of right-of-way acquisition and obtaining the necessary permits to the Puerto Rico Highway and Transportation Authority. This saved the Concessionaire valuable time and also increased the certainty of the project to investors.

The fifth policy cited, the Davis Bacon Act, regulates wage rates for highway work. Building trade unions have raised the question of whether Davis-Bacon or state prevailing wage rates will be in effect on private highway work (ENR [1989]). The sixth act cited, Title 23 of the Federal Aid Highway Program, has recently been amended to facilitate development of toll roads. Initially, it required the repayment of all federal moneys spent on a highway if it was converted to a toll road. However, in November 1991, Congress amended the federal highway aid program to allow states to use federal funds to pay 50% of the cost of building a toll road, provided that the facility was new or substantially improved, and was not part of the Interstate System.
Financing privatization projects has also become a major obstacle due to the uncertainty surrounding the first-time nature of the projects. For example, the Dulles Toll Road Extension was delayed for over a year because it could not finalize long-term financing arrangements. However, if the financial markets become accustomed to privatized toll road projects, they may respond more favorably to future privatization projects.

Some government agencies are opposed to privatization because of the reduction of central government support for the road task (Beesley and Hensher [1990]). For example, the Treasury Department is against having infrastructure in the private sector because it may hamper its ability to control the overall direction of the economy (Reina [1991]). Government organizations such as the Professional Engineers in California Government (PECG) are opposed to privatization because they see it as a threat to their jobs. If government contracts are issued to private firms, engineers who work for the government may not be needed as much in the future. In fact, the PECG sued the California State Department of Transportation to prevent losing design work to the private toll road franchises but were defeated in the courts (ENR [1992]).

In addition to federal government regulation, all projects are subject to local regulation as well. A project must conform to each local government's growth management program through zoning provisions, subdivision requirements, etc. The question of who is liable in the event a road franchise defaults on its bond issues also has to be answered before a project can be implemented.

The extent of enforcement of government regulations is heavily dependent on political support from various organized interest groups. Groups who oppose toll roads include (Poole [1988]):

1) the American Automobile Association
2) transit advocates
Groups who support toll roads include:
1) highway builders
2) construction unions
3) major employers
4) developers
5) business/taxpayer organizations

The public however, when faced with a choice between raising taxes and the use of toll roads, are generally in favor of toll roads (Wuestefeld [1988]).

The Midstate Toll Road project in California faces particularly severe environmental opposition. This 85-mile project cuts through the valley of Northern California and has seen intense opposition from groups such as the Sierra Club. In addition, the project cuts through many small counties who are opposed to development and have separate growth management agendas.

2.3.2.4 Advantages of Privatization

The two advantages of the privatization of toll roads most cited are an increase in speed of construction and certain advantages related to financing. With demand for freeway expansion increasing everyday, speed of construction is an important consideration. The sooner a facility is built, the sooner motorists can take advantage of the improvements to possibly decrease travel times. Before a facility can be constructed,
however, proper financing must be established to ensure that sufficient funds are available to complete the project. Governments are limited in the number of projects they can handle because, as noted earlier, the amount of funding available from the government for freeway improvements is decreasing due to budgetary constraints.

Once governments approve the process of privatization, it tends to speed up the decision making process as well as construction and opening of a facility (Beesley and Hensher [1990]). The main reason for this may be that private toll projects do not always have to comply with federal statutes, standards, and regulations. For example, the San Jose Lagoon Bridge used the fast-track construction method whereby construction was performed on designs completed on a section by section basis, even though the final design had not been completed yet. This construction method allowed for completion of the bridge in only two years. If the government had been contracted to build the facility, it would probably have taken longer to complete the project since the government is unable to use this type of construction method. Another contributing factor to the speed of construction of a private firm is that there is usually no need to go through a review process by federal and state agencies (Wuestefeld [1988]). The extent to which a decrease in government regulation speeds up construction depends on each state's policy toward privatization. These policies not only affect the manner in which a facility is constructed, but also may affect the method by which a highway improvement is financed.

Privatization, and toll roads in general, may be a viable method of constructing an improvement that otherwise might never be built or could take many more years to implement using conventional tax funds alone (Wuestefeld [1984]). In California, for example, potential privatization projects were solicited from various private firms in response to the passing of privatization demonstration project legislation. Projects that had been abandoned by the California Department of Transportation were resurrected by private firms. A project in Orange County would complete a long planned and missing
north-south link in the County's freeway network and would relieve congestion on parallel
freeway and local streets (Gomez-Ibanez [1991]).

Financing a toll road privately also has many advantages over financing a toll road
publicly. By financing a toll road privately, capital would be freed for the government to
use on other programs. For example, in Mexico, the concession program, together with
public investment, has quadrupled the amount of money spent on highway infrastructure in
only four years (Mahbub [1991]). In addition to leveraging capital, tax benefits, which are
not available to tax-exempt governmental entities, can be used by the private sector to
lower service delivery costs even further (Kemp [1991]). One of the major obstacles to
financing the improvement of a facility is the large capital cost associated with the
initiation of a project. With privatization, this capital constraint would be removed and
complete funding would be available at the beginning of a project. In addition,
landowners may donate rights-of-way since a freeway improvement may increase the
property value around the facility and landowners may be able to negotiate certain
concessions with a private firm (ENR [1986]). For example, The Dulles Toll Road
Extension project relied heavily on donations of rights-of-way to complete land acquisition
for their project in exchange for concessions. These advantages in financing, together
with an increased speed in construction, may result in a decrease in total construction
costs.

Once a project is completed, benefits of privatization may also occur in the
maintenance of a facility. Private firms have an incentive for cost-efficient and cost-
effective operation of freeways (Drummond [1991]). The competition in the development
and operation of facilities, leads to lower operational costs and creative implementation
strategies (Gomez-Ibanez [1991]). In fact, one theory predicts that for any given physical
maintenance operation, a private highway owner would incur costs less than or equal to
those incurred by a government owner (Geltner [1987]). In addition, revenues from a
tollway operated by an independent authority are often required by law to be dedicated
solely to the project. An independent authority is also able to focus exclusively on building, operating and maintaining the tollway.

The implementation of new technology on privatized toll roads may benefit politically as well. One of the arguments against the use of Automatic Vehicle Identification (AVI) is that records would be kept on the movements of individual users. This privacy issue associated with implementation of AVI is likely to be much less of a problem if electronic toll collection is operated by private firms rather than by a government agency (Poole [1988]).

2.3.2.5 Disadvantages of Privatization

The two disadvantages of privatization of toll roads most cited are the risks associated with private financing and the higher cost to the user. Private firms must be able to guarantee that they will be able to complete a project once it has begun. Once a project is initiated, a public authority would be more likely to complete a project, regardless of cost, in the long run. The incentive for private firms to invest in toll roads is a return on capital. The rate of return that a private firm receives will have a direct effect on the price a user pays to use the facility.

There are many risks associated with private financing of toll roads. Reliance on private financing adds more risk in programming long-term transportation plans. The future of a private firm's cash flow is less certain than that of government's and therefore the completion of a project is not ensured (Walton [1990]). Furthermore, private firms lack the power of eminent domain and therefore right-of-way acquisition is not guaranteed (Stodghill [1989]). However, the concession agreements of the California projects state that the government would use the power of eminent domain "only as a last resort." Private firms also have a greater sensitivity to delays and development costs (Gomez-Ibanez [1991]).
Another important consideration is liability. The safety of a privatized toll road may or may not be guaranteed by the government, depending on its policies. One proposal, in Colorado, would potentially not be under state control. A developer wants to build a private, 210 mile toll road from Pueblo to Fort Collins. It would not recognize the 65-mph speed limit most states have and would allow drivers to go as fast as 85-mph legally (Schulz [1990]). Such questions of private versus public jurisdiction is a major contributor to an increase in delay of construction of a new facility.

There would probably be substantial administrative costs associated with highway privatization in the form of needed regulatory oversight of the private highways for safety and economic efficiency purposes (Geltner [1987]). Depending on the policies of the state, a private authority may have monopoly power over a tolled road and may receive windfall benefits if price is used to control demand on a given toll road (Gomez-Ibanez [1991]). Many concession agreements stipulate that the government is not allowed to build a competing facility or upgrade existing alternate free routes for the duration of the private project. The regulation of toll rates or rate of return would be needed to ensure that the private firm is not exploiting the toll rate to maximize profits.

In addition, this joint cooperation between public and private authorities may slow the planning and implementation phases of development by adding more oversight by the government to the process (Walton [1990]). For example, the Dulles Toll Road Extension project was delayed because a comparison had to be made between the privatized proposal and a public proposal.

The costs to the user of a facility owned and operated privately may be higher than those of a facility owned and operated publicly. Since private enterprise requires full cost recovery, privatizing ownership of infrastructure may result in higher costs to users since profits are added to costs (Johansen [1989]). For example, a comparison between the private Dulles Toll Road Extension proposal and a public proposal showed that tolls would be $1.50 for the private proposal and only $1.00 for the public one.
2.4 Summary

Choosing a policy to raise revenues is always a difficult decision. Those who are affected must be identified and benefits and costs must be weighed against each other. Table 2.6 summarizes the arguments for and against each policy.

<table>
<thead>
<tr>
<th>Policy</th>
<th>Winners/Goals achieved</th>
<th>Losers/Goals not achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>raising fuel taxes</td>
<td>increases revenues</td>
<td>auto users</td>
</tr>
<tr>
<td></td>
<td>congestion management</td>
<td>equity issues</td>
</tr>
<tr>
<td>raising vehicle registration fees</td>
<td>increases revenues</td>
<td>specific vehicle owners</td>
</tr>
<tr>
<td>raising parking fees</td>
<td>increases revenues</td>
<td>auto users</td>
</tr>
<tr>
<td></td>
<td>congestion management</td>
<td>local business</td>
</tr>
<tr>
<td>tolling facilities</td>
<td>increases revenues</td>
<td>specific auto users</td>
</tr>
<tr>
<td></td>
<td>congestion management</td>
<td>equity issues</td>
</tr>
<tr>
<td>HOV Buy-in</td>
<td>increases revenues</td>
<td>carpoools</td>
</tr>
<tr>
<td></td>
<td>congestion management</td>
<td></td>
</tr>
<tr>
<td>head-of-the-line Privileges</td>
<td>increases revenues</td>
<td>equity issues</td>
</tr>
<tr>
<td>public/private partnerships</td>
<td>increases resources available</td>
<td>business must pay</td>
</tr>
<tr>
<td>privatization</td>
<td>increases resources available</td>
<td>specific auto users</td>
</tr>
<tr>
<td></td>
<td>congestion management</td>
<td>equity issues</td>
</tr>
</tbody>
</table>

This summary gives only a qualitative assessment of each policy and does not attempt to quantify the benefits and costs. Each situation is unique and must be treated as such. Policies should be chosen not only based on potential revenue that can be gained, but also on the congestion management goals of the area.
Research has shown that, in general, toll revenues can be increased substantially by changing toll policies (Bernstein and Muller [1993b]). The privatized San Jose Lagoon Bridge represents a unique opportunity to study the effects of different tolling schemes on both revenue and users. Provisions outlined in the Concession Agreement give the private firm the flexibility to vary toll rates below a certain level in order to maximize profits (Concession Agreement [1992]). In addition to assessing the impact of different tolling schemes on revenue, the effects on users is also of interest to the government. Any toll policy for the San Jose Lagoon Bridge must consider the two conflicting goals of profit maximization by the private firm versus maximizing public benefit by the government. The following chapter outlines the procedure used to develop a model that predicts demand for the bridge and this model is subsequently used to estimate the effects of various tolling schemes on both revenues and users.
Chapter 3

Development of a Demand Model

The focus of this study is to estimate the effects of different toll rates on traffic and revenue for the San Jose Lagoon toll bridge. The models developed are based on traffic forecasts prepared by Vollmer Associates (VA) and Barton Aschman Associates (BAA). The Vollmer Associates study was conducted specifically for the San Jose Lagoon bridge while BAA study was conducted as part of the San Juan Regional Transportation Plan. While the numbers in neither study reflect actual conditions, they are the best estimates available concerning the bridge and the San Juan Area.

The results of the VA study were used to estimate a basic demand model for the bridge. This demand model was used to estimate traffic levels at toll rates other than those used by Vollmer Associates. Once this functional relationship was determined, the results of the BAA study were used to isolate specific market segments within the traffic, based on trip purpose. In addition, since the bridge is a specialized facility serving the Luis Munoz Marin International Airport, airport landings were used to estimate trip time distributions for this market segment. The travel times of the different groups were used to estimate an overall travel time distribution for traffic on the bridge. The results of this estimate were compared to actual traffic counts in the area to calibrate the model. Once
the different market segments were determined, direction of travel over the bridge was also estimated using BAA data.

3.1 Base Data

In September, 1990, Vollmer Associates submitted a preliminary traffic and revenue report for the San Jose Lagoon Toll Bridge to assess the feasibility of privatizing the bridge (Vollmer Associates [1990]). Traffic surveys were conducted at several locations on April 25, 1990 in order to gather data concerning traffic characteristics in the area. The survey questions asked motorists to disclose the type of vehicle, origin and destination of the trip, purpose of the trip, and the number of persons in the vehicle. In addition, manual classification counts were made of all vehicles larger than two axles which passed through the stations. The Puerto Rico Department of Transportation and Public Works (DTPW) also performed automatic traffic recorder machine counts for a seven-day period, including the survey day.

The counts that Vollmer Associates received from surveys were combined with the traffic counts from the DTPW in order to estimate average annual daily traffic (AADT) for the area. The origin and destination information along with reconnaissance passenger car trips were used to estimate potential traffic for the bridge. Traffic on the bridge is a function of a variety of factors including travel costs which consist of time costs, operating costs, and toll rates. The reconnaissance car trips recorded the time and distance for each trip and times and distances via the proposed new toll bridge were estimated to compare the two costs. Table 3.1 illustrates the savings that were estimated by using the bridge over alternate routes.
Table 3.1: Illustrative Time and Distance Savings

<table>
<thead>
<tr>
<th>Trip Between</th>
<th>Time Savings (min)</th>
<th>Distance Savings (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Puerto Rico and Airport</td>
<td>13.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Rio Piedras and Airport</td>
<td>10.5</td>
<td>5.0</td>
</tr>
<tr>
<td>Medical Center and Los Angeles Area</td>
<td>6.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Santurce and San Juan, Southeast of Lagoon</td>
<td>6.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Intersection of PR 17 &amp; PR 18 and Isla Verde</td>
<td>4.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Plaza Las Americas and Airport</td>
<td>2.0</td>
<td>---</td>
</tr>
</tbody>
</table>

Source: Vollmer Associates [1990]

The results of the study showed that there were 73,400 potential trips for the bridge. At the time of the initial Vollmer Associates study, no specific toll rate had been set so Vollmer Associates performed traffic analyses for several different tolls. They estimated the diversion to the bridge based on the time and distance comparisons of the toll bridge route versus the toll-free route, the toll rate, other driving considerations, and their experience on numerous other toll facilities. For toll rates between 50 cents and $1.00, traffic was estimated to decrease by 20% for each 25 cent increment. When tolls were increased to $1.25, traffic was estimated to decrease by approximately 25%. A summary of the results is presented in Table 3.2.
Table 3.2: Results of the Vollmer Associates Traffic Study (1990)

<table>
<thead>
<tr>
<th>Toll</th>
<th>Daily Traffic</th>
<th>Yearly Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.00</td>
<td>73,400</td>
<td>---</td>
</tr>
<tr>
<td>$0.50</td>
<td>34,375</td>
<td>$6.3 M</td>
</tr>
<tr>
<td>$0.75</td>
<td>27,500</td>
<td>$7.6 M</td>
</tr>
<tr>
<td>$1.00</td>
<td>22,000</td>
<td>$8.0 M</td>
</tr>
<tr>
<td>$1.25</td>
<td>16,438</td>
<td>$7.5 M</td>
</tr>
</tbody>
</table>

Source: Vollmer Associates [1990]

In conjunction with the Vollmer study, Post, Buckley, Schuh and Jernigan (PBSJ), a consulting firm based in Miami, Florida, performed an analysis to estimate traffic growth in the area. PBSJ's model took into account population, employment, trip generation rates, modal splits, and growth factors for the demographic area and projected an average annual growth rate of 2.1 percent (Bond Prospectus [1992]).

3.2 Toll Sensitivity Functions

The toll sensitivity of users of a toll facility is a function of a variety of factors including socioeconomic characteristics, trip purpose, and travel costs. The socioeconomic characteristics of the San Juan area was not taken into account explicitly by the 1990 Vollmer Associates study. The omission of this data from their forecasts may result in a less accurate demand forecast. However, trip purpose and travel costs were taken into account by using the survey and the reconnaissance car trips.

As mentioned earlier, travel costs include operating costs, travel time costs, and toll rates. The potential traffic estimated by Vollmer Associates took into account the operating costs and travel time costs and varied the toll rate to estimate daily traffic.
Assuming the same distance and time savings for the toll facility versus the toll-free route for different levels of traffic, the traffic becomes a function of only the toll rate.

The traffic on the toll bridge can be modeled in an aggregate fashion by assuming that traffic is a function of toll rate. Several possible functional relationships are explored below.

3.2.1 Linear Model

The simplest way of modeling the relationship between traffic and toll rate is using a linear model. It has the form:

\[ Q = a + bP + \varepsilon \]

where \( a \) and \( b \) are demand parameters, \( Q \) is the number of vehicles per day, \( P \) is the toll rate, and \( \varepsilon \) is the random error term, assumed to be normally distributed with \( E(\varepsilon) = 0 \).

In this case, \( a \) represents the total potential traffic (i.e., the traffic when the toll rate is $0.00) and \( b \) is a toll sensitivity parameter. Using the data from the Vollmer study, linear regression was used to estimate the parameters \( a \) and \( b \). The model was estimated using Statistical Software Tools and the results of the regression are shown in Table 3.3.

The number of degrees of freedom for this sample is \( n-1 \), or 4. A significance level of 0.05 is achieved for t-statistics of 2.776 or greater (Devore [1987]). The t-statistics for \( a \) and \( b \) are greater than this level and therefore we can accept the null hypothesis that demand is a function of \( a \) and \( b \). The estimates for \( a \) and \( b \) are 65,950 and -44,583 respectively. The resulting demand function is:

\[ \hat{Q} = 65,950 - 44,583 \hat{P} \]
Table 3.3: Results of the Linear Demand Model Regression

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Estimated Coefficient</th>
<th>Standard Error</th>
<th>t-statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a )</td>
<td>6.59506e+004</td>
<td>7.07634e+003</td>
<td>9.31987</td>
</tr>
<tr>
<td>( b )</td>
<td>-4.45828e+004</td>
<td>8.61305e+003</td>
<td>-5.17620</td>
</tr>
</tbody>
</table>

Number of Observations: 5
R-squared: 0.89931
Corrected R-squared: 0.86574
Sum of Squared Residuals: 2.05862e+008
Standard Error of the Regression: 8.28376e+003
Durbin-Watson Statistic: 1.75508
Mean of Dependent Variable: 3.47426e+004

A comparison of the model forecasts with the Vollmer forecasts is shown in Figure 3.1 and a quantitative comparison is given in Table 3.4.

Figure 3.1: Linear Demand Model

![Linear Demand Model Graph](image-url)
Table 3.4: Vollmer Forecast vs. Linear Model Forecast

<table>
<thead>
<tr>
<th>Toll</th>
<th>Vollmer Forecast</th>
<th>Model Forecast</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ 0.00</td>
<td>73,400</td>
<td>65,950</td>
<td>+7,450</td>
</tr>
<tr>
<td>$ 0.50</td>
<td>34,375</td>
<td>43,659</td>
<td>-9,284</td>
</tr>
<tr>
<td>$ 0.75</td>
<td>27,500</td>
<td>32,513</td>
<td>-5,013</td>
</tr>
<tr>
<td>$ 1.00</td>
<td>22,000</td>
<td>21,367</td>
<td>+633</td>
</tr>
<tr>
<td>$ 1.25</td>
<td>16,438</td>
<td>10,221</td>
<td>+6,217</td>
</tr>
</tbody>
</table>

The corrected R-squared for the regression is 0.866. This gives the proportion of observed $Q$ variation that can be explained by the simple linear regression model (attributed to an approximate linear relationship between $Q$ and $P$) (Nicholson [1992]). While 0.866 is a good figure, a major problem occurs as a result of using the model for values outside the original range. To be more specific, if the toll rate is greater than about $1.50, traffic becomes negative. Of course this is not possible so a different model has to be used.

One method to solve this problem is to create a piecewise linear function where demand is modeled using two functions over different ranges of values. This type of function may take the following form:

$$Q(P) = \begin{cases} 
Q_1(P) & T \geq P \geq 0 \\
Q_2(P) & P > T 
\end{cases}$$

where $T$ is the toll rate where the function changes. In this way, the negativity could be avoided. But since the fit would still not be very good, this model is rejected as well.
3.2.2 Constant Toll Elasticity Model

The underlying assumption for the second model is that toll elasticities are constant. The constant toll elasticity model has the following form:

\[ Q = aP^b + \varepsilon \]

Again, using data from the Vollmer study, linear regression was used to estimate the parameters \( a \) and \( b \). The following log-linear version of the model was estimated:

\[ \ln Q = \ln a + b \ln P + \varepsilon \]

The dependent variable is the natural logarithm of traffic volume. The regression was run using SST as before. An ordinary least squares estimate was used and the results of the regression are shown in Table 3.5.

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Estimated Coefficient</th>
<th>Standard Error</th>
<th>t-statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \log(a) )</td>
<td>9.94523</td>
<td>4.30282e-002</td>
<td>2.31133e+002</td>
</tr>
<tr>
<td>( b )</td>
<td>-078165</td>
<td>0.10991</td>
<td>-7.11151</td>
</tr>
</tbody>
</table>

Table 3.5: Results of the Constant Elasticity Demand Model Regression

Number of Observations: 4
R-squared: 0.96196
Corrected R-squared: 0.94294
Sum of Squared Residuals: 1.13437e-002
Standard Error of the Regression: 7.53115e-002
Durbin-Watson Statistic: 1.98300
Mean of Dependent Variable: 10.09329
For this analysis, the first observation from the Vollmer study where the toll rate is 0 had to be excluded since the natural log of 0 is infinity. Therefore, this sample only has 3 degrees of freedom and the resulting criteria for the t-statistic with a level of significance of 0.05 is 3.182 (Devore [1987]). Again, the two dependent variables meet the criteria and the estimates for $a$ and $b$ are 20,853 and -0.78165 respectively. The resulting demand function is:

$$Q = 20,853P$$

A comparison of the model forecasts with the Vollmer forecasts is shown in Figure 3.2 and a quantitative comparison is given in Table 3.6.

Figure 3.2: Constant Elasticity Demand Model
The corrected R-squared for this regression is 0.943. While this figure is much better than the linear demand function's corrected R-squared, again, a major problem occurs as a result of using the model for values outside the original range. To be more specific, as the toll rate approaches zero, traffic approaches infinity. The Vollmer study estimates potential traffic as being limited to 73,400 and therefore this model is rejected as well.

### 3.2.3 Exponential Model

The linear model is inappropriate because traffic can be negative while the constant elasticity model is inappropriate because traffic approaches infinity as the toll rate approaches zero. An exponential model solves both of these problems. An exponential function has the following form:

\[ Q = a e^{bp} + e \]

where \( e \) is the base of the natural logarithm (i.e., 2.7182818...).
Once again, using data from the Vollmer study, linear regression was used to estimate the parameters $a$ and $b$. The following semi-log-linear model was estimated:

$$\ln Q = \ln a + bP + \varepsilon$$

The data was run using SST and the results of the regression are shown in Table 3.7.

<table>
<thead>
<tr>
<th>Table 3.7: Results of the Exponential Demand Model Regression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent Variable</td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>log($a$)</td>
</tr>
<tr>
<td>$b$</td>
</tr>
</tbody>
</table>

Number of Observations: 5
R-squared: 0.98494
Corrected R-squared: 0.97992
Sum of Squared Residuals: 1.93432e-002
Standard Error of the Regression: 8.02977e-002
Durbin-Watson Statistic: 2.05788
Mean of Dependent Variable: 10.31537

As with the linear demand function case, the number of degrees of freedom for this sample is 4. The 0.05 level of significance is achieved for t-statistics of 2.776 or greater. Again, the two dependent variables meet the criteria and the estimates for $a$ and $b$ are 68,462 and -1.16953 respectively. The resulting demand function is:

$$\hat{Q} = 68,462e^{-1.16953P}$$

A comparison of the modeled forecasts with the Vollmer forecasts is shown in Figure 3.3 and a quantitative comparison is given in Table 3.8.
Table 3.8: Vollmer Forecast vs. Exponential Model Forecast

<table>
<thead>
<tr>
<th>Toll</th>
<th>Vollmer Forecast</th>
<th>Model Forecast</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.00</td>
<td>73,400</td>
<td>68,462</td>
<td>+4,938</td>
</tr>
<tr>
<td>$0.50</td>
<td>34,375</td>
<td>38,150</td>
<td>-3,775</td>
</tr>
<tr>
<td>$0.75</td>
<td>27,500</td>
<td>28,478</td>
<td>-978</td>
</tr>
<tr>
<td>$1.00</td>
<td>22,000</td>
<td>21,258</td>
<td>+742</td>
</tr>
<tr>
<td>$1.25</td>
<td>16,438</td>
<td>15,869</td>
<td>+569</td>
</tr>
</tbody>
</table>

The corrected R-squared for this regression is 0.980. Considering the advantages of using this model and the high R-squared, this model is accepted for use to forecast demand at other toll rates.
3.3 Using the Revised Base Data

On March 11, 1992, Vollmer Associates issued a revised traffic and revenue report for the San Jose Lagoon Bridge that was the culmination of two years of study and analysis. This report was included in the bond prospectus and was the basis for the bond issue (Bond Prospectus [1992]). As noted in the report, "The extent of motorists' resistance to the continually increasing tolls will depend to a great degree on the annual rates of inflation and the actual value of the dollar." Over the two years of analysis, the number of potential users of the bridge that Vollmer forecast increased from 73,400 to 75,400. The new traffic forecasts replaced the old forecasts for purposes of forecasting revenue and consequently, for the issuance of bonds by the PRHTA. In addition, Autopistas de Puerto Rico (APR), the private concessionnaire, chose an initial toll rate of $1.50 for passenger cars and Vollmer Associates forecasted traffic levels only for this toll rate in the revised report.

Clearly, the model estimated earlier should be revised to take these new forecasts into account. The functional form of the model is assumed to be the same as that used for the earlier forecasts, but with different parameters. The new report forecasts traffic levels of 20,100 at a toll rate of $1.50. Using this information and the revised potential traffic, a model can be constructed. As before (dropping the notation that indicates that these are estimates):

\[ Q = ae^{bp} \]  

(3-1)

Taking the natural log of both sides yields:

\[ \ln Q = \ln a + bP \]

Solving for \( b \) yields:

\[ b = \frac{\ln Q - \ln a}{P} \]  

(3-2)
From equation 3-1, when the toll rate, \( P \), is $0.00, \( Q = 75,400 \) and therefore \( a = 75,400 \). When \( P \) is $1.50, \( Q = 20,100 \) and therefore from equation 3-2:

\[
b = \frac{\ln(20,100) - \ln(75,400)}{1.50} = -0.8813916
\]

The new equation for demand on the toll bridge is:

\[
Q = 75,400e^{-0.8813916P}
\]

The quantity obtained from this equation is total demand for the bridge. Vollmer Associates segmented total demand on the bridge into two markets, "Airport" and "All Other." A summary of the demand by each group is shown in Table 3.9.

<table>
<thead>
<tr>
<th></th>
<th>Airport</th>
<th>All Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential Traffic</td>
<td>17,100</td>
<td>58,300</td>
<td>75,400</td>
</tr>
<tr>
<td>Bridge Traffic</td>
<td>9,600</td>
<td>10,500</td>
<td>20,100</td>
</tr>
<tr>
<td>Percent Bridge</td>
<td>56.1%</td>
<td>18.0%</td>
<td>26.7%</td>
</tr>
</tbody>
</table>

Source: Bond Prospectus [1992]

By using the same methods as above, demand equations can be derived for each market segment using data from Table 3.9.

From equation 3-1, for airport traffic, \( Q = 17,100 \) when \( P = $0.00 \) and therefore \( a = 17,100 \). When \( P = $1.50 \), \( Q = 9,600 \). Solving for \( b \) using equation 3-2 yields the following equation:
\[ b = \frac{\ln(9,600) - \ln(17,100)}{1.50} = -0.3848769 \]

The equation for airport traffic demand is:

\[ Q = 17,100e^{-0.3848769p} \]

Similar calculations yield the following equation for "all other" traffic:

\[ Q = 58,300e^{-1.1428179p} \]

In addition to average daily traffic, the distribution of traffic throughout the day is also an important factor to analyze if separate time-of-day tolls are to be used.

### 3.4 A Closer Look at Airport Related Traffic

The San Jose Lagoon Bridge is a specialized facility in that it connects the Luis Munoz Marin International Airport with areas to the south of the San Jose Lagoon. Traffic to and from the airport will depend mainly on flight arrivals and departures. When a plane arrives, passengers use ground transportation such as taxis or private autos to get to their final destination. A passenger who has to catch a plane usually takes ground transportation and arrives at the airport early. Therefore, by documenting aircraft landings and departures on an hourly basis, traffic flow to and from the airport can be forecast. Data was unavailable for flights leaving the Luis Munoz Marin International Airport but a comparison between flight arrivals and flight departures published in Profiles of Scheduled Air Carrier Departure and Arrival Operations for Top 100 U.S. Airports (DOT [1978]) showed a fairly even distribution between departures and arrivals on an hourly basis.
The OAG Desktop Flight Guide published by Official Airline Guides, a division of Reed Travel Group, gives detailed airline landing information for both international and domestic flights (OAG [1994]). The distribution of flights into the Luis Munoz Marin International Airport is shown in Figure 3.4.

Figure 3.4: Airline Landings at the Luis Munoz Marin International Airport

As shown above, airline landings, much like vehicular traffic, experiences peak periods. For the Luis Munoz Marin International Airport, peak hours occur between 1 p.m. and 2 p.m. and between 5 p.m. and 6 p.m. As soon as an airplane lands, passengers disembark and contribute to vehicular traffic relatively quickly. Furthermore, departing passengers are assumed to be traveling to the airport as their airplane arrives, allowing enough time for baggage check-in and for the airplane to be serviced.
3.5 A More Disaggregate Analysis

In order to gain a better understanding of who is affected by toll rate increases, the "all other" segment of the market must be further disaggregated into separate groups. The Barton Aschman Associates study provided market segment data for further analysis.

As part of the San Juan Regional Transportation Plan study, Barton Aschman Associates (BAA) developed a detailed travel demand model for the entire region. Between 1990 and 1992, a full set of state-of-the-practice travel demand forecasting models was developed and validated for the 12 municipios comprising the San Juan Region (BAA [1993]). The development of the models was initiated in 1990 with the collection of transportation system data and travel survey data including:

- An inventory of the major roadway network.
- A home interview travel survey of daily travel characteristics for over 1,600 households in the region.
- An establishment survey of travel characteristics of employees and visitors to commercial and public establishments.
- Comprehensive traffic counts at ten external stations.
- A survey of travel characteristics of passengers in autos entering and passing through the San Juan Region at ten external stations.
- Relevant transit data.
- 1990 census data.
The travel model employed follows the basic travel demand forecasting process with a slight modification to include time-of-day travel. This process is summarized below:

1) Trip generation
2) Trip Distribution
3) Mode choice
4) Time-of-day of travel
5) Trip Assignment

The models were implemented using EMME/2, a state-of-the-art travel modeling package. Once the models were constructed, they were validated by inputting observed data into the models, running the models, and comparing the output from the models to observed data (BAA [1992]).

3.5.1 Trip Generation Model

The data collected through survey and census data was analyzed to estimate demographic characteristics of the San Juan region. First, BAA used survey and census data to estimate households by income group and household size. The trip generation model developed by BAA used these variables as independent variables to estimate the number of trips produced by each household. Then, trip attraction models were developed based on traffic analysis zones using basic employment, retail employment, service employment, government employment, households, and population as the primary independent variables (BAA [1992]).

As part of their analysis, trip purposes were disaggregated into the following groups (BAA [1992]):
Home-Based Work (HB Work)
This purpose includes all travel made in motorized vehicles for the purpose of work and which begins or ends at the traveler's home. This trip is the most regularly made trip and has definite peaking characteristics in the morning and afternoon peak periods.

Home-Based Shop (HB Shop)
This purpose includes trips made in motorized vehicles for any type of shopping with one end of the trip being at the traveler's home.

Home-Based School (HB School)
This purpose includes all trips made in motorized vehicles for the purpose of school with one end of the trip being at the traveler's home. As with work purpose, school trips have definite peaking characteristics in the morning and afternoon.

Home-Based Other (HB Other)
This trip purpose includes all trips made in motorized vehicles that have one end at the home, with the exception of trips made for work, shop, or school purposes. This could include trips made for social visits, recreation, personal business such as to a doctor's or dentist's office or a bank, etc.

Non-Home-Based (Non HB)
This trip purpose includes all trips made in motorized vehicles for which neither end is at the trip maker's home. This trip purpose is a "grab bag" since the true trip purpose could be for work, shopping, school, or other.

The 1991 home-interview travel survey revealed the breakdown of trip purposes as shown in Table 3.10.
Table 3.10: 1991 Trip Purposes From Survey Data

<table>
<thead>
<tr>
<th>Trip Purpose</th>
<th>Percent of Total Trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>HB Work</td>
<td>18.4%</td>
</tr>
<tr>
<td>HB Shop</td>
<td>8.6%</td>
</tr>
<tr>
<td>HB School</td>
<td>14.5%</td>
</tr>
<tr>
<td>HB Other</td>
<td>34.2%</td>
</tr>
<tr>
<td>Non-HB</td>
<td>24.3%</td>
</tr>
</tbody>
</table>

Source: BAA [1992]

In addition to performing an area-wide analysis based on traffic analysis zones, the Luis Munoz Marin International Airport was treated as a special generator. The survey data was further disaggregated into different modes. The distribution of vehicle trips is given in Table 3.11.

Table 3.11: 1991 Vehicle Trip Purposes From Survey Data

<table>
<thead>
<tr>
<th>Trip Purpose</th>
<th>Percent of Total Trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>HB Work</td>
<td>29.4%</td>
</tr>
<tr>
<td>HB Shop</td>
<td>8.8%</td>
</tr>
<tr>
<td>HB School</td>
<td>4.2%</td>
</tr>
<tr>
<td>HB Other</td>
<td>33.4%</td>
</tr>
<tr>
<td>Non-HB</td>
<td>24.2%</td>
</tr>
</tbody>
</table>

Source: BAA [1992]

The results show that more trips to and from work (HB Work) are being made by auto as a percentage of auto trips than for all trips using all modes. In addition, less trips to and from school are being made by auto as a percentage of auto trips than for all trips.
using all modes. These two results are not surprising considering that people who work are likely to have higher incomes than students, resulting in more trips being made by auto.

An alternative way to disaggregate trips when data is unavailable for a certain region is to use data obtained by The Department of Transportation which regularly conducts a national survey to estimate the characteristics of traffic. The 1990 Nationwide Personal Transportation Survey gives a breakdown similar to the BAA study but for the entire nation. The time of day is divided into seven segments of 3 to 5 hours each. By grouping departure times together like this, a better estimate of the characteristics of actual traffic flow can be achieved. The NPTS study divides traffic into five separate groups as summarized in Table 3.12.

<table>
<thead>
<tr>
<th>Trip Purpose</th>
<th>Percent of Total Trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earning a Living</td>
<td>21.6%</td>
</tr>
<tr>
<td>Family and Personal Business</td>
<td>41.5%</td>
</tr>
<tr>
<td>Civic, Educational, &amp; Religious</td>
<td>11.4%</td>
</tr>
<tr>
<td>Social and Recreational</td>
<td>24.8%</td>
</tr>
<tr>
<td>Other</td>
<td>0.7%</td>
</tr>
</tbody>
</table>

Source: NPTS Databook [1993]

### 3.5.2 Time-of-Day Analysis

The BAA survey data also revealed when people made trips. The results of which are summarized in Figure 3.5.
The aggregate trip time distribution shows peaking in the morning and afternoon due to HB Work and HB School trips. Heaviest flows occur between the hours of 7 a.m. and 8 a.m. in the morning and 5 p.m. and 6 p.m. in the afternoon. The following Figures disaggregate time-of-day behavior into the five market segments outlined previously.

Figure 3.5: Total BAA Trip Time Distribution

Source: BAA[1992]

Figure 3.6: Home-Based Work Trip Time Distribution

Source: BAA[1992]
As discussed earlier and shown in Figure 3.6, the Home-Based Work segment of the traffic experiences definite peaking in the morning and afternoon. Since HB Work trips make up a large percentage of overall vehicle trips (29.4%), they have a big influence on total traffic in the area during peak periods.

Figure 3.7: Home-Based Shop Trip Time Distribution

Source: BAA[1992]

The Home-Based Shop trip time distribution (Figure 3.7) shows a more evenly spread distribution of trips relative to HB Work trips. A majority of the trips are made inter-peak with off-peak periods not having much traffic at all. The distribution is indicative of the hours that businesses are open and since shopping can be done at any time during these hours, the distribution is more evenly spread.
The Home-Based School trip time distribution (Figure 3.8) shows a high peak in the morning with a smaller peak in the afternoon. This may be due to students arriving to school at about the same time and being let out at different times. For example, both grade school and college may start at the same time but grade school students are more likely to be let out earlier since their academic workload is not as intense as college students'.

The distribution for Home-Based Other trips (Figure 3.9) is similar to that of Home-Based School. This segment of travelers includes doctor's appointments and other errands. The peak in the morning may be due to people wanting to run errands at the beginning of the day in order to get them out of the way so that they can have the rest of the day to work or go to school. However, the length of the errand may vary depending on the purpose. Consequently, the number of trips is fairly evenly distributed after the morning peak.
The Non Home-Based trip time distribution (Figure 3.10) is similar to the Home-Based Shop trip time distribution with a clearly visible peak between 12 p.m. and 1 p.m. These trips consist of trips taken during the day while at work or at school. The peak between 12 p.m. and 1 p.m. probably reflects lunch hour traffic during the business day.
The shape of the distribution is pyramid-like, culminating in the lunch hour peak. Since most home-based trips occur during the peak period, these Non HB trips occur inter-peak, after people get to work or school and before they leave for home.

Since the NPTS data was aggregated into time blocks, the distribution of trips for the NPTS model was divided evenly among the hours within each group. For example, if 12% of the traffic traveled between the hours of 6 a.m. and 9 a.m., 4% of the traffic was allocated for each of the three hours within the time group. The resulting distributions are shown in the following figures.

Figure 3.11: Earning a Living Trip Time Distribution

![Graph showing the distribution of earning a living trips by time. The graph shows two peaks in the morning and afternoon.]

Source: NPTS Databook [1993]

As with the HB Work segment of the BAA analysis, the Earning a Living trip time distribution has two distinct peaks in the morning and afternoon as shown in Figure 3.11.

The distribution for Civil, Educational & Religious trips shown in Figure 3.12 is similar to the Home-Based School distribution obtained by BAA.
Figure 3.12: Civic, Educational, & Religious Trip Time Distribution

![Bar graph showing Civic, Educational, & Religious Trip Time Distribution](image)

Source: NPTS Databook [1993]

Figure 3.13: Family and Personal Business Trip Time Distribution

![Bar graph showing Family and Personal Business Trip Time Distribution](image)

Source: NPTS Databook [1993]

The Family and Personal Business trip time distribution (Figure 3.13) shows a similar pattern to the Non Home-Based distribution. However, these trips make up a larger percentage of total trips when compared to the Non Home-Based percentage.
The Social and Recreational trip time distribution (Figure 3.14) is similar to the Family and Personal Business trip time distribution but is shifted more toward the afternoon. This may be due to trips made after work or for dinner.
The "Other" segment of the market only makes up 0.7% of all trips. However, within this small segment, there exists a peak in the early afternoon as shown in Figure 3.15. These totals have a small effect on the total traffic distribution (Figure 3.16).

![Figure 3.16: Total NPTS Trip Time Distribution](image)

Source: NPTS Databook [1993]

In order to get an idea of what current conditions were like, Vollmer Associates obtained traffic counts at eight different locations for a seven day period. These counts were performed between Saturday, April 21, 1990 and Friday, April 27, 1990 (Vollmer Associates [1990]). The stations were located at various points related to airport traffic and were performed by the Puerto Rico Department of Transportation and Public Works (DTPW).

The data was aggregated to reflect average daily traffic distribution. In addition, peak and minimum flows were identified for certain stations to indicate possible variability in the average traffic distribution. A summary of the results is shown graphically in Figure 3.17.
Figure 3.17: Existing Traffic Conditions

The results obtained by aggregating the actual traffic counts shows a more even distribution of traffic than that predicted by the BAA model. Unlike the BAA model, there are no significant peaks in the morning. A comparison of the two results is shown in Figure 3.18.

The discrepancy between the BAA model and the actual traffic counts may be due to the difference in what each is measuring. The BAA model gives departure times for various trip purposes while the traffic counts are actual conditions on the road at different times. For example, if many commuters live far from work, they may depart significantly earlier than the time their vehicle would register at a traffic count station. Moreover, the discrepancy between the BAA model and the actual traffic counts in the period after 6 p.m. also suggests that this is the case. The BAA model predicts more departures before 6 p.m. while the traffic counts suggest greater traffic at periods after 6 p.m.
The total traffic from the NPTS shows less peaking than the BAA study which is more in agreement than the BAA analysis with the actual traffic counts (see Figure 3.19).

Sources: Puerto Rico DTPW [1990] and BAA [1992]
As mentioned earlier, averaging departure times over time periods may be a better way of gauging what actual road conditions will be like. Motorists who live closer to a facility will have an immediate impact on traffic while motorists who live far away will not impact the facility until later. If the BAA data is segmented in the same time groupings as the NPTS study, the results agree more favorably with actual traffic conditions but still overestimates the peak in the morning as shown in Figure 3.20.

Figure 3.20: Average BAA vs. Actual Traffic Counts

Since the NPTS model agrees more with actual observed traffic conditions, both models will be used to assess the impacts of toll increases on traffic on the San Jose Lagoon bridge. While the BAA model was constructed specifically for the San Juan area, the pattern of traffic does not match observed traffic distributions.
3.5.3 Direction Split Factors

From the output obtained from their model, BAA identified an AM peak between the hours of 6:30 a.m. and 8:29 a.m. and a PM peak between the hours of 3:00 p.m. and 6:29 p.m. Directionality of traffic during these hours was estimated using data obtained in the home-survey. Trips were allocated into different categories based on trip purpose, direction, and time of day. The results of their analysis is shown in Table 3.13.

Table 3.13: Directional Trip Time Distribution

<table>
<thead>
<tr>
<th>Trip Purpose</th>
<th>Direction</th>
<th>AM Peak</th>
<th>PM Peak</th>
<th>Off-Peak</th>
<th>Total Daily</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>6:30 - 8:29</td>
<td>3:00 - 6:29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HB Work</td>
<td>From Home</td>
<td>0.303</td>
<td>0.013</td>
<td>0.221</td>
<td>0.537</td>
</tr>
<tr>
<td></td>
<td>To Home</td>
<td>0.003</td>
<td>0.321</td>
<td>0.140</td>
<td>0.463</td>
</tr>
<tr>
<td>HB Shop</td>
<td>From Home</td>
<td>0.041</td>
<td>0.092</td>
<td>0.307</td>
<td>0.440</td>
</tr>
<tr>
<td></td>
<td>To Home</td>
<td>0.014</td>
<td>0.192</td>
<td>0.354</td>
<td>0.560</td>
</tr>
<tr>
<td>HB School</td>
<td>From Home</td>
<td>0.276</td>
<td>0.073</td>
<td>0.203</td>
<td>0.552</td>
</tr>
<tr>
<td></td>
<td>To Home</td>
<td>0.015</td>
<td>0.140</td>
<td>0.293</td>
<td>0.448</td>
</tr>
<tr>
<td>HB Other</td>
<td>From Home</td>
<td>0.134</td>
<td>0.068</td>
<td>0.268</td>
<td>0.471</td>
</tr>
<tr>
<td></td>
<td>To Home</td>
<td>0.065</td>
<td>0.151</td>
<td>0.313</td>
<td>0.529</td>
</tr>
<tr>
<td>Non HB</td>
<td>N/A</td>
<td>0.098</td>
<td>0.240</td>
<td>0.662</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Source: BAA [1992]

The data was converted to percentiles for each time period resulting in Table 3.14.
### Table 3.14: Directional Trip Time Distribution by Percentage

<table>
<thead>
<tr>
<th>Trip Purpose</th>
<th>AM Peak</th>
<th>PM Peak</th>
<th>Total Daily</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6:30 - 8:29</td>
<td>3:00 - 6:29</td>
<td>Off-Peak</td>
</tr>
<tr>
<td>HB Work</td>
<td>From Home</td>
<td>99.0%</td>
<td>3.9%</td>
</tr>
<tr>
<td></td>
<td>To Home</td>
<td>1.0%</td>
<td>96.1%</td>
</tr>
<tr>
<td>HB Shop</td>
<td>From Home</td>
<td>74.5%</td>
<td>32.4%</td>
</tr>
<tr>
<td></td>
<td>To Home</td>
<td>25.5%</td>
<td>67.6%</td>
</tr>
<tr>
<td>HB School</td>
<td>From Home</td>
<td>94.8%</td>
<td>34.3%</td>
</tr>
<tr>
<td></td>
<td>To Home</td>
<td>5.2%</td>
<td>65.7%</td>
</tr>
<tr>
<td>HB Other</td>
<td>From Home</td>
<td>67.3%</td>
<td>31.1%</td>
</tr>
<tr>
<td></td>
<td>To Home</td>
<td>32.7%</td>
<td>68.9%</td>
</tr>
</tbody>
</table>

The data above can be used to allocate traffic during different times of the day by direction based on trip purpose. For example, if 100 people are classified as HB Work during the AM peak period, approximately 99 of them are expected to be headed to work while only 1 of them is expected to be headed toward home. Data for Non-Home-Based trips was not analyzed. For the San Jose Lagoon Bridge analysis, Non HB trips will be assumed to be split 50-50 between the two directions. In addition, trips from home were assumed to be made from North of the bridge while trips to home were assumed to be made from South of the bridge.

#### 3.5.4 The Resulting Disaggregate Models

Three different approaches were used to model demand for the San Jose Lagoon Bridge. The first model (BAA) used hourly market segment data from Barton Aschman Associates for trip time distributions of the various groups. The second model (BAA1),
used BAA data but divided the day into the same time groups as the NPTS model. This was done to adjust for the fact that data was only given for departure times, not actual usage of roads. The third model used the Nationwide Personal Transportation Survey (NPTS) to model how different market segments distribute their trips during the day.

First, the percentage trip time distributions by trip purpose were applied to the "all other" segment of the market from the revised Vollmer study to estimate the number of users that would use the facility if there was no toll. Then, using the equation developed earlier, demand for each segment, each hour, and in each direction were estimated. The equation developed earlier has the form:

\[
Q_i = a_i e^{-0.3845769P}
\]

\[
Q_j = a_j e^{-1.1428179P}
\]

for airport related traffic

for "all other" traffic

where 1 denotes airport related traffic, \( i \) denotes the hour, and \( j \) denotes the market segment group. Different market segments have different demand equations. However, data was unavailable to quantitatively distinguish the various market segments used in this study. Therefore, for the models used in this study, all \( j \)'s were modeled with the same parameters within the "all other" market segment. A discussion of the qualitative differences in demand is given in the following section.

Several different scenarios were established to estimate the effects of different toll rates on both revenues and traffic flows. The Barton Aschman Study determined two distinct peak periods in the morning and afternoon. Traffic flows were estimated to be heaviest during the hours of 6:30 a.m. and 8:29 a.m. for the morning and 3:00 p.m. to 6:29 p.m. in the afternoon. Therefore, rounding to a whole hour, a 24 hour day was divided into the following four periods:
3.5.5 Toll Sensitivity of Different Market Segments

A key concept when analyzing toll rates is the toll sensitivity. A good measure of toll sensitivity is the percentage change in traffic divided by the percentage change in toll rate. The equation for this is:

\[
\text{Toll Sensitivity} = \frac{dQ}{Q} = \frac{dQ}{dP} \cdot \frac{P}{Q}
\]

where \( Q \) is the traffic flow and \( P \) is the toll rate. Using the equation developed earlier relating traffic to price, the change in traffic divided by the change in price can be determined by taking the first derivative of the function as shown below:

\[
\frac{dQ}{dP} = \frac{d(\text{ae}^{bp})}{dP} = bae^{bp}
\]

The resulting price sensitivity becomes:

\[
\text{Toll Sensitivity} = bae^{bp} \frac{Q}{P}
\]
Disaggregating the "all other" group of the Vollmer analysis is approximated by using the five different market segments outline by Barton Aschman Associates.

- Home-Based Work
- Home-Based Shop
- Home-Based School
- Home-Based Other
- Non-Home-Based

Each market segment has its own characteristics and its own price sensitivities. In order to gain a better understanding of how these different groups differ in toll sensitivity, previous studies were used to estimate the qualitative implications.

A particularly relevant study was conducted in Norway for a toll road leading to the airport that has alternate free routes, much like the San Jose Lagoon Bridge (Tretvik [1993]). This study assessed the effect of a toll increase on diversion for the following three different market segments.

- Commuting
- Business
- Other

The first tolled section was opened in 1988 on the E6 national highway route east of the city of Trondheim in the direction of the airport. The motivation for building a new road was to divert through traffic from the heavily built-up area of the old route for environmental and traffic safety reasons and to provide a faster connection between the city and the airport. Tolling is done in both directions, similar to the San Jose Lagoon bridge.
In 1989 a second section was opened and the toll company offered motorists 12.5 km of high performance roadway. The old route had a much lower standard and passed through built-up areas with several local speed limits of 50, 60, or 70 km/hr. Its length was roughly equal to that of the new route, and it was available free of charge.

During 1990, the new motorway was lengthened by 7.5 km in conjunction with an increase in toll rates. The mean costs of using the toll facility increased from 8.85 kroner in 1989 to 17.63 kroner in 1990 (in early January 1993, 1 U.S. Dollar was equivalent to 7 kroner). Interview surveys were conducted on users of both routes in November 1989 and November 1990, and average driving time between key origins and destinations were measured. The average daily traffic on the two routes passing the cross section where the toll plaza is situated was around 18,000 for both interview periods. The average time savings increased from 4.4 minutes in 1989 to 6.8 minutes in 1990. The results of the survey showed that groups labeled as "Commuting" and "Other" reacted more sharply to the price increases than did the "Business" group. A summary of the results is shown in Table 3.15.

<table>
<thead>
<tr>
<th>Year</th>
<th>Commuting</th>
<th>Business</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>45.0%</td>
<td>71.2%</td>
<td>53.0%</td>
<td>53.8%</td>
</tr>
<tr>
<td>1990</td>
<td>27.8%</td>
<td>61.5%</td>
<td>36.8%</td>
<td>39.6%</td>
</tr>
</tbody>
</table>

Source: Tretvik [1993]

Since average daily traffic remained about the same for both years, the price sensitivities of each group can be measured indirectly. For example, if there were 100 users classified as "Commuting" in 1989 and 100 users classified as "Commuting in 1990, approximately 45 of those in 1989 used the tolled section while only about 28 of them
used it in 1990. Since the magnitude of the change in toll rate is known, toll sensitivities can be approximated using equation 3-3. Using this equation, the price sensitivities were calculated as shown in Table 3.16.

Table 3.16: Toll Sensitivities

<table>
<thead>
<tr>
<th>Price Sensitivity</th>
<th>Commuting</th>
<th>Business</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-0.385</td>
<td>-0.137</td>
<td>-0.308</td>
<td>-0.266</td>
</tr>
</tbody>
</table>

An attempt at using these values for the San Jose Lagoon Bridge was made but the results obtained in Table 3.16 turned out not to be applicable to the bridge (see Appendix A for calculations). Although these market groups were found to have different toll sensitivities, data was unavailable for the San Juan area. Therefore, it was assumed that each market segment within the "other" group had the same toll sensitivities. This is a limitation of data available, not of the model itself.
Chapter 4

Analysis of Different Toll Policies

The magnitude and variability of toll rates can be set depending on the specific goals of the operator of a toll facility. If revenue maximization is the goal, then the trade-offs between a higher toll rate and a lower number of users must be considered. If regulation of the rate of return for the toll road operator is the goal, then toll rates could be set so as to maximize use by the public while still achieving a required rate of return. If congestion management is the goal, then toll rates could be varied within the day to spread demand more evenly throughout the day. If revenue maximization is the goal with an allowance for price discrimination, different toll rates could be charged to different market segments.

This chapter first examines the impacts of revenue maximization using three separate models. Then, one model is used to design a tolling scheme to regulate rate of return. The third section uses one model to explore different toll rates that could be used for congestion management purposes. The fourth section examines toll rates that could be used to maximize revenue using price discrimination. The chapter concludes by discussing limitations of the model.
4.1 Revenue Maximization

First, revenue maximization was set as the objective function with various decision variables and constraints of non-negativity and equal toll rates for various periods. Daily revenue is defined as the sum over all hours of the day (i.e., 12:00 a.m. to 11:59 p.m.) of the product of toll rate and traffic flow. This is expressed mathematically as:

\[ R = \sum_{i=1}^{24} P_i \cdot Q_i \]

where \( R \) is the daily revenue, \( P_i \) is the toll rate for the \( i \)th period and \( Q_i \) is the traffic flow for the \( i \)th period. No constraints on capacity were used because traffic flows were forecast not to approach the capacity of the bridge. If flows were found to be significant enough to impact travel times, then a constraint on the number of users per period could be set. This type of scheme is explored in the congestion pricing section of this chapter.

The scenarios shown in Table 4.1 were analyzed for each of the three different traffic distribution models: BAA, BAA1, and NPTS.

Scenarios 1 through 3 were modeled because each period has distinct traffic distributions as discussed near the end of Chapter 3. Scenario 4 was modeled in order to determine the theoretical maximum revenue that could be achieved by varying toll rates on an hourly basis. For this scenario, toll rates change each hour based on traffic characteristics. A similar type of scenario is being considered for the SR-91 median toll road in Orange County, California as toll rates would change continuously throughout the day depending on traffic conditions.
Table 4.1: Revenue Maximizing Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maximize revenue using one toll rate throughout the entire day.</td>
</tr>
<tr>
<td>2</td>
<td>Maximize revenue using different peak and off-peak toll rates throughout the day.</td>
</tr>
<tr>
<td>3</td>
<td>Maximize revenue using different a.m. peak, inter-peak, p.m. peak, and off-peak toll rates throughout the day.</td>
</tr>
<tr>
<td>4</td>
<td>Maximize revenue using different toll rates for each hour throughout the day.</td>
</tr>
</tbody>
</table>

The general form of the math program is as follows:

$$\text{maximize } \sum_{j=1}^{6} \sum_{i=1}^{24} P_i Q_j(P_i)$$

where $j$ is the specific market segment and $i$ is the hour. As mentioned in the previous chapter, $j=1$ describes airport related traffic while $j=2,3,4,5$ and 6 describe the various market segments within the "all other" group in the revised Vollmer study. The equations for $Q_j$ are the same for $j=2,3,4,5$ and 6 because data was unavailable to differentiate the market segments. However, it is still useful to disaggregate the "all other" group to estimate the impact of toll rates on each market segment. The hours were assigned values based on military time depending on the last minute within the hour. For example, the period between 12:01 a.m. and 1 a.m. was assigned an $i$ of 1. The difference between the
various scenarios lies in the constraints that are used. The specific math program for scenario 1 is:

$$\begin{align*}
\text{maximize} & \sum_{j=1}^{6} \sum_{i=1}^{24} P_i \cdot Q_j(P_i) \\
\text{subject to: } & P_1 = P_2 = \ldots = P_{24} \\
& P_i \geq 0 \quad i = 1, 2, 3, \ldots 24
\end{align*}$$

The specific math program for scenario 2 is:

$$\begin{align*}
\text{maximize} & \sum_{j=1}^{6} \sum_{i=1}^{24} P_i \cdot Q_j(P_i) \\
\text{subject to: } & P_1 = P_2 = P_3 = P_4 = P_5 = P_6 = P_{20} = P_{21} = P_{22} = P_{23} = P_{24} \\
& P_7 = P_8 = P_9 = \ldots = P_{19} \\
& P_i \geq 0 \quad i = 1, 2, 3, \ldots 24
\end{align*}$$

The specific math program for scenario 3 is:

$$\begin{align*}
\text{maximize} & \sum_{j=1}^{6} \sum_{i=1}^{24} P_i \cdot Q_j(P_i) \\
\text{subject to: } & P_1 = P_2 = P_3 = P_4 = P_5 = P_6 = P_{20} = P_{21} = P_{22} = P_{23} = P_{24} \\
& P_7 = P_8 = P_9 = \ldots = P_{19} \\
& P_i \geq 0 \quad i = 1, 2, 3, \ldots 24
\end{align*}$$

The specific math program for scenario 4 is:

$$\begin{align*}
\text{maximize} & \sum_{j=1}^{6} \sum_{i=1}^{24} P_i \cdot Q_j(P_i) \\
\text{subject to: } & P_i \geq 0 \quad i = 1, 2, 3, \ldots 24
\end{align*}$$
The Solver function in Microsoft Excel was used to determine optimal solutions. It uses the simplex method with bounds on the variables and the branch and bound method for linear and integer problems.

First, the BAA trip distribution model was used for the above four scenarios. The results are summarized in Table 4.2.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original Toll Rate</td>
<td>$1.50</td>
<td>$1.50</td>
<td>$1.50</td>
<td>$1.50</td>
</tr>
<tr>
<td>New Toll Rate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 a.m. to 9 a.m.</td>
<td>$1.22</td>
<td>$1.20</td>
<td>$0.94</td>
<td>varies¹</td>
</tr>
<tr>
<td>9 a.m. to 3 p.m.</td>
<td>$1.22</td>
<td>$1.20</td>
<td>$1.34</td>
<td>varies</td>
</tr>
<tr>
<td>3 p.m. to 7 p.m.</td>
<td>$1.22</td>
<td>$1.20</td>
<td>$1.28</td>
<td>varies</td>
</tr>
<tr>
<td>7 p.m. to 6 a.m.</td>
<td>$1.22</td>
<td>$1.30</td>
<td>$1.30</td>
<td>varies</td>
</tr>
<tr>
<td>Additional Rev/year</td>
<td>$195,550</td>
<td>$198,620</td>
<td>$280,340</td>
<td>$350,500</td>
</tr>
</tbody>
</table>

Debt service for the bridge is $7.38 million each year between 1993 and 1998. The additional revenue that can be achieved represents an increase of 2.65% to 4.75% of the debt service. The effects of the new toll rate on different market segments relative to the initial toll of $1.50 is shown in Table 4.3.

The market segment that would benefit most from a flat decrease in toll rate (Scenario 1) would be Home-Based Other trips. This is because these trips make up the largest percentage of trips out of the groups categorized in the "all other" market and therefore would benefit most in number to a decrease in the toll. Airport related trips are projected by Vollmer Associates to make up almost half of the bridge traffic at the initial toll.

¹ For the exact toll rate for each hour, refer to Appendix B.
toll rate of $1.50. However, since this group is less price sensitive than the "all other" market segment, the toll decrease does not have a proportional effect.

Table 4.3: Effects of the New Toll Rate on Traffic in Model BAA

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airport Related</td>
<td>+1,100</td>
<td>+1,089</td>
<td>+798</td>
<td>+549</td>
</tr>
<tr>
<td>HB Work</td>
<td>+1,173</td>
<td>+1,182</td>
<td>+1,587</td>
<td>+1,816</td>
</tr>
<tr>
<td>HB School</td>
<td>+168</td>
<td>+167</td>
<td>+213</td>
<td>+217</td>
</tr>
<tr>
<td>HB Other</td>
<td>+1,333</td>
<td>+1,302</td>
<td>+1,388</td>
<td>+1,365</td>
</tr>
<tr>
<td>HB Shop</td>
<td>+351</td>
<td>+357</td>
<td>+273</td>
<td>+259</td>
</tr>
<tr>
<td>Non HB</td>
<td>+965</td>
<td>+992</td>
<td>+800</td>
<td>+867</td>
</tr>
<tr>
<td>Total</td>
<td>+5,090</td>
<td>+5,089</td>
<td>+5,059</td>
<td>+5,073</td>
</tr>
</tbody>
</table>

As the day is divided into two periods and four periods (Scenarios 2 and 3 respectively), the number of Home-Based Work trips crossing the bridge increases markedly. The reasons behind this lie in the assumption that there are no capacity constraints. The results show that, in order to maximize revenue, the toll should be reduced during peak hours. Since the facility has capacity to spare, the additional traffic added to the bridge more than makes up for the reduction in toll rate. This policy may be contradictory to congestion management goals for highways in the immediate area. Traffic must be analyzed from a broad perspective as changing traffic levels on one facility will have an impact on other facilities in the area. However, if there is capacity to spare throughout the region, then this type of scheme may be acceptable. Scenario 4 gives a theoretical maximum toll rate on an hourly basis. This tolling scheme may be impractical to implement but serves as an upper-bound to the amount of additional revenue that can be achieved by varying the toll rates throughout the day.
The second model used was a modified version of the Barton Aschman model. It averaged traffic distributions for various periods throughout the day in order for the model to agree more with actual measured traffic counts. The results of the revenue maximizing analysis is summarized in Table 4.4.

Table 4.4: Results of the BAA1 Model

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original Toll Rate</td>
<td>$1.50</td>
<td>$1.50</td>
<td>$1.50</td>
<td>$1.50</td>
</tr>
<tr>
<td>New Toll Rate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 a.m. to 9 a.m.</td>
<td>$1.22</td>
<td>$1.20</td>
<td>$0.94</td>
<td>varies²</td>
</tr>
<tr>
<td>9 a.m. to 3 p.m.</td>
<td>$1.22</td>
<td>$1.20</td>
<td>$1.33</td>
<td>varies</td>
</tr>
<tr>
<td>3 p.m. to 7 p.m.</td>
<td>$1.22</td>
<td>$1.20</td>
<td>$1.29</td>
<td>varies</td>
</tr>
<tr>
<td>7 p.m. to 6 a.m.</td>
<td>$1.22</td>
<td>$1.30</td>
<td>$1.30</td>
<td>varies</td>
</tr>
</tbody>
</table>

The effects of the new toll rate on different market segments is outlined in Table 4.5. The results show that averaging the traffic for different periods, as in model BAA1, does not have much of an effect on either the optimal toll rate or aggregate changes of different market segments on the bridge when compared to model BAA. However, the theoretical maximum additional revenue changes from $350,500 to $338,160. Since traffic distribution was averaged over various periods in model BAA1 and toll rates were set for specific periods as well, the results agree well with model BAA up to scenario 3. However, as the day is divided further, the effects of averaging traffic distributions is seen as in scenario 4.

² For the exact toll rate for each hour, refer to Appendix B.
Table 4.5: Effects of the New Toll Rate on Traffic in Model BAA1

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airport Related</td>
<td>+1,100</td>
<td>+1,088</td>
<td>+800</td>
<td>+591</td>
</tr>
<tr>
<td>HB Work</td>
<td>+1,172</td>
<td>+1,182</td>
<td>+1,573</td>
<td>+1,715</td>
</tr>
<tr>
<td>HB School</td>
<td>+168</td>
<td>+167</td>
<td>+213</td>
<td>+218</td>
</tr>
<tr>
<td>HB Other</td>
<td>+1,333</td>
<td>+1,302</td>
<td>+1,391</td>
<td>+1,393</td>
</tr>
<tr>
<td>HB Shop</td>
<td>+351</td>
<td>+357</td>
<td>+274</td>
<td>+287</td>
</tr>
<tr>
<td>Non HB</td>
<td>+964</td>
<td>+991</td>
<td>+807</td>
<td>+861</td>
</tr>
<tr>
<td>Total</td>
<td>+5,087</td>
<td>+5,087</td>
<td>+5,057</td>
<td>+5,065</td>
</tr>
</tbody>
</table>

While model BAA and model BAA1 agree with each other in terms of revenue maximizing toll rate and effects on market segments, model NPTS resulted in different revenue maximizing toll rates for scenarios 2, 3, and 4 as shown in Table 4.6.

Table 4.6: Results of the NPTS Model

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original Toll Rate</td>
<td>$1.50</td>
<td>$1.50</td>
<td>$1.50</td>
<td>$1.50</td>
</tr>
<tr>
<td>New Toll Rate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 a.m. to 9 a.m.</td>
<td>$1.22</td>
<td>$1.24</td>
<td>$0.99</td>
<td>varies³</td>
</tr>
<tr>
<td>9 a.m. to 3 p.m.</td>
<td>$1.22</td>
<td>$1.24</td>
<td>$1.34</td>
<td>varies</td>
</tr>
<tr>
<td>3 p.m. to 7 p.m.</td>
<td>$1.22</td>
<td>$1.24</td>
<td>$1.25</td>
<td>varies</td>
</tr>
<tr>
<td>7 p.m. to 6 a.m.</td>
<td>$1.22</td>
<td>$1.14</td>
<td>$1.14</td>
<td>varies</td>
</tr>
<tr>
<td>Additional Rev/year</td>
<td>$195,620</td>
<td>$200,660</td>
<td>$236,650</td>
<td>$281,570</td>
</tr>
</tbody>
</table>

³ For the exact toll rate for each hour, refer to Appendix B.
The effects of the new toll rate on different market segments is outlined in Table 4.7. The tolling scheme for Scenario 1 agrees with the BAA and BAA1 models because the day is analyzed at an aggregate level. However, the NPTS model, unlike the BAA models, uses a higher toll rate during peak periods than off-peak periods in order to maximize revenue for the two period scenario (Scenario 2). This is because the Barton Aschman Model forecasts higher volumes of traffic during peak periods than the NPTS model. Therefore, as noted earlier, the higher volume can make up for lost revenues due to lower toll rates. When the day is divided into four periods, the results of the NPTS model agree more with the BAA and BAA1 models for the peak periods but has a toll rate 12% less during the off-peak period.

Table 4.7: Effects of the New Toll Rate on Traffic in Model NPTS

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airport Related</td>
<td>+1,100</td>
<td>+1,082</td>
<td>+953</td>
<td>+792</td>
</tr>
<tr>
<td>Earning a Living</td>
<td>+862</td>
<td>+845</td>
<td>+1,085</td>
<td>+1,149</td>
</tr>
<tr>
<td>Civic, Educ., &amp; Religious</td>
<td>+455</td>
<td>+433</td>
<td>+536</td>
<td>+551</td>
</tr>
<tr>
<td>Family &amp; Personal</td>
<td>+989</td>
<td>+961</td>
<td>+867</td>
<td>+903</td>
</tr>
<tr>
<td>Social &amp; Recreational</td>
<td>+1,656</td>
<td>+1,741</td>
<td>+1,614</td>
<td>+1,654</td>
</tr>
<tr>
<td>Other</td>
<td>+28</td>
<td>+27</td>
<td>+27</td>
<td>+28</td>
</tr>
<tr>
<td>Total</td>
<td>+5,091</td>
<td>+5,090</td>
<td>+5,080</td>
<td>+5,077</td>
</tr>
</tbody>
</table>

Even though traffic is categorized into different market segments, the total number of users affected remains the same for all three demand models. The reason is that as an aggregate group (i.e. "all other"), all three models use the same price sensitivity parameters. All three models also agree fairly well with respect to the magnitude of the toll rate as shown in Table 4.8.
The NPTS study gives a general description of demand for the entire United States. This model may be appropriate if no other data is available regarding market segmentation and trip distributions. However, the BAA trip distribution model gives specific data for the San Juan area and may be more appropriate to use in order to model demand on the San Jose Lagoon Bridge. If model BAA is found to be inaccurate, then model NPTS could be used as a generic model. The following scenarios use model BAA for simplicity but any of the three models could be used if desired.

4.2 Rate of Return Constraints

Since there was not much of a difference between the models BAA and BAA1 for scenarios one, two, and three, model BAA will be used to model the effects of rate of return constrained scenarios outlined in Table 4.9.

Scenario 1 would give APR the base rate of return outlined in the Concession Agreement. Any revenues above 19% would be shared between the PRHTA and APR. It may be in the PRHTA's interest to maintain a rate of return at this level since users may question whether excessive toll rates are being charged if the return is higher than 19%.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Toll Rate</td>
<td>$1.22</td>
<td>$1.14</td>
<td>$0.94</td>
<td>$0.87</td>
</tr>
<tr>
<td>Maximum Toll Rate</td>
<td>$1.22</td>
<td>$1.30</td>
<td>$1.34</td>
<td>$1.59</td>
</tr>
</tbody>
</table>
Table 4.9: Maximizing Use Scenarios Subject to Rate of Return Constraints

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maximize number of users subject to a rate of return of 19% constraint using one toll rate throughout the day.</td>
</tr>
<tr>
<td>2</td>
<td>Maximize number of users subject to a rate of return of 0% constraint using one toll rate throughout the day.</td>
</tr>
</tbody>
</table>

If the bridge is turned over to the PRHTA from APR under the termination option, the PRHTA may just want to "break-even" and collect just enough revenues to cover debt service. This event is modeled in Scenario 2. The specific math program for scenario 1 is:

\[
\text{maximize } \sum_{j=1}^{6} \sum_{i=1}^{24} Q_j(P_i) \\
\text{subject to: } \sum_{j=1}^{6} \sum_{i=1}^{24} P_i Q_j(P_i) \leq 1.19D \quad i = 1, 2, 3, ..., 24, j = 1, 2, 3, 4, 5, 6 \\
P_i = P_2 = ... = P_{24} \\
P_i \geq 0 \quad i = 1, 2, 3, ..., 24 
\]

where \( D \) is the revenue necessary for debt service. The specific math program for scenario 2 is:

\[
\text{maximize } \sum_{j=1}^{6} \sum_{i=1}^{24} Q_j(P_i) \\
\text{subject to: } \sum_{j=1}^{6} \sum_{i=1}^{24} P_i Q_j(P_i) \leq 1.00D \quad i = 1, 2, 3, ..., 24, j = 1, 2, 3, 4, 5, 6 \\
P_1 = P_2 = ... = P_{24} \\
P_i \geq 0 \quad i = 1, 2, 3, ..., 24 
\]
The above scenarios each have two solutions. Revenue from the toll bridge is a function of two variables: the toll rate and the number of users (see Figure 4.1).

Figure 4.1: Toll Rate vs. Revenue

Therefore, when using revenue as one of the constraints, one solution gives a low number of users and a high toll rate while the other solution gives a high number of users and a low toll rate. As shown in Figure 4.1, only the maximum revenue has a unique solution.

The debt service for the bonds issued by the PRHTA for the San Jose Lagoon Bridge are constant from 1993 to 1998 at $7.38 million per year. Debt service for the bridge up to the year 2000 is shown in Table 4.10.
Therefore, a rate of return of 19% for the years 1993 to 1998 would require $8.78 million per year. Using this value as an upper limit to revenue in the Excel Solver spreadsheet for scenario 1 results in the two solutions shown in Table 4.11.

Table 4.10: Debt Service for the San Jose Lagoon Bridge

<table>
<thead>
<tr>
<th>YEAR</th>
<th>PRINCIPAL (MILLIONS)</th>
<th>INTEREST (MILLIONS)</th>
<th>TOTAL REQUIRED (MILLIONS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>$0.00</td>
<td>$1.84</td>
<td>$1.84</td>
</tr>
<tr>
<td>1993</td>
<td>$0.00</td>
<td>$7.38</td>
<td>$7.38</td>
</tr>
<tr>
<td>1994</td>
<td>$0.00</td>
<td>$7.38</td>
<td>$7.38</td>
</tr>
<tr>
<td>1995</td>
<td>$0.00</td>
<td>$7.38</td>
<td>$7.38</td>
</tr>
<tr>
<td>1996</td>
<td>$0.00</td>
<td>$7.38</td>
<td>$7.38</td>
</tr>
<tr>
<td>1997</td>
<td>$0.00</td>
<td>$7.38</td>
<td>$7.38</td>
</tr>
<tr>
<td>1998</td>
<td>$0.00</td>
<td>$7.38</td>
<td>$7.38</td>
</tr>
<tr>
<td>1999</td>
<td>$0.57</td>
<td>$7.38</td>
<td>$7.95</td>
</tr>
<tr>
<td>2000</td>
<td>$1.11</td>
<td>$7.34</td>
<td>$8.44</td>
</tr>
</tbody>
</table>

Source: Bond Prospectus [1992]

Table 4.11: Toll Rates Required for a 19% Rate of Return

<table>
<thead>
<tr>
<th>Toll Rate</th>
<th>Number of Users</th>
<th>Annual Revenue (Mill)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.52</td>
<td>46,092</td>
<td>$8.78</td>
</tr>
<tr>
<td>$2.61</td>
<td>9,225</td>
<td>$8.78</td>
</tr>
</tbody>
</table>

From a societal perspective, the lower toll rate should be used in order to maximize the number of users. At the lower toll level, the model forecasts a maximum
flow of 3,052 users going north on the bridge between 5 p.m. and 6 p.m. While this figure does not exceed the capacity of the bridge (assumed to be 4,000 vehicles/hour, i.e., 2 * 2,000 vehicles/lane-hour (TRB [1993])), caution should be taken when using low toll rates.

Another scenario that is useful is the break-even point, where toll revenues just cover debt service. Under this scenario, the maximum revenue that could be earned is $7.38 million per year. The results of this analysis is shown in Table 4.12.

Table 4.12: Toll Rates Required to Break-Even

<table>
<thead>
<tr>
<th>Toll Rate</th>
<th>Number of Users</th>
<th>Annual Revenue (Mill)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.39</td>
<td>52,165</td>
<td>$7.38</td>
</tr>
<tr>
<td>$3.31</td>
<td>6,107</td>
<td>$7.38</td>
</tr>
</tbody>
</table>

Again, the lower toll should be selected if the objective is to maximize the number of users. However, the model forecasts 3,442 users traveling north on the bridge between 5 p.m. and 6 p.m. at that toll rate. The large number of users may cause congestion on the facility and decrease throughput. Although travelers would be happy to be paying a lower toll, the increase in congestion may raise their overall travel costs. Therefore, a toll rate should be chosen to control traffic flows below a certain level so that congestion does not develop.

4.3 Incorporating Congestion Impacts

An alternative use of constructing a tolling scheme for the San Jose Lagoon Bridge is to control traffic. Higher tolls during peak periods will discourage use of the bridge while lower tolls during off-peak hours will induce traffic during those periods. The effect
of congestion on travel time is modeled most commonly by the Bureau of Public Roads (BPR) function:

\[ T_f = T_o * [1 + a * (\frac{v}{c})^b] \]

where

- \( T_f \) = the final link travel time
- \( T_o \) = the original (free-flow) link travel time
- \( a \) = a constant (often set at 0.15)
- \( v \) = the assigned traffic volume
- \( c \) = the link capacity (often set at 2000 vehicles/lane/hour)
- \( b \) = a constant (often set at 4.0)

The San Jose Lagoon Bridge has two lanes in each direction and therefore is estimated to have a capacity of 4000 vehicles/hour (TRB [1993]). Using the BPR model and the parameters outlined above, the effects of different levels of traffic on travel time can be calculated as shown in Table 4.13.

<table>
<thead>
<tr>
<th>Traffic Level</th>
<th>% increase in travel time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>0.06%</td>
</tr>
<tr>
<td>2000</td>
<td>0.94%</td>
</tr>
<tr>
<td>2500</td>
<td>2.28%</td>
</tr>
<tr>
<td>3000</td>
<td>4.75%</td>
</tr>
<tr>
<td>4000</td>
<td>15.00%</td>
</tr>
</tbody>
</table>

The level of congestion on the bridge at current forecast levels only reaches a maximum of about 1500 vehicles/hour in one direction. However, should traffic levels
exceed those forecast, the model developed could be used to determine the toll rate that would limit traffic to a certain number per hour.

To illustrate this concept, two scenarios will be constructed as shown in Table 4.14. A value of 4,000 vehicles per hour was chosen as an upper limit to capacity for each direction.

Table 4.14: Congestion Pricing Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maximize revenue subject to a maximum of 4,000 vehicles per hour per direction using peak and off-peak toll rates throughout the day.</td>
</tr>
<tr>
<td>2</td>
<td>Maximize revenue subject to a maximum of 4,000 vehicles per hour per direction using a.m. peak, inter-peak, p.m. peak, and off-peak toll rates throughout the day.</td>
</tr>
</tbody>
</table>

The specific math program for scenario 1 is:

\[
\begin{align*}
\text{maximize} & \sum_{k=1}^{2} \sum_{j=1}^{6} \sum_{i=1}^{24} P_i Q_{jk}(P_i) \\
\text{subject to:} & \quad P_1 = P_2 = P_3 = P_4 = P_5 = P_6 = P_{20} = P_{21} = P_{22} = P_{23} = P_{24} \\
& \quad P_7 = P_8 = P_9 = \ldots = P_{19} \\
& \quad P_i \geq 0 \quad i = 1, 2, 3, \ldots, 24 \\
& \quad \sum_{j=1}^{6} Q_{jk}(P_i) \leq 4,000 \quad i = 1, 2, 3, \ldots, 24, \; k = 1, 2 \\
\end{align*}
\]

where \( k \) is the direction of travel (i.e., \( k=1= \text{north}, \; k=2= \text{south} \)).
The specific math program for scenario 2 is:

\[
\text{maximize} \sum_{k=1}^{2} \sum_{j=1}^{6} \sum_{i=1}^{24} P_i * Q_{ijk}(P_i)
\]

subject to:

\[
P_1 = P_2 = P_3 = P_4 = P_5 = P_6 = P_{20} = P_{21} = P_{22} = P_{23} = P_{24}
\]

\[
P_{10} = P_{11} = P_{12} = P_{13} = P_{14} = P_{15}
\]

\[
P_{16} = P_{17} = P_{18} = P_{19}
\]

\[
P_i \geq 0 \quad i = 1, 2, \ldots, 24
\]

\[
\sum_{j=1}^{6} Q_{ijk} \leq 4,000 \quad i = 1, 2, \ldots, 24, \quad k = 1, 2
\]

\[
Q_{ijk} \geq 0 \quad i = 1, 2, \ldots, 24,
\]

\[
j = 1, 2, 3, 4, 5, 6,
\]

\[
k = 1, 2
\]

Since the one of the math program's constraints is nonlinear, the calculation could not be performed using linear programming. However, methods are available to perform the analysis but since traffic levels currently are forecast not to approach capacity, the calculations were not carried out.

4.4 Price Discrimination

The price sensitivity of airport related users is less elastic than the price sensitivity of the "all other" users. Therefore, a higher toll would result in less airport related users being tolled off the facility than the "all other" users. This section examines optimal pricing policies to maximize revenue. One scenario is examined as shown in Table 4.15.
Table 4.15: Price Discrimination Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maximize revenue using a flat toll rate but different toll rates for airport related users and &quot;all other&quot; users</td>
</tr>
</tbody>
</table>

The specific math program for scenario 1 is:

\[
\text{maximize} \sum_{j=1}^{6} \sum_{i=1}^{24} P_{ij} * Q_j(P_i) \\
\text{subject to:} \quad P_{ij} = P_{2j} = \ldots = P_{24j} \quad j = 1, 2, 3, 4, 5, 6 \\
P_{ij} \geq 0 \quad i = 1, 2, 3, \ldots 24, \\
\quad j = 1, 2, 3, 4, 5, 6 \\
\quad k = 1, 2
\]

Using the Excel Solver with the appropriate constraints, the toll rates were set as shown in Tables 4.16.

Table 4.16: Price Discrimination Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original Toll Rate</td>
<td>$1.50</td>
</tr>
<tr>
<td>New Toll Rate</td>
<td>&quot;all other &quot;</td>
</tr>
<tr>
<td>6 a.m. to 9 a.m.</td>
<td>$0.88</td>
</tr>
<tr>
<td>9 a.m. to 3 p.m.</td>
<td>$0.88</td>
</tr>
<tr>
<td>3 p.m. to 7 p.m.</td>
<td>$0.88</td>
</tr>
<tr>
<td>7 p.m. to 6 a.m.</td>
<td>$0.88</td>
</tr>
<tr>
<td>Additional Rev/year</td>
<td>+$1,810,630</td>
</tr>
</tbody>
</table>
An optimal toll for maximizing revenue for the two market segments of "all other" and airport related were found in Scenario 1. The maximum revenue obtainable from the "all other" segment was found to be $18,767/day and from the airport related segment was found to be $16,342/day. The effects of these price discrimination toll rate scheme on the different market segments is summarized in Table 4.17.

Table 4.17: Effects of the Price Discrimination Toll Rate on Traffic

<table>
<thead>
<tr>
<th>Scenario</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Airport Related</td>
<td>-3,308</td>
</tr>
<tr>
<td>HB Work</td>
<td>+3,218</td>
</tr>
<tr>
<td>HB School</td>
<td>+460</td>
</tr>
<tr>
<td>HB Other</td>
<td>+3,657</td>
</tr>
<tr>
<td>HB Shop</td>
<td>+963</td>
</tr>
<tr>
<td>Non HB</td>
<td>+2,649</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>+7,638</strong></td>
</tr>
</tbody>
</table>

The results show that maximizing revenue using price discrimination greatly benefits the "all other" segment of the market. In addition, over $1.8 million in additional revenue could be achieved through such a scheme.

Distinguishing between airport related and "all other" traffic may be difficult, however. Tags may be used on taxis or rental cars on the bridge which register a higher toll when electronic toll collection is used. However, this type of scheme would not capture the private autos using the airport. This problem may be solved by applying a separate toll at the entrance and exits to the airport. The results of the model would remain the same but a flat toll rate could be charged to all users on the bridge itself.
The additional cost of constructing a toll facility and political opposition may make this plan unfavorable but as demonstrated using the model above, the excess revenue that may be generated through price discrimination is significant and all groups within the "all other" market segment benefit.

4.5 Model Limitations

The results obtained above should be viewed qualitatively since the models are not based on observed conditions. The models use the best available data for the San Jose Lagoon Bridge and the San Juan area. Some of the assumptions made in developing the model and interpreting results are outlined below.

Demand for the bridge was assumed to be homogeneous and users were assumed to either make the trip during the desired time period or not at all. Of course in reality people may change trip times based on traffic conditions and/or different toll rates but this was not incorporated into the model. Only the use of automobiles was modeled for the bridge. In reality, trucks and buses are charged a higher toll but also contribute more to damaging the bridge and to congestion as well. The assumption that congestion was not a factor may be valid, however, since forecasted traffic levels were moderate and did not approach capacity. The financial results represent a lower bound of potential revenue that can be realized based on the model since only autos are modeled.

Applying demographic data obtained by Barton Aschman Associates to the "all other" segment of the market may cause some error in market segmentation results. For example, Home-Based Work trips may make up proportionately more of the traffic on the bridge than for the entire San Juan area. A discussion of how these model limitations can be addressed is given at the end of the next chapter.
Chapter 5

Conclusions and Future Research

The original goals of this research were to assess various methods that can be used to finance Puerto Rico's transportation improvements and to look at alternative tolling schemes for the San Jose Lagoon Bridge and their effects on both revenues and the users.

The following sections offer recommendations to the Puerto Rico Highway and Transportation Authority based on the conclusions drawn from this study and also outlines a plan for future research.

5.1 Recommendations

The PRHTA has many options to choose from to finance their transportation improvements. Considering Puerto Rico's extremely low gas tax rate, raising the gas tax may be one of the most easily implementable ways of raising revenue in the future. In addition, its vehicle registration fees are also low and haven't been changed since 1982 (Parker [1992b]). Raising the vehicle registration fees may also be a source of revenue in the future.
In addition to these measures, various tolling schemes could be used to both manage traffic conditions and to raise revenue. The use of private capital to finance transportation improvements could also be further expanded in the future. Puerto Rico has taken a first-step toward privatization through authorizing the privatization of the San Jose Lagoon Bridge.

The current toll rate on the San Jose Lagoon Bridge is $1.50. Using the best available data (i.e. the Vollmer study and the BAA study), the optimal revenue maximizing toll rate was found to be $1.22. This figure was determined using a demand model developed specifically for the bridge. Reducing the toll rate from $1.50 to $1.25 instead of $1.22 for convenience of toll collection is estimated to result in an additional $192,590 in revenue per year.

If different peak and off-peak toll rates were allowed, the revenue maximizing toll rates were found to be $1.20 and $1.30 respectively. This difference may be too small for congestion management purposes but would serve to maximize revenue. Other scenarios were also looked at but in order to keep the tolling scheme as simple as possible (as outlined in the Smeed report), only one or two toll rates should be used within a day.

If the goal of regulating toll rates is to maximize throughput, then a much lower toll rate should be charged. In order for the private firm APR to recover a 19% rate of return over its debt service, a toll rate of only about 50 cents should be charged. The number of users of the facility is estimated to more than double from 20,100 to about 47,000 while the yearly revenue would decrease from $11 million to $8.58 million. A toll rate of 50 cents would give APR a rate of return of 16.2% while a toll rate of 52 cents would give APR a rate of return of 19.0%.

Additional revenues may also be obtained by charging airport related users a separate toll. This type of price discrimination could be achieved by charging taxis and rental cars destined to or originating from the airport a higher rate than private autos. Automatic Vehicle Identification could be used to differentiate such vehicles. Another
scheme that could be used is to charge users a toll at the airport itself. This type of scheme would capture all airport related users and may result in a significant revenue gain.

In addition, in order to facilitate future toll increases, the example of the toll road in Norway (see Appendix A) shows that users with tags are less price sensitive to such increases than those who pay cash. Therefore, the use of electronic toll collection is recommended.

5.2 Future Research

In order to make the model more accurate, future toll increases on the bridge should be documented as in the Norway study. This data could be combined with census data to estimate demand by different market segments using the techniques outlined in this thesis and a resulting toll policy could be established. The Concession Agreement currently stipulates that tolls could be changed according to the following policies (Concession Agreement [1992]):

Section 10.2. Revision of Toll Rates

(a) Concessionaire shall have the right progressively to revise and increase the Toll Rates on January 1st of every year, based on the initial Toll Rate established for 1993, by applying the Consumer Price Index for all families as published by the Department of Labor of the Commonwealth as described in Exhibit D hereof ("CPI") plays such other adjustments which may be required to comply with any rate covenants in the Financing Documents.

(e) The Toll Rates may be temporarily reduced by the Concessionaire, in its sole discretion, during certain holidays, weekends, seasons, hours of the day, or for
any other reason that the Concessionaire deems appropriate. Such reductions may remain in force and effect as long as the Concessionaire deems appropriate or convenient, and the Concessionaire may, in its sole discretion, increase and reinstate the Toll Rates established for the specific year at any time. The Concessionaire shall also have the right to establish, in its sole discretion, any system to charge and collect the Toll Rates, including, but not limited to, automatic toll charges, credit cards or any other device or means to increase the efficiency of the operation and the collection of Toll Rates in the Transportation Facility.

The policy outlined in Section 10.2 (a) will be used in the future to increase the nominal toll rate of the bridge. The effects of this price increase on traffic volume may not be substantial since it is based on the consumer price index. However, Section 10.2 (e) could be used to lower toll rates to test how the market would react to a toll rate change at any time. A lower toll rate may induce travelers to try using the bridge and they may find that the benefit received is greater than the cost even when the toll rate is increased in the future. The effects of any change in toll rate should be well documented at a level of detail sufficient enough so that the effects of future toll increases on different market segments can be modeled.

The models developed in this thesis were based on the best available data, not on actual conditions. If data were available for the bridge, more accurate forecasts could be made. The results of this study suggest that a lower flat toll rate may result in higher revenue for the bridge. The optimal toll rate was found to be $1.22. If the toll rate were reduced to $1.25, the results of this study could be tested and the price sensitivities of users could be measured.

In addition to recording the number of cars that use the bridge, a survey could be used to determine characteristics of traffic both before and after the toll decrease. The
results of this survey would be provide a more accurate description of traffic characteristics on the bridge than the models developed in this thesis. Once these statistics are recorded, a model similar to the one developed in this thesis could be used to predict the effects of future toll rate changes on both revenues and users.

Another problem with the model developed is the assumption that trips are either made at the desired time or not at all. This problem could be addressed by formulating a math program that incorporates the tolls charged on the bridge not only for the hour of travel desired, but for all hours. This is expressed mathematically as:

$$\text{maximize } \sum_{j=1}^{6} \sum_{i=1}^{24} P_i \cdot Q_j(P_1, P_2, \ldots, P_{24})$$

The modeling corrections outlined above would improve the existing model in forecasting demand for the bridge. However, they still should be viewed qualitatively since they are only estimates.
Appendix A

Toll Sensitivity Calculations

This section outlines the method used to apply results obtained in the Norway study to the San Jose Lagoon Bridge. While the quantities obtained from the Norway study may not be directly applicable to the San Jose Lagoon Bridge, the relative magnitudes of the differences between the groups can be used to estimate demand by different groups. Using "Business" as a base, the following ratios of price sensitivities were established.

\[
\begin{align*}
\text{Commuting} & \quad \frac{\text{Business}}{\text{Business}} = 2.81 \\
\text{Other} & \quad \frac{\text{Business}}{\text{Business}} = 2.25 \quad (A-1)
\end{align*}
\]

When the price sensitivities of different groups for the same price changes are made into ratios, the price factor cancels out and the equation becomes a ratio of quantities as shown below.

\[
\frac{P_{S_1}}{P_{S_2}} = \frac{\frac{\Delta Q_i}{Q_i}}{\frac{\Delta P}{P}} = \frac{\frac{\Delta Q_i}{Q_i}}{\frac{\Delta Q_i}{Q_i}} = \frac{\Delta Q_i}{Q_i} \cdot \frac{Q_2}{Q_1} \quad (A-2)
\]
where $PS_n$ is the price sensitivity of the $n$th group.

The five different market segments in the BAA study were categorized into either "Business", "Commuting", or "Other." Since HB Work and HB School trips have similar time-of-day trip distributions, they are categorized into the "Commuting" market segment. Similarly, since HB Other and HB Shop have similar distributions, they were classified as "Other." The Non HB trips consist of many trips made during the day that are related to business and therefore were classified into the "Business" segment.

Using the information obtained from the Norway study, the relative changes in traffic can be determined. Vollmer Associates forecasts that there are 58,300 potential non-Airport related users. However, when a toll rate of $1.50 is charged, the number of actual users drops to 10,500, a net decrease of 47,800 users. Therefore the following equation is obtained.

$$
\Delta Q_{\text{Commuting}} + \Delta Q_{\text{Business}} + \Delta Q_{\text{Other}} = 47,800 \tag{A-3}
$$

In addition, from equations (A-1) and (A-2),

$$
\frac{\Delta Q_{\text{Commuting}}}{\Delta Q_{\text{Business}}} \cdot \frac{Q_{\text{Business}}}{Q_{\text{Commuting}}} = 2.81 \quad \text{; and}
$$

$$
\frac{\Delta Q_{\text{Other}}}{\Delta Q_{\text{Business}}} \cdot \frac{Q_{\text{Business}}}{Q_{\text{Other}}} = 2.25
$$

Since there are three equations and three unknowns, the variables can be determined using the following data.

$$
Q_{\text{Business}} = \text{Non HB} = 14,108
$$

$$
Q_{\text{Commuting}} = \text{HB Work} + \text{HB School} = 17,140 + 2,449 = 19,589
$$

$$
Q_{\text{Other}} = \text{HB Other} + \text{HB Shop} = 19,472 + 5,130 = 24,602
$$
Simplifying the above equations using this data and using equation (A-3) results in the following system of equations.

\[
\Delta Q_{\text{Commuting}} - 3.90* \Delta Q_{\text{Business}} = 0
\]

\[
3.92* \Delta Q_{\text{Business}} - \Delta Q_{\text{Other}} = 0
\]

\[
\Delta Q_{\text{Commuting}} + \Delta Q_{\text{Business}} + \Delta Q_{\text{Other}} = 47,800
\]

Solving for the appropriate variables yields the following solutions:

\[
\Delta Quantity_{\text{Business}} = 5,420
\]
\[
\Delta Quantity_{\text{Commuting}} = 21,136
\]
\[
\Delta Quantity_{\text{Other}} = 21,244
\]

The results obtained above show that even the relative magnitudes of the elasticities are not applicable for the San Jose Lagoon bridge. The total potential traffic for the commuting segment of the market was calculated to be only 19,589 while the change in quantity after the toll is applied was found to be 21,136. The resulting traffic after the toll is in place becomes negative.

One of the main reasons why the results of the Norway study are not applicable to the San Jose Lagoon bridge is the difference in market segments. For example, the "Business" segment of the market for the Norway study was assumed to be analogous to the "Non HB" group of the BAA study. However, not all "Non HB" trips are related to business. As discussed earlier, this segment of the market is a "grab bag" of different trip purposes whose only common link is that they are not home-based. Another reason why the results were not applicable is that Puerto Rican residents may have different values
than Norwegian residents. For example, punctuality in business may be more valued for the Norwegians than for the Puerto Ricans or visa versa.

Even though the results obtained from the Norway study are not applicable quantitatively, they still give general qualitative results that may be applied to traffic on the bridge. For example, the price sensitivities associated with "Business" were found to be less than those of "Commuting" or "Other." Thus, the effect of a toll rate increase would affect the more price sensitive "Commuting" and "Other" groups than the "Business" segment of the market.

**Other Results**

Although the Norwegian study turned out not to be applicable even from a relative magnitude standpoint, certain qualitative characteristics of behavior in the presence of tolls may still be applicable to the San Jose Lagoon Bridge.

In addition to trip purpose, the Norwegian study also segmented the market based on the following categories:

- Income Group
- Frequency of Choice Situation
- Trip Length
- Way of Paying

Income was divided into six groups based on annual yearly income. The percent of users using the toll facility over the free route was determined using the survey and a price sensitivity was calculated. The results are shown in Table A.1.
As might be expected, price sensitivity generally decreases with increasing income. There is, however, an increase in elasticity from the second lowest income category to the third lowest income category. This may be due to workers in the second lowest income category having to use the tolled route to get to work on time for blue-collar types of jobs. The higher income category may be more flexible in their work hours but also are able to afford the toll rate.

The frequency of choice situation was broken down into four categories: daily, weekly, monthly, and more seldom. The results of this analysis is shown in Table A.2.

<table>
<thead>
<tr>
<th>Frequency of Choice</th>
<th>1989</th>
<th>1990</th>
<th>Price Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily</td>
<td>46.1%</td>
<td>30.7%</td>
<td>-0.337</td>
</tr>
<tr>
<td>Weekly</td>
<td>61.6%</td>
<td>43.2%</td>
<td>-0.301</td>
</tr>
<tr>
<td>Monthly</td>
<td>69.1%</td>
<td>51.3%</td>
<td>-0.260</td>
</tr>
<tr>
<td>More Seldom</td>
<td>60.1%</td>
<td>54.0%</td>
<td>-0.102</td>
</tr>
</tbody>
</table>
The results show that as frequency of use decreases, price sensitivity decreases. This means that a user using the facility only once in a while would be willing to pay more to use the facility than a user who uses the facility all the time. The low frequency users make up a large amount of airport related traffic and are less price sensitive since people do not usually fly too often.

In addition to frequency of use, an important consideration is trip length. Longer trips were found to be less price sensitive than shorter trips as shown in Table A.3.

Table A.3: Toll Sensitivity Based on Length of Trip

<table>
<thead>
<tr>
<th>Length of Trip</th>
<th>1989</th>
<th>1990</th>
<th>Price Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td>44.8%</td>
<td>30.0%</td>
<td>-0.333</td>
</tr>
<tr>
<td>Tag</td>
<td>72.8%</td>
<td>57.5%</td>
<td>-0.212</td>
</tr>
</tbody>
</table>

Users of the facility in Norway are given a choice of payment method between a prepaid tag and cash. Slightly less than 30 percent of drivers in both years possessed a tag. These tags had variations in their cost per trip, depending on how many trips the had prebought. For instance, in 1990 the price per trip was reduced from 20 kroner to 18, 16, 15, 12, or 10 kroner if the number of trips bought in advance was 25, 50, 100, 250, or 500, respectively. The method of payment was also analyzed for price sensitivity and the results are shown in Table A.4.

Table A.4: Toll Sensitivity Based on Payment Method

<table>
<thead>
<tr>
<th>Payment Method</th>
<th>1989</th>
<th>1990</th>
<th>Price Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cash</td>
<td>44.0%</td>
<td>29.4%</td>
<td>-0.334</td>
</tr>
<tr>
<td>Tag</td>
<td>80.6%</td>
<td>67.4%</td>
<td>-0.165</td>
</tr>
</tbody>
</table>
The results show that users who have a tag are twice as less price sensitive than those who pay in cash. This suggests that a facility that uses tags will lose less traffic when implementing price increases.
Appendix B

Revenue Maximizing Toll Rates

The revenue maximizing toll rates for each of the three different models developed in Chapter 3 are shown in Table B.1. The variability in these toll rates each hour makes implementation difficult. However, in the future, with the use of electronic toll collection, these types of tolling schemes may become feasible. Figures B.1, B.2, and B.3 illustrate how these tolls vary throughout the day.
Table B.1: Revenue Maximizing Toll Rates

<table>
<thead>
<tr>
<th>Time</th>
<th>BAA</th>
<th>BAA1</th>
<th>NPTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>$1.94</td>
<td>$1.34</td>
<td>$1.12</td>
</tr>
<tr>
<td>1</td>
<td>$1.66</td>
<td>$1.18</td>
<td>$1.27</td>
</tr>
<tr>
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<td>$0.88</td>
<td>$0.88</td>
<td>$0.87</td>
</tr>
<tr>
<td>3</td>
<td>$0.88</td>
<td>$0.88</td>
<td>$0.87</td>
</tr>
<tr>
<td>4</td>
<td>$0.88</td>
<td>$0.88</td>
<td>$0.87</td>
</tr>
<tr>
<td>5</td>
<td>$0.88</td>
<td>$0.88</td>
<td>$0.87</td>
</tr>
<tr>
<td>6</td>
<td>$0.88</td>
<td>$0.88</td>
<td>$0.88</td>
</tr>
<tr>
<td>7</td>
<td>$0.93</td>
<td>$0.95</td>
<td>$1.01</td>
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<tr>
<td>8</td>
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<td>$0.99</td>
<td>$1.09</td>
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<tr>
<td>9</td>
<td>$1.42</td>
<td>$1.33</td>
<td>$1.36</td>
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<tr>
<td>10</td>
<td>$1.55</td>
<td>$1.43</td>
<td>$1.47</td>
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<tr>
<td>11</td>
<td>$1.07</td>
<td>$1.07</td>
<td>$1.09</td>
</tr>
<tr>
<td>12</td>
<td>$1.21</td>
<td>$1.32</td>
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</tr>
<tr>
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<td>$1.57</td>
<td>$1.51</td>
<td>$1.46</td>
</tr>
<tr>
<td>2</td>
<td>$1.28</td>
<td>$1.28</td>
<td>$1.25</td>
</tr>
<tr>
<td>3</td>
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<tr>
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<td>$1.43</td>
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<td>$1.49</td>
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<tr>
<td>10</td>
<td>$1.23</td>
<td>$1.47</td>
<td>$1.19</td>
</tr>
<tr>
<td>11</td>
<td>$1.12</td>
<td>$1.11</td>
<td>$0.99</td>
</tr>
</tbody>
</table>

Figure B.1: BAA Revenue Maximizing Toll Rates
Figure B.2: BAA1 Revenue Maximizing Toll Rates

Figure B.3: NPTS Revenue Maximizing Toll Rates
Bibliography


[31] Institute of Transportation Engineers (ITE), A Toolbox for Alleviating Traffic Congestion, 1989.


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