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Evaluation Study of New Jersey Turnpike Authority's Time of Day Pricing Initiative

FINAL REPORT

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16. Abstract

In September 2000, the New Jersey Turnpike Authority introduced E-ZPass technology along with the first stage of its time of day pricing program. In January 2003, toll levels for each time period and vehicle type were increased as part of the second stage of the NJ Turnpike time of day pricing program.

The project had three main focus areas: *Traffic Impacts*, *Behavioral Impacts* and *Media and Decision Makers Responses*. In the first area, aggregate traffic counts and disaggregate vehicle-by-vehicle traffic and travel time information were used to quantify the impacts of the two phases of the time of day pricing program on the time of day choices of users. In addition, a simulation and toll plaza model were developed to assess the before and after toll plaza and facility-wide throughput, delays both at the toll plazas and mainline, and emissions. In the second focus area, traveler surveys were conducted with passenger cars to gain insights on the behavioral changes, and to evaluate the economic value of travel time savings and elasticities of the NJ Turnpike users. Finally, in the third focus area the acceptability of the time of day pricing program among media and decision makers was investigated.

The aggregate analysis revealed a shift in traffic to off-peak periods after the first phase of time of day pricing program, and a shift to peak periods after the second phase. The disaggregate analysis indicated that given the small toll differential between peak and off-peak periods, commuters responded more to congestion (lower travel times) than slightly higher tolls, and second phase of the time of day pricing program did not have a statistically significant impact on the traffic patterns of the NJ Turnpike. Simulation results revealed that from 2000 to 2001 the average trip delay was reduced by about 3-18 percent, E-ZPass was observed to reduce the toll plaza delays by 44-74 percent, and there was 10.7 percent reduction in vehicle emission levels. However, after 2001 emissions slightly increased due to the increasing demand. In addition, the NJ Turnpike users had relatively high VOT values ($15/hr-$20/hr) and low elasticity values (between -0.06 and -0.18), indicating that give higher values to travel time savings compared to other toll road users in the U.S..

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EXECUTIVE SUMMARY

The concept of value pricing on roadways has been gaining support for several years now both in the United States and around the world. Though often used interchangeably, the terms variable pricing, congestion pricing, and value pricing do have slightly different meanings. Variable pricing simply means that prices fluctuate. Value pricing implies that some additional benefit accrues to those paying premium prices. Finally, congestion pricing signifies that the prices fluctuate based on demand, with lower prices during off-peak times. For purposes of this project, however, the term “time of day pricing” will be used because it provides a more accurate description of the New Jersey Turnpike’s toll structure, in which tolls vary by time of day only.

In September 2000, the New Jersey Turnpike Authority (NJTA) introduced E-ZPass technology along with the first stage of its time of day pricing program. The NJTA saw the time of day pricing program as an incentive to alleviate congestion at peak hours, by providing reduced toll levels for passenger cars with E-ZPass during off-peak hours. As part of this program, different toll levels were charged to users depending on the time of day. In January 2003, toll levels for each time period and vehicle type were increased as part of the second phase of the NJTA’s time of day pricing program. Currently, for passenger cars using E-ZPass the toll differential between peak (7:00-9:00A.M. and 4:30-6:30 P.M.) and off-peak hours is ranging between 10 cents (between Interchanges 1 and 2) and 60 cents (between Interchanges 1 and 18W). On average, peak hour tolls are 15 percent higher than off-peak hour tolls.

The primary objective of this project was to assess the behavioral impacts produced by the NJ Turnpike time of day pricing using traffic, travel time, and survey data.

The overall impacts of the two phases of the time of day pricing program on traffic patterns of the NJ Turnpike were quantified with aggregate and disaggregate traffic data provided by NJTA. The analysis results revealed that users responded more to congestion (lower travel times) than the slightly higher tolls. Moreover, second phase of the time of day pricing program did not have a statistically significant impact on the traffic patterns of NJ Turnpike.

A microscopic simulation model of the NJ Turnpike was developed using Paramics simulation software. Application programming interface feature of Paramics was used to develop a highly detailed toll plaza model that can simulate complex weaving and lane change behavior of vehicles at the toll plazas. The model was then used to obtain delays and emissions at the toll plazas and mainline separately, and to assess before and after toll plaza and facility-wide throughput. The simulation results showed that the simultaneous introduction of E-ZPass and the first phase of time of day pricing program reduced the average trip delay by about 3 -18 percent and reduced the toll plaza delays by 44-74 percent between 2000 and 2001.

A second objective of this project was to quantify behavioral changes of the NJ Turnpike users using behavioral traveler surveys. Focusing on regular users enabled the research team to perform the comparison of behavioral patterns before and after the introduction of time of day pricing on the NJ Turnpike. The project studied the passenger cars with E-ZPass that were the target of the time of day pricing program.

The traveler surveys collected data about socio-economic characteristics, attributes of the most recent trip, E-ZPass usage patterns, opinions about time of day pricing, and a set of stated preference experiments. A total of 513 passenger car users were interviewed. The interviews were conducted by the Rutgers University's Eagleton Institute using computer aided telephone interviews (CATI).

Using the traveler survey data, economic value of travel time savings (VOT) and elasticity of the NJ Turnpike users were computed. The NJ Turnpike users have relatively high VOT values and low elasticity values, indicating that the NJ Turnpike users give higher values to travel time savings compared to other toll road users in the U.S.

The project team also analyzed media and decision makers' reactions to the time of day pricing program. The team has undertaken a descriptive analysis of the decision-making process to gauge the acceptability of the time of day pricing program to opinion leaders and decision makers before and after the implementation of the time of day pricing program. In addition, to provide an overview of the efficiency levels and their pattern of the toll facilities in the U.S., current toll facilities were analyzed using toll data of the selected 83 facilities.

Traffic Impacts

In order to quantify the traffic impacts of the two phases of the time of day pricing program, the project team employed two types of traffic data obtained from NJTA. The first type of data included traffic information at the aggregate level, including total traffic flow at peak (7-9 A.M. and 4:30-6:30 P.M) and off-peak hours for one typical work day from October 1998 to June 2001 and for each day from October 2002 to March 2003. The second type of data set included disaggregate traffic information, providing detailed vehicle-by-vehicle information regarding the entry and exit locations of each E-ZPass vehicle, corresponding travel times and toll amounts paid for each time of the day and day of the week from October 2002 to March 2003. Using these two datasets, various statistical techniques were used to assess the changes in traffic before and after the two phases of the time of day pricing program.

Major Findings:

- The traffic in winter months was observed to be lower than the traffic in summer months. This helped to explain the changes in traffic observed in different months.
- There was a statistically significant increase in the NJ Turnpike demand from 2000 through 2003 despite the two phases of time of day pricing program. Combined with the traveler surveys and estimated elasticity values these results provided no evidence of shift in demand to other modes/routes after time of day pricing.
- After the first phase of the time of day pricing program, between October 1998 and June 2001 the absolute traffic volumes at peak periods increased at a lower rate (6 percent for the A.M. peak and 4 percent for the P.M. peak period) compared to the absolute traffic volumes at off-peak periods (10 percent). In addition, the decrease in

the percent share of peak periods was statistically significant (1.7 percent for the A.M. peak and 3.7 percent for the P.M. peak period); whereas the percent share of off-peak traffic (1.1 percent) increased in a statistically significant manner.

- After the implementation of the second phase of the time of day pricing program, the trend in traffic volumes was reversed. Between October 2000 and March 2003, the absolute traffic flow at peak periods increased at a higher rate (15percent for the A.M. peak and 10 percent for the P.M. peak period) compared to the absolute increase in the traffic flow of off-peak hours (9 percent). In addition, the percent shares of peak periods increased in a statistically significant manner (17 percent for the A.M. peak and 14 percent for the P.M. peak period); whereas the percent share of the off-peak traffic reduced in a statistically significant manner (6 percent).
- The disaggregate analysis, conducted to determine the reasons of this change in the travel patterns, indicated that commuters respond more to congestion (lower travel times) than slightly higher tolls (which can be explained by the fact that the toll differentials and absolute value of the tolls were relatively small with respect to the users' value of travel time). More specifically, given the toll differential of only 15 percent (60 cents at most), in March 2003 for 53 percent of the origin-destination (O-D) pairs, highest traffic flow was observed at peak periods (7-9 A.M. and 4:30-6:30 P.M.) when toll levels were higher but travel times were observed to be lower compared to peak shoulder periods (6-7 A.M. and 9-10 A.M., 3:30-4:30 P.M. and 6:30-7:30 P.M.). Moreover, second phase of the time of day pricing program did not have a statistically significant impact on the traffic patterns of the NJ Turnpike.
- Like the overall behavior observed at the NJ Turnpike, most of the users traveling at the northern section of the NJ Turnpike (most highly utilized section of the NJ Turnpike) preferred to travel at peak periods where the toll levels were slightly higher but travel times were observed to be lower compared to peak shoulder hours. The travel time difference between peak and peak shoulder periods were around five to seven minutes for O-D pairs having travel time more than 15 minutes on the average, and around three to five minutes for O-D pairs having travel time less than 15 minutes on the average. Moreover, the traffic flow of these highly utilized pairs increased at lower travel time periods independent of the time of day pricing program, but the travel

time or traffic flow changes after the second phase of the time of day pricing program were not statistically significant for most of the O-D pairs.

Estimation and Analysis of Delays and Emissions Using Microscopic Traffic Simulation Model of the NJ Turnpike

As mentioned earlier, in this chapter, a special toll plaza model was developed and integrated with Paramics to obtain accurate estimates. The simulation model was calibrated using the network data from GIS files and the historical aggregate and disaggregate traffic and travel time data. The toll plaza model enabled the research team to accurately represent complex weaving and lane change behavior of users at the toll plaza. The level of emission was also investigated using the developed simulation model. Emission estimations were based on the SPASM model developed by FHWA. The detailed output capabilities of *Paramics* where individual vehicles can be traced throughout their journey enabled the research team to estimate fuel consumption better than most macroscopic traffic simulation models.

Major Findings:

- The average trip delay was reduced by about 3 -18 percent from 2000 to 2001 after the concurrent introduction of E-ZPass and the first phase of the time of day pricing program. The major reason for this reduction was, however, observed to be the reduction in toll plaza delays due to the introduction of E-ZPass.
- E-ZPass deployment was observed to reduce the toll plaza delays by 44-74 percent between 2000 and 2001, the year after the introduction of the E-ZPass for the first time. It was also observed that there was no increase in toll plaza delays despite the increase of traffic volumes from 2001 to 2003. This was due to the increase in the percentage of E-ZPass users over the years.
- Simulation analyses showed that between 2000 and 2001 there was a reduction in vehicle emission levels as high as 10.7 percent. After 2001 a slight increase in emissions was observed due to the increasing demand, which can be interpreted as an expected outcome given the relationship among the demand, delays and emissions.

Descriptive Analyses of the Impacts of the Time of Day Pricing Program on Passenger Travel Behavior

The analyses conducted are based on 513 complete passenger surveys collected during the period mid June - mid July, 2004. (Percentages shown are with respect to the total number of trips made by the users.)

Major Findings:

- Only 7 percent of the individuals (36 out of 513 respondents) changed their travel behavior after the first phase of the time of day pricing program. The main reasons for not changing travel behavior included *no flexibility* (40.2 percent) and *my choice, I go when I want to go* (32.3 percent).
- Respondents who reported behavior changes due to the time of day pricing initiative indicated multiple dimensions of response. The main reactions to time of day pricing included *increased car trips along alternate routes* (5.4 percent of entire sample), and *decreased the frequency of travel on Turnpike* (5.2 percent of entire sample).
- Although the majority of respondents (64.0 percent, 303 users) were E-ZPass users, only 10.5 percent of them were aware of discounts associated with the time of travel.
- Current regular users traveled at that time mainly to adapt to their work schedule or avoid congestion rather than to take advantage of cheaper tolls.
- Current regular users did not have much flexibility to shift their current time of travel.

Economic Value of Travel Time Savings at the NJ Turnpike Facilities

In this chapter, an econometric Value of Time (VOT) formulation which incorporated socio-economic and trip related factors of NJ Turnpike users was developed using the traveler survey data. The VOT functions were estimated only for E-ZPass passenger cars, since they are the only users who are eligible for time of day pricing.

Major Findings:

- VOT for a specific E-ZPass user was highly influenced by the trip purpose (work or leisure trip), period choice (peak or peak shoulder periods), income level, toll amount, travel time, and desired arrival time.

- Mean VOT values for E-ZPass users ranged between $15/hour and $20/hour depending on the selected period and trip purpose.
- VOT values of work related trips ($19.72/hour for peak periods) were higher than leisure related trips ($17.16/hour for peak periods), i.e. users having work trips gave higher value to travel time savings than users having leisure trips.
- For each trip type, peak period had the highest VOT value among the other periods, i.e. peak period users gave higher value to travel time savings than peak shoulder users. This difference may be explained by the fact that, more than half of the O-D pair travel times at peak periods were found to be lower than the travel times at peak shoulder periods.

Demand Elasticity at the NJ Turnpike Facilities

The elasticity of traffic demand with respect to toll changes was estimated using traveler survey data and the calibrated VOT model.

Major Findings:

- Average traffic demand elasticity with respect to toll amount was found to be very inelastic compared to most of other toll facilities in the U.S.
- Elasticity of a specific E-ZPass user was affected by trip purpose, toll level, travel time and selected time period.
- Depending on trip purpose, the elasticities ranged between -0.06 and -0.08 for peak period users and between -0.11 and -0.18 for peak shoulder users. In terms of the impacts on traffic levels, these elasticities mean that 10 percent increase in peak toll levels (the level of toll increase in January 1, 2003) would result in a decrease in peak period traffic ranging between 0.6 percent and 0.8 percent depending on trip purpose. Similarly 5 percent increase in off-peak toll levels (the level of toll increase in January 1, 2003) would result in a decrease in peak shoulder period traffic ranging between 0.55 percent and 0.9 percent depending on the trip purpose.
- Elasticity values for work trips (-0.06 for peak periods) were found to be lower compared to elasticity values for leisure trips (-0.08 for peak periods).
- Elasticity values for peak periods were found to be lower compared to elasticity values

for peak shoulder periods.

Media and Decision Makers' Reactions to the Time of Day Pricing Initiative

A descriptive analysis of the decision-making process to gauge the acceptability of the time of day pricing program to opinion leaders and decision makers before and after the implementation of the time of day pricing program was performed.

Major Findings:

- Operationally, the NJTA's time of day pricing was successfully introduced with minimal opposition from the public or various stakeholders.
- Time of day pricing initiative shared media attention with the toll increase and the introduction of E-ZPass, thereby diluting its impact on the public.

Comparative Analyses of Toll Policies in the U.S.

In order to investigate the efficiency of current toll facilities in the U.S., 83 toll facilities across the U.S. were analyzed. The toll data included toll amount, vehicle type, facility type, payment method, time of travel (if toll rates change by time of the day), trip distance (if applicable), and geographic location.

Major Findings:

- The tolls across the US follow a systematic pattern such that:
    a. At facilities that provide Electronic Toll Collection (ETC), ETC tolls were usually lower than cash tolls;
    b. Only six percent of the sampled facilities had time of day pricing programs; these time of day pricing programs were only applied in metropolitan areas;
- The important findings from the regression analysis were:
    a. Passenger car tolls on highways, bridge and tunnel facilities were lowest in the Northeast;
    b. Although highway facilities in the Northeast charged semi trailer and large combinational vehicles the highest fixed tolls among all other regions, the toll per vehicle mile traveled was the lowest;
    c. The two models showed that cash toll policies and ETC toll policies were similar.

CHAPTER I – INTRODUCTION

INTRODUCTION

The concept of value pricing on roadways has been gaining support for several years now both around the United States and worldwide. Though often used interchangeably, the terms variable pricing, congestion pricing, and value pricing do have slightly different meanings. Variable pricing is the most general phrase, simply meaning that prices fluctuate, value pricing implies that some additional benefit to those paying premium prices and, finally congestion pricing signifies that the prices fluctuate based on demand, with lower prices during off-peak times. [1,2] When referring to this project, however, the term "time of day pricing" will be used because it provides a more accurate description of the New Jersey Turnpike's toll structure, in which tolls vary by time of day only.

"Although the potential benefits of road pricing were first described by Vickrey in the 1950s, the technologies necessary to implement his ideas did not exist at that time". [3,4] Over the ensuing decades, pricing has come to be used by many other industries – electric utility companies charge more in peak periods, restaurants offer "early bird" specials, airlines and passenger ships offer premium classes with higher service quality, and commuter rails have long been offering peak and off-peak fares – but the use of pricing on roadways is still a relatively recent application. Proponents argue that value pricing is the key to managing congestion in a world where we can no longer build ourselves out of traffic. Detractors point to privacy issues and regressive fare structures that place undue burdens on lower income individuals, among other concerns.

The NJ Turnpike's time of day pricing initiative is, to date, one of the most significant efforts launched in the United States, not only with respect to the numbers of people affected and the volume of traffic utilizing NJ Turnpike Authority (NJTA) facilities, but also in its attempt to affect the behavior of commuters traveling in peak periods. The main objective of this evaluation study is to assess the impacts produced by the NJTA's time of day pricing initiative.

Brief History of Value Pricing

Prior to its implementation on the New Jersey Turnpike (NJTPK), value pricing had been gaining support around the United States and in several cities worldwide. The concept of value pricing was not new – electric utility companies had adopted similar pricing schemes as a means for lowering peak demand; hotels and resorts had changed their prices based on peak season demand for many years; and restaurants had long had "early bird" specials. [5] In the transportation industry, commuter rails had long been differentiating between peak and off-peak fares. Indeed, the concept of value pricing for transportation had been described as early as 1952 by Vickrey when he recommended instituting "congestion pricing" on roadways. However, the technologies did not exist for many years to effectively implement his ideas. [6]

In 1975, Singapore became the first country to experiment with value pricing, when it instituted its Area License Scheme in which a cordon was drawn around the congested area and anybody entering the restricted area was charged a fee. Norway was the second country to institute a form of value pricing when it introduced a series of toll rings around several key cities – Bergen (1986); Oslo (1990); and Trondheim (1991). France soon followed with a variable toll on its intercity expressway between Paris and Lille in 1989 as a means for controlling weekend congestion (though not always included as an example in discussions of value pricing since the goal was to generate revenues rather than to reduce congestion, they could be readily adapted for congestion management by varying the rates charged throughout the day or on different days). [7] Such experiments were not to be seen in the United States for several more years. However, two key pieces of legislation helped refocus attention on value pricing in the United States.

The first critical piece of legislation was the 1989 California Assembly Bill 680, aimed at attracting private capital to highway projects. It was under this Bill that the first practical application of value pricing in the United States was launched four years later, on 27 December 1995, in Orange County, California. The initiative consists of a 10-mile-long express-lane roadway that runs in the median, parallel to the Riverside Freeway (SR-

91), which remains free of charge. Operating under a public-private partnership, the four-lane toll facility, referred to as the 91X lanes, has two express lanes in each direction separated from the adjacent freeway lanes by a “soft barrier” (i.e., painted buffer with pylons). The express lanes have several innovative elements:

- Tolls that vary during the day in response both to demand and to congestion on the adjacent freeway lanes;
- A requirement for users to be registered customers using transponders;
- Discounted tolls for high occupancy vehicles (three or more riders);
- Photo enforcement of toll collections; and,
- Creation of the toll-way as a for-profit enterprise. (8)

The second critical piece of legislation was the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), under which a Congestion Pricing Pilot Program was established to test and assess the potential of value pricing initiatives. Under this program (renamed the Value Pricing Pilot Program in the 1998 Transportation Equity Act for the 21st Century – TEA-21), several more demonstration projects were planned and/or implemented, beginning with Interstate Highway 15 in San Diego, California (1996). Similar to the 91X value pricing scheme, the I-15 initiative is an 8-mile stretch of roadway consisting of two reversible lanes in the median of the I-15 freeway. Vehicles on the median lanes with two or more occupants are not charged a toll, while single occupancy vehicles are charged variable rates according to the level of congestion on the main roadway. Again, the adjacent freeway lanes remain untolled. (9) A different version of value pricing was instituted in 1998 on the Katy Freeway (I-10) in Houston, Texas. A 13-mile reversible lane in the median of the freeway does not allow single occupancy vehicles, requires a peak-hour toll for vehicles with two occupants, and is always free to vehicles with three or more occupants. In 1999, a similar system was established on Houston’s Northwest Freeway (US 290). (10)

The first example of value pricing on bridges began in August 1998 in Lee County, Florida with variable tolls instituted on two of the four bridges connecting Cape Coral and Fort Meyers. Deep discounts (50 percent) were offered to those traveling immediately before and after peak hours (6:30 – 7:00 AM; 9:00 – 11:00 AM; 2:00 – 4:00 PM; and 6:30 – 7:00 PM) and using electronic tolling. [11]

Description of the New Jersey Turnpike

This section provides a brief historical description of the NJTPK, which is necessary to understand the institutional context in which this time of day pricing initiative was implemented.

The New Jersey Turnpike is a 148 mile-toll road that extends from the Delaware Memorial Bridge in the South of New Jersey to George Washington Bridge in New York City. The road was constructed between December 1949 and January 1951 after legislation was enacted establishing the New Jersey Turnpike Authority. [12] The Authority's mandate included the construction and implementation of a 'pay-as-you-use' facility, and the management of the facility to enhance traffic flow and quality of service for users. The Turnpike was constructed on the State Highway 100 corridor at a cost of $278 million. A schematic of the NJ Turnpike and the surrounding transportation network is shown in Figure 1. [13]

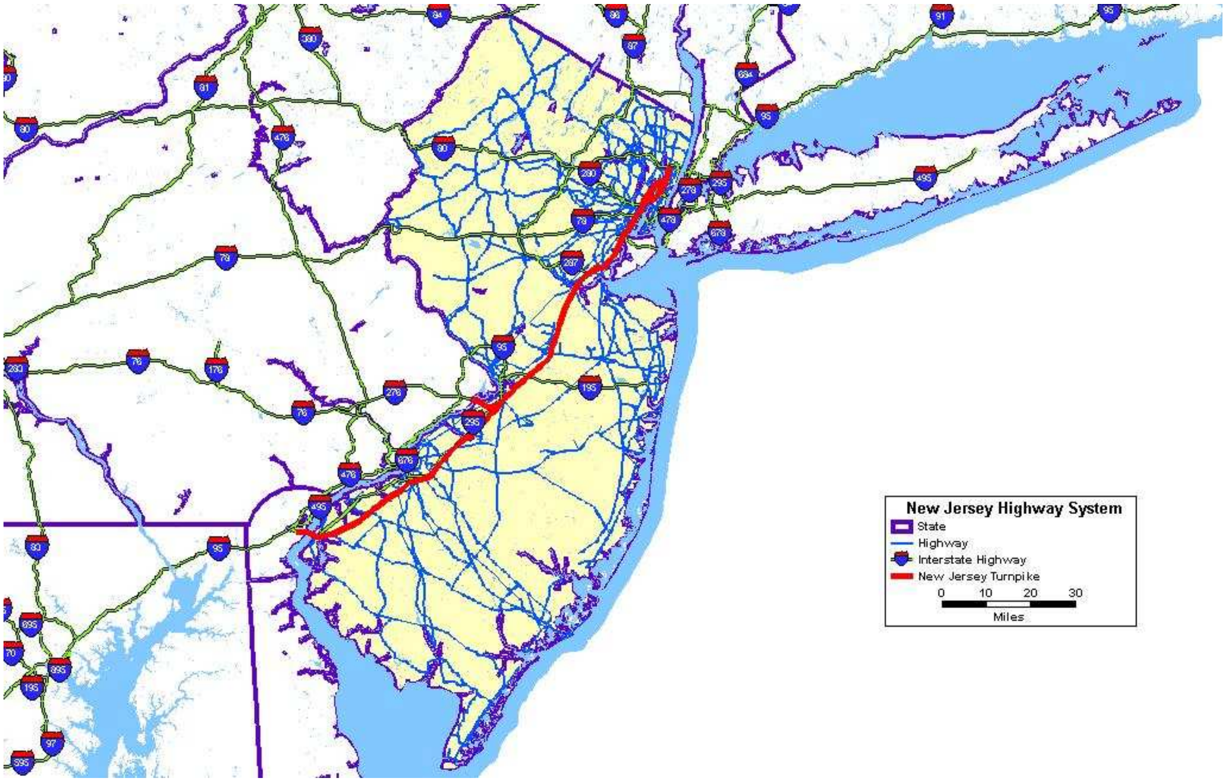

Figure 1. Map of New Jersey Turnpike (13)

Since its completion in 1952, the NJ Turnpike has played a key role in facilitating the economic development of the State of New Jersey, its neighboring municipalities, and the entire mid-Atlantic region. Trips between Boston, New York, Philadelphia and Washington D.C. for work, vacations, shopping, recreation, or delivery of goods and services almost always include a trip on the NJ Turnpike. According to NJTA's 1998 report, approximately 35 percent of the total trips on the Turnpike do not originate in New Jersey. (14)

Currently, the road has 28 interchanges, commonly referred to as exits with two more planned in the next decade. Because of increased demand, the number of exits was increased to 21 in 1956 and to 24 in 1970. (15) The NJ Turnpike was one of the most densely used roadways in the country with an average daily traffic that exceeds 700,000 vehicles. The interchanges connect to New Jersey's major highways and vast transportation network, institutions, and economic hubs. The NJTPK also has 12 service centers, six are accessible to southbound traffic, five to northbound traffic, and one is accessible to both directions. [16] The centers, operated under contract by Marriott, sell gasoline, consumables and gifts. In 1992, the service centers dispensed approximately 50,000,000 gallons of gasoline, a factor that helps keep the tolls at minimum.

History of Time of Day Pricing at NJTPK

The toll-road concept was developed by Governor Alfred Driscoll to connect the shipping and industrial hubs of Camden and Trenton to Elizabeth and Newark. [15] To minimize queuing delays, the NJ Turnpike was to have a minimal number of toll plazas over its 148 miles and the toll plazas were located at the exits off the NJ Turnpike. The NJ Turnpike has employed price differentiation based on: [17]

- *Use of Facility*: The distance traveled between entrance and exit pairs (the longer the distance the higher the toll level)
- *Vehicle Classification*: The amount of toll is based on the number of axles, vehicle type, and tare weight (2 classes for buses, 5 classes for trucks, and 1 class for passenger cars)
- *Time of day*: Toll discounts during off-peak hours (not for commercial vehicles or cash users)
- *E-ZPass Availability*: Toll discounts during off-peak hours only for passenger cars with E-ZPass.

Although generally the longer the trip the higher the toll, the tolls are not a function of distance only, but incorporate some measure of attractiveness of the different zones/cities. U-turns on the toll road attract penalties amounting to the maximum toll. On the whole the toll is not based on dynamic traffic demand characteristics like congestion. Originally, the tolls were intended to raise funds for operational and maintenance activities, which has been achieved with the increase in demand from 765 million passenger-miles in 1952 to 5 billion passenger miles in 1998. [12]

Starting from its operation, the NJ Turnpike has experienced several toll structure changes in its history. Based on the information directly received from the NJTPK [18], after the toll increase in 1991 until September 2000, single toll value is charged for each type of vehicle, regardless of time of the day. After September 2000, several operational changes are occurred, having potentially important impacts on the use of the facility. These changes include:

1. Starting from September 2000, E-ZPass technology was introduced to the facility, eliminating the need for cash, ticket or token usage to travel on the facility.
2. In September 2000, the New Jersey Turnpike Authority implemented the first stage of the time of day pricing application and increased the toll levels for cash users and peak E-ZPass users, while E-ZPass off-peak period users continued to pay the same toll amounts as in 1991. As part of this program, different toll levels are charged to users depending on time of day and vehicle type; such that, E-ZPass users started to pay discounted tolls while using the NJ Turnpike during non-peak hours.
3. In January 2003, toll levels for each time period and vehicle type are increased as the second stage of the NJ Turnpike time of day pricing program.

The percent of increase in the toll amount and the resulting toll amounts for the toll structure implemented as part of these two stage program are shown in Table 1. The percentage values in the Table 1 represent the percent of increase in the toll amount, and the values in the parentheses represent the resulting toll amount between entry-exit pairs (1,18W), the highest toll amount.

Table 1. History of the NJ Turnpike time of day pricing program (18)

Toll	Passenger Cars			Trucks and Trailers with 5 axle[4]		
	1991	September 2000	January 2003	1991	September 2000	January 2003
Cash all day [1]	70 % (4.60)	20% ($5.50)	17% ($6.45)	100 % ($18.20)	13% ($20.55)	13% ($23.20)
E-ZPass peak[2]	-	8% ($4.95)	10% ($5.45)	-	8% ($19.65)	8% ($21.20)
E-ZPass off peak	-	0%($4.60)	5 % ($4.85)	-	8% ($19.65)	8%($21.20)
E-ZPass[3] (all weekend)	-	8% ($4.95)	10 % ($5.45)	-	8 % ($19.65)	8 % ($21.20)

1: Cash users pay the highest toll levels on both weekdays and weekends irrespective of time of day.

2: For autos Weekday peak hour tolls are effective from 7:00 A.M. to 9:00 A.M in the morning and from 4:30 P.M. to 6:30 P.M. in the afternoon

3: On weekends the only E-ZPass discount is in place, and tolls are the same as those during the peak weekday periods.

4: Trucks are not eligible to pay discounted tolls during off-peak hours. Trucks with E-ZPass tag pay lower tolls compared to cash truck users.

In December 21, 2004, the NJTA approved a plan that calls eliminating E-ZPass discounts starting from January 1, 2006. Under this new time of day pricing program, the discounts given to cars using E-ZPass during peak hours and on weekends will be eliminated. However, trucks will not be affected from this new regulation and toll discounts given to cars during off-peak hours will remain in effect. (19,20)

METHODOLOGICAL FRAMEWORK

The project had three main focus areas that could be broadly described as: *Traffic Impacts*, *Behavioral Impacts* and *Media and Decision Makers Responses*. Rutgers University was in charge of the first and third area; while the second area was joint responsibility of Rutgers University and The Rensselaer Polytechnic Institute.

The research on the *Traffic Impacts* was conducted in two main steps. First, aggregate traffic counts and disaggregate vehicle-by-vehicle traffic and travel time information obtained from New Jersey Turnpike Authority were used to quantify the impacts of the two phases of the time of day pricing program on the time of day choices of the NJ Turnpike users. In the second step, a microscopic simulation model of the New Jersey Turnpike was developed and calibrated using Paramics simulation software. Application programming interface feature of Paramics was used to develop a detailed toll plaza model that can simulate complex weaving and lane change behavior of vehicles at the toll plazas. The model was then used to obtain delays and emissions at the toll plazas and mainline separately, and also assess before and after toll plaza and facility-wide throughput.

The second area of the research, *Behavior Impacts*, focused on the analysis of passenger traveler survey data which was gathered by Rutgers University Eagleton Institute by means of computer aided telephone interviews. In the first part of this task, socio economic characteristics of the NJTPK users and the impacts of time of day pricing initiative on the travelers' behavior were investigated and a detailed description of the surveys were given. Using traveler surveys, an econometric value of time and demand elasticity formulations that incorporated the socio-economic and trip related factors of the NJ Turnpike users were developed and estimated,.

The third line of the inquiry focused on *Media and Decision Makers Responses*. This focus area provided the process followed and the key insights how the NJTA implemented time of day pricing program, and reactions of the media and stakeholders to the implementation strategy.

BASIC RESEARCH QUESTIONS

In general terms, this project tried to answer a set of key questions, some of which are listed next:

- Did the time of day pricing initiative have a significant impact on traffic levels, and traffic composition by time of day? (Chapter II)
- What are the delays and emissions before and after the introduction of E-ZPass and Value Pricing program in September 2000? (Chapter III)

- Did the time of day pricing initiative produce behavioral changes on the users? (Chapters IV)
- What are the economic values of travel time savings and traffic elasticities, and how do they compare with elasticities estimated in other similar studies? (Chapter V and Chapter VI)
- What were the reactions of the media, decision makers and users to the time of day pricing initiative? (Chapters VII)

OVERVIEW OF THE REPORT AND LEAD CONTRIBUTORS

The project reported here attempted to provide a comprehensive assessment of the impacts of the NJTA time of day pricing initiative on user behavior and traffic patterns. The project also studied media and decision makers' reaction to the time of day pricing initiative. The report is comprised of ten major chapters, including this introduction.

Chapter I: Introduction (Lead contributors: Professor Kaan Ozbay, Professor José Holguín-Veras)

Chapter II: Traffic Impacts (Lead contributors: Professor Kaan Ozbay, Ms. Ozlem Yanmaz-Tuzel, Ms. Jeevanjot Singh).This chapter describes the analyses pertaining to the impacts of two phases of the time of day pricing program, first phase in September 2000, and the second phase in January 2003, on the traffic of the New Jersey Turnpike; and the users' response to time of day pricing and prevailing travel times.

Chapter III: Estimation and Analysis of Delays and Emissions Using Microscopic Traffic Simulation Model of the NJ Turnpike (Lead contributors: Professor Kaan Ozbay, Mr. Sandeep Mudigonda, Mr. Bekir Bartin). This chapter uses a Microscopic Simulation model of the NJ Turnpike developed and calibrated using Paramics simulation tool to assess before and after toll plaza and facility-wide throughput, vehicular queuing, travel times and emissions. It also presents the estimated costs of delays and emissions from 2000 through 2003.

Chapter IV: Descriptive Analyses of the Impacts of the Time of Day Pricing Initiative on Passenger Travel Behavior (Lead Contributors: Professor José Holguín-Veras, Mr. Juan Zorilla, Ms. Ning Xu, Ms. Qian Wang, Mr. Michael Silas).This chapter analyzes the socio economic characteristics of the NJTPK users and the impacts of time of day pricing initiative in September 2000 on the travelers' behavior using the passenger surveys conducted by Eagleton Institute at Rutgers University.

Chapter V: Economic Value of Travel Time Savings at the NJ Turnpike Facilities Using Travel Surveys (Lead contributors: Professor Kaan Ozbay, Ms. Ozlem Yanmaz-Tuzel). In this chapter, an econometric value of time formulation is developed and estimated using traveler surveys. The estimated model incorporates socio-economic and trip related factors of the NJ Turnpike users.

Chapter VI: Estimation of Demand Elasticity at the NJ Turnpike Facilities Using Travel Surveys (Lead contributors: Professor Kaan Ozbay, Ms. Ozlem Yanmaz-Tuzel). This chapter focuses on the estimation of elasticity of traffic demand with respect to toll changes using traveler surveys and calibrated value of time models.

Chapter VII: Media and Decision Makers' Reactions to the Time of Day Pricing Initiative (Lead contributors: Dr. Alan Lichtenstein, Mr. Martin Robins). This chapter provides the key insights how the NJTA implemented its time of day pricing program, and how the media and stakeholders perceived the implementation strategy.

Chapter VIII: Comparative Analyses of Toll Policies in the U.S. (Lead Contributors: Professor José Holguín-Veras, Professor Mecit Cetin, Ms. Shuwen Xia). This chapter intends to discuss the equity and fairness issues an lead to the analyses of efficiencies of current toll policies in the U.S..

CHAPTER II – TRAFFIC IMPACTS

INTRODUCTION

The main goal of this chapter is to investigate the impacts of the two phases of the time of day pricing program, which were implemented in September 2000, and January 2003, respectively, on the travel behavior of the NJ Turnpike users.

Specifically, responses to the two phases of the time of day pricing program and prevailing travel times were investigated both for the individual as well as the complete set of origin-destination (O-D) pairs of the NJ Turnpike. The before and after analysis was performed at both aggregate and disaggregate levels considering the seasonal variations among months. The significance level of observed changes after the time of day pricing was tested using appropriate statistical tests.

In the following sections, first a detailed description of data sources is provided, followed by a before and after analysis of the two phases of the time of day pricing program. This is followed by the detailed analysis of the relationship between the changes in travel behavior and travel time for different periods. Finally, conclusions and discussions are presented.

DATA SOURCES

The data collected for this study was comprised of classified traffic counts by time of day and facility. However, this data were not electronically available and had to be manually processed from printouts. After the implementation of E-ZPass system, vehicle-by-vehicle disaggregate data also became available. Although, this data were also processed and archived, they were not generally available for traffic studies. Both aggregate and disaggregate data sets for different time periods were provided to the research team depending upon their availability. In summary, the database obtained from New Jersey Turnpike Authority (NJTA) [18] can be divided into two main parts: aggregate level data and disaggregate level data. The detailed description of the two data sets and considered time periods are shown in Table 2. This data set was used to analyze impacts of time of day pricing implementations in September 2000 and January 2003, on the hourly and daily distribution of traffic by vehicle type.

Aggregate level data included the information used to establish a baseline for traffic conditions for different days of the week, different hours of the day, and for peak/off-peak periods from 1998 to 2003 with some exceptions shown in Table 2.

The first part of the data set included total traffic flow observed at the NJ Turnpike for a typical work day at peak and off-peak hours from October to June for years 1998, 1999, 2000 and 2001. The traffic flow at peak hours included the total traffic from 7:00 A.M. to 9:00 A.M. in the morning and from 4:30 P.M. to 6:30 P.M. in the afternoon; whereas off-peak traffic flow included the total traffic observed during the rest of the day.

The second part of the aggregate data set included the total daily traffic observed at each day of May and June for 2000 and 2003.

Lastly, the third part of the aggregate data set included the total hourly traffic flow for four days namely, May 11, 2000, May 15, 2003, June 15, 2000 and June 12, 2003. This data set did not include any traffic information about entry-exit pairs, vehicle types or payment types (E-ZPass or cash). The data set after September 2001 until October 2002 was not available to the research team since this period is just after the events of September 11th. In addition, travel time data needed for the evaluation of delays both on the mainline and at toll booths were not available. On the other hand, the disaggregate level data provided detailed vehicle-by-vehicle information regarding the entry and exit locations of the vehicles, observed vehicle travel times and tolls paid for each time of the day and day of the week.

Table 2. Description of data provided by NJTA (18)

Type	Time interval	Data Type
Aggregate Data Set	October 1998 – June 1999 October 1999 – June 2000 October 2000 – June 2001	Average traffic for A.M. peak hours, P.M. peak hours and off-peak hours
	May 2000, May 2003 June 2000, June 2003	Daily traffic for each day of the month
	May 11, 2000, May 15, 2003 June 15, 2000, June 12, 2003	Hourly traffic for each interchange entry and exit points
Disaggregate Data Set	October 2002 – March 2003	Vehicle by vehicle entry/exit times and locations, and tolls paid for each E-ZPass vehicle

Note: Weekday peak hour tolls are effective from 7:00 A.M. to 9:00 A.M in the morning and from 4:30 P.M. to 6:30 P.M. in the afternoon

METHODOLOGY

The research methodology used to investigate the NJ Turnpike users' behavior, their response to time of day pricing and prevailing travel times is composed of three parts:

1. Seasonal factor analysis was conducted using aggregate traffic data between October 1998 and June 2000, to investigate the sources of time-dependent variations.
2. Before-after analysis was conducted using the aggregate data set to determine the changes in the total yearly and daily traffic flows from 1998 to 2003, and to determine the changes in travelers' behavior during peak and off-peak periods using average traffic volumes before and after the two phases of the time of day pricing program. Appropriate statistical significance tests were applied to determine the significance level of the changes in traffic.
3. To better understand the reasons of traffic shift, the relationship between the changes in traffic and travel time for different periods were investigated using the vehicle-by-vehicle disaggregate data.
4. In order to get a better insight of the individual and combined impacts of travel time and toll differentials on the NJ Turnpike user behavior, traffic patterns of highly utilized pairs were investigated using appropriate statistical tests.

ANALYSIS OF SOURCES OF VARIATIONS USING AGGREGATE DATA SET

While investigating the travel patterns at the NJ Turnpike, it is important to differentiate the facility specific seasonal changes in traffic levels for different time periods when no external factor, i.e., new toll schedule, is imposed to the system from the changes in the travel patterns due to time of day pricing program. In this part of the analysis, the role of seasonal variations in traffic levels was investigated through a simple statistical model. It is important to note that this model does not attempt to analyze the role of the underlying economic conditions on variations in traffic levels, but treats these factors as part of the random errors related to external factors. This analysis identifies three sets of factors using the data set from October 1998 to December 2000 before the first phase of the time of day pricing program and from October 2002 to December 2002, before the second phase of the time of day pricing program:

a. Factor_1: Temporal variations due to the fluctuations in traffic depending on the time of the day, days of the week and months of the year.
b. Factor_2: Traffic flow fluctuations among years for a specific time period (peak and off-peak periods) of a day of a month due to the changes in the amount of tolls, travel time, or demand.
c. Other random errors: Fluctuations due to external factors which are difficult to capture, such as economic growth and sampling errors.

The statistical model for representing the distribution of traffic can be written as follows. (22)

$$y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij} \quad (1)$$

where;

y_{ij}: Observed percent share of traffic depending of Factor_1 (*i*), and Factor_2 (*j*)

μ: Mean of all observations y_{ij}

α_i: Effect of Factor_1 (*i*)

β_j: Effect of Factor_2 (*j*)

ε_{ij}: Random error term

To reduce the fluctuations in the traffic flow, (1) The A.M./P.M. and peak/off-peak period traffic volumes were investigated separately using two separate data sets, namely the aggregate traffic data from October 1998 to December 2000 and the aggregate traffic data from October 2002 to December 2002; (2) Typical work days and years with fixed toll amounts were selected, (3) Traffic demand was represented in terms of percentage share with respect to total daily traffic. Therefore, Factor_1 represents the seasonal variation among months, and Factor_2 represents the yearly changes in traffic volumes when everything else in the system remains unchanged.

In order to fully determine the significance of these factors and their effects on the traffic, a two-way Analysis of Variance (ANOVA) test was employed by constructing a two-factor full factorial design without replications using the following data sets, as shown in Table 3. An ANOVA test is closely related to the t-test. The major difference lies in the fact that the t-test measures the difference between the means of two groups, whereas an ANOVA tests the difference between the means of two or more groups. The main advantage of using the ANOVA test instead of multiple t-tests is that it reduces the type-I error which is the probability of rejecting the null hypothesis that is in fact true. The main reason for this is that by making multiple comparisons using t-test, one increases the alpha value automatically. This, in turn, increases the likelihood of making a type-I error. The ANOVA test is also called the F-test which tells if there is a statistically significant difference between groups. While conducting a two-way ANOVA test, the data points are divided into relatively homogenous subgroups, and significance tests are implemented within and across each homogenous group. The key idea is to determine the effect of each subgroup to the total variation.

Table 3. Details of the data sets utilized in the two-way ANOVA

Data set	Compared Time Periods	Type of Data
Set 1	**October 1998 – June 1999**	A.M. peak percent share P.M. peak percent share Off-peak percent share
	October 1999 – June 2000	A.M. peak percent share P.M. peak percent share Off-peak percent share
Set 2	**October 2000 – December 2000**	A.M. peak percent share P.M. peak percent share Off-peak percent share
	October 2002 – December 2002	A.M. peak percent share P.M. peak percent Share Off-peak percent share

During the analysis of data set 1, monthly data pairs that were collected before both phases of the time of day pricing program were compared. This case provided information regarding seasonal variations among months/seasons prior to the first phase in September 2000, when everything else in the system was fixed. The ANOVA structure for data Set 1 is presented in Table 4.

Table 4. Two-way ANOVA structure for data set 1

October 1998	November 1998	…..	May 1999	June 1999	Changes among years
October 1999	November 1999	…..	May 2000	June 2000	

Changes among months

Similarly, during the analysis of data set 2, monthly data pairs that were collected before the second phase of the time of day pricing program, were compared. This case provided information regarding seasonal variations among months/seasons between the first and the second phases of the time of day pricing program, when everything else in the system was fixed. The ANOVA structure for data set 2 is presented in Table 5.

Table 5. Two-way ANOVA structure for data set 2

October 2000	November 2000	December 2000	Changes among years
October 2002	November 2002	December 2002	
Changes among months			

The results of the two-way ANOVA for each time period are presented in Table 6. The analysis results for set 1 indicated that there was a statistically significant seasonal variation among the months (Factor_1). However, from set 2 it is observed that the fluctuation among the consecutive months was statistically insignificant. This is due to the fact that in data set 2, only three consecutive months that had a similar trend were compared. On the other hand, in data Set 1, a wider range of months was compared. Moreover, the analysis results of data set 1 showed that the changes in the percent share of specific time periods with respect to total daily traffic (Factor_2) were statistically insignificant before 2000. However, data set 2 indicated that between the first and second phase of the time of day pricing program, there was a statistically significant change in the percent shares of peak and off-peak periods. The main reason for these different results among two data sets is probably due to the fact that the data set 1 involved the time period from October 2000 to December 2000, right after the first phase of the time of day pricing program. Therefore, the system might still be experiencing fluctuations due to the new toll structure. The analysis of data set 2 indicated that from 2000 to 2002 the percent shares of peak and off-peak periods with respect to total daily traffic were changing. In order to fully explain this change in percent shares of traffic demand mainly due to user behavior, traffic demands for peak and off-peak hours are investigated in the next sections.

Table 6. Two-way ANOVA results for sources of variation

Data Set	Time Period	Source of Variation	Mean Square Error	F	F critical	Significance
Set 1 (Before the 1st phase) Oct 98-June 00	A.M. peak (7-9A.M.)	Among months	0.58	16.72	5.32	**Yes**
		Among years	0.11	3.26	3.44	No
		Random Error	0.035	-	-	-
	P.M. peak (4:30-6:30P.M.)	Among months	0.43	13.44	5.32	**Yes**
		Among years	0.1	3.12	3.44	No
		Random Error	0.032	-	-	-
	Off-peak	Among months	2	18.9	5.32	**Yes**
		Among years	0.2	1.9	3.44	No
		Random Error	0.1	-	-	-
Set 2 (Before the 2nd phase) Oct 00-Dec 02	A.M. peak (7-9A.M.)	Among months	3.8	6.91	19.00	No
		Among years	13.7	24.9	18.51	**Yes**
		Random Error	0.55	-	-	-
	P.M. peak (4:30-6:30P.M.)	Among months	3.10	7.75	19.00	No
		Among years	8.38	20.95	18.51	**Yes**
		Random Error	0.4	-	-	-
	Off-peak	Among months	6.95	2.92	19.00	No
		Among years	53.64	22.54	18.51	**Yes**
		Random Error	2.38			

To further investigate the traffic flow fluctuations between consecutive months, monthly adjustment factors were calculated for each month of the time period between October 2000 and June 2000 using the methodology proposed by a recent paper by Aunet [(21)]. In this methodology, monthly adjustment factors were calculated as the ratio of traffic flow at each month to the average traffic flow observed within the whole time period. The seasonal factor analysis and the monthly adjustment factor results indicated that:

1. Traffic demand between December and February was lower compared to the traffic between March and June, and the traffic in October and November of all the tested years.
2. Monthly adjustment factors between October and June were found to be similar to the values observed in the paper by Aunet (21) (Figure 2). Monthly adjustment factors were similar to each other for consecutive months. However, they became different for months further away from each other. This result supports the results obtained from the two-way ANOVA analysis, indicating that there is a statistically significant difference in the traffic flows of winter and summer months,

and the differences in traffic flows for the months within the same season are statistically insignificant.

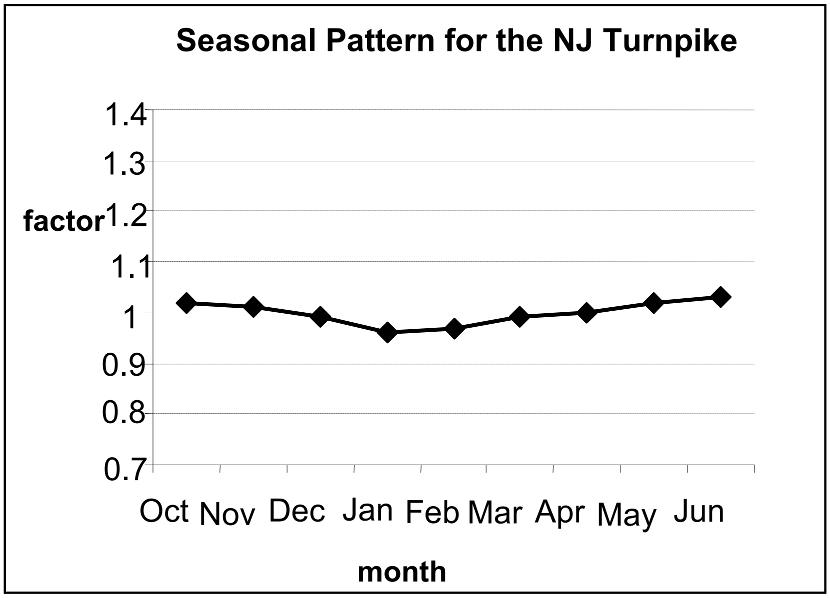

Figure 2. Seasonal traffic demand patterns for the NJ Turnpike between October 1999 and June 2000

AGGREGATE LEVEL ANALYSIS FOR THE IMPACTS OF FIRST AND SECOND PHASE OF THE TIME OF DAY PRICING PROGRAM

In this section, the changes in the yearly, daily, peak and off-peak period traffic patterns after the implementation of both phases of the time of day pricing program were investigated. Using the results obtained from the seasonal variation analysis presented in the previous section, yearly and total daily volumes and percentage shares of peak/off-peak period traffic were compared for the same months of years 1998 through 2003 to minimize the effects of seasonal variation. The methodology can be summarized as follows.

1. Analysis of the traffic fluctuations among different days of the week.

2. Analysis of changes in total yearly volumes of the NJ Turnpike from 1998 to 2003
3. Analysis of changes in the total daily volumes of the NJ Turnpike from 1998 to 2003
4. Analysis of the changes in the percent shares of AM. and P.M. peak periods.
5. Application of statistical tests to determine the statistical significance level of these changes

Traffic Flow Distribution among Different Days of the Week

The fluctuations among different days of the week were analyzed using daily traffic information for each day of May and June (2000 and 2003). The results indicated that the traffic patterns were different for Monday through Thursday (14.5 percent of total weekly volume), Friday (17 percent of total weekly volume), and weekends (12.5 percent of total weekly volume).

Changes in the Total Yearly Volumes

In this section, the changes in total yearly volumes observed at the NJ Turnpike were investigated. The main goal was to determine whether or not the two phases of the time of day pricing program had an impact on the total yearly traffic demand of the NJ Turnpike. To achieve this goal, the time period from 1998 to 2003 was considered. This data set extended from two years prior to the first phase of the time of day pricing program to one year after the second phase of time of day pricing program. The absolute yearly traffic volumes were obtained from the 2003 Annual Report of NJTA [(22)].

In Table 7, total yearly traffic demand from 1998 to 2003 is shown along with the rate of increase in demand for each consecutive year. The results indicated that there was an increasing trend in annual demand. The increase in demand from 2000 to 2001, after the first phase of the time of day pricing program was 4.81 percent. This rate of increase was higher than the rate of increase in the previous year, which was 2.41 percent. These findings indicated that despite the time of day pricing initiative and the events on 9/11, the traffic demand at the NJ Turnpike increased each year at a higher rate compared to the previous year. More importantly the time day pricing implementations initiated in 2000 and 2003 did not have an impact on the increasing trend in the NJ Turnpike traffic demand.

Table 7. Total yearly demand at the NJ Turnpike [22]

Year	Yearly Demand	increase in demand (%)
1998	209,408,270	-
1999	213,150,447	1.79
2000	218,280,591	2.41
2001	228,773,394	4.81
2002	241,695,190	5.65
2003	255,080,865	5.54

Changes in the Total Daily Volumes

After investigating the changes in total yearly traffic volumes, the changes in total daily volumes observed at each month of the specified time period were analyzed. The main purpose was to determine whether or not the two phases of the time of day pricing program had an impact on the total daily traffic demand at the NJ Turnpike. To achieve this purpose, the time period from 1998 to 2003 shown in Table 8 was utilized. The data set obtained from NJTA [18], included total daily volumes between October and December for 1998, 1999, 2000, and 2002; and between January and June for 1999, 2000, 2001, and 2003 (excluding total daily demand in April 2003). Due to 9/11 the traffic data after September 2001 until October 2002 was not available to the research team.

Daily volumes were calculated as the average of total traffic volumes observed on weekdays of each month. An average of 20 weekdays, excluding the holidays per month were considered.

Table 8. Data set for the total daily volume analysis

1998	1999	2000	2001	2002	2003
Oct – Dec	Jan-June Oct-Dec	Jan-June Oct-Dec	Jan-June	Oct-Dec	Jan-Mar May-June

The trends in the total daily volumes from 1998 to 2003 are shown in Figure 3. As it is observed from Figure 3, the daily traffic demand in each year represent the same trend in the same months of the consecutive years; such that from October to January the total daily demand decreases, then from February to June the total daily demand increases for each month. This trend was observed for each year included in the analysis, including the time period of September 2000 and January 2003, during which the time of day pricing program and toll increases were implemented.

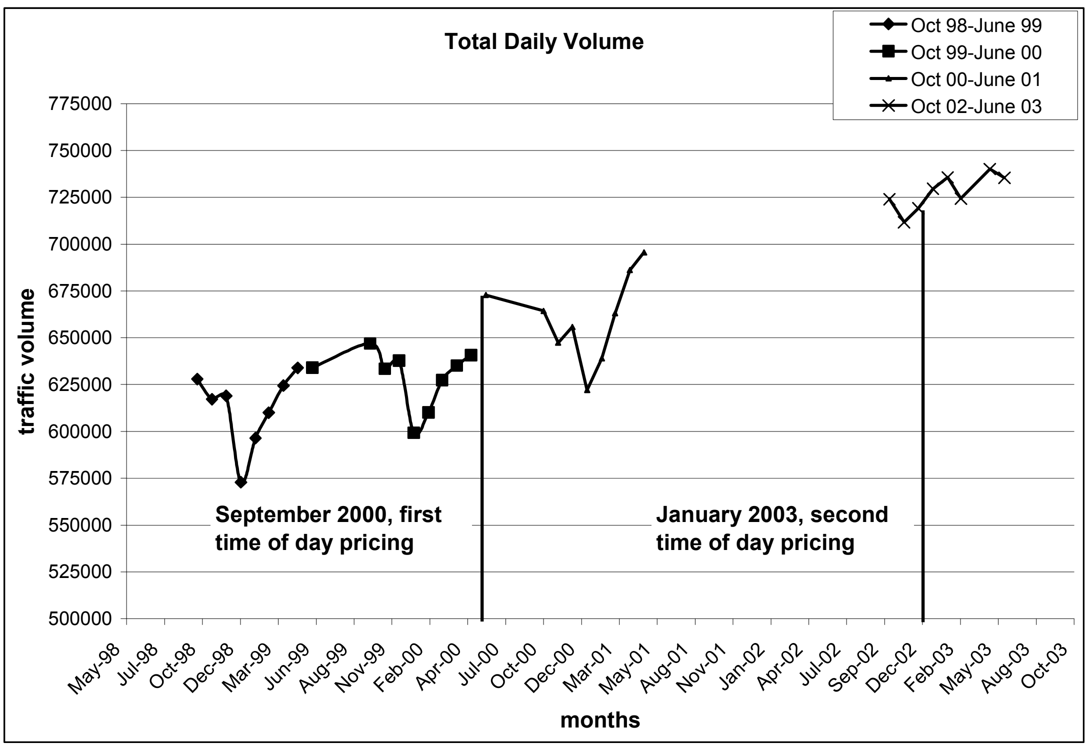

Figure 3. Total daily demand at the NJ Turnpike between 1998 and 2003

In Table 9, the rates of increase in total daily traffic demand from 1998 and 2003 along with the absolute traffic volumes are shown. As depicted in Table 9, the rates of increase were calculated for a one-year basis and a two-year basis, to compare the rates of increase before and after the both phases of the time of day pricing program. The results indicated that total daily volumes continued to increase from 1998 to 2003, despite the time of day pricing. As shown in Table 9, from 1998 to 2003 the total daily traffic demand increased by more than 100,000 vehicles per day. After the first phase of the time of day pricing program in September 2000, from October 2000 to December 2000, the rate of increase in total daily demand was 2.57 percent, slightly less than the rate of increase of the previous year which was 2.90 percent. On the other hand, the rate of increase in total daily demand from January-June 2000 to January-June 2001 was 6.22 percent, which was higher than the rate of increase in the total daily demand of the same months (3.1 percent) from 1999 to 2000. These results indicated that during the three months right after the first phase of the time of day pricing program, the rate of increase in traffic demand was lower compared to previous years. However, in the following months a higher rate of increase was observed compared to previous years. Therefore, it can be concluded that, from 2000 to 2001 despite the time of day pricing initiative, the total daily traffic volumes continued to grow at an increasing rate. A similar trend was observed after the second phase of the time of day pricing began in January 2003. However due to the events of 9/11, data was not available from September 2001 to October 2002 and thus the increase in demand could only be calculated using the time periods between January-June 2001 and January-June 2003. The results indicated that after the second phase of the time of day pricing program, the rate of increase of total daily demand slightly increased to 10.13 percent in 2003 compared to the 9.55 percent increase in 2002.

Table 9. Changes in the total daily demand from 1998 to 2003

Comparison	Time period	daily demand	increase %	Comment
1-year	Oct -Dec 1998 Oct -Dec 1999	621,350 639,397	2.90	before the 1st time of day pricing
	Oct -Dec 1999 Oct -Dec 2000	639,397 655,832	2.57	before&after the 1st time of day pricing before the 2nd time of day pricing
2-year	Oct -Dec 1998 Oct -Dec 2000	621,350 655,832	5.55	before&after the 1st time of day pricing before the 2nd time of day pricing
	Oct -Dec 2000 Oct -Dec 2002	655,832 718,232	9.51	after the 1st time of day pricing, before the 2nd time of day pricing
1-year	Jan -June 1999 Jan -June 2000	611,939 630,919	3.10	before the 1st time of day pricing
	Jan -June 2000 Jan -June 2001	630,919 670,397	6.22	before&after the 1st time of day pricing before the 2nd time of day pricing
2-year	Jan –June 1999 Jan -June 2001	611,939 670,397	9.55	before&after the 1st time of day pricing before the 2nd time of day pricing
	Jan -June 2001 Jan -June 2003	670,397 733,000	10.13	before &after the 2nd time of day pricing

Statistical Tests for the Changes in Total Daily Volumes

In order to determine whether or not the increase in total daily volumes was statistically significant, 1-tailed paired two-sample t-tests were conducted at 95 percent confidence level. Since there is seasonal variation in the traffic demand of the NJ Turnpike for different months of the year, in the t-tests, same months of consecutive years were compared with each other. In order to analyze the impacts of only first phase of the time of day pricing program on the regular traffic flow trends, the total daily traffic flow from October to December in consecutive years was compared. Similarly, the total daily traffic flow from January to June in consecutive years was compared to analyze the impacts of first and second phase of the time of day pricing program on the regular traffic flow trends.

Since the main objective of the analysis is to assess whether or not the trend in the total daily demand has changed after the two phases of the time of day pricing program, the alternate hypothesis was selected as being that the total daily traffic demand reduced after the time of day pricing. This hypothesis can be tested by conducting 1 tailed t-test that can be represented mathematically as follows [23]:

$$H_0 : (\mu_{i.})_{before} - (\mu_{i.})_{after} = 0$$
$$H_1 : (\mu_{i.})_{after} - (\mu_{i.})_{before} > 0 \qquad (2)$$

where;

$(\mu_{i.})$ = mean traffic volume

i: time period index, (1: October-December, 2: January – June)

The analysis results for each time of day pricing initiative are shown in Table 10. The results indicated that for each time period between 1998 and 2003, the increase in the total daily traffic was statistically significant. Therefore it can be concluded that the total daily traffic demand on the NJ Turnpike continued to increase from 1998 to 2003, despite the time of day pricing initiative and increased toll levels.

Table 10. Statistical significance test results for the changes in total daily traffic

Time period	% increase	p-value	significance	Comment
Oct -Dec 1998 Oct -Dec 1999	2.91	0.0012	yes	before the 1st phase
Oct -Dec 1999 Oct -Dec 2000	2.57	0.0030	yes	before&after the 1st phase before the 2nd phase
Oct -Dec 1998 Oct -Dec 2000	5.55	0.0019	yes	before&after the 1st phase before the 2nd phase
Oct -Dec 2000 Oct -Dec 2002	9.52	0.0003	yes	after the 1st phase before the 2nd phase
Jan -June 1999 Jan -June 2000	3.12	0.0055	yes	before the 1st phase before the 2nd phase
Jan -June 2000 Jan -June 2001	6.22	0.0003	yes	before&after the 1st phase before the 2nd phase
Jan -June1999 Jan -June 2001	9.51	0.0001	yes	before&after the 1st phase before the 2nd phase
Jan -June 2001 Jan -June 2003	10.13	0.0121	yes	before &after the 2nd t phase

The analysis results obtained from total annual traffic demand and total daily traffic demand on the NJ Turnpike indicated that there was a statistically significant increase in the demand despite the two phases of time of day pricing program. Moreover, the traffic demand continued to increase and showed a similar behavior before and after the time of day pricing. In addition, as mentioned in Chapter IV, the travel survey results revealed that among the 238 respondents who could recall the 2000 time of day pricing, only 36 respondents (7 percent) changed their travel time behavior in response to time of day pricing, and only 22 users out of the 36 respondents who changed their travel behavior increased trips along alternative routes. These important results indicate that there was no significant shift to other modes/routes after time of day pricing.

Changes in Peak and Off-peak Traffic after Two Phases of the Time of Day Pricing Program

In this section, the changes in peak and off-peak traffic flow after the two phases of the time of day pricing program were analyzed. The analysis focused on the changes after two distinct time periods, namely September 30, 2000 (first phase of time of day pricing program) and January 1, 2003 (second phase of time of day pricing program). A.M. peak hours (7:00 A.M. – 9:00 A.M.), P.M. peak hours (4:30 P.M. – 6:30 P.M), and off-peak hours (9:00 A.M. – 4:30 P.M. and 6:30 P.M. – 7:00 A.M.) were analyzed separately. Since the traffic volumes showed differences among the weekdays, the whole analysis was conducted using traffic data on typical workdays. Moreover, since there is seasonal variation among different months, throughout the analysis percentage values were used instead of absolute values. Also same months were compared with each other over the selected time period. For example, percent share of A.M. peak period in October 1999 was compared with the percent share of A.M. peak period in October 2000, and so on.

<u>Changes after September, 2000: First Phase of the Time of Day Pricing Program</u>

For the analysis of impacts of the first phase of the time of day pricing program in September 2000, two different sets of analyses were conducted considering two different time periods. In the fist case, the time period between October 1998 and June 1999 (two years before the first phase of the time of day pricing program) was compared with the time period from October 2000 through June 2001 (right after the first phase of the time of day pricing program). In the second case, the time period from October 1999 through June 2000 (one year before the first phase of the time of day pricing program) was compared with the time period from October 2000 through June 2001 (right after the first phase of the time of day pricing program). In order to obtain a better understanding of the level of absolute and percent share of traffic values during different times of day, the changes in absolute traffic flow at different time periods and the changes in the percent share of traffic at different times of day with respect to total daily traffic were analyzed simultaneously. The data sets and results for changes in the absolute and percentage traffic are shown in Table 11.

Table 11. Changes in absolute and percent share of traffic after September 2000, first phase of the time of day pricing program

Period	Case	Time - Period	Absolute		Percent Share	
			Mean	change	Mean	change
A.M. peak (7:00-9:00)	1st Case	Oct 98 - June 99	86477	6.27%	14.07	-1.7%
		Oct 00 - June 01	91900		13.83	
	2nd Case	Oct 99 - June 00	86843	5.82%	13.95	-1%
		Oct 00 - June 01	91900		13.83	
P.M. peak (16:30-18:30)	1st Case	Oct 98 - June 99	91495	4.17%	14.88	-3.7%
		Oct 00 - June 01	95310		14.33	
	2nd Case	Oct 99 - June 99	92301	3.26%	14.47	-1%
		Oct 00 - June 01	95310		14.33	
Off Peak	1st Case	Oct 98 - June 99	437104	9.4%	71.06	1.1%
		Oct 00 - June 01	478332		71.84	
	2nd Case	Oct 99 - June 00	444601	7.59%	71.72	0.2%
		Oct 00 - June 01	478332		71.84	

The analysis results of the first case indicated that (See Table 11), after the first toll increase and the introduction of E-ZPass technology, from October 1998 to June 2001, the absolute traffic volumes during A.M. peak, P.M. peak and off-peak hours increased by 6.27 percent, 4.17 percent and 9.4 percent, respectively. This result indicated that despite the increase in the demand of the NJ Turnpike, the rate of increase of peak period traffic demand was lower than the rate of increase in off-peak period traffic demand, supporting the results obtained from Jerry Kraft [(24)]. In addition, after the first phase of the time of day pricing program, the percent share of A.M. peak and P.M. peak period traffic reduced by 1.7 percent and 3.7 percent respectively; while the percent share of off-peak period traffic increased by 1.1 percent. In addition, the reduction in the percent share of the A.M. peak period was lower compared to the reduction in the percent share of the P.M. peak period. The reason for this difference is probably due to the fact that most of the morning trips are home to work trips, whereas afternoon trips are from work to home. Therefore, due to arrival time restrictions in the morning, travelers may have less flexibility in the morning compared to afternoon, which resulted in higher reduction in P.M. peak percent share of traffic.

As shown in Table 11, the analysis results of the second case depicted a trend similar to the first case. However the changes from October 1999 to June 2001 were lower compared to the changes from October 1998 to June 2001. From October 1999 to June 2001, the absolute traffic volumes during A.M. peak, P.M. peak and off-peak hours increased by 5.82 percent, 3.26 percent and 7.59 percent, respectively. In addition, after the first phase of the time of day pricing program, from October 1999 to June 2001, the percent share of A.M. peak and P.M. peak period traffic both reduced by 1 percent; while the percent share of off-peak period traffic increased by 0.2 percent.

<u>Changes after January 2003: Second Phase of the Time of Day Pricing Program</u>

For the traffic impact analysis of the second phase of the time of day pricing program in January 2003, two different sets of analyses were conducted considering two different time periods. In the first case, the time period between January 2001 and March 2001 (two years before the second phase of the time of day pricing program) was compared with the time period between January 2003 and March 2003 (right after the second time of day pricing implementation). On the other hand, in the second case, to increase the sample size, time period between October 2000 and June 2001 (after the first phase of the time of day pricing program) was compared with the time period between January 2003 and March 2003 (after the second time of day pricing program). Similar to the traffic impact analysis of the first phase of the time of day pricing, the changes in absolute traffic flow at different time periods and the changes in percent share of traffic at different times of day with respect to total daily traffic were analyzed simultaneously. It should be mentioned that, since there is seasonal variation among different months of the year, the changes in absolute and percent values of traffic demand considered in the second case include both impacts of time of day pricing and seasonal variations among the months. The data sets and results for changes in the absolute and percentage traffic are shown in Table 12.

Analysis results of the first case indicated that, after the second phase of the time of day pricing program, from January 2001 to March 2003, the absolute traffic during A.M. and P.M. peak periods increased by almost 14.93 percent and 9.84 percent, respectively; whereas absolute traffic during off-peak volume increased at a lower rate by almost 8.84 percent. This result indicated that, unlike the changes after the first phase of the time of day pricing program from year 2001 to 2003, peak period traffic flow increased at a higher rate compared to the off-peak period. Additionally, unlike the first phase of the time of day pricing program, as shown in Table 12, the percent share of A.M. and P.M. peak period traffic increased by 16 and 13 percent respectively; while the percent share of off-peak period traffic reduced by 6 percent from 2001 to 2003.

As shown in Table 12, analysis results of the second case represent a trend similar to the analysis results of the first case in terms of the changes in absolute traffic and percent of traffic at different times of day. However, the rate of increase of A.M. peak period was higher compared to the first case; whereas the rate of increase of P.M. peak and off-peak periods was lower compared to the first case. From October 2000 to March 2003, the absolute traffic volumes during A.M. peak, P.M. peak and off-peak hours increased by 15.67 percent, 7.79 percent and 3.62 percent, respectively. In addition, the percent shares of A.M. peak and P.M. peak period traffic increased by 21.7 percent, 15.5 percent; while percent shares of off-peak period traffic reduced by 7.26 percent.

Table 12. Changes in absolute and percent share of traffic after January 2003, second phase of the time of day pricing program

period	Data Set	Absolute		Percent Share	
		Mean	change	Mean	Change
A.M. peak	Jan 01 – March 01	92446	14.93%	14.42	16.71%
	Jan 03 – March 03	106295		16.83	
	Oct 00 - June 01	91900	15.67%	13.83	21.7%
	Jan 03 – March 03	106295		16.83	
P.M. peak	Jan 01 – March 01	93530	9.84%	14.58	13.51%
	Jan 03 – March 03	102738		16.55	
	Oct 00 - June 01	95310	7.79%	14.33	15.5%
	Jan 03 – March 03	102738		16.55	
Off-peak	Jan 01 – March 01	455416	8.84%	70.99	-6.15%
	Jan 03 – March 03	495684		66.62	
	Oct 00 - June 01	478332	3.62%	71.84	-7.26%
	Jan 03 – March 03	495684		66.62	

In summary, the analysis of the changes in the absolute and the percent share of traffic during peak and off-peak periods after the two phases of the time of day pricing program revealed different results. After the first phase of the time of day pricing program, even though the traffic demand continued to increase, the percent share of peak period traffic reduced; whereas the percent share of off-peak period traffic increased. On the other hand, after the second time of day pricing implementation, the percent share of peak period traffic increased; whereas the percent share of off-peak period traffic reduced.

Statistical Testing of the Changes in the Peak and Off-Peak Traffic after the Implementation of the Time of Day Pricing Program

In order to determine whether or not the changes in traffic at peak and off-peak periods after the implementation of each phase of the time of day pricing program were statistically significant, 1-tailed paired two-sample t-tests were conducted at 90 percent and 95 percent confidence levels. The analysis was performed separately for A.M. peak

(7:00 A.M. – 9:00 A.M.), P.M. peak (4:30 P.M. – 6:30 P.M.) and off-peak periods. Since traffic flow shows differences for different days of the week and different months of the year, typical workday traffic data (Wednesdays) were analyzed and same months of consecutive years were compared with each other. While conducting the t-test, percent shares of traffic at different time periods with respect to total daily traffic were used instead of absolute traffic values.

The main incentive of the time of day pricing is to make the travelers to shift to peak shoulder periods, by introducing toll discounts during these periods. Therefore, the alternative hypothesis for peak period traffic would be that the percent share of peak period after the time of day pricing initiative is smaller than the percent share of the peak period traffic before the time of day pricing. This hypothesis can be tested by conducting 1 tailed t test for each peak period separately based on the following hypothesis [23]:

$$\begin{aligned} H_0 &: (\mu_{j.})_{before} - (\mu_{j.})_{after} = 0 \\ H_1 &: (\mu_{j.})_{after} - (\mu_{j.})_{before} < 0 \end{aligned} \tag{3}$$

where;

$(\mu_{j.})$= mean percent share of period j, j: 1=A.M. peak, 2=P.M. peak)

Similarly, the alternate hypothesis for off-peak period traffic would be that the percent share of off-peak period after the time of day pricing initiative is larger than the percent share of the off-peak period traffic before the time of day pricing. This hypothesis can be tested by conducting 1 tailed t test based on the following hypothesis [23]:

$$\begin{aligned} H_0 &: (\mu_{j.})_{before} - (\mu_{j.})_{after} = 0 \\ H_1 &: (\mu_{j.})_{after} - (\mu_{j.})_{before} > 0 \end{aligned} \tag{4}$$

where;

$(\mu_{j.})$= mean percent share of off-peak period

Statistical Testing of the Changes in Peak and Off-Peak Traffic after September 2000, First phase of the Time of Day Pricing Program

For the analysis of the impacts of the first phase of the time of day pricing program, two different sets of analyses were conducted for two different time periods, namely Case1 and Case 2. In Case 1, the time period between October 1998 and June 1999 was compared with the time period between October 2000 and June 2001, and in Case 2 the time period between October 1999 and June 2000 was compared with the time period between October 2000 and June 2001. In each case, nine pairs of data points were compared for A.M. peak, P.M. peak and off-peak periods.

The results of the statistical significance tests for Case 1 and Case 2 are presented in Table 13 and Table 14, respectively. As observed from the t-statistics, there was a statistically significant reduction in the percent share of peak periods, and an increase in the share of off-peak periods for the analysis period. These changes were statistically significant for Case 1 at the 90 percent confidence level for A.M. peak hours, and at the confidence level of 95 percent for P.M. peak, and off-peak periods. For Case 2, only the decrease in P.M. peak hours was found to be statistically significant at the 95 percent confidence level.

Table 13. t-test results for first phase of the time of day pricing program, Case 1

Time-period	Mean	Variance	t-stat	t-critical	significance
Oct 98 - June 99 (A.M. peak)	14.07	0.11	1.70	1.396	**Yes**
Oct 00 - June 01 (A.M. peak)	13.83	0.34			
Oct 98 - June 99 (P.M. peak)	14.88	0.02	8.83	1.859	**Yes**
Oct 00 - June 01 (P.M. peak)	14.33	0.06			
Oct 98 - June 99 (off-peak)	71.06	0.15	-4.57	1.859	**Yes**
Oct 00 - June 01 (off-peak)	71.84	0.61			

Table 14. t-test results for first phase of the time of day pricing program, Case 2

Time-period	Mean	Variance	t-stat	t-critical	significance
Oct 99 - June 00 (A.M. peak)	13.71	0.04	-0.82	1.859	No
Oct 00 - June 01 (A.M. peak)	13.83	0.34			
Oct 99 - June 99 (P.M. peak)	14.57	0.10	2.34	1.859	**Yes**
Oct 00 - June 01 (P.M. peak)	14.33	0.06			
Oct 99 - June 99 (off-peak)	71.72	0.16	-0.58	1.859	No
Oct 00 - June 01 (off-peak)	71.84	0.61			

<u>Statistical Testing of the Changes in the Peak and Off-Peak Traffic after January 2003, Second Phase of the Time of Day Pricing Program</u>

In this section, the statistical significance level of the impacts of the second phase of the time of day pricing program was determined using 1-tailed t tests. Since the data for the second toll change in January 2003 was available for only three months before and after the second toll change, the aggregate level analysis for the second phase of the time of day pricing program was conducted using the three month data after the first phase of the time of day pricing program between January 2001 and March 2001, and the three month data collected after the second phase of the time of day pricing program between January 2003 and March 2003. The comparison of A.M. peak, P.M. peak and off-peak periods were done separately. The aggregate level analysis for the second phase of the time of day pricing program (in January 2003) was conducted based on the hypothesis presented in Equation 3 (peak periods) and Equation 4 (off-peak). The 1 tailed paired-two-sample t-test results at the 95 percent confidence level, shown in Table 15, indicated that after the time of day pricing implementation in January 2003, the increase in the percent share of A.M. and P.M. peak traffic, and the decrease in the percent share of off-peak period traffic were statistically significant.

Table 15. t-test results for the second phase of the time of day pricing program, 3-month comparison

Time-period	Mean	Variance	t-stat	t-critical	significance
Jan 01 - March 01 (A.M. peak)	14.42	0.11	-5.83	2.919	**yes**
Jan 03 - March 03 (A.M. peak)	16.83	0.49			
Jan 01 - March 01 (P.M. peak)	14.58	0.03	-11.84	2.919	**yes**
Jan 03 - March 03 (P.M. peak)	16.55	0.1			
Jan 01 - March 01 (off-peak)	70.99	0.25	7.49	2.919	**yes**
Jan 03 - March 03 (off-peak)	66.62	1.04			

Next, in order to increase the sample size for the statistical tests, the A.M. and P.M. peak periods and the off-peak period percent shares were compared utilizing the time period between October 2000 and June 2001 (nine data points) and the time period between January 2003 and March 2003 (three data points). Since the sample sizes were not equal and that there is a seasonal variation among different months, a paired sample test with equal variances could not be conducted. Therefore, the statistical comparison was based on the two-sample t-test assuming unequal variances. The t-test results presented in Table 16, show a significant increase in the percent share of peak period traffic and a significant decrease in the percent share of off-peak period traffic. This result supports the results obtained from the t-test conducted using smaller sample size.

Table 16. t-test results for the second phase of the time of day pricing program, increased sample size

Time-period	Mean	Variance	t-stat	t-critical	significance
Oct 00 - June 01 (A.M. peak)	13.83	0.34	-6.71	2.35	**yes**
Jan 03 - March 03 (A.M. peak)	16.83	0.49			
Jan 01 - March 01 (P.M. peak)	14.33	0.06	-11.33	2.35	**yes**
Jan 03 - March 03 (P.M. peak)	16.55	0.1			
Jan 01 - March 01 (off-peak)	71.84	0.61	8.13	2.35	**yes**
Jan 03 - March 03 (off-peak)	66.62	1.04			

In summary, the comparison of the impacts of the two phases of time of day pricing program at the NJ Turnpike indicated that the response of the users to the second phase of the program was different from their response to the first phase. Between the time period after the first phase and the time period after the second phase, there was a significant increase in the percent share of peak period traffic. Therefore, given the small differential between the peak and off-peak toll levels, it is likely that the change in the percent shares of peak and off-peak periods can be due to higher travel times rather than the toll differentials.

However, since no travel time data for these time periods was available, the analysis of the aggregate data could not provide information about the relationship between the shift in traffic and congestion levels. Therefore, it cannot be concluded that the change of traffic between peak and off-peak periods is solely due to the difference between peak and off-peak tolls. In order to better identify the reasons of the changes after the implementation of the time of day pricing program, the third part of analysis is conducted using vehicle-by-vehicle disaggregate data.

DISAGGREGATE LEVEL ANALYSIS FOR THE IMPACTS OF SECOND PHASE OF THE TIME OF DAY PRICING PROGRAM

In this section, the vehicle-by-vehicle E-ZPass data, obtained for the time period between October 2002 and March 2003, were analyzed. As shown in Table 2, the database only contained entry-exit locations (O-D pairs), times and the amount of toll paid; but it did not contain any other vehicle data to ensure the privacy of the users. This analysis was conducted to further investigate the changes in traffic after the second phase of the time of day pricing and to determine the sources of the changes in the user behavior. Based on the information obtained from the NJTA, E-ZPass users form 63 percent of the total users; and for a typical work day 88 percent of all the vehicles are passenger cars. [(18)] In addition, during peak hours and peak shoulders, more than 90 percent of the vehicles are passenger cars. [(18)] Since time of day pricing is only applicable to passenger cars with E-ZPass, the behavior of cash users is not directly affected by the toll differences between peak and off-peak periods. It is also safe to assume that most of the E-ZPass users are frequent users of the NJ Turnpike and are likely to be well aware of daily traffic conditions and variable tolls. E-ZPass users are thus the focus of this analysis conducted to understand the behavioral change of every day commuters who are eligible for toll discounts and familiar with the overall system.

Disaggregate level analysis was divided into two main parts. In the first part, individual vehicle-by-vehicle traffic information was used to create hourly traffic and travel time data between each O-D pair during peak periods and peak shoulders. Then, using this hourly traffic and travel time information between each O-D pair, the disaggregate level analysis was conducted to determine the shifts among peak and peak shoulder periods after the second phase of the time of day pricing program. In the second part of the analysis, individual vehicle-by-vehicle traffic information was used to create traffic and travel time data between each O-D pair for each 15 minute interval of during peak periods and peak shoulders. Then, using this 15 minute traffic and travel time information between each O-D pair, the disaggregate level analysis was conducted to determine the changes within each peak and peak shoulder periods.

Disaggregate Level Analysis of Second Phase of the Time of Day Pricing Program Using Hourly Traffic and Travel Time Data

While conducting disaggregate level analysis, a computer program was written in MATLAB to sort out the individual vehicle data obtained from NJTA with respect to entry times. Then, for a total of 26 O-D pairs, two 26x26 matrices were created for each hour of the day, representing the traffic between each O-D pair, and the travel times corresponding to that specific traffic level. As presented in the “Analysis of Sources of Variations” Section, monthly fluctuations between two consecutive months were found to be negligible compared to the fluctuations between months further away from each other. Thus, to minimize the error due to the seasonal differences, the analysis was conducted by utilizing consecutive months. The shifts in traffic and travel times were determined based on percentages, rather than absolute values, to capture the changes in traffic independent of the time of day pricing and seasonal variations. Since the traffic pattern for weekdays, Fridays and weekends were found to be different from each other, the traffic and travel time values observed for each O-D pair, totally 676 (26x26) pairs, were investigated separately for each day type. Each day was divided into eight sub-periods for weekdays and Fridays as follows:

1. Pre-peak period (6:00 A.M. – 7:00 A.M. and 3:30 P.M. – 4:30 P.M.)
2. Peak-1 period (7:00 A.M. – 8:00 A.M. and 4:30 P.M. – 5:30 P.M.)
3. Peak-2 period (8:00 A.M. – 9:00 A.M. and 5:30 P.M. – 6:30 P.M.)
4. Post peak period (9:00 A.M. – 10:00 A.M. and 6:30 P.M. – 7:30 P.M.)

On the other hand, for weekends, since the toll value is the same for the whole day, each day is divided into two sub-periods:

1. Period-1 (12:00 A.M. – 12:00 P.M.)
2. Period-2 (12:00 P.M. – 00:00 A.M.)

For each month two matrices were constructed to represent total traffic and average travel time between each O-D pair. The first one for weekdays and Fridays is a 26x26x8 matrix and the second for weekends is 26x26x2 matrix. The individual E-ZPass database had to be further processed to identify clusters of vehicle data that were large enough to be statistically significant while conducting statistical analyses. Since some of these clusters are too small to be statistically significant and they are not included in the analysis.

The following notation is used to better explain the steps of the data processing approach used to develop the analysis set. Let d_{ijk}^{ml} and t_{ijk}^{ml} be the traffic and travel time between each entry-exit pair (*i,j*) at time "*k*" for month "*m*" during day "*l*" where:

i: Index for origin (entry) point i=1, 2,…26

j: Index for destination (exit) point j=1, 2,…26

k: Index for time of day k=1, 2,...24

m: Index for month m=1, 2,…6 (1: October, 2: November.….6: March)

l: Index for day type l=1, 2 (1: Weekdays and Fridays, 2: Saturdays and Sundays)

The following steps for each two consecutive months were implemented to obtain a useful data set for analysis.

1. Determine O-D pairs satisfying at least one of the following two criteria and include these pairs in the final analysis set.

Criteria 1: Determine the destination "*j*", which attracts at least 10 percent of the total daily traffic, generated from a specific origin "*i*". If all O-D pairs were analyzed without using this criterion, the percent changes at pairs with low traffic would be high even if these changes are not significant enough to affect the overall traffic pattern. Therefore, to reduce the bias, the pairs forming the most significant share of the total daily traffic were determined. The algorithm for this criterion first calculated total traffic for each origin point for every day of every month within the analysis set. Then, it calculated the total daily traffic between every O-D pair as the sum of traffic between each O-D pair for every time period. Finally, it determined the O-D pairs that satisfy Criteria 1 by calculating the ratio of total traffic between each O-D pair and total daily traffic generated at the entry location of each pair. The mathematical representation of this algorithm is presented in Appendix 1-Part 1.

Criteria 2: Determine O-D pairs (*i*,*j*) which have at least 100 veh/hr demand during the pre-specified sub-periods. This is almost 10 percent of hourly traffic between an O-D pair during sub-periods. The reason for this criterion is to capture the O-D pairs that are highly utilized only during certain sub-periods, and that have almost no traffic during off-peak periods. Therefore, these pairs generate most of the traffic during specific sub-periods even if they do not satisfy the first criterion. It is thus important to identify these O-D pairs for the specific sub-periods during which they contribute significantly to the demand. The logic of this criterion is presented in Appendix 1-Part 2.

The data set was determined based on these two criteria, represented approximately 80 percent of the total traffic flow observed for pre-specified sub-periods.

After generating the data set, a preliminary analysis was conducted to investigate the distribution of traffic and travel times. The results indicated that before the second phase of the time of day pricing program, for almost 65 percent of the O-D pairs, maximum traffic was observed at peak periods; whereas, for 50 percent of the O-D pairs the highest travel time was observed during peak periods. On the other hand, after the toll increase these percentages decreased slightly to 62 percent and 47 percent, for traffic and travel times, respectively. These results indicated that the highest travel times were not always observed at peak periods.

Based on these preliminary observations, the disaggregate level analysis was conducted in two main parts. In the first part, for each consecutive month "*m*" and day type "*l*", periods with maximum hourly traffic was investigated. The main goal was to understand if a change in the distribution of percentages of traffic occurred at periods with the highest traffic flow before and after the second phase of time of day pricing program. Then, in the second part of the analysis periods with the highest travel time were investigated for each consecutive month "*m*" and day type "*l*". The main goal was to understand if a change in the distribution of percentages of traffic occurred at periods with the highest travel time before and after the second phase. The details of these two main parts of the analysis were provided in Appendix 1- Part 3 and Part 4. The analysis results conducted for consecutive months are shown in Table 17.

Table 17. User responses to time of day pricing and travel times after the second phase of the time of day pricing program, hourly data

Day type	Time-Period	$N^{ml}+M^{ml}$	Max. traffic demand				Max. travel time			
			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Weekdays	Oct, 2002 – Nov, 2002	323	48%	25%	17%	10%	38%	67%	88%	74%
	Nov, 2002 – Dec, 2002	324	49%	27%	14%	10%	33%	67%	76%	73%
	Dec, 2002 – Jan, 2003	365	45%	23%	18%	14%	41%	65%	69%	61%
	Jan, 2003 – Feb, 2003	324	43%	23%	16%	18%	43%	73%	79%	64%
	Feb, 2003 – Mar, 2003	349	53%	20%	16%	11%	40%	80%	87%	68%
Fridays	Oct, 2002 – Nov, 2002	345	64%	15%	10%	11%	39%	70%	63%	72%
	Nov, 2002 – Dec, 2002	324	67%	18%	5%	20%	37%	81%	66%	75%
	Dec, 2002 – Jan, 2003	308	51%	19%	13%	13%	41%	67%	61%	69%
	Jan, 2003 – Feb, 2003	313	58%	18%	11%	13%	44%	72%	65%	71%
	Feb, 2003 – Mar, 2003	345	63%	16%	6%	15%	35%	83%	70%	75%
Saturdays	Oct, 2002 – Nov, 2002	307	-	-	-		40%	61%	60%	-
	Nov, 2002 – Dec, 2002	295	-	-	-		42%	62%	59%	-
	Dec, 2002 – Jan, 2003	286	-	-	-		46%	58%	57%	-
	Jan, 2003 – Feb, 2003	279	-	-	-		45%	57%	55%	-
	Feb, 2003 – Mar, 2003	305	-	-	-		42%	60%	58%	-
Sundays	Oct, 2002 – Nov, 2002	328	-	-	-		42%	66%	62%	-
	Nov, 2002 – Dec, 2002	314	-	-	-		37%	61%	57%	-
	Dec, 2002 – Jan, 2003	324	-	-	-		48%	55%	51%	-
	Jan, 2003 – Feb, 2003	316	-	-	-		40%	53%	59%	-
	Feb, 2003 – Mar, 2003	290	-	-	-		36%	57%	61%	-

(1): ϕ_{k*}^{ml} **, (2):** r_{k*}^{ml} **, (3):** a_{k*}^{ml} **, (4):** d_{k*}^{ml} **, (5):** $\Delta_{k'}^{ml}$ **, (6):** $\gamma_{k'}^{ml}$ **, (7):** $\vartheta_{k'}^{ml}$ **, (8):** $\chi_{k'}^{ml}$ **.** The explanation of each column is given in Appendix 1 Part 3 and Part 4

Results of disaggregate level analysis shown in Table 17, can be used to draw some interesting observations. A summary of these observations for each consecutive pairs of months are given below.

October 2002-November 2002, November 2002-December 2002:

R_B (1): For 50 percent of the O-D pairs, maximum traffic was observed during peak periods that have less travel time than peak shoulders (Column (1) in Table 17).

R_B (2): For 25 percent of the O-D pairs maximum traffic was observed at peak shoulders that have less travel times than peak periods (Column (2) in Table 17).

R_B (3): For 10 percent of the O-D pairs, maximum traffic was observed during sub-periods with the highest travel times. These pairs either had average total travel times higher than 15 minutes, or they would provide more than 10 percent travel time savings when a shift to other sub-periods occurred (Column (4) in Table 17).
R_B (4): For almost 35 percent of the O-D pairs there was a change in absolute traffic flow at sub-periods with the highest travel time (Column (5) in Table 17).
R_B (5): For 67 percent of the O-D pairs where traffic flow patterns changed compared to the period prior to January 2003, absolute traffic flow at sub-periods with the highest travel time decreased (Column (6) in Table 17).
R_B (6): For 80 percent of the O-D pairs of which traffic flow increased, either had average total travel times less than 15 minutes or would provide less than 10 percent time savings when a shift to other sub-periods occurred (Column (7) in Table 17).
R_B (7): Almost 65 percent of the changes in departure times were to or within peak periods (Column (8) in Table 17).

December 2002-January 2003, January 2003– February 2003:
R_{F1} (1): For 45 percent of the O-D pairs, maximum traffic was observed during peak periods that have less travel time than peak shoulders (Column (1) in Table 17).
R_{F1} (2): For 23 percent of the O-D pairs maximum traffic was observed at peak shoulders that have less travel times than peak periods (Column (2) in Table 17).
R_{F1} (3): For 18 percent of the O-D pairs, maximum traffic was observed during sub-periods with the highest travel times. These pairs either had average total travel times higher than 15 minutes, or they would provide more than 10percent travel time savings when a shift to other sub-periods occurred (Column (4) in Table 17).
R_{F1} (4): For almost 42 percent of the pairs, there was a change in absolute traffic flow at sub-periods with the highest travel time (Column (5) in Table 17).
R_{F1} (5): For 65 percent of the pairs where traffic flow patterns changed compared to the period prior to January 2003, absolute traffic flow at sub-periods with the highest travel time decreased (Column (6) in Table 17).

R_{F1} (6): For 69 percent of the pairs of which traffic flow increased, either had average total travel times less than 15 minutes or would provide less than 10 percent time savings when a shift to other sub-periods occurred (Column (7) in Table 17).
R_{F1} (7): Almost 65 percent of changes in departure times were to or within peak periods (Column (8) in Table 17).

February 2003-March 2003:
R_{F2} (1): For 53 percent of the O-D pairs, maximum traffic was observed during peak periods that have less travel time than peak shoulders (Column (1) in Table 17).
R_{F2} (2): For 20 percent of the O-D pairs maximum traffic was observed at peak shoulders that have less travel times than peak periods (Column (2) in Table 17).
R_{F2} (3): For 16 percent of the O-D pairs, maximum traffic was observed during sub-periods with the highest travel times. These pairs either had average total travel times higher than 15 minutes, or they would provide more than 10 percent travel time savings when a shift to other sub-periods occurred (Column (4) in Table 17).
R_{F2} (4): For almost 40 percent of the pairs there was a change in absolute traffic flow at sub-periods with the highest travel time (Column (5) in Table 17).
R_{F2} (5): For 65 percent of the pairs where traffic flow patterns changed compared to the period prior to January 2003, absolute traffic flow at sub-periods with the highest travel time decreased (Column (6) in Table 17).
R_{F2} (6): For 80 percent of the pairs of which traffic flow increased, either had average total travel times less than 15 minutes or would provide less than 10percent time savings when a shift to other sub-periods occurred (Column (7) in Table 17).
R_{F2} (7): Almost 68 percent of changes in departure times were to or within peak periods (Column (8) in Table 17).

A similar pattern was observed for the weekends, apart from the fact that on weekends the sample size was smaller, thus a smaller percent of travelers tried to minimize their travel time, and the number of travelers who prefer not to change their travel periods were slightly more compared to weekdays. The reason for these slight differences between weekdays and weekends were probably a result of the fact that the peak tolls were effective throughout the weekend, traffic flows on weekends were almost 25 percent lower than weekday traffic, and most of the travelers did not have a strict departure time constraints since most of the trips were not work related.

<u>Summary of the Results</u>

The second phase of time of day pricing program that started in January 2003 did not have a statistically significant impact on traffic. Apart from some fluctuations during January and February 2003, traffic conditions were found to be similar before and after the toll changes. The only differences between traffic conditions before and after the toll increase were:

(1) For February-March 2003, the percentage of pairs with the highest traffic observed at peak periods but less travel time than peak shoulders increased from 50 percent to 53 percent after the second phase of time of day pricing program (R_{F2}(1))

(2) For February-March 2003, the percentage of pairs with the highest traffic observed at peak shoulders but less travel time than peak periods decreased from 25 percent to 20 percent after the second phase of time of day pricing program (R_{F2}(2)).

Since these differences were counterintuitive in terms of the purpose of time of day pricing, they cannot be attributed to the toll increase. They can only be explained by travel time differences between peak periods and peak shoulders.

Disaggregate Level Analysis of Second Phase of the Time of Day Pricing Program Using 15 min Traffic and Travel Time Data

After investigating the travel behavior using one hour disaggregate data, the analysis was repeated by further disaggregating the traffic data into 15 minute intervals. The purpose of this further disaggregation was to investigate behavior of users within each sub-period, namely pre-peak sub-period (6:00-7:00A.M. and 3:30-4:30P.M.), peak1 sub-period (7:00-8:00A.M. and 4:30-5:30P.M.), peak2 sub-period (8:00-9:00A.M., 5:30-

6:30P.M.), and post-peak sub-period (9:00-10:00A.M., 6:30-7:30P.M.), where the toll amount was fixed within each time interval. In order to accomplish this goal, for each consecutive month the change in the percentage share of the traffic in each entry-exit pair during each 15 minute period with the highest travel time was investigated. Weekdays, Fridays and weekends were analyzed separately for each month. While determining the change in user behavior after the second phase of the time of day pricing program, the steps similar to the ones conducted for one hour disaggregate data were employed. Table 18 shows the results of this analysis.

Table 18. Disaggregate analysis of the second phase of the time of day pricing program, 15 min intervals

	Time period	**Pre-peak**		**Peak1**		**Peak2**		**Post-peak**	
		$N^{ml}+M^{ml}$	$\gamma_{k'}^{ml}$	$N^{ml}+M^{ml}$	$\gamma_{k'}^{ml}$	$N^{ml}+M^{ml}$	$\gamma_{k'}^{ml}$	$N^{ml}+M^{ml}$	$\gamma_{k'}^{ml}$
Weekdays	Oct 2002 – Nov 2002	256	62%	280	52%	290	50%	244	33%
	Nov 2002 – Dec 2002	266	65%	290	64%	296	51%	240	50%
	Dec 2002 – Jan 2003	258	60%	322	54%	300	43%	256	38%
	Jan 2003 – Feb 2003	248	61%	304	60%	298	48%	244	42%
	Feb 2003– Mar 2003	254	62%	280	59%	290	47%	242	48%
Fridays	Oct 2002 – Nov 2002	296	50%	328	49%	330	48%	268	54%
	Nov 2002 – Dec 2002	286	56%	338	55%	308	54%	260	52%
	Dec 2002 – Jan 2003	286	53%	346	45%	322	45%	264	43%
	Jan 2003 – Feb 2003	294	46%	342	55%	342	51%	274	47%
	Feb 2003– Mar 2003	300	47%	346	51%	338	47%	282	42%
Weekends	**Time period**	**Period-1**		**Period-2**					
	Oct 2002 – Nov 2002	276	42%	288	62%	-	-	-	-
	Nov 2002 – Dec 2002	286	46%	298	61%	-	-	-	-
	Dec 2002 – Jan 2003	297	40%	316	56%	-	-	-	-
	Jan 2003 – Feb 2003	305	50%	316	60%	-	-	-	-
	Feb 2003– Mar 2003	284	49%	290	62%	-	-	-	-

Note: The explanation of each column is given in Appendix 1 Part 3 and Part 4

As it can be observed from Table 18, for each day type, the traffic with the highest travel time decreased for most of the sub-periods before the second time of day pricing program. This reduction was almost 60 percent, 55 percent and 60 percent of the entry-exit pairs on weekdays, Fridays and weekends, respectively. On the other hand, after the second phase of the time of day pricing program, between January and February 2003, on weekdays and Fridays this decrease in percent share was almost 40 percent and 45 percent at peak2 (8:00-9:00A.M. and 5:30-6:30P.M.) and post-peak (9:00-

10:00A.M. and 6:30-7:30P.M.) sub-periods, respectively. Similarly, on weekends shift to sub-periods with less travel time decreased to almost 45 percent at sub-period Period-1 (12 A.M. – 12 P.M.). In March 2003, the percent of the users trying to minimize their travel time started to increase for each day type. These results were consistent with the results obtained from the analysis conducted using one hour disaggregate data, indicating that given the slight toll differential between peak and off-peak periods, most of the users were adjusting themselves to minimize their travel times within each sub-period where the toll amount is fixed.

COMPARISON OF TIME OF SUB-PERIODS WITH THE HIGHEST TRAVEL TIME AND THE HIGHEST TRAFFIC FLOW

In this part of the traffic impact analysis, sub-periods with the highest travel time and the highest traffic flows were compared. The comparison was done for each of the selected O-D Pair, for morning and afternoon periods separately.

Table 19 shows sub-periods where maximum travel time and maximum traffic flow were observed during the morning period, for selected entry-exit pairs between October 2002 and March 2003. For all O-D pairs, except (14-16E) and (11-14C), maximum traffic flow was observed at morning peak periods (7:00-9:00 A.M.). On the other hand, as shown in Table 19, for most of the O-D pairs the highest travel times were not always observed during peak periods. More importantly, after the second phase of the time of day pricing program for all of the selected O-D pairs except, (9-11), the time of sub-period with the highest traffic flow did not change. For O-D pair (9-11) the change was from peak1 sub-period (7:00-8:00 A.M.) to peak2 sub period (8:00-9:00 A.M.), irrespective of the time of day pricing since both sub-periods have the same toll amount. On the other hand, more fluctuations were observed for the sub-periods with the highest travel time (*k'*).For most of the pairs and months, the highest travel time and the highest traffic flow did not always occur at the same sub-period. These results indicated that for A.M. users, the highest traffic flow at the northern section of the NJ Turnpike were observed during peak periods when the toll levels were slightly higher but travel times were lower compared to peak shoulder hours.

Table 19. Location of sub-periods (*k'*) and (*k"*) for selected pairs, A.M. period

entry-exit pair	sub-period	oct-02	nov-02	Dec-02	Jan-03	feb-03	mar-03
9-11	(*k'*)	pre [1]	peak1 [2]	pre	post [3]	peak2 [4]	pre
	(*k"*)	peak1	peak2	peak1	peak2	peak2	peak2
11-13A	(*k'*)	peak2	peak2	peak1	peak1	peak2	peak1
	(*k"*)	peak1	peak1	peak1	peak1	pre	peak1
13-14	(*k'*)	peak1	peak1	peak1	peak1	pre	peak2
	(*k"*)	peak1	peak1	peak1	peak1	peak2	peak1
14-16E	(*k'*)	peak2	peak2	peak1	post	peak2	post
	(*k"*)	pre	pre	pre	pre	pre	pre
18W-14	(*k'*)	post	pre	post	pre	peak2	pre
	(*k"*)	peak1	peak1	peak1	peak1	peak1	peak1
14A-14C	(*k'*)	peak1	peak1	pre	peak1	peak1	pre
	(*k"*)	peak1	peak1	peak1	peak1	peak1	peak1
11-14C	(k')	peak1	peak2	peak1	peak1	peak1	post
	(k")	pre	pre	pre	pre	pre	pre
18W-16W	(k')	pre	post	pre	post	post	pre
	(k")	peak2	peak2	peak2	peak2	peak2	peak2

Note: [1] pre: 6:00-7:00 A.M. [2] peak1: 7:00-8:00 A.M.
[3] peak2: 8:00-9:00 A.M. [4] post: 9:00-10:00 A.M.

The results of a similar analysis for the afternoon period are presented in Table 20. As observed from the Table 20, the behavior during afternoon periods was similar to the behavior in morning periods. Similar to the morning period, for all O-D pairs, maximum traffic flow was observed at peak periods in the afternoon period (4:30-6:30 P.M.) after the second phase of the time of day pricing program. The fluctuations of the sub-period location (*k'*) were higher compared to sub-period (*k"*). In addition, for most of the pairs and months the highest travel time and the highest traffic flow did not always occur at the same sub-period. The only difference was that in December 2002 and January 2003, for the O-D pairs (16E-11), (16E-15W), (9-11), (13A-11) and (14C-11) the time of the sub-period with the highest traffic flow (*k''*) was observed at peak shoulder periods (3:30-4:30 P.M. and 6:30-7:30 P.M.). However, in March 2003, the highest traffic flow for each O-D pair was observed during the peak periods. These results indicated that for afternoon period users, the highest traffic flow at the northern section of the NJ

Turnpike were observed during peak periods where the toll levels were slightly higher but travel times were lower compared to peak shoulder hours.

Table 20. Location of sub-periods (*k'*) and (*k"*) for selected pairs, P.M. period

entry-exit pair	sub-period	oct-02	nov-02	dec-02	jan-03	Feb-03	mar-03
16E-11	(*k'*)	post [4]	peak1[2]	peak1	peak1	peak1	peak1
	(*k"*)	pre [1]	pre	pre	peak2 [3]	peak2	peak2
13A-11	(*k'*)	peak1	peak1	peak1	peak1	peak1	peak1
	(*k"*)	peak2	peak2	pre	peak2	peak2	peak2
14C-14A	(*k'*)	peak1	peak1	post	pre	post	pre
	(*k"*)	peak1	peak1	peak1	peak1	peak1	peak1
16E-14	(*k'*)	peak2	peak2	post	peak2	peak2	peak2
	(*k"*)	peak1	peak1	peak1	peak1	peak1	peak1
16E-15W	(*k'*)	peak1	peak1	post	peak1	peak1	peak1
	(*k"*)	peak1	peak1	peak1	post	peak1	peak1
16W-14	(*k'*)	pre	pre	pre	pre	pre	pre
	(*k"*)	peak1	peak1	peak1	peak1	peak1	peak1
14C-11	(k')	pre	peak1	post	peak1	peak1	pre
	(k")	peak1	peak1	pre	pre	pre	peak1
9-11	(k')	peak2	peak2	peak2	peak2	peak2	peak2
	(k")	peak1	peak1	pre	peak1	peak1	peak1

Note: [1] pre: 3:30-4:30 P.M. [2] peak1: 4:30-5:30 P.M. [3] peak2: 5:30-6:30 P.M. [4] post: 6:30-7:30 P.M.

Statistical Tests of the Changes in the Time of the Sub-periods with the Highest Travel Time and the Highest Traffic Flow

After comparing of the occurrence time of sub-periods with the highest travel time (*k'*) and the highest traffic flow (*k"*) between October 2002 and March 2003, in this section the detailed analysis of the selected entry-exit pairs was performed using the appropriate statistical tests. A total of four different before and after analyses were conducted based on the comparison of traffic flow and travel time changes during sub-periods (*k'*) and (k"). These tests are summarized below.

1. Traffic flow change in the sub-period (*k'*)
2. Travel time change in the sub-period (*k'*)
3. Traffic flow change in the sub-period (*k"*)
4. Travel time change in the sub-period (*k"*)

In order to determine whether or not the traffic and travel time values changed in a statistically significant manner t-tests were conducted. To this extent, the six-month time period was divided into two 3-month sets. The first set covered the months from October 2002 to December 2002 (before the second phase of the time of day pricing program). The second set covered the months from January 2003 and March 2003 (after the second phase of the time of day pricing program). Since the travel trends during morning and afternoon periods were different, the statistical tests were applied for each period separately.

Since there is a seasonal variation in the system, the two sample sets form an independent group and have different variances. Therefore, 1-tailed two-sample t-test with an unequal variance at the 95 percent confidence level needs to be employed. (23) This version of the independent group t-test takes into account the differences in variances and adjusts the p-values accordingly.

The null-hypothesis claims that after the time of day pricing program, there was a reduction in demand at the time of the sub-periods with the highest traffic flow and the highest travel times because the main goal of this analysis was to determine the changes in congestion levels and travel times,. This hypothesis can be expressed mathematically as follows: (23)

$$\begin{aligned} H_0 &: (\mu_{ij.})_{before} - (\mu_{ij.})_{after} = 0 \\ H_1 &: (\mu_{ij.})_{before} - (\mu_{ij.})_{after} > 0 \end{aligned} \tag{5}$$

where;

$(\mu_{ij.})$= mean demand/travel time in period *i* and sub-period j

i=1, 2 (1=A.M. peak, 2=P.M. peak) *j*=1, 2 (1=sub-period (*k'*), 2= sub-period (*k''*))

The results of four different t-tests conducted for the selected O-D pairs during the morning period are shown in Table 21. For all O-D pairs, except (18W-16W), the traffic flow at the sub-period with the highest travel time (*k'*) reduced after the second phase of the time of day pricing program. However this reduction was not statistically significant. Similarly, for all OD pairs, except (14-16W), the travel times at the sub-period (*k"*) reduced after the second phase of the time of day pricing program for O-D pairs. However this reduction was statistically significant only for the O-D pair 11-13A. These results indicated that the traffic flow at the highly utilized pairs increased at A.M. time periods with lower travel time independent of the time of day pricing program, but this increase was not statistically significant for most of the OD pairs.

Table 21. t-test results for the before and after analysis, morning period

entry-exit pair	t-test results	max travel time period				max traffic flow period			
		traffic flow		travel time (min)		traffic flow		travel time (min)	
		before	after	before	after	before	after	before	after
9-11	Mean	292	279	9.509	8.782	347	378	8.713	7.963
	t Stat	0.259		1.020		-1.898		1.831	
	t-critical	2.353		2.353		2.353		2.920	
13-14	Mean	298	244	10.183	9.635	298	303	10.183	7.797
	t Stat	1.085		0.372		-0.281		2.067	
	t-critical	2.920		2.132		2.353		2.920	
18W-14	Mean	369	346	19.254	16.925	560	503	15.770	14.391
	t Stat	0.529		0.533		0.574		0.421	
	t-critical	2.132		2.132		2.132		2.353	
11-13A	Mean	454	379	22.171	13.308	514	520	19.276	13.165
	t Stat	0.728		2.584		-0.345		**3.024**	
	t-critical	2.132		2.920		2.353		**2.132**	
14-16E	Mean	471	430	11.095	17.038	562	605	9.041	12.032
	t Stat	0.555		-1.801		**-2.202**		-0.758	
	t-critical	2.920		2.920		**2.132**		2.920	
14A-14C	Mean	521	549	5.853	3.924	621	665	5.193	3.340
	t Stat	-0.194		1.352		**-2.628**		1.158	
	t-critical	2.132		2.353		**2.132**		2.920	
11-14C	Mean	417	391	34.347	25.712	578	592	25.613	21.237
	t Stat	0.332		2.290		-1.387		2.360	
	t-critical	2.353		2.920		2.353		2.920	
18W-16W	Mean	262	313	9.822	5.507	608	561	4.042	2.817
	t Stat	-0.698		1.379		0.378		2.205	
	t-critical	2.353		2.353		2.353		2.353	

Similarly, before and after analysis conducted to analyze the changes in the traffic flows and travel times during the afternoon period is shown in Table 22. As shown in Table 22, for all O-D pairs, except (15E- 16W) and (9-11), the traffic flow at the sub-period with the highest travel time (*k'*) reduced after the second phase of the time of day pricing program. However, the reduction in traffic flow was not statistically significant for any pairs. On the other hand, the increase in the traffic flow at sub-period with the highest traffic flow was statistically significant only for O-D pair (9-11) and for this pair the highest travel time was observed at peak period (see Table 20). Similarly, for all O-D pairs, the travel times at the sub-period with the highest traffic flow (*k"*) reduced after the second phase of the time of day pricing program. However, this reduction was statistically significant only for O-D pair (13A-11). These results indicated that the traffic flow between highly utilized pairs increased at time periods with lower travel times in the afternoon independent of the time of day pricing program, but this increase was not statistically significant for most of the O-D pairs.

Table 22. t-test results for the before and after analysis, afternoon period

entry-exit pair	t-test results	max travel time period				max traffic flow period			
		traffic flow		travel time(min)		traffic flow		travel time min)	
		before	after	before	after	before	after	before	after
16E-11	Mean	625	611	13.810	12.641	647	611	13.798	12.641
	t Stat	0.112		0.810		0.301		0.805	
	t-critical	2.353		2.132		2.920		2.132	
13A-11	Mean	668	580	26.216	12.220	593	668	18.697	13.620
	t Stat	1.635		1.784		-1.746		**4.138**	
	t-critical	2.353		2.920		2.353		**2.920**	
14C-14A	Mean	485	454	7.089	6.846	526	594	6.386	3.763
	t Stat	0.342		0.106		-1.633		1.354	
	t-critical	2.353		2.132		2.920		2.920	
16E-14	Mean	625	611	13.810	12.641	647	611	13.798	12.641
	t Stat	0.112		0.810		0.301		0.805	
	t-critical	2.353		2.132		2.920		2.132	
16E-15W	Mean	335	375	11.265	8.316	347	362	9.767	7.974
	t Stat	-0.752		1.309		-0.237		1.341	
	t-critical	2.353		2.353		2.920		2.353	
16W-14	Mean	250	223	17.180	9.343	278	318	14.061	8.820
	t Stat	2.119		**14.049**		-1.771		**7.060**	
	t-critical	2.353		**2.920**		2.132		**2.920**	
14C-11	Mean	357	325	32.795	22.661	382	373	29.993	21.721
	t Stat	1.125		2.039		0.891		3.499	
	t-critical	2.920		2.920		2.353		2.920	
9-11	Mean	284	318	10.011	8.329	322	352	8.539	8.076
	t Stat	**-5.038**		1.871		-2.263		1.005	
	t-critical	**2.353**		2.920		2.920		2.920	

CONCLUSIONS

The traffic impact study conducted for the NJ Turnpike facility, has attempted to gain insights into the behavior of users as a response to the time of day pricing program and travel time fluctuations using reliable and accurate traffic and travel time data. Among the two different levels of analysis, the results indicate that disaggregate level analysis provides more accurate and reliable results compared to aggregate level analysis, and help to better understand the user behavior under the time of day pricing applications. The details of the results can be summarized as follows:

1. Using the aggregate data, it was shown that the traffic flow patterns were different for different months of the year. Traffic in winter months was lower compared to the traffic in summer months. Traffic was observed to be different for the three different portions of a week, namely, Monday through Thursday, Friday, and weekends. Fridays and weekends had the highest and lowest share of the total weekly traffic, respectively.
2. The analysis results obtained from total yearly traffic demand and total daily traffic demand at the NJ Turnpike indicated that there was a statistically significant increase in the demand of the NJ Turnpike in spite of toll increases and the two phases of the time of day pricing program during the same time period. Moreover, the rate of change of the traffic demand was increasing and represented a similar behavior before and after the time of day pricing implementation. In addition, as mentioned in Chapter IV, only 22 users out of the 36 respondents who changed their travel behavior increased trips along alternative routes increased using alternative routes after the first phase of the time of day pricing program. These important results indicated no shift to other modes/routes after the time of day pricing implementations.
3. Aggregate level analysis conducted for the first phase of the time of day pricing program indicated that the rate of increase of absolute traffic at peak periods was lower than the rate of increase of absolute traffic at off-peak period. From October 1998 to June 2001, the rate of increase of absolute traffic was 6 percent and 4 percent for the AM. peak period (7:00-9:00 A.M.) and the P.M. peak period

(4:30-6:30 P.M), respectively; whereas, rate of increase of off-peak period absolute traffic was 10 percent. On the other hand, the percent shares of morning and afternoon peak periods had a statistically significant decrease by 1.7 percent, and 3.7 percent, respectively. Moreover, percent share of the off-peak traffic yielded a statistically significant increase by 1.1 percent.

4. Aggregate level analysis conducted for the second phase of the time of day pricing program indicated that time period between January 2001–March 2001 and January 2003–March 2003, the trend in traffic was reversed. From January 2001 to March 2003, the absolute traffic flow at the A.M. peak and P.M. peak periods increased by 15 percent and 10 percent, respectively; whereas, absolute traffic of off-peak period traffic flow increased by 9 percent. On the other hand, percent shares of A.M. and P.M. peak periods for a typical weekday increased in a statistically significant manner by almost 17 percent and 14 percent, respectively. Moreover, percent share of the off-peak period decreased in statistically significant manner by almost 6.0 percent.
5. These differences among the two phases of time of day pricing implementation can be due to the impacts of the first phase of the time of day pricing program which might have encouraged commuters to shift to peak shoulders and, in turn, increased travel times during these periods. However, due to the lack of more detailed traffic and travel time data at the aggregate level, it is not possible to pinpoint the exact reason of this shift in traffic.
6. Disaggregate analysis showed that on weekdays and Fridays, before the second phase of the time of day pricing program, for almost 75 percent (50 percent at peak periods and 25 percent at peak shoulders) of the O-D pairs, the highest traffic was observed during the periods with lower travel time. Whereas for 10 percent of the O-D pairs, the highest traffic was observed during periods with the highest travel time. After the second phase of the time of day pricing program, between January 2003 and February 2003, the percentage of pairs for which the highest traffic was observed during periods with the lowest travel time, reduced to 68 percent (45 percent at peak periods and 23 percent at peak shoulders). Also the percentage of O-D pairs for which the highest traffic was observed

during periods with the highest travel time increased to 16 percent. However, in March 2003, three months after the second phase time of day pricing, the system started to return to its original state observed before the second phase of the time of day pricing program.

7. A similar pattern was observed for weekends, despite the fact that, on weekends the sample size was smaller and smaller percent of travelers tried to minimize their travel times, and the number of the travelers who prefer not to change their travel periods was slightly more compared to weekdays. The reason for these slight differences can be due to the fact that peak toll levels were effective during weekends. The traffic on weekends was almost 25 percent lower than weekday traffic, and most of the travelers did not have a strict departure and arrival time constraints since most of the weekend trips were not work related.
8. The disaggregate analysis conducted using 15-minute traffic data indicated that for most of the sub-periods for almost 58 percent of the O-D pairs, the traffic during the quarters with the highest travel time decreased before the second phase of the time of day pricing program. On the other hand, after the second phase, at sub-periods peak2 (8:00 A.M.-9:00A.M. and 5:30 P.M.-6:30P.M.) and post-peak (9:00 A.M.-10:00A.M. and 6:30 P.M.-7:30P.M.) this decrease in percentage share was almost 43 percent, during January and February. Beginning in March 2003, the percentage of the users trying to minimize their travel time started to increase again. These results were consistent with the results obtained from the analysis conducted using 1 hour disaggregate data, indicating that most of the users were adjusting themselves to minimize their travel times within each sub-period where the toll amount were fixed.
9. 1-tailed two-sample t-test with unequal variance at the 95 percent confidence level, conducted for the before and after analysis of traffic flow and travel time at highly utilized O-D pairs indicated that for most O-D pairs, at the sub-periods with the highest travel time, traffic has reduced after the second phase of the time of day pricing program. However, this reduction in traffic flow was not statistically significant for any pairs. Similarly, for most of the O-D pairs, the travel times at the sub-period with the highest traffic flow has reduced after the second phase of

the time of day pricing program. However, this reduction was also not statistically significant for most of the O-D pairs.

10. The disaggregate analysis that was conducted to determine the reasons of this shift indicated that commuters respond more to congestion (lower travel times) than slightly higher tolls. More specifically, given the small differential between peak and off-peak period toll levels, most of the users prefer peak periods with lower travel times and higher tolls instead of peak shoulders with higher travel times but lower tolls. In addition second phase of the time of day pricing program did not have a quantifiable impact on the traffic patterns at NJ Turnpike.
11. In some of the empirical studies (See references 8,25,26,27,and 28) that investigated the impact of variable pricing on traffic using traffic counts, maximum traffic was observed during peak periods where the toll is higher and the shift in traffic is always from the peak hours to peak shoulders. However, the traffic at the NJ Turnpike is observed to be more uniformly distributed between mid-peak hours and peak shoulders. Thus, the maximum traffic is not always observed at mid-peak hours on the NJ Turnpike.
12. Same studies (See references 8,25,26,27,and 28) concluded that the discount tolls caused a reduction in peak period traffic and this reduction in traffic led to lower travel times during the peak periods. However, the toll differences between peak and off-peak periods at the NJ Turnpike are quite small. Given these facility specific traffic conditions and small toll differences, travel time differences between different periods were found to have more effect than the toll differences on user behavior. This was an important finding specific to this study.
13. All of the aforementioned empirical studies also emphasized that the lack of reliable travel time data had a negative and limiting effect on the reliable statistical assessments of travel time changes due to the implementation of variable pricing policies. Thus, these studies concluded that the individual and combined impact of toll and travel time differences between periods on the user behavior could not be determined properly without reliable travel time data. The same problem was encountered in this study too when it was attempted to understand the changes in traffic shifts using the aggregate data. However, the

disaggregate vehicle based data enabled the research team to overcome this problem and to clearly explain the reasons behind the change in traffic before and after the second phase of the time of day pricing implementation. Thus, in order to fully understand the user responses to time of day pricing implementations, disaggregate data which include detailed traffic, travel time and toll amount information at the same time is necessary.

14. As indicated in 2003 New Jersey Turnpike annual report (22), over 12 years after the first toll increase in 1991, the total demand for the NJ Turnpike increased by almost 3.5 percent every year until 2003, revealing that the demand continued to increase despite the changes in toll amounts.

CHAPTER III - ESTIMATION AND ANALYSIS OF DELAYS AND EMISSIONS USING MICROSCOPIC TRAFFIC SIMULATION MODEL OF THE NJ TURNPIKE

INTRODUCTION

Time of day pricing policies aim to charge users for the external costs of their travel; i.e. congestion costs that they impose on other users. The main purpose of this practice is to discourage users from making trips during the peak hours or change their modes of transportation by charging tolls at the margin of the supply curve.

Time of day pricing programs have two main objectives, namely revenue generation and congestion management. The expected positive impacts of time of day pricing programs include reductions in:

- vehicle-miles-traveled
- vehicle trips
- delay
- fuel consumption
- vehicle emissions

First phase of the time of day pricing program at the New Jersey Turnpike (NJTPK) was launched in September 2000 to realize the same objectives. The history of time of day pricing program at the NJTPK is presented in the next subsection section in detail.

Although the theoretical bases of the time of day (value, congestion) pricing is well established in the economics literature, due to the limited number of time of day pricing projects worldwide, there is still limited amount of empirical evidence that time of day pricing programs actually meet all of the desired objectives. The main goal of this chapter is to perform an economic evaluation of the mobility and environmental impacts of the time of day pricing initiative at the NJTPK. This chapter presents the efforts to evaluate the time of day pricing program using a microscopic simulation model of the NJTPK modeled in *Paramics* simulation software. Estimation of delays, vehicle emissions and fuel consumption were obtained for different time periods and for different years. It is clear that, even if the sensor infrastructure was available, it would have been extremely time consuming and expensive to collect this kind of data for a very large and heavily used traffic facility such as NJTPK.

The key findings of the simulation analyses conducted in this chapter can be listed as follows:

- The average trip delay was reduced by about 3 -18 percent from 2000 to 2001 after the introduction of E-ZPass and the first phase of the time of day pricing program. The major reason for this reduction is, however, observed to be the reduction in toll plaza delays due to the introduction of E-ZPass.
- E-ZPass deployment was found to reduce the toll plaza delays by 44-74 percent between 2000 and 2001. It was also observed that despite the increase in traffic volumes there was a clear pattern in terms of the reduction of delays at the toll plazas from 2001 to 2003 compared to 2000.
- Simulation analyses showed that between 2000 and 2001 there was a reduction in emission levels as high as 10.7 percent. However, after 2001 a slight increase in emissions was observed due to the increasing demand. This was an expected outcome given the relationship among the demand, delays and emissions.

Overview of Time of Day Pricing Projects

The projects that currently utilize peak-period pricing as a congestion management tool in the U.S. fall into two types: High occupancy toll (HOT) lanes and time of day pricing on existing tolled facilities.

One of the popular time of day pricing project in use is the Interstate 15 project in San Diego, California. Express lanes are two reversible lanes, located in the freeway median, that flow southbound in the morning and reverse in the afternoon. The lanes were initially opened as a High Occupancy Vehicle (HOV) facility in 1988, but did not fill to capacity, while the main lanes were over congested [(28)]. To overcome this problem, the San Diego Association of Governments (SANDAG) Board passed a resolution that would allow the conversion of the HOV lane into a HOT lane, or HOV and toll lanes.

The project was implemented in two phases. The Phase 1, ExpressPass program, was effective from 1996 to 1998, which allowed single occupancy drivers to buy-in to the HOV lane with a monthly pass. By 1997, an automated vehicle identification (AVI) transponder system was deployed. In 1998, Phase 2 that instituted the FasTrak program began.

The evaluation of the I-15 value-pricing project is described in Supernak et al [(28)]. The evaluation methodology included calculation of delay costs and vehicle emission levels. Delay costs were calculated using two factors. The first factor was the total amount of delay on roadways as compared to free-flow conditions. Free flow conditions were obtained from vehicle speed data in 1996 (pre-project), Fall 1997 (Phase I), and Fall 1998 (Phase II). The traffic data were collected for five days Monday through Friday because of the high day-to-day variability. The data were obtained from the loop detectors as six minute counts during the A.M. and P.M. peak periods from August through December for 1997, and for all the months of 1998 and 1999. In addition, 15-minute counts during the A.M. and P.M. peak periods were obtained for two days in each month within the study period. The volume data were collected at the loop detector stations spread at 0.5 mile spacing. The second factor was the value of time of vehicle defined as the drivers' willingness to pay to avoid delays. In addition to delays, the air quality study estimated total emissions of four main pollutants along the corridor, namely volatile organic compound (VOC), nitrogen oxides (NO_x), carbon monoxide (CO) and particulate matter (PM_{10}). The delay and vehicle emission levels were estimated using the average speed data obtained from probe vehicles over a length of 7.7 miles of the I-15 corridor.

Another time of day pricing project was initiated on State Route 91 Express Lanes (SR 91X), which opened on December 27, 1995 in Orange County, California. This is the nation's first value-priced roadway. The express lanes extend about 10 miles in the former median of the Riverside Freeway, connecting the major employment centers of Orange County and southern L.A. County. These are predominantly residential communities of Riverside and San Bernardino Counties. Tolls in the express lanes vary hour by hour to control demand and maintain free flow traffic.

In order to evaluate travel time savings and the vehicle emission levels, an aggregate model developed in TP+/ Viper planning software was utilized [(8)]. To represent travel conditions for eleven different time periods in the day, as well as for different modes (single occupancy vehicle (SOV) vs. HOV) and toll-paying decisions (91X, Eastern Toll Road (ETR), or free lanes), various scenarios were created in the model. Time dependent link speeds collected from loop detector stations and floating car runs were also included in the model for various time periods of the analysis.

The network model provides consistent estimates of the travel times and costs of trips, as well as consistent time and cost estimates for the choice alternatives accepted / rejected by the travelers. On this basis, the model parameters can quantify the impacts of the differences in travel times and costs among the travel choices made and the alternative choices not made. This permits the estimation of behavioral properties such as travelers' values of time and travelers' time and cost elasticities.

Another time of day initiative began in Lee County Florida as a pilot project on the Cape Coral and Midpoint bridges, two of the four bridges that connect Cape Coral and Fort Meyers. The project started in August 1998. Both bridges served a large number of commuters during peak periods, although neither of them suffered from severe congestion. This demonstration was intended to be a proactive measure to examine the impacts of time of day pricing on existing congestion, as well as to install the technical infrastructure needed for future congestion management projects [(29)]. In November 1997, electronic toll collection (ETC) equipment was deployed on the bridges, allowing for a variable pricing toll structure and extensive data collection. By varying the toll structure, the project used pricing mechanisms to induce patrons traveling during peak periods to change their time of travel without making the peak period trips more expensive. Only ETC customers were eligible for variable discounts, requiring patrons to obtain a transponder and an account.

The objective of the evaluation study of the Lee County Value Pricing Project was to assess the impacts of time of day pricing on the temporal distribution of traffic demand, and to investigate the role of time of day pricing as a travel demand management tool [(29)]. The vehicle speed data were collected for the periods before and after the time of day pricing initiative using a standard radar gun as the vehicles approached to the toll plaza [(30)]. The traffic volume data were collected for every 30 minutes from 6:00 A.M. through 7:00 P.M. for the months from January to July 1998 (before value pricing initiative) and from August to December 1998 (after value pricing initiative) [(31)]. The travel time data were collected through floating car runs, where a trained driver made eight runs along each of the two routes and a device mounted on the vehicle records the distance traveled and travel time [(32)].

May and Milne [(33)] conducted a study where they analyzed the impact of four different time of day pricing programs in the city of Cambridge, UK. The evaluation of the time of day pricing program was not based on an actually deployed time of day pricing system. Cordon crossed, distance traveled, time spent in traveling and time spent in time of day pricing systems were tested using the congested assignment network model SATURN and its elastic assignment demand response routine, SATEASY [(33)]. Their analyses results were evaluated based on the level of impact of each pricing system on the increase in average speed of the study area.

The evaluation of these existing studies described above is mostly based on limited before and after aggregate traffic data. However, it is well known that the accurate estimation of the delay and vehicle emission levels highly depend on the time dependent vehicle speeds and the number of vehicles between each origin-destination (O-D) pair during each time period. This is even more important when time of day pricing polices are evaluated, since time dependent impact of the pricing policy rather than daily or average impact on travel times and emissions are needed. As described in detail in the following sections of this report, microscopic traffic simulation tools enable analysts to trace individual vehicles throughout their trips in the network, while estimating their travel times and amount of pollutants they emit. Provided that the network model is well calibrated, using actual traffic data specific to the study network, the simulation models can be of great use in evaluating the impact of time of day pricing systems on the congestion and vehicle emission levels.

The important features of the evaluation analysis presented in this chapter can be listed as follows:

- The use of a well calibrated microscopic simulation software to model and to analyze the impacts of the time of day pricing program. The developed simulation model reflects the actual infrastructure characteristics of the study network (See the Background and Methodology Section for detailed description of the model)
- The use of actual system data obtained from E-ZPass users that comprise six-months of traffic and travel time data between each O-D pair of the study network for the development of reliable O-D pair demand and travel time matrices.
- Modeling and calibration of the developed network based on the actual traffic data (See the Input and Output Variables and Calibration of the Network Model Section for further details)
- Incorporation of a highly complex coding of toll plaza operations sub-model that reflects the actual traffic behavior at the toll plaza level (See Toll Plaza and Network Model Section)
- Evaluation of the impact of the time of the day pricing program based on the estimations of the developed simulation model. The presented analyses include the changes in vehicle delays and vehicle emission levels based on detailed data obtained from individual vehicles traveling in the simulated network.

The next section gives an overview of the methodology, along with some background information on the tools and software packages used for the network and database creation. The following section discusses the development of the appropriate toll plaza and the network model for the NJTPK. The input and output variables, and the calibration procedure are described in the next section. The following two sections present the results of delay and vehicle emission levels, respectively. Concluding remarks are presented in the Summary and Conclusions Section.

BACKGROUND AND METHODOLOGY

Microscopic Simulation for Modeling

Microscopic Traffic simulation is a powerful tool that allows planners and analysts to simulate and evaluate the effects of various operational and policy decisions. Micro-simulation also allows controlling various input parameters of the traffic models at the most disaggregate (car-by-car) level. Thus, microscopic simulation is well suited for the evaluation of the impacts of variable tolls on congestion and emissions.

PARAMICS® (PARAllel MICrosimulation Software) from Quadstone Ltd. is one of the most widely used microscopic traffic simulation software. *Paramics* has a large set of functionalities, which can be used to simulate and evaluate various policies, control strategies and their effects such as delays, emission levels. The most important feature of *Paramics* is the ability of overriding or extending the default models such as car following, lane changing, route choice, etc. using the "Application Programming Interface" (API). This feature helps the modelers to incorporate customized functionalities and test their own customized models.

Paramics also has the capability of two- and three-dimensional visualization of simulated traffic operations (as shown in Figure 4). This feature helps users to better analyze and understand the output of the simulation model.

Figure 4. Modeling 3-D effects in *Paramics* – toll plaza at Exit 11

Requirements for Microscopic Simulation Model

One of the first and the most important steps in the process of microscopic modeling of any transportation system is the preparation of a detailed geometry of the road network. This includes information about the geometry of the lanes, number of the lanes and control devices, etc. *Paramics* simulates driver behavior according to the driver's response to the alignment and geometry of the roadway, and the prevailing traffic conditions. Thus, it is a very important task to obtain and incorporate the correct geometric characteristics. The level of difficulty of this task increases with the size of the network.

There is a considerable difference in the creation of the network in Paramics and Geographical Information Systems (GIS). Unlike the polyline (a series of connected points) concept used in GIS, *Paramics* uses straight lines and circular arcs to define the roadway geometry. Format of the databases used by Paramics and GIS is also different. This creates a direct incompatibility. On the other hand, manual creation of the large networks in *Paramics* is prohibitively time consuming. It is not only difficult to obtain an accurate overlay of the entire NJTPK but it is also well known that a network created using a GIS map overlay would be quite inaccurate. It is thus desirable to use any tool that could convert the GIS networks to the *Paramics* networks using binary network files without manual input procedures required by the overlays.

"Shape to Paramics" (S2P) is a software developed by Vehicle Intelligence and Transportation Analysis Laboratory, National Center for Geographic Information and Analysis, University of California, Santa Barbara. S2P converts the ArcView® (from Environmental Systems Research Institute (ESRI) shape files to *Paramics* network files. [34,35] Although eventually there is a need to make additional corrections in *Paramics*, S2P greatly reduces the time consumed as compared to when the network is input manually.

S2P takes a shape file as input and produces a *Paramics* (version 4.0) file as output. The quality of *Paramics* files is as good as the quality of the GIS input data. There are few additional attributes that should be specified in the GIS database for the conversion (of shape files to *Paramics* files) to ensure conversion efficiency. For instance, when there are two links crossing each other in the GIS map, it is impossible for the conversion software to determine if the intersection would be an at-grade or grade separated one. Therefore, the elevation of 'from' and 'to' nodes of the links has to be specified in the database. These attributes are the following:

- Number of lanes.
- Speed limit.
- Direction – Specify whether a link is one-way or two-way.
- Ramps.
- Type of the roadway.

Paramics has a special procedure for coding ramps. It does not change the number of lanes at the intersection of the ramp and the freeway. However, it automatically merges the external node that is connected to the freeway and adds the acceleration lane at the intersection. S2P also checks whether there is a change in the number of lanes in the merging section and adds the ramp automatically. Hence the GIS database requires the information about the feature class code to specify whether the link is a ramp or not. In addition, if no data are available for a network characteristic, S2P employs a default value for all these missing attributes.

The complete process for the creation of the microscopic simulation model of the NJTPK involves the following steps:

- Network creation.
- Incorporation of additional "driver behavior model" to simulate the toll plaza operations.
- Model calibration and validation.
- Extraction and analysis of the output to evaluate impacts of the NJTPK value-pricing initiative.

The methodology followed is shown in Figure 5.

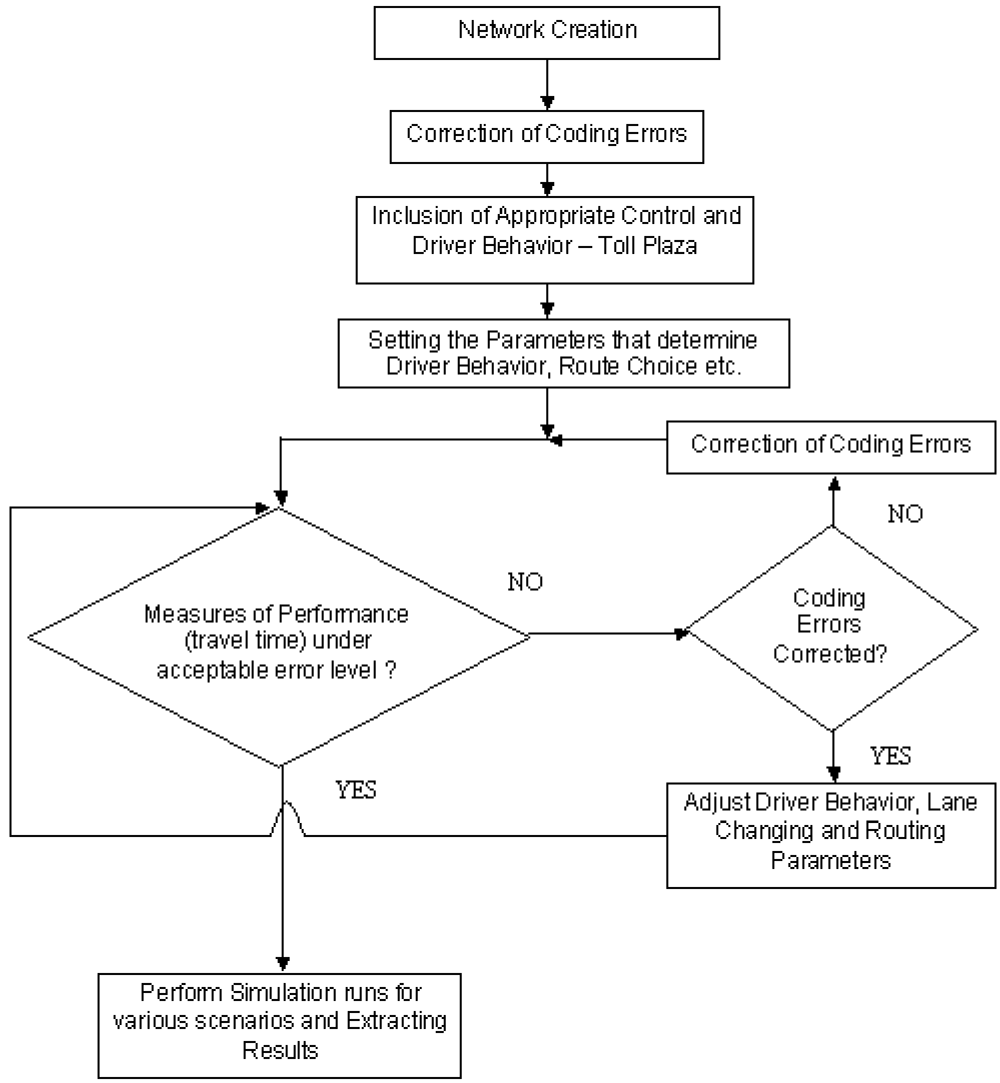

Figure 5. Flowchart of the simulation modeling methodology

NETWORK AND DATABASE CREATION

Creation of Basic *Paramics* Network

Since there was no existing *Paramics* network for the NJTPK, and other connecting links, the existing GIS databases and maps were used to create the network from shape files. S2P conversion program was used. The detailed geometry of NJTPK was obtained from TransCAD® (from Caliper Corp.) built-in data files which allow networks to be exported to the format of shape files. Figure 6 shows the network created in TransCAD.

Figure 6. Basic NJTPK network

TransCAD has two kinds of in-built road networks for the United States, in the form of 'US Streets' and 'US Highways and Interstates'. The US Streets network had the detailed geometry including the alignment of ramps and other minor roads. Figure 7 shows the detailed geometry of a portion of the same network. However, the corresponding database did not have the data required for microscopic simulation model including, the number of lanes in each section of the roadway, speed limits, and roadway type (urban, highway, etc.) etc. On the other hand, the US Highways and Interstates network had some of the necessary data that were required for the conversion of shape files to *Paramics* networks but the data lacked the geometric details. There was an attempt to join these two networks, but the geometries of the networks were found to be incompatible. Since, the goal of this process was to have a complete network with detailed geometry and corresponding data, one of the TransCAD databases had to be updated to combine all the required information. Therefore, the research team decided to use the US Streets map with detailed geometry and then add the required data from US Highways and Interstates network databases. This network was then converted into the format of a *Paramics* network using S2P software. Some geometric features such as ramps, ramp-awareness distances, and speed limits were later corrected in the *Paramics* network. Figure 8 shows the steps followed in the process of Network Creation. Figure 9 is a snapshot of a portion of the *Paramics* network after conversion using S2P.

Figure 7. Detailed geometry of the TransCAD network

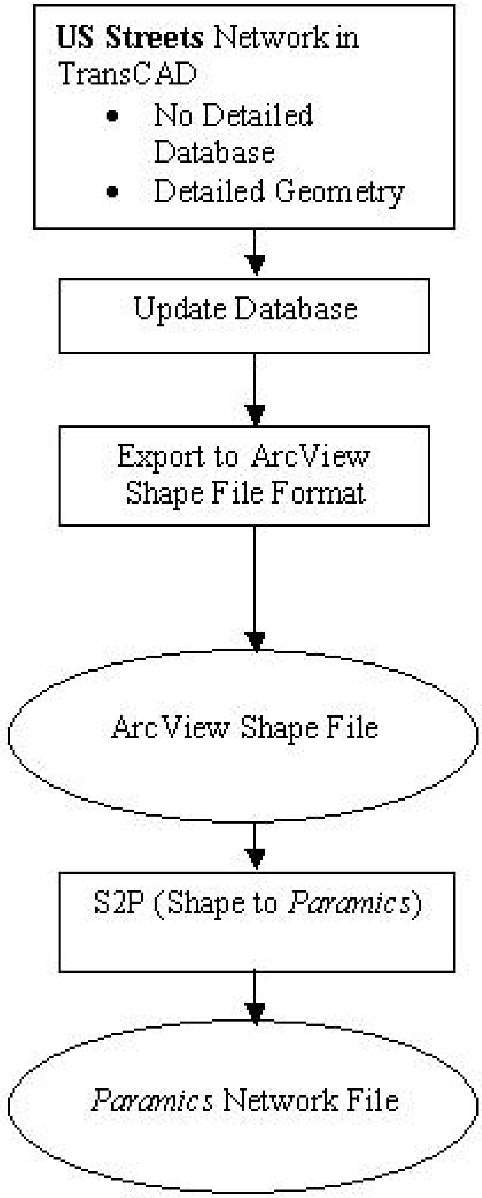

Figure 8. Flowchart of network creation process

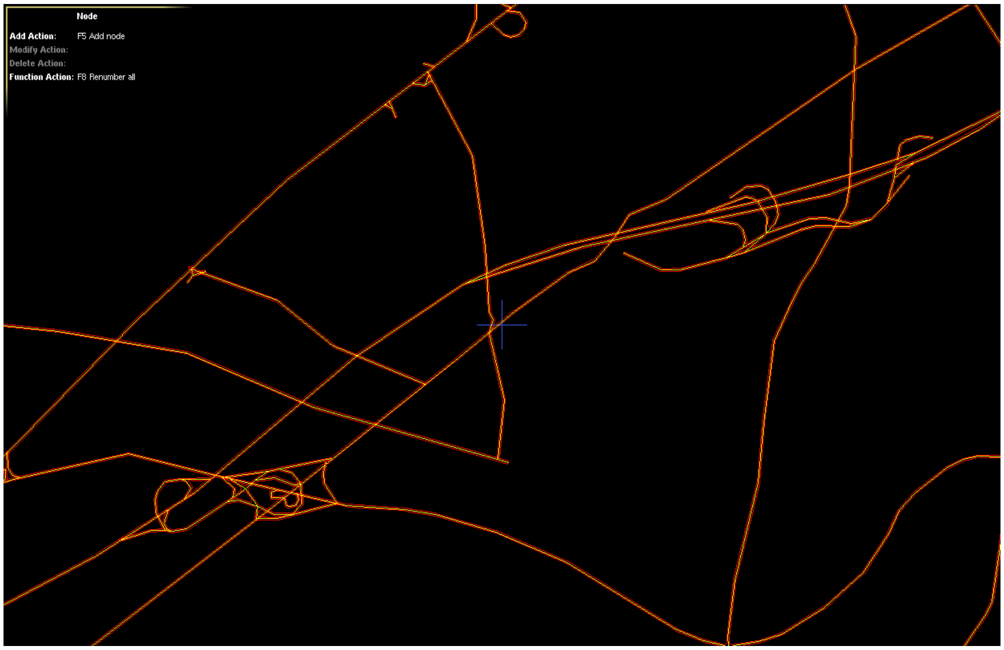

Figure 9. Paramics network

Corrections for the Complete *Paramics* Network

The majority of the corrections required for the geometry were related to the ramps. In *Paramics*, on-ramps are called “ramps” and the off-ramps are coded as links preceded by a highway link with slip-lanes. The presence of on-ramps on the highway has to be known in advance by the vehicles. This is measured by the “ramp awareness distance” parameter when coding ramps in *Paramics*. The value of this parameter has to be positive. When the road characteristics of the GIS network is incomplete in terms of the number of lanes in the network due to incorrect coding of ramps, the ramps are not detected by the S2P software and thus not coded properly. As a result, sometimes the ramp awareness distance may turn out to be negative. This causes problems with the stability of the network file in *Paramics*. In order to fix this problem, all the ramps in the network were checked for their ramp awareness distance (as shown in Figure 10) and then edited appropriately if there were any coding errors.

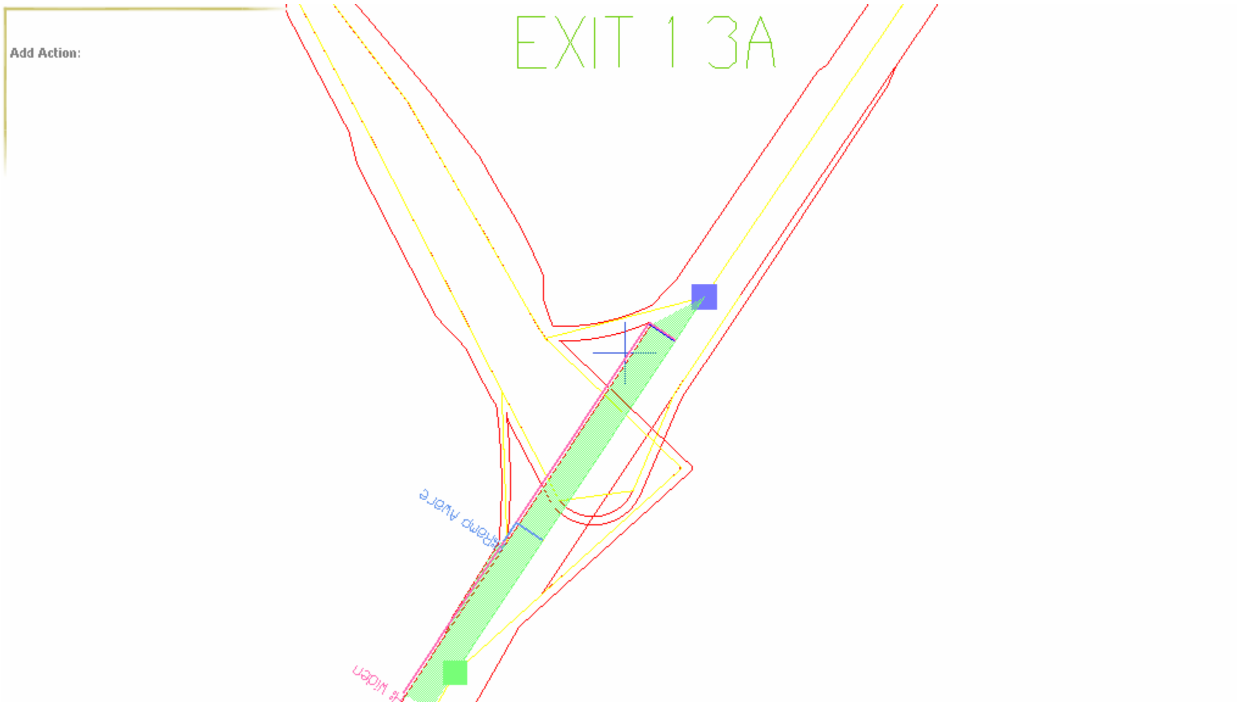

Figure 10. Positive ramp awareness distance (It can be seen as the line across the roadway beside the area indicated by "Ramp Awareness")

Other inputs such as speed limits and number of lanes in the NJTPK were also inserted into the GIS network database. The missing speed limits and number of lanes information were obtained from the New Jersey straight-line diagrams available at the New Jersey Department of Transportation (NJDOT) website [36].

TOLL PLAZA AND NETWORK MODEL

Overview

NJTPK toll plazas serve as toll-collecting areas after the vehicles exit the freeway. This kind of toll plaza configuration does not impede the existing traffic flow on the freeway. In fact, the NJTPK started with a vision of "…118 miles safely and comfortably ~ without a stop! That's what this modern 'magic carpet'…" [37]. However, the toll plazas are important features of the network since they affect the travel time between origins and destinations. Therefore, it is important to develop an accurate model of the toll plaza operations.

Since most of the available microscopic simulation software packages, including *Paramics*, do not have any built-in toll plaza model, some researchers developed customized toll plaza simulation models [38,39,40]. Al Deek et al. [38] developed a toll plaza simulation model for different configurations and characteristics for the Holland East toll plaza, Orange County, Florida. The model requires various inputs such as approach speed, acceleration, deceleration, etc, and it generates various outputs such as throughput and delays. Chien et al [39] studied the impact of removal of five toll plazas on the Garden State Parkway, New Jersey. The study used a *Paramics* model built for the above stated network and found the optimal configuration. The authors used the lane changing behavior provided by the default *Paramics* simulation engine. Moreover, the toll plazas on the Garden State Parkway are barrier tollbooths, therefore the complexity of lane change is much less as compared to the toll plazas located on the NJTPK.

Although, *Paramics* has some of the basic features that can be used to build a toll plaza model, additional work using the Application Programming Interface (API) had to be performed to accurately represent toll plaza operations at the NJTPK. The major differences of the approach followed in this study compared to previous studies can be summarized as:

- Unlike other models, the toll plaza model developed in this study was fully integrated with the freeway model [38,40].
- Different from the model developed by Chien et al [39], the model in this study was not a barrier tollbooth but it was a stand-alone configuration at the exit or entry points. This type of configuration required additional lane changing and merging logic that can only be achieved through the use of APIs in *Paramics*.
- The toll plaza model was calibrated using the entry and exit times of all the E-ZPass users provided by the New Jersey Turnpike Authority (NJTA). In addition, the percentage of E-ZPass users at each interchange was taken from the report by Wilbur Smith Associates [43].

Input variables

In order to model the toll plazas in *Paramics* the following input parameters were needed:

- Toll plaza geometry: Number of lanes at the toll plaza and the geometry of the toll plaza area.
- Toll plaza configuration: Number of lanes dedicated to each vehicle type that uses the network.
- Percentages of the type of vehicles traveling on the network (electronic or manual toll payment).
- Service time distribution at the toll plaza for each vehicle type.

Toll Plaza Geometry

The geometry of the toll plazas on the network was not available in the GIS network database. To obtain this information for each toll plaza, satellite pictures available on the Internet were used (as shown in Figure 11). These pictures were used as overlays for the network and the geometry of each toll plaza.

Figure 11. Arial photograph of Exit 14 of NJTPK

Vehicle and Lane Types

There are only two payment types for the vehicles using the NJTPK namely, the electronic toll collection (ETC), called E-ZPass and the manual toll payment. The types of lanes that serve these vehicle types are E-ZPass lanes, cash lanes and in some cases mixed lanes, shown in Figure 12 as a *Paramics* network snapshot. The number of lanes dedicated to each payment type was obtained from NJTA report [41]. This report contained the information about the configuration of each toll plaza at all times of the day and the year, classified on the basis of A.M./P.M. peak, off-peak, summer, winter, holiday, one-day after holiday.

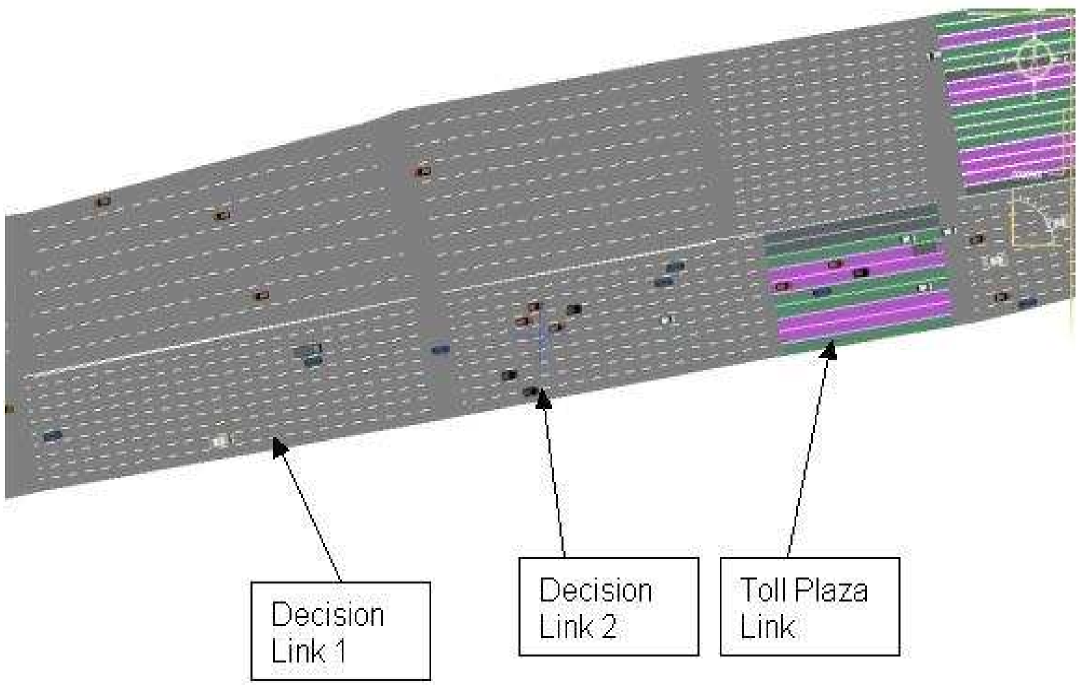

Figure 12. Toll plaza transaction lane types

Toll Plaza Service Time

Service time for the vehicles is defined as the amount of time that the vehicle spends at the toll plaza to pay the toll. Manual toll payment at the NJTPK involves two steps, picking up the ticket at the entry and paying the toll at the exit. Whereas in case of E-ZPass, the vehicles with E-ZPass pass through the toll plaza (at a certain specified speed limit) and the appropriate toll is deducted from the users' account.

Most of the available literature does not distinguish these entry and exit service times, though this difference would matter only for cash users. In addition, few studies that do differentiate between the two service times, though the differentiation is not accurate [42], Wilbur Smith Associates' study [43] on the benefits of E-ZPass on the NJTPK used an entry service time of around 5.7 s and exit service time of around 10 s. The same service time values were used for the Toll Plaza simulation as a mean service time. Each individual vehicle service time was randomly generated from a normal distribution with this mean service time. Most of the available studies in the literature specify only the mean of the distribution of service time. So in this study a variance of 0.3 seconds was chosen arbitrarily.

Toll Plaza Modeling in Paramics

Toll plaza simulation broadly involves the three following processes:

- Updating the queue lengths for each lane of the toll plaza.
- Lane choice of the vehicles based on the queue lengths.
- Processing of the vehicles at the toll plaza.

Updating the Queue Lengths

The queue length was updated at every simulation time step for each lane of the toll plaza. The concept of queue length is not quite appropriate for the vehicles equipped with E-ZPass, since they do not stop at the toll plaza instead they just slow down. However, when there are more vehicles with E-ZPass on a particular lane then the vehicles behind tend to use lanes with lower number of vehicles. However, in spite of this behavior lane change is quite minimal for the vehicles with E-ZPass mainly due to short queues, since the vehicles without E-ZPass have to stop for a certain period of time that is equivalent to the service time; longer queues are expected for the cash lanes. Thus, for cash paying vehicles, the lane change depends, to a large extent, on the queue length (Note that this observation is only intuitive and the available literature on toll plazas does not elaborate on this behavior). This discussion, which leads to the implementation of the concept of perceived queue length used to make lane choice decisions at the toll plaza, is explained in the following sections.

Lane Choice Behavior of Vehicles

The lane changing behavior at a toll plaza is extremely complicated to model, especially if the number of service lanes is high and the lane configuration at the toll plaza does not segregate the electronic toll collection lanes and the manual lanes. The demand at the toll plaza also affects the toll plaza simulation.

Lane Choice Behavior

The lane configuration at the toll plazas does not always completely segregate the electronic lanes from the manual or cash payment lanes at the NJTPK. The reason for this is, as stated before, toll plazas are external to the freeway (non “barrier tolls”) and vehicles must be allowed to merge into (when entering the freeway) and diverge out (when exiting the freeway) to their intended direction of travel. This requires a system of ramps at each toll plaza that should allow for movement in various directions, as shown in Figure 13.

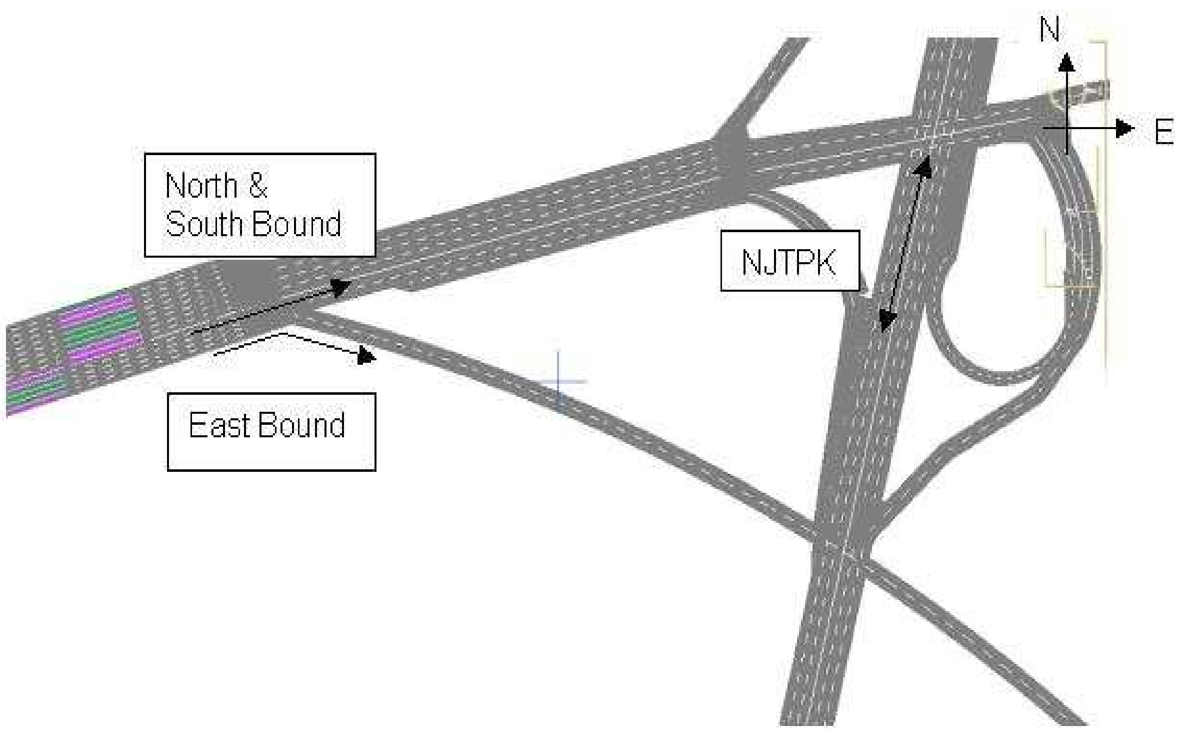

Figure 13. Path-based lane choice

As a result of this configuration, the northbound or southbound vehicles tend to choose the lanes closer to the median and eastbound vehicles tend to choose lanes closer to the curb. Intuitively, this behavior is shown by the vehicles to avoid weaving conflicts (after crossing the toll plaza) that would result from a lane choice that does not follow this logic (See Figure 13). *Paramics* by default does not support this kind of lane choice behavior, since it does not have a *path-based* route choice model that allows vehicles to determine a path based on their destination. Instead, it uses a *link-based* route choice model. In fact, for each vehicle the routing decision in *Paramics* is made just for two links ahead of the current link. (44,45) This decision is made using a lookup table that stores the costs involved in traversing each link. Partial vehicle routes made of two links are only built based on the link costs obtained from this lookup table. More importantly, in the case where the network has short links (such as a toll plaza) the vehicles will not be able to make a reasonable routing decision because of the link-based route choice logic followed in *Paramics.* In reality, drivers have an abstract idea of the route as a path connected by points, (i.e., an intersection or a split) where a decision of which path to choose next is made. (44,45) Hence, a path-based route choice model, which is similar to the process explained above, is more realistic for the toll plaza case. As a result, the appropriate lane decision cannot be made at the intended point in time and space by causing unrealistic delays that are not observed in real world. Hence, it can be concluded that the lane choice at the toll plazas, similar to those observed at NJTPK, is not completely based on the queue length, but also depends also on the travel direction and thus the path to be followed.

More specifically, if the lane choice was purely based on the queue length, then there would be weaving conflicts among the vehicles after crossing the toll plaza. Therefore, an extended lane choice model that realistically captures all of the behavioral considerations has to be implemented, tested and incorporated using API in the *Paramics Programmer.*

Path-based Lane Choice Model

The need for a “path-based” approach in microscopic simulation, more specifically in *Paramics*, has been addressed in the literature. [44,45] If the paths have to be updated dynamically for each and every link in *Paramics*, the lane choice modeling based on the above described path-dynamics approach gets computationally very demanding and memory consuming, proportional to the size of the network and network-wide demand. Instead there is a way to circumvent this problem of memory.

For the study network, there is only one possible path between each O-D pair. Therefore, the paths from each origin to each other destination are fixed and do not need to be dynamically updated. The vehicles have to make a lane choice based on the path only at the entry toll plaza. In other words, there is only one location where the vehicles have to make lane choice based on their path. To achieve this, a path matrix was created. As shown in Figure 13, if a vehicle had to take the eastbound link of the NJTPK, then his/her lane choice would be whether to take a lane closer to the median or away from the median, in order to avoid the weaving conflicts after passing the toll plaza. This path matrix stores the information about the lane choice. This concept is similar to the path dynamics approach used by several other researchers. [44,45]

	1	2	…	i	N
1	0	0	…	0	0
2	-1	0	…	1	1
⋮					
i	-1	-1	…	0	1
⋮					
N	0	0	…	0	0

Figure 14. Example of path matrix

For the path matrix (refer to Figure 14), a value of “1” implies that the vehicle has to be in a lane range closer to the median, a value of “–1” indicates that the vehicle has to be closer to the kerb, and a value of “0” indicates the vehicle can choose any lane range. Since the decision is made only at one place i.e. at the entry Toll Plaza, the “path” information is stored as an n x n matrix, where n is the number of zones, and the value is a cell (i, j) is the “path” information from zone i to zone j. The “lane choice” model, which uses both the perceived queue length approach (explained in the assumptions stated below), and the “path-based” model were implemented using an API. [46,47,48]

The assumptions of the model described below follow a similar logic to that presented by Al Deek et al. [38]

The primary assumption was that vehicles or drivers make the “path-based” lane choices two links before the toll plaza link (See Figure 15). The link here means a link in “*Paramics*” sense, and it can be of any length. So, the two “decision” links before the toll plaza were created by observing specifically at each toll plaza and deciding the possible distance from which the drivers would observe the lane transaction types and make their lane choice. Thus, the model used a toll plaza specific logic based on the configuration of each toll plaza.

Another assumption was that for vehicles equipped with E-ZPass, if the difference in queue length between the “target” lane (based solely on the actual queue length) and the current lane was two vehicles or less, the vehicle would not make a lane change to the target lane. This two-vehicle difference assumption can be called as the *perceived queue* for the driver. Also, it was assumed that E-ZPass vehicle did not make lane changes that were more than four lanes away from the current lane, since the processing of queues in E-ZPass lanes was relatively fast and such a drastic maneuver was not warranted to save few seconds.

In the case of the “path-based” model, in addition to the above assumptions, it was assumed that the vehicle decided the lane range (based on the Path Matrix) in the first decision link, and then in the second decision link decided which particular queue or lane to join. The flowchart of the lane choice logic is shown in Figure 16.

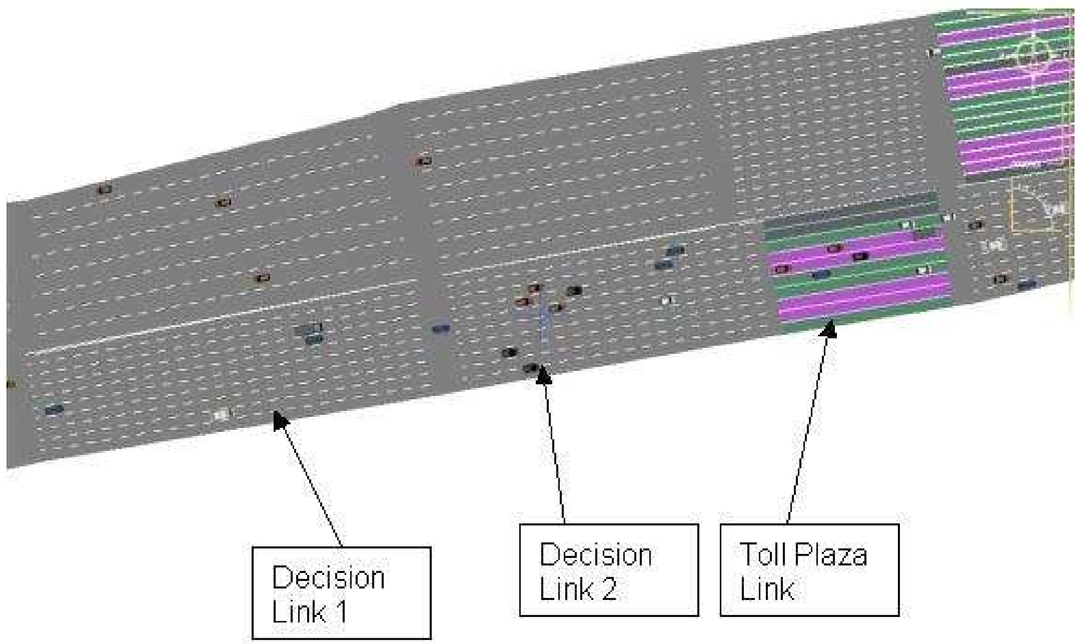

Figure 15. Graphical depiction of toll plaza lane changing behavior

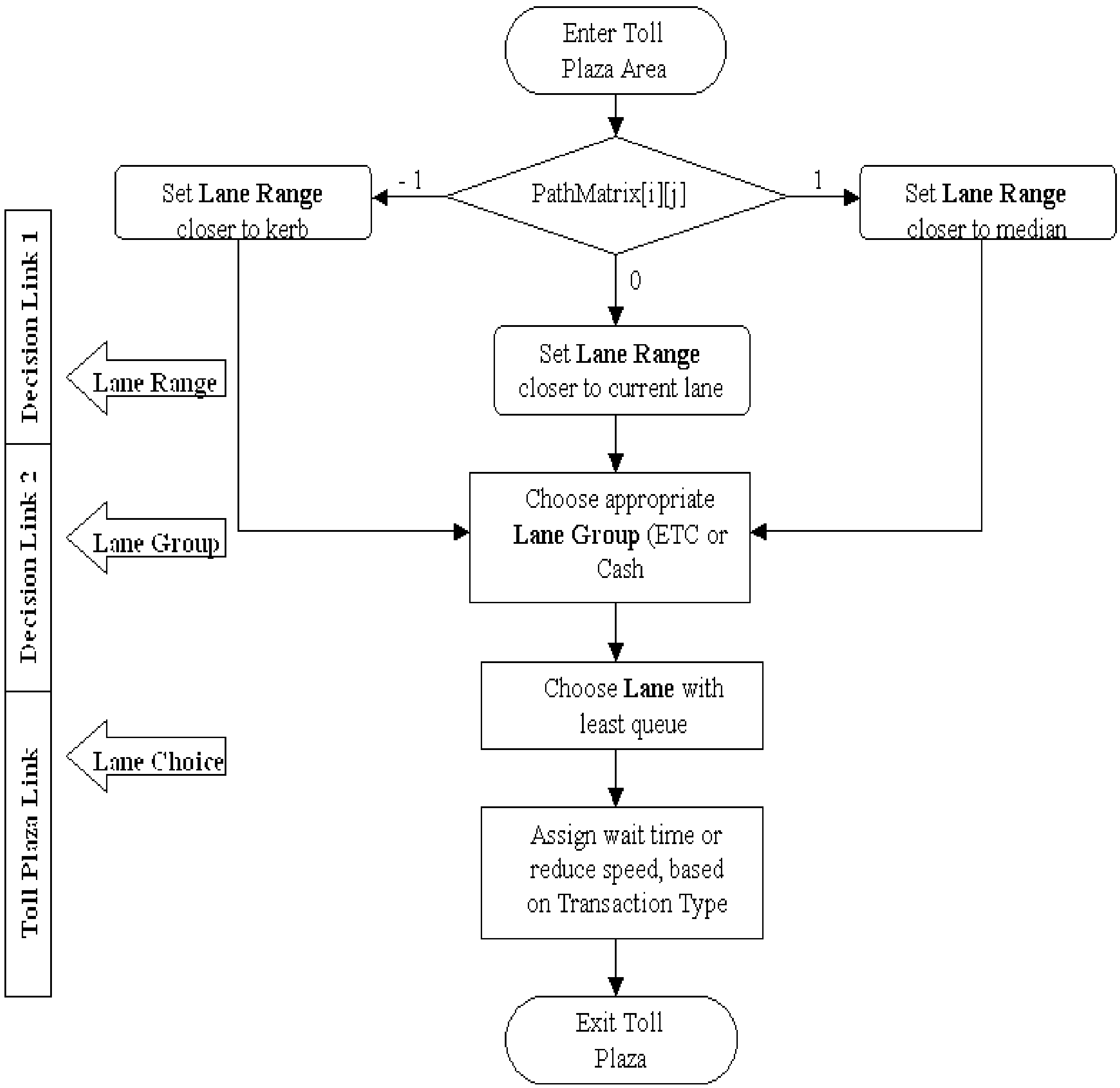

Figure 16. Flowchart for the lane changing behavior

Processing of vehicles

The processing of vehicles in the toll plaza model was done based on the service time. For manual toll payment vehicles the service time was expressed as stop-time at the end of the toll plaza link (see Figure 15) at the location of the tollbooth. The E-ZPass equipped vehicles would just pass through the tollbooth (at the end of the toll plaza link) at a specified speed limit of five mph.

Incorporation of Mixed Transaction-Type Lanes and Normal Service Time Distribution

Apart from the manual (cash) and electronic (E-ZPass) payment lanes, there are several mixed payment lanes at the NJTPK toll plazas. *Paramics Modeller*, the visualization and modeling tool in the *Paramics* Micro-simulation suite, does not have the capability to model mixed-transaction type lanes. An API for the toll plaza model was constructed to incorporate the mixed payment lanes. Also, *Paramics Modeller* has the capability for modeling only the uniformly distributed service times at the toll plaza [(49)]. However, usually the service time distribution at any queue handled by human operators is a normal distribution (Al Deek et al [(38)] use an empirical distribution of observed service times at toll plazas in Florida, which is close to normal distribution). This API also incorporates the use of a normal distribution for the service times at toll plazas.

The pseudo code for the API is shown in Figure 17.

```
If vehicle (from origin i to destination j) at decision link 1 of the toll plaza
        If PathMatrix [i][j] = 1
                Choose the lane range closer to the median
        Else If PathMatrix [i][j] = -1
                Choose the lane range closer to the kerb
        Else If PathMatrix [i][j] = 0
                Choose the lane range closer to the current lane

If vehicle at decision link 2
        If payment type of vehicle = E-ZPass
                Choose the lane group (within the lane range) among the E-ZPass
                lane groups closest to the current lane
        Else
                Choose the lane group (within the lane range) among the Cash
                lane groups with the lowest average "perceived" queue

If vehicle at Toll Plaza Link
        Choose the lane (within the lane group) with the lowest queue
        If vehicle is the lead vehicle in the Toll Link
                If payment type of vehicle = E-ZPass
                        Reduce the speed such that the speed at end of link= 5 mph
                Else
                        Reduce the speed such that the speed at end of link= 0 mph
                        Wait till the service time ends
...
If vehicle is a "non-passenger car" vehicle
        If link chosen by the vehicle leads to the "Cars Only" lanes on the NJTPk
                Change the chosen link to the other link – which leads to the Trucks
                and Buses lanes
```

Figure 17. Pseudo code showing the working of the toll plaza API

Other Network Features

The *Paramics* network of the NJTPK alone consists of 2766 nodes, 6042 links, and 26 zones. Each zone represents an interchange of the NJTPK. O-D zones were modeled as sources and sinks of demand located at some distance outside the toll plazas. The reason for the use of this kind of configuration was that the trips at the NJTPK were sensitive to the increased toll by changing the departure time choice rather than the route choice. Thus, additional alternate routes, although a part of the network, would not be used by most of the previous (before the increase in the toll) NJTPK users (Please refer to Chapter II for the information regarding the route choice sensitivity of the users of NJTPK to the toll increase). Also since O-D demand data for alternate routes were not available, the use of this kind (located outside the toll plaza – connected only to the NJTPK) of origin and destination pairs was chosen (See Figure 18).

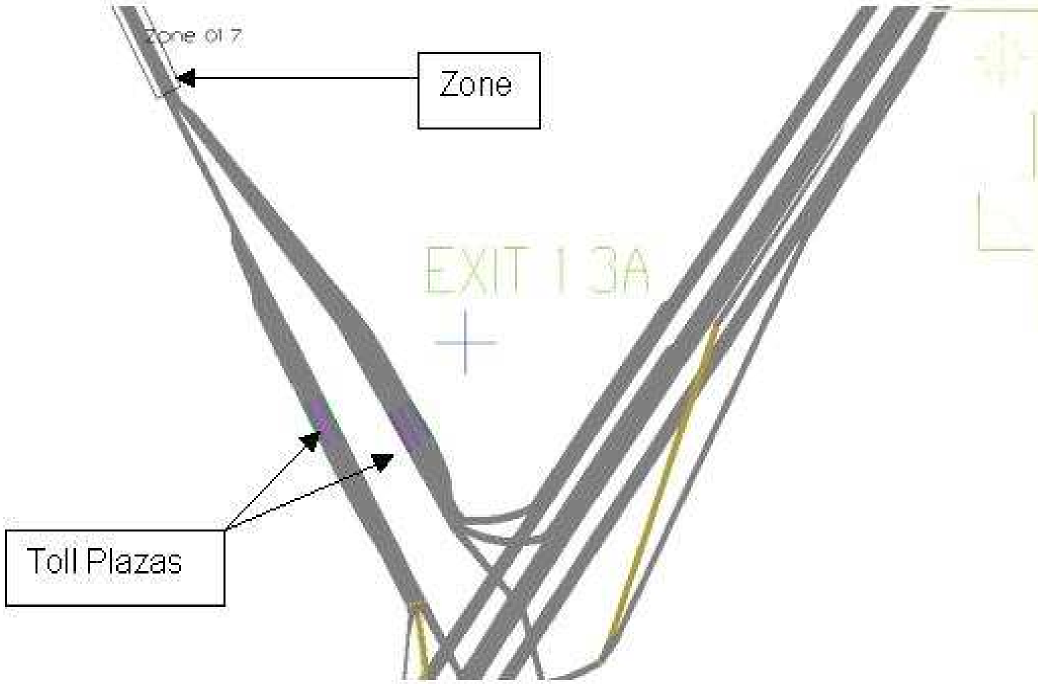

Figure 18. Zones at an NJTPK toll plaza

<u>Inclusion of "Car Only" lanes</u>

From Interchange 8A to Interchange 14 the NJTPK is a dual-dual roadway, meaning that there are both inner (car only) and outer (car, truck and bus) travel lanes in both the northbound and southbound directions. In order to model this operational set-up, the route choice of trucks had to be slightly altered. The route choice in *Paramics* is in such a way that the link that a particular vehicle has to take is known two links before. So, to model the "Car Only" lanes, the route of the trucks is changed to the alternate roadway when they are at the "decision making" links. This simple alteration forced trucks to use outer lanes only.

INPUT AND OUTPUT VARIABLES AND CALIBRATION OF THE NETWORK MODEL

Input Variables

E-ZPass Percentage

For this study, the raw data, consisting of the vehicle-by-vehicle E-ZPass entry and exit time data, were provided by the NJTA. Since the database included information only for E-ZPass users, the proportion of vehicles on the NJTPK had to be determined to have the vehicle information for cash vehicles as well. The E-ZPass users were estimated to be 65 percent of the total number of vehicles. The data were very aggregate and more accurate data were needed for the percentage of E-ZPass users in the network. The accurate E-ZPass percentages were obtained from a report prepared by Wilbur Smith Associates [(43)]. This report provided the number of E-ZPass users and vehicles using manual payment at the NJTPK, the percentage of trucks and buses for the year 2001 on a typical weekday as a function of time of the day. For some interchanges the average of the E-ZPass percentages for all the interchanges provided in the report by Wilbur Smith Associates [(43)] was used. The E-ZPass information was not available from Interchange 12 through Interchange 1 in the southbound direction and the default E-ZPass percentage assumed was giving large delays. To remedy this problem, various levels of percentages were tested and the best (in terms of closer match of travel time) percentage was selected for each interchange.

O-D Demand Data Percentage of Vehicle Types

Origin-Destination data for the network was obtained using the raw E-ZPass entry and exit data of the NJTPK. The percentage of E-ZPass users was used to determine the full level of demand by inflating the E-ZPass demand.

Annual average daily traffic (AADT) data of the NJTPK obtained from the NJDOT website [(36)] were used to calculate the average peak hour flow assuming peak hour factors in the range of 0.8 – 0.95. Although this approach is very aggregate, the average flows were used to cross-validate the volumes at different sections of the NJTPK. In the cases where the volumes were lower than the average peak hour flows, the O-D demand data were adjusted accordingly. The percentage of each vehicle type within the E-ZPass users were obtained from the disaggregate data given by the report prepared by Wilbur Smith Associates [43]. The report prepared by Wilbur Smith Associates provided the information about the percentage of each vehicle type for both cash and E-ZPass users [43]. This information was utilized to determine the percentage of each vehicle type for each hour of analysis.

Calibration of the Microscopic Simulation Model

When the system and the simulation model output data are compared, there often are substantial differences in the comparison. In order to reduce the discrepancy in the results, some correction factors are added in the input data. Then the simulation model and system output data are compared again. This procedure of input modification to meet the target output measures is called "calibration".

Calibration is a crucial yet time consuming step of the microscopic traffic simulation model development process. There are several approaches that use a systematic methodology for the calibration of traffic simulation models [50,51,52]. The calibration procedure can be divided into multiple steps: (1) volume-based calibration, (2) speed-based calibration and (3) optional objective-based calibration by Hourdakis et al [51]. For example, in volume-based calibration, Hourdakis et al [51] used the mainline loop detector station volumes. Whereas in speed-based procedure a close match is sought between the speeds observed by the detectors in the field and speeds observed from the simulation. Although constructing an objective function for the evaluation of the optimal or near-optimal correlation with the real-world behavior seems to be an attractive approach, it is not always feasible for a network as large as the one developed in this study. Ma and Abdhulai [52] used genetic algorithm for the convergence of various parameters used for calibration of a part of the street network of downtown Toronto. A "mistfit" function is defined for the deviation of flows and is optimized by varying the mean reaction time and mean target headway. Lee et al [53] also made use of Genetic Algorithm to calibrate a freeway, Interstate-5 (I-5), in California.

However, for large networks, use of the genetic algorithm is not only time-consuming, but it is also infeasible due to the stochastic nature of traffic demand and the large number of parameters that needs to be optimized. Therefore, in this study, a trial-and-error approach was selected to adjust various important input variables to achieve an acceptable level of accuracy. (Please see the discussion at the end of the Calibration Section for the level accuracy achieved by various studies using microscopic traffic simulation models)

In this study, travel times of E-ZPass users between each O-D pair were used to calibrate the NJTPK network for peak and peak-shoulder hours for a typical weekday.

Calibration Procedure

The basic steps of calibration of traffic simulation models involved the modification of several inputs: (50)

- Calibration of driver behavior.
- Calibration of route choice.
- Adjustment of the OD demand matrix.
- Fine tuning of the Network Model.

Calibration of Driver Behavior

In *Paramics* version 5, there are many parameters based on which the driver behavior can be calibrated. These are mean reaction time, mean target headway, speed memory, minimum queue gap, etc. (54). These parameters are explained briefly below.

- Mean Reaction Time: This is a global network-wide parameter that is used to set the average reaction time of the users.
- Mean Target Headway: Another global parameter which is used to set the average headway that the vehicles aim to maintain during the simulation.

The simulation is very sensitive to both mean reaction time and mean target headway, since these parameters control the car following, gap-acceptance and lane-changing behavior of the vehicles in the simulation. These are the two basic parameters that analysts use to calibrate the simulation models in *Paramics*.

- Speed Memory: It is the number of time steps that each vehicle "remembers" its current speed. It must be increased or decreased in conjunction with the number of time steps of the simulation and the mean reaction time, so that higher or lower reaction times can be modeled accurately for the same number of time steps per second.
- Minimum queue gap: This parameter is used to set the minimum gap between the vehicles when they are in a queue. Minimum gap can be useful when simulating queues at intersections and toll plazas.

Calibration of Route Choice

It should be noted that the route choice of vehicles in the study network needs not be calibrated since there is only a single route between any given O-D pair in the NJTPK network.

Calibration of OD demand matrix

In order to run the simulation model, the O-D demand matrices were required for the years 2000, 2001, 2002, and 2003. For the years of 2002 and 2003 disaggregate (vehicle-by-vehicle) data were available for the E-ZPass users. Therefore, for the years of 2002 and 2003, the O-D demand matrices were easily obtained by increasing all O-D pairs equally by the E-ZPass market share percentage of that year. Then O-D demand matrices for the year 2001 were projected backwards using the yearly increase factor of 6.21percent from 2001 to 2002 (Please refer to Chapter II for a detailed discussion). Similarly, year 2000 demand matrices were projected backwards by using the annual increase factor of 5.69 percent. However, due to the expected demand shift after the implementation of time of day pricing after September 2000, the estimation of O-D demand of 2000 should reflect the traffic shift from peak to peak shoulder periods. Therefore, the O-D matrices for the year 2000 were obtained using two different methodologies.

In methodology-A, the demand shift in the O-D demand matrices was based on the results of the elasticity analysis conducted using travel surveys. The elasticity analysis results indicated a shift of 0.48 percent in demand (as opposed to 8 percent increase in the peak toll levels in September 2000) from peak to peak shoulder periods (for detailed analysis please refer to Chapter VI). In order to obtain the O-D matrices before the implementation of the first time of day pricing program, this specific result was used. The percent share of peak period O-D demand was increased by 0.48 percent and the percent share of peak shoulder period O-D demand was decreased by 0.48 percent to obtain the demand matrices before the implementation of the first phase of the time of day pricing program.

In methodology-B, the results of the aggregate level before-and-after analysis were used to capture the demand shift. The before-and-after analysis indicated that the demand shift from peak to peak shoulder periods were 1 percent after September 2000 (for detailed analysis please refer to Chapter II). Based on this result, the percent share of the peak period O-D demand was increased by 1 percent and the percent share of the peak shoulder period O-D demand was decreased by 1 percent to obtain the demand matrices before the first phase of the time of day pricing program [56].

Fine Tuning of the Network Model

Fine-tuning of the simulation model was aimed to reduce the difference between the observed and the simulated vehicle travel times between each O-D pair. Since *Paramics* allows users to trace each vehicle in the network, travel times of vehicles between each O-D pair can easily be recorded.

The model was first run with the default *Paramics* parameters and the travel times were obtained based on these input parameters. Along with the driver behavior parameters, the following *link specific* features of the network were modified to reduce the difference between the observed and the simulated travel times:

- Sign posting distance: Signposting is the location on the link where drivers become aware of any hazards i.e. change in geometry, presence of any intersections or split in the roadway (Y-junction for instance), etc.
- Sign range: Sign range is the distance over which the drivers make lane-changing decisions when reacting to a hazard. In most cases for the study network of NJTPK, the sign range had to be corrected, so that not all the vehicles change their lanes at the same location.

The difference between the observed and the simulated vehicle travel times was used as a parameter to compare the results of various simulation runs with different mean target headway and mean reaction time. In the process of modifying the link specific and the global mean target headway and mean reaction time parameters, approximately one hundred runs were performed before the final simulation model was obtained.

The trip lengths on the NJTPK network varied from 0.4 miles to 140 miles. As a result, higher percentages of travel time errors occurred for the trips that have smaller trip length. In other words, for short trips even small errors in travel times were reflected as large percentage errors. The trip delay for the short trips may be under-estimated or over-estimated as a result. Therefore, the percentage errors were scaled for all trips based on trip distance. The scaled percentage error and the number of trips in each category of error are shown in Table 23 and Figure 19.

The next subsection discusses the range of errors that other studies obtained in the calibration of traffic simulation models. It is argued that the error of accuracy presented in this section is very close to the error range reported in the literature.

Table 23. Range of percentage error in travel time and the percentage of O-D trips

Range of Percentage Error	Percentage of O-D Trips
0-5%	93.24
5-10%	3.15
10-15%	2.03
15-20%	0.0
20-25%	0.225
25% - more	1.35

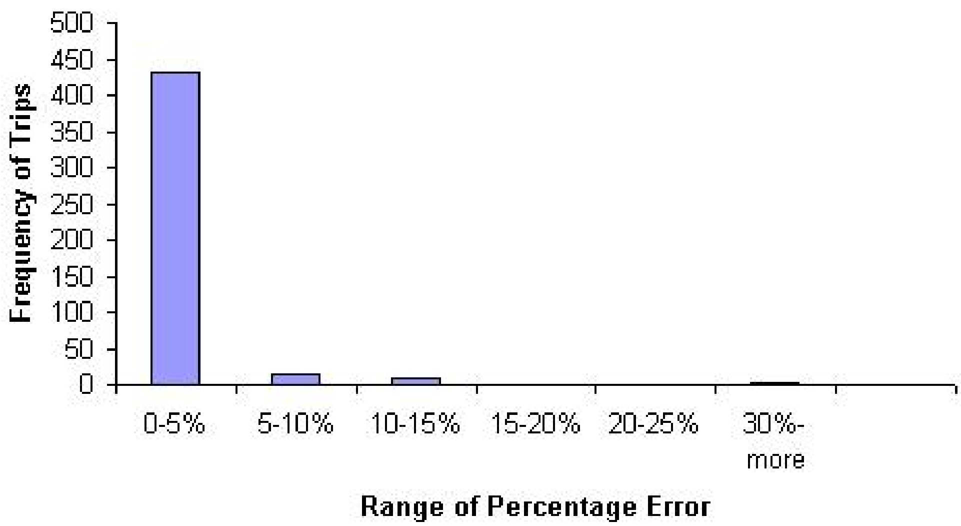

Figure 19. Percentage error of inter-zonal travel times and number of trip pairs

Calibration Efforts of Previous Studies

A brief discussion about the procedure followed and the range of errors that other researchers obtained in the calibration of traffic simulation models is presented below. Chu et al [50] used deviation between the observed and simulated volume and travel time to calibrate the microscopic traffic simulation model of a highly congested network in the city of Irvine, California. The network consists of a 6-mile section of I-405, 3-mile section of I-5, 3-mile section of SR-133 and adjacent surface streets. The average travel time error was found to be 3.1 percent. The other calibration studies used measures of performance such as GEH statistic (which is a modified chi-squared statistic incorporating both absolute and relative errors used by British Engineers) for volumes measured by loop detector located at different points on the freeway. Theil's Inequality coefficient for speeds and volumes at different loop detector stations are also utilized in the literature (50,51,52). Hourdakis et al (51) suggested a root mean squared error of around 15 percent to be satisfactory in the volume-based calibration step where a close match of volumes in the simulation model and real-time at the loop detector stations was performed. The network in this study consisted of a 12-mile circumferential freeway TH-169 and adjoining surface streets, located in the state of Minnesota, United States. Lee et al (53) obtained an average relative error of around 15 percent in volume in the calibration of the traffic simulation model of a five-mile section of I-5 interstate freeway in California using Genetic Algorithm. Zhang and Owen (57) validated the multi-regime simulation (MRS) for an advanced microscopic traffic simulation model, by using various microscopic and macroscopic parameters. As a part of this study the authors compared the simulated and observed travel times in a weaving section of Baltimore-Washington Parkway located in Prince George's County, Maryland. They obtained a travel time of 21.72 s in the simulation model as compared to an observed travel time of 21.8 s – a percentage error of 0.3 percent. Jha et al (58) developed a microscopic traffic simulation model for the Des Moines area located in Iowa, United States. In a comparison of travel times for four corridors that is presented, an error of 4 percent was obtained for a freeway (I-235). Table 24 summarizes the above discussion.

Table 24. A Comparison of calibration parameters used and percentage error obtained in various studies

Authors of the Study	Parameters Used for Calibration	Percentage Error in Travel Time
Chu et al. (50)	Volume, Speed, Travel Time	3.1 %
Hourdakis et al (51)	Volume, Speed, Queues	N/A (did not use travel time)

Lee et al [53]	Volume, Occupancy	N/A (did not use travel time)
Zhang and Owen [57]	Speed, Headway, Travel Time	0.3% (for a weaving section)
Jha et al [58]	Volume, Travel Time	4%
Present Study of NJTPK	AADT, Travel Time	5.5%

From Table 24 it can be inferred that the range of error in the simulated vehicle travel times for the current study was on par with the error ranges reported by other studies. When the size of NJTPK network and the networks used in the other studies are compared, the level of accuracy, presented in Table 24, is promising. In this study for the trips that have trip length less than one mile, the percentage error would be magnified when the percentage error per mile is considered, since the mileage for these trips is less than 1. These trips (which form 1.5 percent of all the trips) fall under the group of trips that have the percentage error above 20 percent or more

It can be observed in Table 24 that most of the other simulation studies used volume and speed data for calibration. The advantage of using volume and speed data is that the traffic count and speed data at the mid-sections in the simulation model can be cross verified with the real-world data. For this study, only the volumes at the entry and exit toll plazas were available. The availability of volume and speed data at few mid-sections on the mainline of the NJTPK would be helpful in improving the accuracy of the travel times and the simulation model as a whole.

DELAY ANALYSIS AND RESULTS

The comparison of the impacts of time of day pricing and E-ZPass usage percentages on the traffic delays was performed using the integrated Paramics freeway and toll plaza model. The advantage of using a high fidelity traffic simulation model is that individual vehicles can be traced throughout their journey in the network. Hence, the travel time of each vehicle between each O-D pair can be determined accurately.

The results presented here are based on the simulation analysis for the following scenarios:

- 2000 – Time period before the introduction of E-ZPass
- 2001 – Time period after the introduction of E-ZPass and first phase of the NJTA's time of day pricing program
- 2002 – Time period before the second phase of the NJTA's time of day pricing program
- 2003 – Time period after the second phase of the NJTA's time of day pricing program

All the scenarios presented are for a typical weekday in the month of October. The analysis was performed for the two peak hours and two peak-shoulder hours for both A.M. (6 A.M. to 10 A.M.) and P.M. periods (3:30 P.M. to 7:30 P.M.). Due to the daily variations in traffic pattern at the NJTPK, a typical weekday is chosen. The percentage of peak hour traffic volume from Monday to Thursday was around 14.5 percent, for Friday it was 17 percent and for a weekend day it was 12 percent [56] of the total daily traffic volume.

Delay was the first type of Measure of Effectiveness (MOE) that was used for studying the changes before and after the introduction of time of day pricing and the deployment of E-Z Pass. There are two types of delays that were used in the analysis:

- Toll plaza delay (in seconds)
- Trip delay (in seconds)

The trip delays were analyzed for those O-D demands that are more than 100 trips/hour. The trip length ranges were 0-5 mi, 5-10 mi, 10-15 mi, 15-20 miles, 20-25 miles, 25-30 miles and, 30-more miles. Trip delays between O-D pairs were then averaged for the selected trip range for each hour.

The following sections present an overview of the delay results, and discuss the changes in trip and toll plaza delays over the years after the time of day pricing initiative and E-ZPass deployment.

It should be noted that in this section the delay results for year 2000 were based on the O-D demand estimation methodology-A. (See Calibration of O-D Demand Matrix subsection for details). It should be noted that the difference between the two methodologies cannot be easily seen in individual graphs. However, the results of the analysis show that there were substantial differences in delay results based on these two methodologies employed to generate O-D demand matrices. The comparison of the results of each methodology is presented in Table 33.

A.M. Period Average Trip Delays

In the following discussion the four hours of analysis are referred to as pre-peak, peak-1, peak-2 and post peak periods respectively as shown in Table 25.

Table 25. Morning time periods used in the simulation analyses

	Weekday			
	6 – 7 A.M.	7 – 8 A.M.	8 – 9 A.M.	9 – 10 A.M.
Period Name	Pre-Peak	Peak-1	Peak-2	Post Peak

Figure 20-Figure 23 given below present the change in delay with respect to years from 2000 through 2003 for different trip distance categories. These figures show that there was an overall increase in delay between 2001 and 2003 within the A.M. peak and peak shoulder periods. However, there was a reduction in trip delays between years 2000 and 2001 during the peak hours. This decrease of about one percent, although not significant, was observed to be during the peak hours because of the demand shift from peak to peak shoulders after the implementation of the first phase of the time of day pricing and the introduction of E-ZPass in September 2000. The observed increase in delay during the peak-shoulders as shown in Figure 20 and Figure 23 is due to this demand shift.

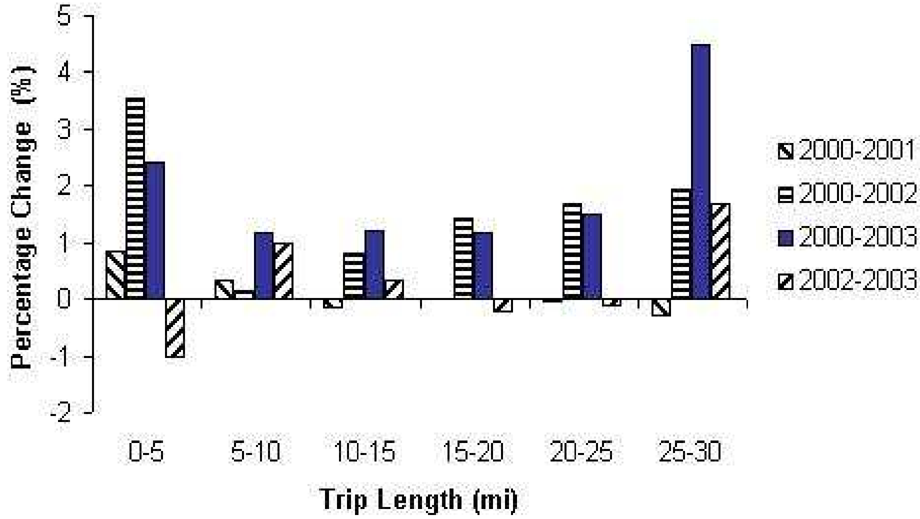

Figure 20. Percentage change in average trip delays during the A.M. pre-peak period

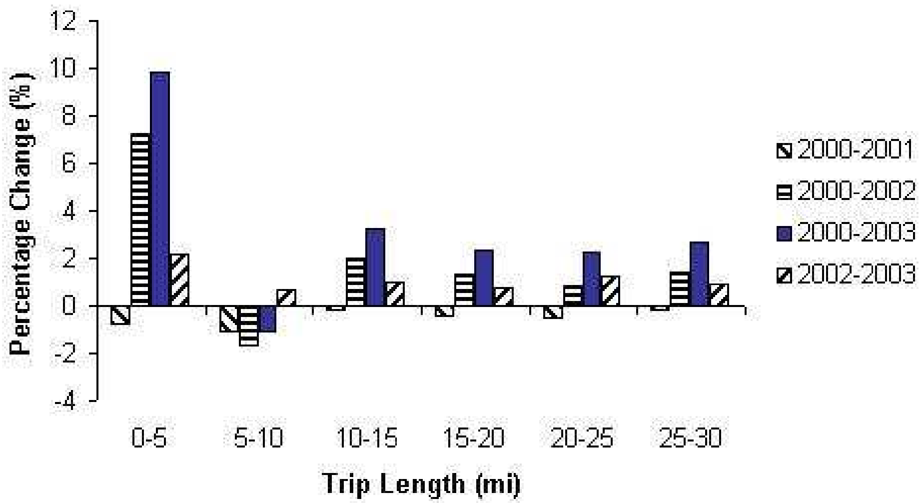

Figure 21. Percentage change in average trip delays during the A.M. peak-1 period

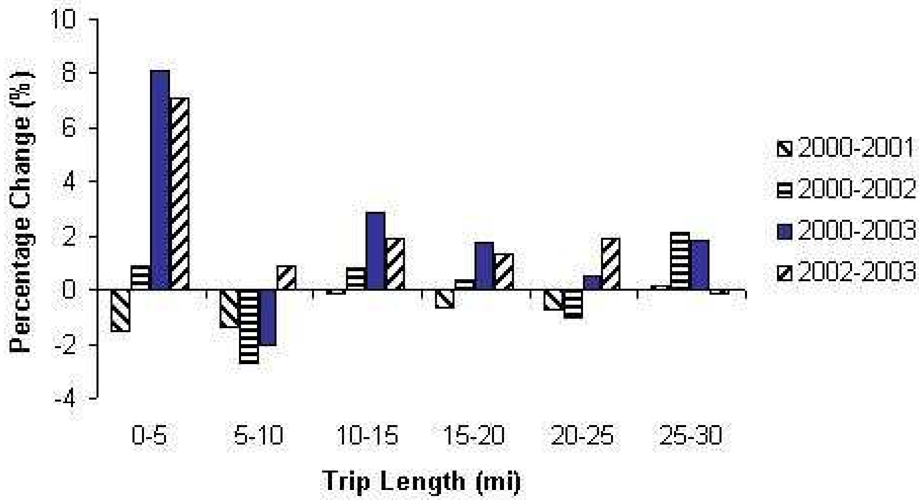

Figure 22. Percentage change in average trip delays during the A.M. peak-2 period

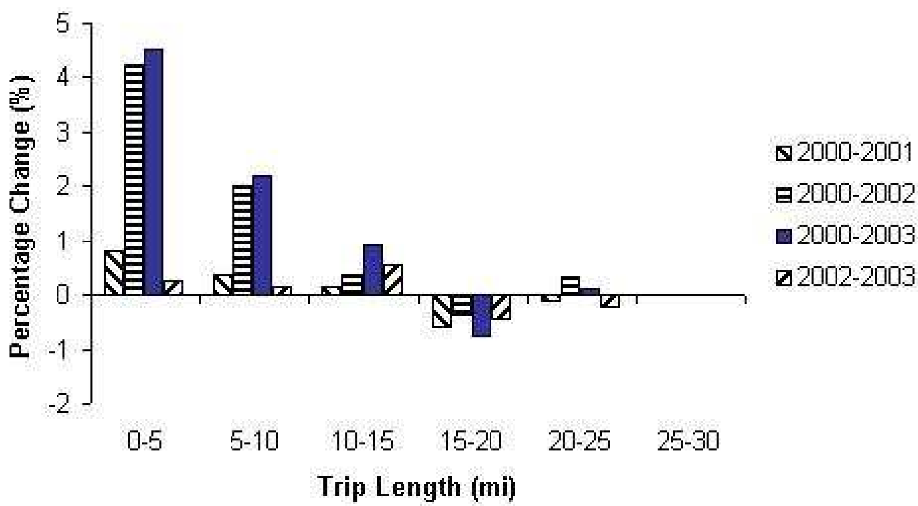

Figure 23. Percentage change in average trip delays during the A.M. post-peak period

However, the change in average vehicle delays between 2002 and 2003, i.e. the second phase of the time of day pricing, is the opposite. It can be seen in the above figures that there was an increase in delay during the peak hours. This is the opposite of the expected effect of the time of day pricing between 2002 and 2003. However, the traffic impact analysis presented in Chapter II concluded that although there was a definite shift of demand from peak to peak-shoulder hours between 2000 and 2001 due to the first phase of the time of day pricing, this pattern of demand shift reversed after 2001. Chapter II concluded that there was an overall increase in peak hour traffic between 2001 and 2003.

Since the toll plaza delays were relatively smaller compared to mainline delays, the major reason for the increase in delay in all the periods for the year 2002 and 2003 can be attributed to the increase in mainline delays due to the natural increase in demand over the years (See Table 26).

Table 26. Annual percentage increase in demand for A.M. peak and peak shoulder periods

Year	Period			
	Pre-Peak	Peak-1	Peak-2	Post Peak
2001 (Methodology A)	3.55	3.48	3.53	3.75
2002	5.19	5.36	9.17	5.09
2003	6.85	5.11	5.59	-0.11

As it can be observed in the above graphs there were no definite patterns of the effect of time of day pricing on the *overall* reduction of trip delays for various time periods and trip distance categories. In fact, an increase in trip delays was observed over the years. For example, the analysis showed that the percentage increase in trip delays in the network was one percent between years 2000 and 2001, 12 percent between 2001 and 2002, and 11 percent between 2002 and 2003. As mentioned above the major reason for the increase in delay can be attributed to the annual increase in demand. (See Table 26)

A.M. Period Toll Plaza Delays – Representative Cases

Figures showing the percentage change in toll plaza delays over the years are presented in Appendix 2 for representative toll plazas. These figures indicate a clear change in the toll plaza delays before and after the E-ZPass deployment, i.e. between years 2000 and 2001. Figure 24 shows the delay at exit 14C toll plaza for E-ZPass and cash users during the morning peak period. Since there were no E-ZPass users in year 2000, the comparison between the E-ZPass users in year 2001 and cash users in year 2000 clearly shows the positive impact of the E-ZPass deployment. Figure 24 shows that the delay estimated using the simulation model is reduced approximately by three minutes on the average at exit 14C.

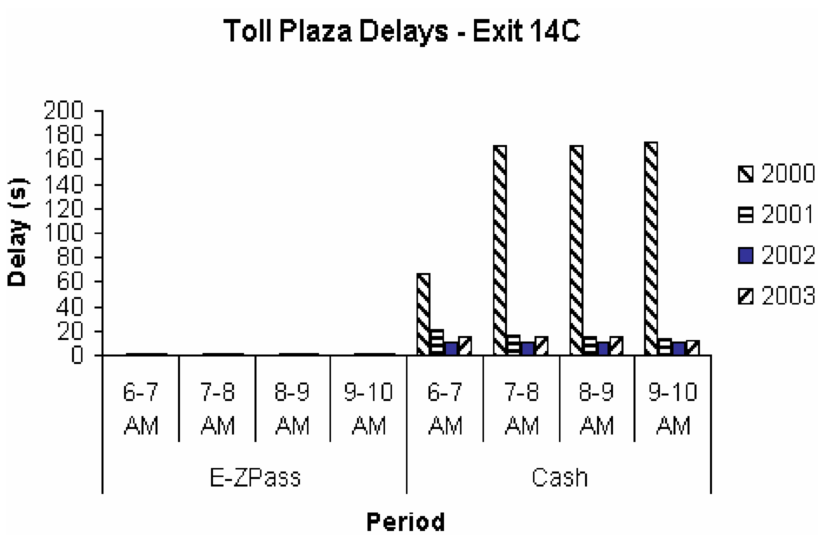

Figure 24. Distribution of delays at the exit 14 C toll plaza during A.M. period

The effect of E-ZPass toll collection after year 2000 can be clearly observed in Figure 24 and the graphs presented in Appendix 2. The reduction in delay is not only attributable to the reduced number of cash users but also to the less weaving between the same types of tollbooths. However, the reduction in delay at toll plazas for 2001, 2002, and 2003 did not affect the overall trip travel times considerably, since the toll plaza delay was a small portion of total trip delay as compared to the mainline delay for a large percentage of all the trips.

The analyses showed that between 2000 and 2001 there was an overall reduction of 77.5 percent in toll plaza delays during the morning period. The reduction in toll plaza delays was 11.8 percent between 2001 and 2002. On the other hand, the results showed that there was an overall increase of 2.4 percent in toll plaza delays between years 2002 and 2003. This increase in delay is attributed to the natural increase in demand as shown in Table 26.

P.M. Period Average Trip Delays

The selected hours of afternoon peak and shoulder peak periods that are used for the analysis are shown in Table 27.

Table 27. P.M. time periods used in the simulation analyses

	Weekday			
	3:30 – 4:30 PM	**4:30 – 5:30 PM**	**5:30 – 6:30 PM**	**6:30 – 7:30 PM**
Period Name	Pre-Peak	Peak-1	Peak-2	Post Peak

Figure 25-Figure 28 present the change in average trip delays over the years during each selected time period. These graphs showed that there was an overall increase in trip delays throughout the years, especially a substantial increase from 2002 to 2003. As mentioned before this overall increase in delays was due to the annual increase in traffic demand in the study network. For instance, between 2002 and 2003, the demand increase within the pre-peak period was around six percent whereas for the pre-peak period it was close to eight percent and for the peak-2 and post peak periods there was

around 8.5 percent increase in demand. Table 28 summarizes the annual percentage changes in demand for P.M. peak and peak shoulder periods.

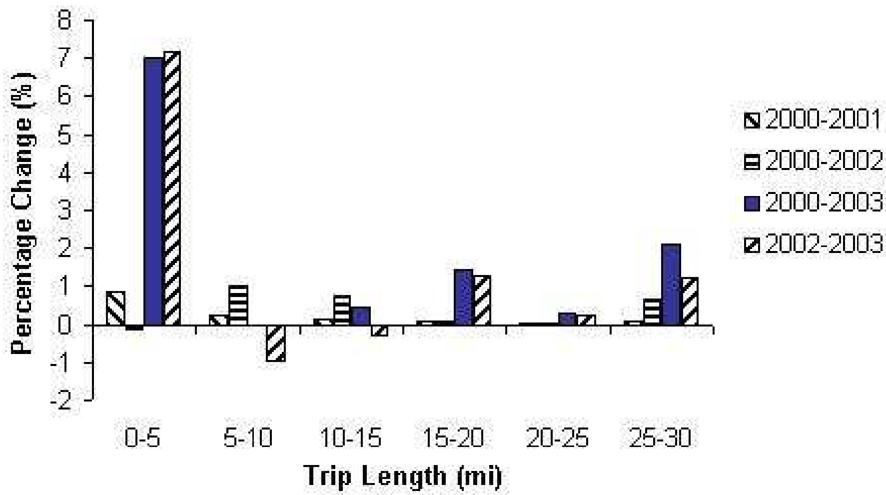

Figure 25. Percentage change in average trip delays during the P.M. pre-peak period

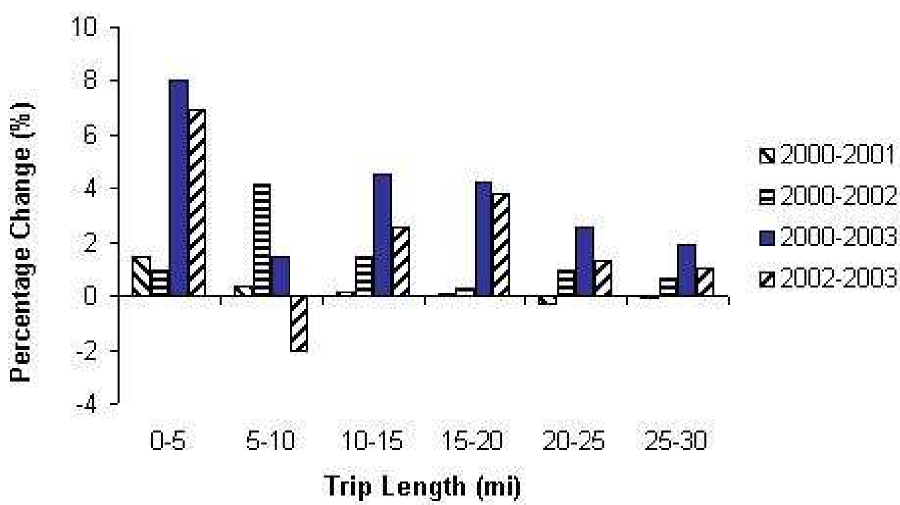

Figure 26. Percentage change in average trip delays during the P.M. peak-1 period

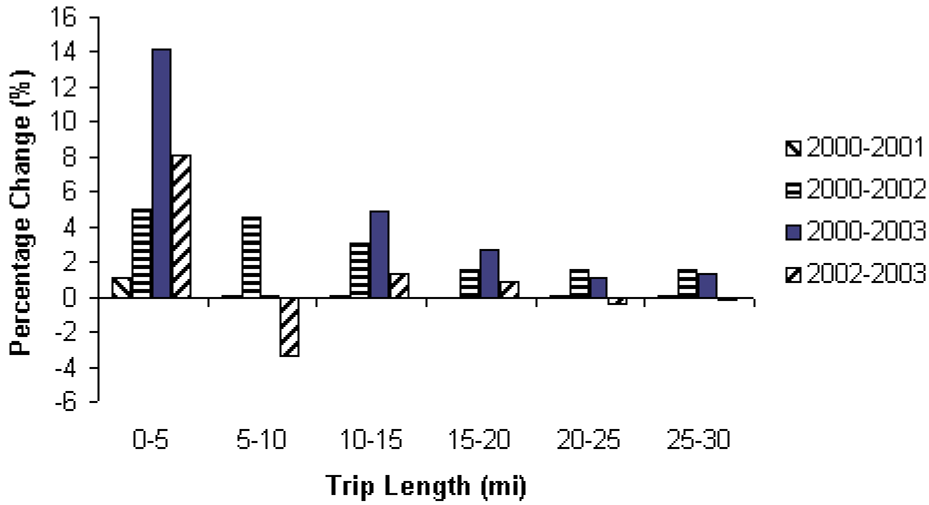

Figure 27. Percentage change in average trip delays during the P.M. peak-2 period

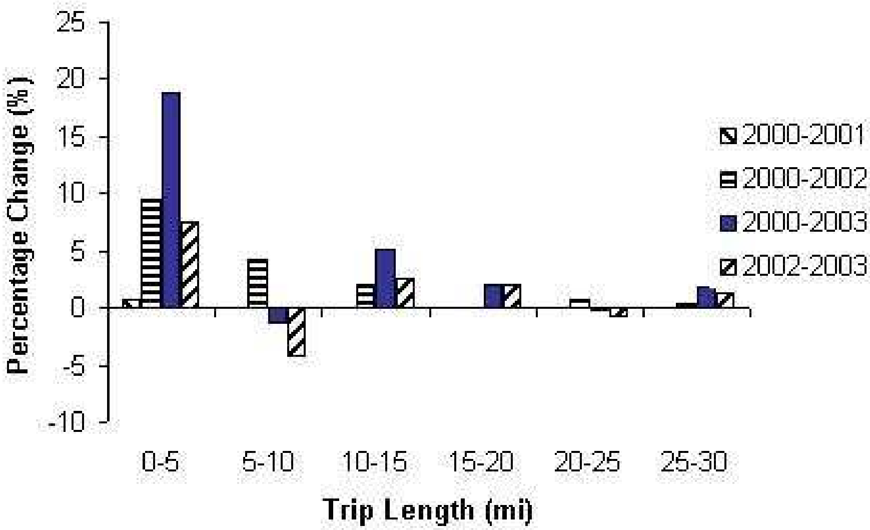

Figure 28. Percentage change in average trip delays during the P.M. post-peak period

As shown in the above figures, average trip delays were not reduced as a result of the first and second phases of the time of day pricing. In fact, simulation results showed that there was a pattern of increase in delays for each year during P.M. peak and peak-shoulder periods.

It should be noted again that the deployment of E-ZPass had little effect in reducing the trip delays since the reduction in toll plaza delay was relatively lower when compared to the total trip time. The analyses showed that the overall increase of delays during the P.M. peak for the entire network was 2.5 percent between 2000 and 2001, 18.2 percent between 2001 and 2002 and 6.7 percent between 2002 and 2003.

Table 28.Annual percentage increase in demand for P.M. peak and peak shoulder period

Year	Period			
	Pre-Peak	Peak-1	Peak-2	Post Peak
2001	3.65	3.57	3.69	3.61
2002	5.30	5.34	5.39	5.32
2003	6.10	6.59	7.76	8.37

P.M. Period Toll Plaza Delays – Representative Cases

The graphs showing the changes in toll plaza delays for the afternoon period are presented in Appendix 3. As observed in the morning period analysis, there was a clear change in the toll plaza delays before and after the E-ZPass deployment. Also toll plaza delays for years 2001, 2002 and 2003 did not show any significant change.

Figure 29 shows the average delay at 18W entry toll plaza over the years for the afternoon period. The average delay reduction between 2000 and 2001 was clear, and approximately amounts to 20 seconds on the average. Note that this reduction is the difference between the delay of cash users in 2000 and the E-ZPass users in 2001. On the other hand, there was no change in the delays of cash users between 2001 and

2002 and between 2002 and 2003. The change in demand was a major factor that affects the delays at toll plazas. Table 28 summarizes the annual percentage change in demand for the P.M. peak and peak shoulder periods.

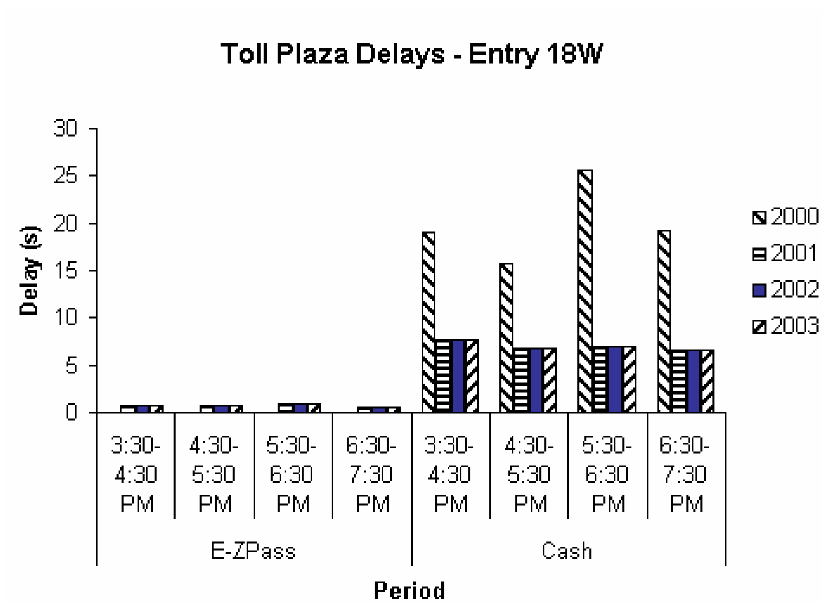

Figure 29. Distribution of delays at the Exit 18W toll plaza during P.M. period

The analyses showed that the overall reduction in toll plaza delay at Exit 18W between 2000 and 2001 was 44 percent. This reduction was 19.6 percent between 2001 and 2002. On the other hand, the results showed that there was an overall increase of 24.5 percent in toll plaza delays between years 2002 and 2003.

EMISSION ANALYSIS AND RESULTS

The consequences of vehicle emission are pervasive and far-reaching, and it is difficult to keep track of its effects. Detailed and meticulous research is essential to formulate a reliable vehicle emission cost function, which is not within the scope of this study. However, an important impact that can be analyzed using microscopic simulation is the change in the emission levels due to the demand changes caused by the time of day pricing and other operational changes such as the introduction of E-ZPass technology. The following paragraphs summarize the process used to measure this change in emission levels:

The FHWA model on emissions, SPASM, was used to determine the quantity of emissions at a range of speeds for various kinds of vehicle types. [59] The quantities of various kinds of emissions that are estimated are:

- Fuel consumption
- Hydrocarbons (HC)
- Carbon monoxide (CO)
- Oxides of Nitrogen (NO_X)

First, the fuel consumption function as given in SPASM was adopted. This function calculates the fuel burnt in grams per mile based on vehicle speed for different vehicle types. Table 29 and Table 30 show the emission levels of each pollutant for each vehicle type at various speeds. It should be noted that the vehicle emission estimates will not include other pollutants, such as particulate matters (PM_{10}), sulfur oxides (SOx) and volatile organic compounds (VOC). Only the pollutants considered by the SPASM[59] are included in the analysis.

Table 29. Emission rates of HC and CO for auto, truck and bus at various speeds [59]

	HC Emission Rates (grams/mile)			CO Emission Rates (grams/mile)		
Speed (mph)	**Auto**	**Truck**	**Bus**	**Auto**	**Truck**	**Bus**
5	8.04	11.16	5.00	66.71	112.24	32.28
10	4.30	7.59	3.93	35.55	75.19	22.26
15	3.15	5.77	3.15	25.30	53.13	16.06
20	2.51	4.60	2.58	20.25	39.59	12.13
25	2.14	3.83	2.17	16.86	31.12	9.59
30	1.89	3.30	1.86	14.55	25.78	7.93
35	1.71	2.93	1.63	12.89	22.53	6.87
40	1.56	2.67	1.46	11.67	20.76	6.22
45	1.44	2.49	1.34	10.78	20.18	5.90
50	1.38	2.36	1.25	10.36	20.68	5.85
55	1.36	2.29	1.20	10.36	22.37	6.08
60	1.60	2.25	1.17	18.93	25.53	6.61
65	1.84	2.26	1.17	27.51	30.74	7.51

Paramics plug-in, *Monitor*, (60,61) was used to estimate the amount of emissions that vehicles emitted at each simulation time step. *Monitor* can take up to a maximum of five variables such as, speed, acceleration, gradient, speed multiplied by acceleration and the time the vehicle spends on the network, etc. Emission level depends on these variables. At each time step, each of the above specified variables were measured and the emission level for each vehicle was estimated based on the input emission rates. These rates were based on the emission levels from SPASM (See Table 29 and Table 30).

Table 30. Emission rates of NOx and fuel consumption for auto, truck and bus at various speeds (59)

	NOx Emission Rates (grams/mile)			Energy Consumption Rates (units/mile)		
Speed (mph)	**Auto**	**Truck**	**Bus**	**Auto**	**Truck**	**Bus**
5	2.01	16.79	22.86	0.117	0.503	0.250
10	1.78	14.28	18.96	0.075	0.316	0.250
15	1.71	12.60	16.30	0.061	0.254	0.250
20	1.68	11.50	14.52	0.054	0.222	0.250
25	1.73	10.84	13.40	0.050	0.204	0.250
30	1.77	10.53	12.81	0.047	0.191	0.250
35	1.80	10.53	12.69	0.045	0.182	0.250
40	1.82	10.84	13.03	0.044	0.176	0.250
45	1.85	11.47	13.86	0.042	0.170	0.250
50	2.00	12.50	15.28	0.041	0.166	0.250
55	2.37	14.02	17.45	0.041	0.163	0.250
60	2.74	16.22	20.64	0.040	0.160	0.250
65	3.11	19.40	25.31	0.039	0.158	0.250

The quantities of each kind of pollutant can be found over the speed range of 5 mph to 65 mph for various vehicle types like car, truck and bus from Table 29 and Table 30. For vehicle speeds less than 5 mph (the cash users stop at the toll plazas), the data for the emission rates were not available from Table 29 and Table 30. Therefore, the emission levels for the speeds less than 5 mph were extrapolated linearly from the data presented in Table 29 and Table 30. These pollutant quantities can later be converted into monetary value based on previous studies. (63)

Results of Emission Analysis

The change in emission levels for three types of pollutants, namely, Hydrocarbons (HC), Carbon monoxide (CO), Oxides of Nitrogen (NOx) were compared for various scenarios. The changes in annual emission levels for the AM period for the four scenarios are shown in Table 31.

Table 31. Percent change in A.M. period annual network-wide emission levels

		HC (%)	CO (%)	NOx (%)	Fuel (%)
2000-2001 (Methodology A)	Pre-Peak	0.87	0.71	-7.9	-3.6
	Peak-1	-2.88	-3.1	-4.1	-3.8
	Peak-2	-16.0	-16.5	-11.2	-14.5
	Post Peak	-21.1	-21.9	-20.0	-21.8
	Average	*-10.4*	*-10.8*	*-10.5*	*-11.1*
2000-2001 (Methodology B)	Pre-Peak	-3.54	-3.61	-2.69	-3.22
	Peak-1	-8.44	-8.76	-3.62	-6.72
	Peak-2	-31.4	-32.5	-17.9	-26.4
	Post Peak	-51.9	-48.5	-53.9	-70.2
	Average	*-22.8*	*-22.5*	*-17.8*	*-24.5*
2001-2002	Pre-Peak	3.15	3.24	4.14	3.70
	Peak-1	3.42	3.50	3.43	3.52
	Peak-2	5.60	5.68	5.22	5.46
	Post Peak	2.00	1.98	2.88	2.42
	Average	*3.69*	*3.75*	*3.97*	*3.88*
2002-2003	Pre-Peak	6.20	6.31	7.97	7.17
	Peak-1	7.94	8.10	8.43	8.40
	Peak-2	3.19	3.13	2.68	2.90
	Post Peak	-1.18	-1.10	1.07	-0.018
	Average	*4.39*	*4.46*	*5.19*	*4.87*

The changes in annual emissions levels for the P.M. period for the four scenarios are also shown Table 32.

Table 32: Percent change in P.M. period annual network-wide emission levels

		HC (%)	CO (%)	NOx (%)	Fuel (%)
2000-2001 (Methodology A)	Pre-Peak	1.58	1.61	3.35	2.44
	Peak-1	2.43	2.58	3.39	3.02
	Peak-2	1.23	1.08	2.24	1.57
	Post Peak	-0.73	-0.84	-2.52	-1.77
	Average	*1.12*	*1.09*	*1.58*	*1.28*
2000-2001 (Methodology B)	Pre-Peak	-3.97	-4.13	3.89	-0.29
	Peak-1	-14.02	-14.4	-1.7	-8.47
	Peak-2	-10.3	-10.8	1.91	-4.96
	Post Peak	-4.00	-4.48	6.09	0.032
	Average	*-8.35*	*-8.75*	*2.40*	*-3.64*
2001-2002	Pre-Peak	4.52	4.59	3.73	4.2
	Peak-1	3.80	3.73	3.33	3.48
	Peak-2	7.97	8.09	4.20	6.22
	Post Peak	12.8	12.9	9.32	11.2
	Average	*7.34*	*7.41*	*5.11*	*6.29*
2002-2003	Pre-Peak	8.69	8.69	8.96	8.76
	Peak-1	9.89	10.3	7.27	8.98
	Peak-2	9.52	9.79	11.1	10.6
	Post Peak	10.1	10.3	13.9	12.0
	Average	*9.61*	*9.83*	*10.4*	*10.2*

Table 31 and Table 32 show that there was a change in the vehicle emission and fuel consumption amounts over the years. Demand continued to increase annually in the NJTPK (refer Table 26 and Table 28). Since the emission levels are directly related to the demand levels, e.g. if the demand increases, then higher emission levels should be expected. Although between 2000 and 2001 there was a decrease in overall emission levels due to E-ZPass deployment and the first phase of the time of day pricing, the total amount of vehicle emission increased at a network–wide level throughout the years. It should be noted that when only toll plaza sections were considered, there was a substantial reduction in the vehicle emission levels. The representative cases for the entry toll plazas of exit 9 and 18W are shown in Figure 30 and Figure 31. The results of other toll plaza are presented in Appendix 3. Note that the percentage changes are shown only for the emission levels of hydrocarbons (HC). However, the percentage changes in emission levels for the other pollutants are very similar to that of HC (within 1-2 percent) and they are not shown here for brevity.

Note that in this section the vehicle emission results for year 2000 are based on the O-D demand estimation Methodology-A. The comparison of the results of each methodology is presented in Table 35.

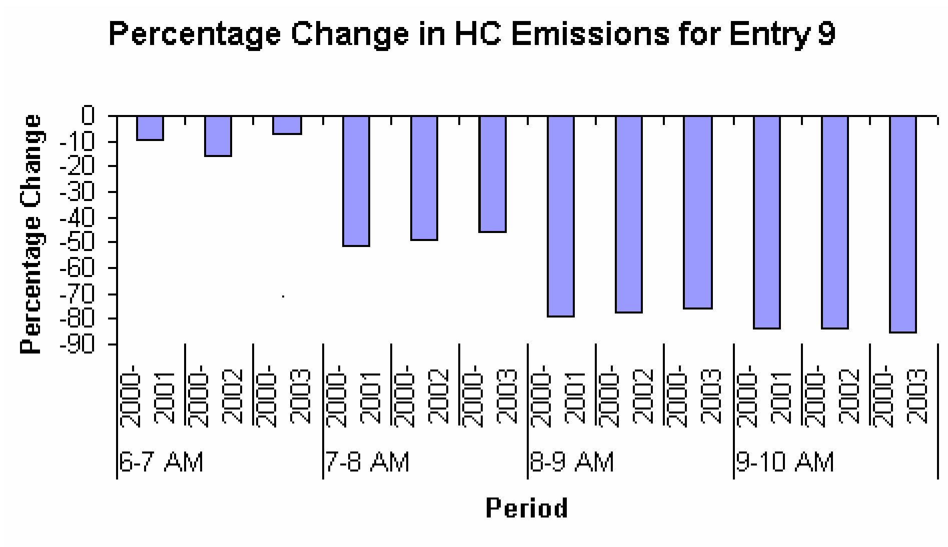

Figure 30. Percentage change in emission levels of HC at entry toll plaza 9 during A.M. period

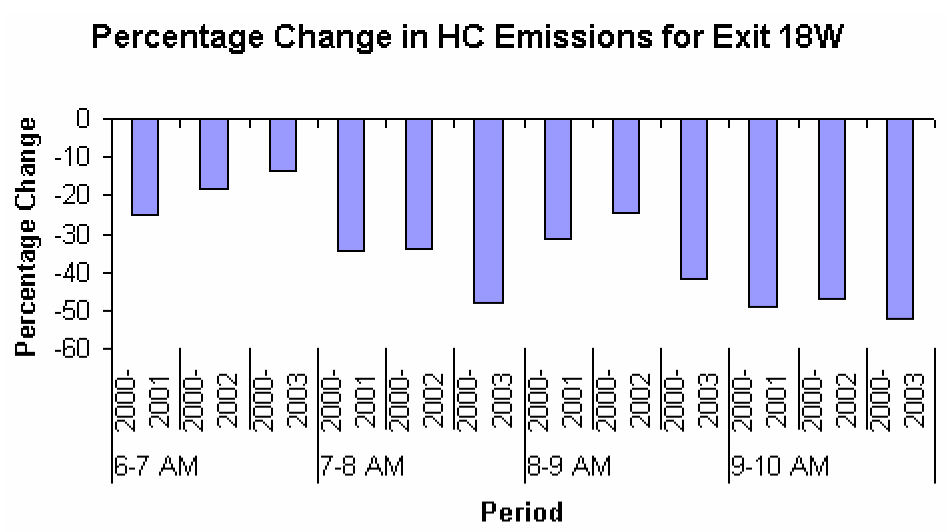

Figure 31. Percentage change in emission levels of HC at entry toll plaza 18W during P.M. period

Figure 30 and Figure 31 presented above showed that there was a clear reduction in HC levels at these two toll plazas. This was mainly due to the increase in vehicle speeds at the toll plazas after the deployment of E-ZPass. It is well known that the fuel consumption increases drastically for speed levels between 0-10 mph (See Table 29 and Table 30). The increase in fuel consumption in return caused an increase in the level of pollutants emitted. Similarly, as the speeds increased at the toll plaza, emission levels were reduced considerably.

ESTIMATION OF THE DELAY AND VEHICLE EMISSION COSTS

In order to estimate the impact of time of day pricing and E-Z pass deployment in monetary units, it is necessary to first assume unit costs of delay and vehicle emissions. Delay costs are based on value of time (VOT) assumptions given in Chapter VI. Vehicle emission unit costs are adopted from Small and Kazimi [63].

Delay Costs

A value of time (VOT) assumption is required to monetarize the delays. VOT under time of day pricing is defined as the ratio between the marginal utility of travel time and the marginal utility of travel cost. Therefore in order to estimate user specific value of travel time formulation, in this report a user specific econometric utility model is developed. The value of time for work trips is found to be within a range of [16.72-19.72] dollars per hour.

The delays are separated for mainline and toll plaza to observe the delay change patterns. Table 33 shows that mainline delays have been increasing over the years. On the other hand, toll plaza delays decreased drastically between years 2000 and 2001. These figures are in agreement with the discussion on delays and vehicle emission levels reported in the previous section. The highest effect on delays has been due to the E-ZPass deployment. The time of day pricing did not have a significant long-term effect on delays due to increasing demand levels over the years.

Average cost of delays is presented in Table 33 below. The delay costs are presented within a range that is based on the VOT range.

Table 33. Total demand and average delay for A.M. and P.M. peak periods

Peak Period	Year	Average Mainline Delay per Period (seconds)	Average Toll Plaza Delay (seconds)	Average Total Delay (seconds)	Average Delay Cost ($)
A.M.	2000-A	163.3	50.6	213.9	[1.0-1.17]
Period	2000-B	172.6	73.3	245.9	[1.14-1.37]
	2001	163.3	11.4	174.6	[0.81-0.96]
	2002	185.2	10.0	195.3	[0.91-1.07]
	2003	207.4	10.3	217.7	[1.0-1.19]
P.M.	2000-A	269.6	20.8	290.4	[1.35-1.59]
Period	2000-B	281.4	45.5	326.9	[1.52-1.79]
	2001	269.6	11.5	281.1	[1.3-1.54]
	2002	323.2	9.2	332.4	[1.54-1.82]
	2003	343.3	11.5	354.8	[1.65-1.94]

As mentioned in the earlier sections of this Chapter, the effect of demand shift from peak to peak shoulder periods due to the implementation of first time of day pricing (from 2000 to 2001) was captured in year 2000 O-D demand matrices by using two different methodologies. Methodology A assumed 0.48 percent peak to peak shoulder demand shift (as opposed to 8.0 percent increase in peak period toll levels) after the time of day pricing initiative to project the peak and peak shoulder O-D demand. This assumption was based on the travel demand surveys (please see Chapter VI for details). Whereas, methodology B assumed 1.0 percent peak to peak shoulder demand shift compared to 2000 O-D demand patterns observed before the time of day pricing initiative. This assumption was based on the aggregate level before and after analysis presented in Chapter II.

The results based on Methodology B showed higher mainline travel time delays and toll plaza delays. This result was expected since Methodology B assumed more demand shift to peak shoulder period due to time of day pricing as opposed to Methodology A. In other words, the total demand was 6.5 percent higher during the peak period in

Methodology B, which resulted in higher mainline and toll plaza delays. Hence, though the total demand remained the same, O-D matrices estimated by Methodology B assumed the existence of higher number of vehicles during the peak period before the first phase namely, September 2000.

Figure 32 shows the differences of mainline delays between Methodology A and B for a representative case. It can be seen that there are substantial delay differences in results based on the two different methodologies.

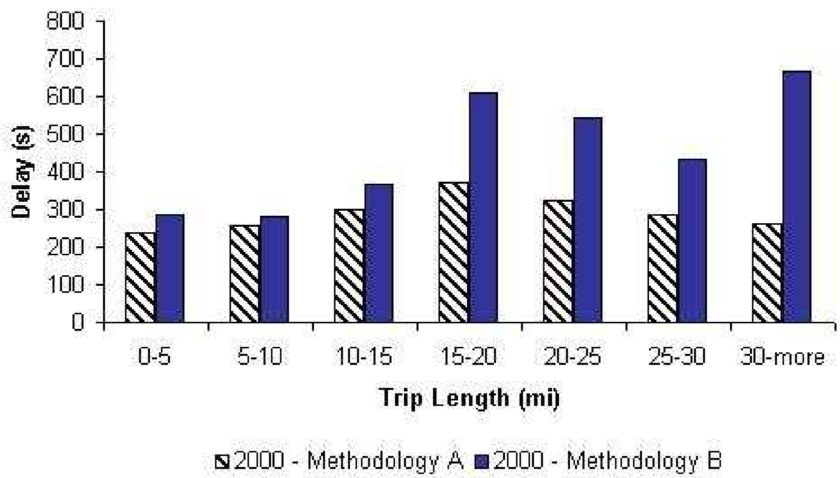

Figure 32. Mainline delay differences of two methodologies in year 2000 for A.M. Peak-2 period

Figure 33 shows the differences in delay estimates of the two methodologies in year 2000 at entry toll plaza of 18W. This representative figure demonstrated that there was a clear trend of increase in delays as a result of a different approach employed in estimating O-D demand matrices. The overall effect of methodology B can be clearly seen in Table 33. The difference in delays is approximately 25 seconds on the average at all toll plazas in the study network.

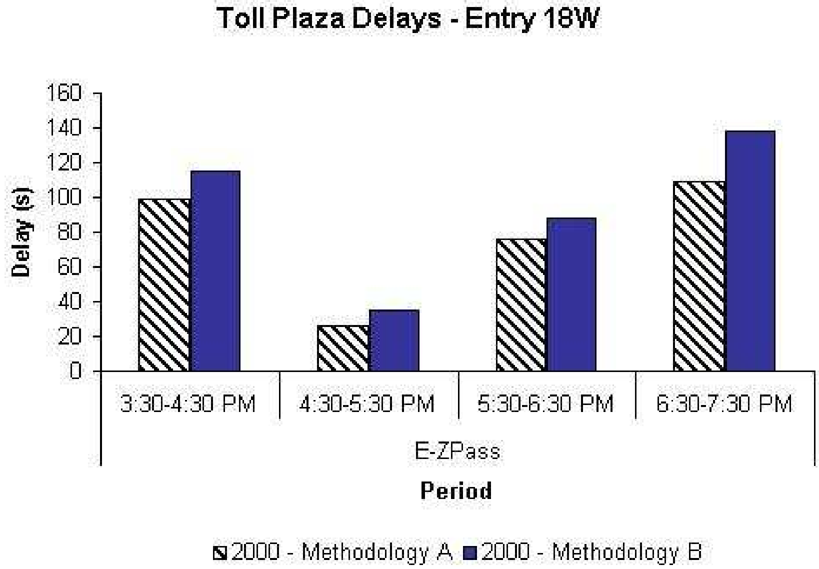

Figure 33. Toll plaza delay difference of two methodologies in year 2000 during P.M. period

It should be mentioned that although the average delay cost presented in Table 33 does not seem to be significant, i.e. between $1.0 and $1.8, when the total demand at the NJTPK was considered, the total delay results in considerable monetary value due to congestion. For instance, during the P.M. peak and peak shoulder there are approximately 120,000 vehicles in the network. Utilizing the range of average delay cost given in Table 33, the total delay cost was in the range of $198,000 - $232,800 for the P.M. period in year 2003. This range was between $120,000 and $142,800 for the A.M. period for the same year. Consequently, the annual weekday peak hour cost of delay was computed to be in the range of $65.7 M- $107.7 M (assuming 250 working days per year). It should be emphasized that this range of annual delay costs was only due to delays during the peak and peak-shoulder periods. It should also be emphasized that these costs are external costs, not out-of-pocket costs and they are based on estimated VOT. However, based on these results it is clear that a slight shift (decrease / increase) in demand can impact these external costs considerably.

Vehicle Emission Costs

Vehicle emission costs considered in this study are comprised of local effects only. However, it is commonly known that air pollution can be trans-boundary or even global. The further its effects are explored the harder it becomes to measure its monetary cause. However, even the measurable costs of vehicle emission are high enough to justify the substantial expenditures to control vehicle emission rates [(63)]. Therefore, findings from literature have been adopted to formulate a vehicle emission cost function specific to NJ [(62)]. Vehicle emission costs were estimated by multiplying the amount of pollutant emitted from vehicles by the unit cost values of each pollutant. Detailed explanation of the formulation of the vehicle emission cost function is given in Heaney et al [(64)]. Table 34 lists the estimated unit costs of each pollutant considered in this study. Based on these values the difference in vehicle emission costs for each time period can be easily computed based on the vehicle emission results obtained in the previous sections.

Table 34. Unit cost of pollutants

Pollutant	Dollar per kilogram	
	Low	High
HC	-	2.04
CO	0.92	3.82
NO_x	2.9	22.25

Source: Heaney et al. [(64)], US EPA [(65)] and Puget Sound Regional Council [(66)]
Note: The values are projected to 2004 dollars.

The estimated vehicle emission costs for A.M. and P.M. peak and peak-shoulder periods are given in Table 35. The results also show the sensitivity of vehicle emission cost results based on the methodology employed for estimating O-D demands for year 2000.

Table 35. Vehicle emission costs for A.M. and P.M. periods per day

Peak Period	Year	Range of Total Mainline Emission Cost ($)	Range of Total Toll Plaza Emission Cost ($)	Range of Total Emission Cost ($)
A.M.	2000-A	22,838 – 99,866	6,304 – 22,838	24,372 – 106,171
Period	2000-B	24,537 – 106,684	1,927 – 7,857	26,464 – 114.541
	2001	21,092 – 92,029	678 – 2,787	21,770 – 94,817
	2002	21,892 – 95,556	702 – 2,880	22,594 – 98,446
	2003	22,933 – 100,207	700 – 2,890	23,633 – 103,097
P.M.	2000-A	21,796 - 96,239	963 – 4,023	22,759 - 100,263
Period	2000-B	23,171 - 100,683	1,300 – 5,428	24,472 - 106,110
	2001	22,382 - 98,792	650 – 2,750	23,032 - 101,541
	2002	23,924 - 105,233	695 – 2,938	24,619 - 108,171
	2003	26,166 - 115,218	893 – 3,802	27,060 - 119,021

It can be observed in Table 35 that system-wide emission costs were increasing between 2001-2002 and 2002-2003. After the simultaneous introduction of the first phase of time of day pricing and the E-ZPass deployment, there was a substantial reduction in vehicle emission costs at the toll plazas as compared to vehicle emission costs in 2000. According to the results shown in Table 33, the highest reduction in delays was experienced at the toll plazas, especially between 2000 and 2001. This pattern can also be observed in Table 35 under total toll plaza emission costs.

Reduced delay levels connote higher speed. Thus, it is expected to have decreased vehicle emission levels at the toll plazas. This fact is demonstrated in Emission Analysis and Results section. However, the effect of the emission reduction at the toll plazas was not high enough to compensate the increased emission levels due to the mainline traffic. Therefore, increasing system-wide emission costs was observed throughout the years.

Utilizing the values presented in Table 35 for the peak period, the annual weekday peak hour cost of vehicle emission in 2003 was computed to be approximately $12.67 – 55.53 million (assuming 250 working days per year).

SUMMARY AND CONCLUSIONS

This chapter describes the evaluation of the time of day pricing initiative at the NJTPK in terms of changes in delay and emission levels. Instead of depending on limited before and after traffic data, microscopic simulation model of the NJPTK developed in *Paramics* traffic simulation software was used for this purpose.

The availability of a well-calibrated simulation model of the study network offers unlimited opportunities for the evaluation of various alternatives. Trip delay and vehicle emission levels were investigated using the simulation model. API feature of *Paramics* enables modelers to trace individual vehicles throughout their journeys in the network. Hence, detailed information about the travel time and speed trajectory could be obtained easily.

The realistic representation of the study network was largely affected by the realistic representation of toll plaza operations. Thus, the simulation model had to be integrated with an accurate toll plaza model. *Paramics* is well suited for this type of advanced modeling, since it allows modelers to change the default simulation models to suit to their specific purposes using API capabilities. A new toll plaza model was developed using the API capability, integrated into *Paramics* base simulation engine, and finally calibrated using data obtained from various sources.

O-D demand matrices were estimated based on the traffic impact analysis presented in Chapter II of the report. Simulation analyses based on these estimated demand matrices were then used to estimate travel times of individual vehicles between each origin-destination for each time period for each year between 2000 and 2003. The change in travel delays due to the change in demand as a result of time of day pricing and E-ZPass usage percentages were studied using the detailed simulation output.

Analyses of the simulation output showed that the average trip delays have reduced by about 3.0 percent to 18.0 percent from 2000 to 2001 after the simultaneous introduction of E-ZPass and first phase of the time of day pricing program. However, the major reason for this reduction was found to be the reduction in toll plaza delays due to the introduction of E-ZPass. E-ZPass deployment was observed to reduce toll plaza delays by 44 percent to 74 percent in the first year of time of day pricing depending on the O-D pairs. Despite the increase traffic volumes over the years, a clear pattern in the reduction of delay at the toll plaza was observed.

Table 33 shows that although delays decreased at the toll plazas, there was a pattern of delay increase of 27 percent in the mainline between 2001 and 2003. This delay increase was due to higher annual demand levels as shown in Table 26.

A sensitivity analysis of the results for the year 2000 was also performed to study the impact of the expected demand shift after the implementation of time of day pricing. This demand shift was found out to be 1.0 percent based on aggregate level before-and-after analysis (see Chapter II), and around 0.48 percent based on the elasticity analysis conducted in Chapter VI. This difference was mainly due to the different modeling methodologies and the data used to estimate the demand shifts. The overall results were presented based on these two different assumptions of percentage of demand shift. The difference between the two methodologies resulted in 6.5 percent change in total network demand for the peak periods. Table 33 show a toll plaza delay change of 25 seconds and the mainline delay change of 9 seconds on the average. These variances in delay values showed that relatively changes in O-D demand matrices could have considerable impact on the overall network performance.

The vehicle emission level was also investigated using the developed simulation model. The vehicle emission estimations were based on the SPASM model developed by FHWA [59]. The level of emissions due to highway traffic was directly related to the fuel consumption. The detailed output capabilities of *Paramics* where individual vehicles can be traced throughout their journey enabled analysts to estimate fuel consumption accurately.

Table 31 and Table 32 show that between the 2000 and 2001, there was a reduction in emission levels as high as 10.7 percent. However, it can also be observed that the emission levels also increased between 2001 and 2003 by as much as 9.8 percent. This result was mainly attributable to the increased demand levels (See Table 26). Higher emission levels were expected due to increased annual traffic demand that causes reduced mobility.

However, the simulation results for each toll plaza showed that there was a definite trend of reduction in vehicle emission levels at the toll plazas. Figure 30 and Figure 31 show the reduction of HC emissions at the selected toll plazas. This result was attributed to the increased speed levels due to the increased number of E-ZPass users. However, network-wide vehicle emission levels have increased over the years due to higher annual traffic demand.

It should be mentioned that the positive effect of E-ZPass deployment was noticeable based on the changes in delay and emission levels, especially between 2000 and 2001. However, the effect of time of day pricing was not found to be significant based on the simulation results. Toll plaza delays remained at approximately at the same level between 2002 and 2003 (See Table 33). Therefore, it can be concluded that the toll plazas have not yet reached their capacity. Between 2000 and 2001, the effect of E-ZPass on the overall delay was considerably higher than the expected effect of time of day pricing.

Estimation results of delay and vehicle emission costs were also presented in this chapter. Table 33 and Table 35 presented the cost of vehicle delays and emissions, respectively, for the peak periods. The annual weekday peak hour vehicle delay and emission costs were estimated to be in the range of $65.7-107.7 million, and $12.67 – 55.53 million, respectively. It should be emphasized that these costs are external costs, not out-of-pocket costs and they are based on estimated VOT and vehicle emission costs. Thus, they should not be considered as real out-of pocket costs but instead they should be looked as a measure of possible savings that can be achieved by reducing congestion. That is the main reason for providing a range for these costs so that the decision makers can better evaluate the impact of changes in demand.

CHAPTER IV – DESCRIPTIVE ANALYSES OF THE IMPACTS OF THE TIME OF DAY PRICING INITIATIVE ON PASSENGER TRAVEL BEHAVIOR

INTRODUCTION

This chapter analyzes the impacts of the time of day pricing initiative of September 2000 on travelers' behavior. The data used in the analyses was collected by means of a survey instrument that included questions pertaining to the socio-economic profile of respondents, the impacts of the time of day pricing initiative on travel behavior, as well as a set of hypothetical toll scenarios (stated preference), among others. The survey instrument was designed by the project team in close consultation with the project partners (i.e., Federal Highway Administration, New Jersey Department of Transportation, and New Jersey Turnpike Authority (NJTA)) who provided invaluable comments and suggestions. Rutgers University's Eagleton Institute was in charge of conducting the computer aided telephone interviews (CATI) and submitting a clean data set to the project team. The CATI were conducted from the beginning of June to the middle of July, 2004.

In order to maximize the efficiency of data collection, the survey instrument and the overall data collection process were designed in conjunction with a sister project, i.e., the *Evaluation Study of the Port Authority of New York and New Jersey's Time of day Pricing Initiative*. The resulting survey instruments had two branches: one that focused on the Port Authority of New York and New Jersey (PANYNJ) facilities, and another that focused on the New Jersey Turnpike. In both cases, the target population was defined as all individuals who have used any of these facilities on a regular basis (at least once per week) during the last four years, i.e., since the implementation of time of day pricing. However, cost considerations suggested collecting the sample from those areas that concentrate the majority of users. For that reason, the sampling process focused on residents of New Jersey for the NJTA survey and residents of New Jersey and Staten Island for the PANYNJ survey.

Once valid respondents were identified during the screening process, the survey branched out to either the NJTA or the PANYNJ version depending on which facility the respondents used the most. The surveys focused on regular users, i.e., individuals that used the facility at least once a week. Sporadic users, those using the facility less than once a week, were screened out of the survey. The surveys made a distinction between: (a) current regular users who have continued using the toll facilities on a regular basis (at least once per week) since the time period before the time of day pricing initiative; and (b) former regular users who drove through the toll facilities on regular basis before the time of day pricing initiative and now travel regularly on alternate routes or by public transportation.

The data collected for the NJTA passenger survey contains 513 complete observations. Among them, 483 respondents (94.2 percent) are current regular users, and 30 respondents (5.8 percent) are former regular users. All respondents reside in New Jersey.

This report describes the survey methodology, and the key findings from the analyses. This will be followed by a detailed discussion of results.

OVERVIEW OF THE DATA COLLECTION PROCESS

This section discusses the survey instrument, the sampling procedure, and the sample expansion process used. The last sub-section focuses on the process of adjusting the data to represent respondents' actual usage of the NJTA toll facilities.

Survey Instrument

The NJTA passenger survey is attached in Appendix 4; it had eight major sections as shown in Figure 34:
(1) Screening Section: This section gathered general information about the respondents and determined if the respondent: (1) is indeed a valid respondent as defined in this study; and (2) could be best classified as a PANYNJ or a NJTA user.
(2) Characteristics of the Most Recent Trip (for current regular users): This section collected information about the most recent car trips that the current regular users made using the New Jersey Turnpike. The information gathered in this section included: trip

purpose, trip frequency, time of travel, departure and arrival time, flexibility of departure and arrival time, payment type, total travel, among others.

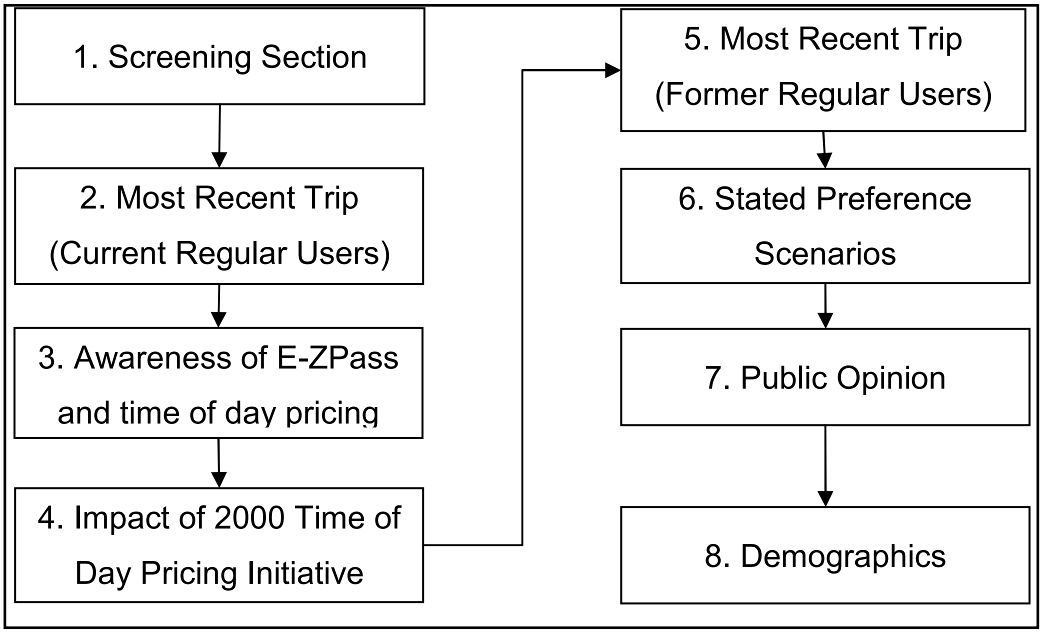

Figure 34. Outline of survey instrument

(3) Awareness of Time of Day Pricing and Toll Discounts: These sections contained questions to assess the respondents' level of awareness of tolls, the time of day pricing program and other toll discount programs.

(4) Impacts of 2000 Time of Day Pricing Initiative: This important section gathered data about the behavioral changes produced by the time of day pricing initiative. It includes questions about trips made before and after the time of day pricing initiative, focusing on trip frequency, mode choice, trip purpose, time of travel, and payment technology used, among others.

(5) Characteristics of the Most Recent Trip (for former regular users): This section is similar to (2), except that it targeted former regular users' most recent trips to the same basic destination by an alternate route or by public transit.

(6) Stated Preference Scenarios: This section was intended to assess the impact of different hypothetical toll rates on respondents' decisions about E-ZPass usage and travel schedules.

(7) Public Opinion: This section gathered respondents' input regarding the fairness of tolls, and other related issues.

(8) Demographics: This section collected socio-economic data that characterizes the respondents, including gender, age, education, household structure, and household income, among others.

Sampling Procedures and Data Collection

The data were collected by means of a single state random sample using random digit telephone calls based on computer aided telephone interviews. The target population was defined as all individuals who have or had used the New Jersey Turnpike on a regular basis (at least once per week) during the last four years, i.e., since the time of day pricing implementation. However, due to the cost constraints and the inherent difficulty of finding valid respondents, the data collection focused on regular users from New Jersey.

Sample Expansion

Ideally, a sample, such as the one collected in this project, is to be expanded so that it represents the collective behavior of the population of users. This is usually accomplished by means of an expansion procedure using a set of control totals (classified by one or more socio-economic attribute) and the number of observations for each stratum. For instance, if the number of users for each income level is known, the corresponding expansion factors could be estimated as the ratio between these control totals and the number of observations in each income level. Unfortunately, the project team did not have data that could be used as control totals (an estimate of the statistical universe) for the expansion procedure.

After considering different alternatives, the project team decided to expand the sample using the trip frequencies for each user as the expansion factor. In this way, the expanded sample represents the entire set of trips made by the respondents. As a result, the expanded sample provides an indication of the attributes of the collection of users using the facilities (in which the same individual uses the facility numerous times during a given time period). In other words, the responses are weighted in proportion to the respondent's trip frequency. Therefore, responses of users who travel more often are counted more heavily than responses of users who travel less often. It is important to remember this later in the paper because it implies that the metric used in the analysis is based on user-trips; as opposed to one based on individual users. After sample expansion, the original 513 observations were found to represent 4044 trips/month, as shown in Table 36.

Table 36. Raw and expanded sample breakdown

User Type	Raw Sample		Expanded Sample	
	Respondents	%	Weighted Responses	%
Current regular users	483	94.2%	3804	94.1%
Former regular users	30	5.8%	240	5.9%
Total	513	100.0%	4044	100.0%

DEMOGRAPHICS

Questions in the demographics section captured the socio-economic profile of the respondents in terms of both individual and household characteristics (e.g., gender, age, education level, household income and car ownership). This section is divided into two subsections; the first discusses the characteristics of the individuals, while the second focuses on the household data. The percentages and the corresponding analyses in this section are based on the 4044 weighted responses unless otherwise specified.

Characteristics of Individuals

The results indicate that white (75.8 percent), middle-aged (average age: 43.9 years) people dominated the sample. Meanwhile, male respondents (58.5 percent) are slightly more than females. It was found that the sample has a higher level of education than the overall population, as shown in Table 37, the majority of respondents have at least some college education (69.9 percent).

Table 37. Education level

Education Level	Weighted Responses	Percentage
8th grade or less	28	0.7%
High School Incomplete (Grades 9, 10, and 11)	90	2.2%
High School complete (Grade 12)	841	20.8%
Vocational/Technical School	88	2.2%
Some College	687	17.0%
Junior College Graduate (two year, Associates Degree)	268	6.6%
Four year College Graduate (Bachelor's Degree)	1138	28.1%
Graduate Work (Masters, Law/Medical School, etc)	732	18.1%
Do not know/Refused	172	4.3%
Total	**4044**	**100.0%**

Approximately three-fourths of respondents said they work full time (73.8 percent), while 8.8 percent work part time. The majority (71.1 percent) of those who work said that they cannot work at home, which suggests that work trips are an important component of these individuals travel patterns.

Characteristics of Households

In addition to individual characteristics, the survey gathered data about the socio-economic attributes of respondents' households including: household structure, car ownership and household income, among others. The analysis suggests that most households are typically car-oriented with above average household income. The results are consistent with the individuals' characteristics, such as their education levels and employment status, analyzed in the previous section.

The households captured in the survey tended to be of small size with 2.2 adults and 0.8 children on average (Table 38). The distribution of licensed drivers followed the same pattern as adults', which suggests that almost all adults in the household could generate vehicle trips by themselves.

Table 38. Household structure

Household Structure	Percentage of Weighted Responses
Number of Adults (Average: 2.2)	
1	22.3%
2	52.8%
3+	24.9%
Number of Licensed Drivers (Average: 2.1)	
1	24.8%
2	53.5%
3+	21.7%
Number of Children (Average: 0.8)	
0	55.0%
1	21.4%
2	15.8%
3+	7.8%

Table 39 summarizes the patterns of household car ownership in the sample. It is obvious that the car ownership is consistent with the number of licensed drivers in household. The average number of cars in household (2.1) is the same as the average number of licensed drivers (2.1). It also shows that more than 80 percent of the sampled households have at least as many cars as licensed drivers.

Table 39. Household car ownership

Car Ownership	Percentage of Weighted Responses
Number of Cars (Average: 2.1)	
0	1.0%
1	24.0%
2	47.8%
Fewer cars than licensed drivers	17.2%
Cars = licensed drivers	61.6%
More cars than licensed drivers	21.2%

The distribution of annual household income shown in Table 40 suggests that the households surveyed were typically well off. The median household income of the respondents was approximately $82,000 per year, this is significantly higher than the New Jersey state median income in 2003 ($55,932). [68] As shown, more than half (55.8 percent) of the households had an income of $55,000 per year or higher. Also, 26.7 percent of all respondents reported a yearly household income in excess of $100,000.

Table 40. Annual household income in 2003 before taxes

Income Range	Weighted Responses	Percentage
<15K	59	1.5%
$15-25K	144	3.6%
$25-35K	153	3.8%
$35-45K	338	8.4%
$45-55K	342	8.5%
$55-75K	395	9.8%
$75-100K	782	19.3%
$100K-125K	394	9.7%
$125-150K	242	6.0%
$150-200K	240	5.9%
$200K or more	203	5.0%
Do not know/Refused	752	18.6%
Total	**4044**	**100.0%**

When asked if their household income changed significantly from 2001 to 2003 (Table 41), over half of the respondents (52.8 percent) reported no change, while 24.3 percent reported that income increased and 11.2 percent indicated their income dropped.

Table 41. Change pattern of annual household income between 2001 and 2003

Answer	Weighted Responses	Percentage
Change, went UP	981	24.3%
Change, went DOWN	451	11.2%
Change, direction not given	176	4.4%
NO CHANGE	2137	52.8%
Do not know/refused	299	7.4%
Total	**4044**	**100.0%**

IMPACTS OF THE 2000 TIME OF DAY PRICING INITIATIVE

This section analyzes the impacts of the 2000 New Jersey Turnpike time of day pricing on passenger travel behavior. Since the time of day pricing program was implemented on September 2000, the segment of respondents of interest includes only those who have used the New Jersey Turnpike for at least four years (380 respondents representing 74.1 percent of individuals, 2944 weighted responses representing 72.8 percent of car trips). This number includes both current and former regular users. The majority (64.4 percent) of the valid respondents could recall the 2000 toll increase.

Table 42 shows the breakdown of respondents that could recall the 2000 toll increase. Among 238 respondents who could recall the 2000 toll increase, only 36 respondents changed their travel behavior because of time of day pricing, which accounts for 7.0 percent of individuals and 6.6 percent of car trips. It is important to caveat that the conclusions regarding the users who changed their travel behavior are based upon a sample of 36 auto drivers in a region of 8 million people. It is also important to highlight the possibility that, among those who could not remember the toll changes, there may be some individuals that did change their behavior but do not remember doing so. This would imply that the true percentage of users that changed behavior due to the time of day pricing initiative could be a bit higher.

Table 42. Breakdown of respondents that could recall the 2000 toll increase

Response	Respondents	Percentage	Weighted Responses	Percentage
Changed behavior because of the time of day pricing	36	7.0%	265	6.6%
Did not change behavior because of the time of day pricing	202	39.4%	1632	40.4%
Total	**238**	**46.4%**	**1897**	**46.9%**

Respondents who could recall the 2000 time of day pricing initiative were then asked if they think the time of day pricing had any effect on traffic along the New Jersey

Turnpike, only 13.9 percent said yes, among which over half (54.0 percent) reported that the traffic congestion along the New Jersey Turnpike is somewhat worse or lot worse after the time of day pricing implementation, and 28.2 percent reported traffic congestion is somewhat better or lot better.

Table 43. Change of traffic congestion after time of day pricing in 2000

Change of traffic congestion along the New Jersey Turnpike after the time of day pricing in 2000	Weighted Responses	Percentage (1)	Percentage (2)
Somewhat worse	81	30.8%	4.3%
Lot worse	61	23.2%	3.2%
Somewhat better	48	18.3%	2.5%
Lot better	26	9.9%	1.4%
Combination, sometimes better/sometimes worse	3	1.1%	0.2%
Do not know/Refused	44	16.7%	2.3%
Total	**263**	**100.0%**	**13.9%**

Note: (1) Percentages were calculated based on 263 weighted responses that think the time of day pricing had any effect on traffic along the New Jersey Turnpike.
(2) Percentages were calculated based on 1897 weighted responses that could recall the 2000 time of day pricing initiative.

Among the 36 respondents who changed travel behavior because of time of day pricing, 35 still travel through the New Jersey Turnpike on regular basis (at least once per week), accounting for 6.4 percent of weighted responses. Only one respondent travels regularly by an alternate route (0.2 percent of weighted responses). Table 44 shows the reasons for not changing travel behavior. As shown, the main reasons include no flexibility (40.2 percent) and my choice, I go when I want to go (32.3 percent).

Table 44. Reasons for not changing travel behavior

Reason	Weighted Responses	Percentage
Have no choice, no flexibility	656	40.2%
My choice, I go when I want to go	527	32.3%
Price difference not significant/can afford it	142	8.7%
Do not use it that much	140	8.6%
Toll is paid by employer	81	5.0%
Do not know/Refused	86	5.3%
Total	**1632**	**100.0%**

Characteristics of the Individuals Who Changed Behavior

Although the sample size of those users who changed behavior is small—which suggests caution when analyzing results—the authors did find some interesting results. Compared with those who did not change behavior, the individuals who changed their travel behavior are different in terms of socio-economic attributes such as gender, education level, race, household income, car ownership, and work status. The following analyses compare the socio-economic patterns of both segments of users. The percentages and analyses in this subsection are based on the 1897 weighted responses that have used the New Jersey Turnpike for at least four years and could recall the toll increase, among which 265 weighted responses changed behavior because of time of day pricing and 1632 weighted responses did not (see Table 42).

It was found that females are more likely to change behavior. Among those who changed behavior, 42.6 percent are female while only 34.9 percent of individuals who did not change traveler behavior are female, which is probably because women are more sensitive to price than men.

The average ages of two groups are very similar, about 47 years old. As shown in Figure 35, those who changed behavior exhibit a higher percentage in the age group of 30-39 (16.2 percent higher), and a lower percentage in the age groups of 40-49 and 50-59 (12.9 percent and 9.5 percent lower, respectively).

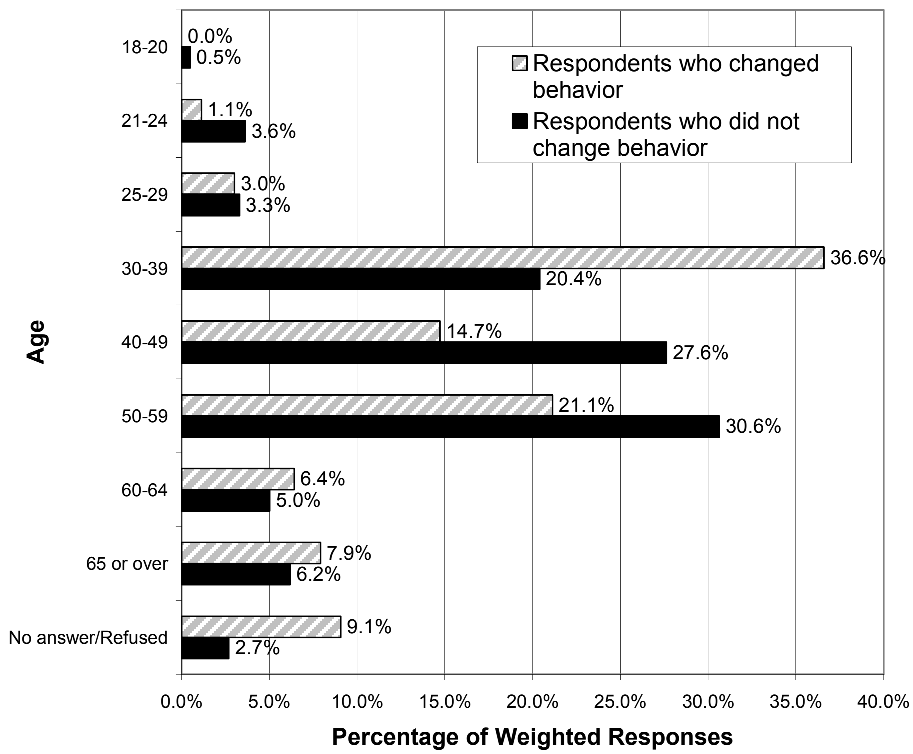

Figure 35. Comparison of age distributions

In terms of education level, as shown in Figure 36, respondents who changed behavior have relatively higher education level. Respondents who graduated with high school incomplete, high school complete, and four year college (bachelor's degree) tend to change behavior, while respondents who graduated with vocational/technical school degree, some college degree, and junior college graduate tend not to change behavior.

The comparison in terms of race indicates that, respondents who changed behavior are less likely to be White (58.9 percent vs. 70.2 percent for those who did not change) or African-Americans (3.4 percent vs. 8.3 percent), and more likely to be Hispanic (27.2 percent vs. 12.6 percent).

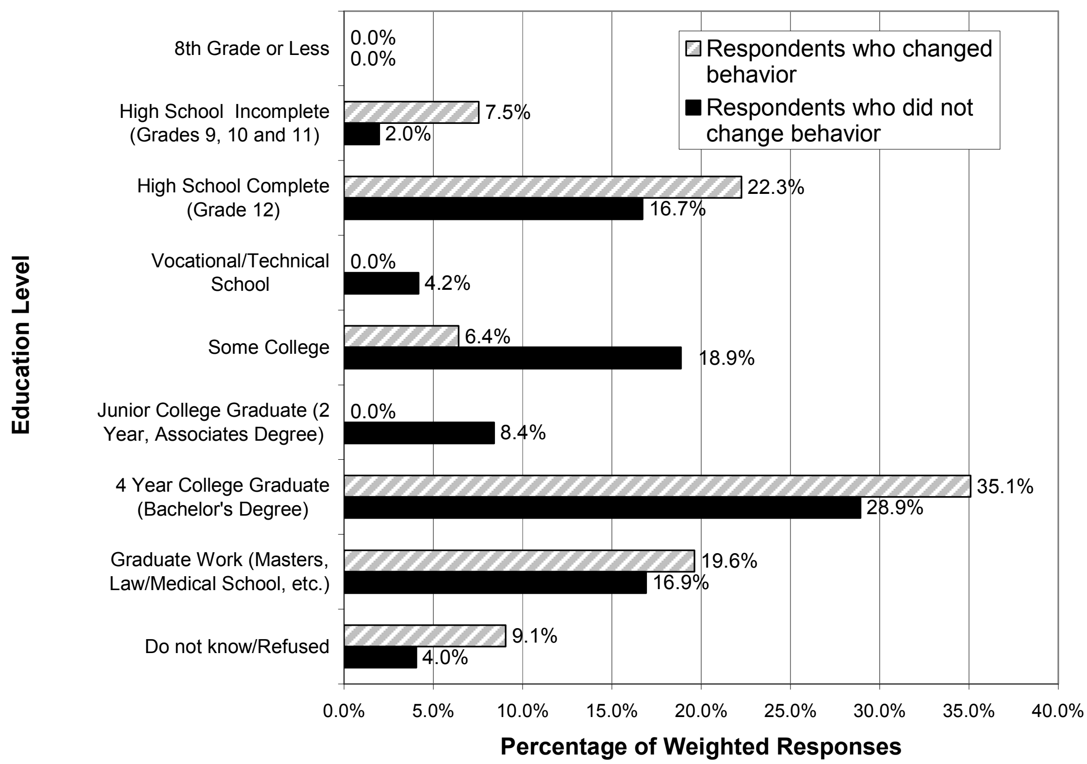

Figure 36. Comparison of education level distributions

Figure 37 shows the comparison of income distribution. The median household incomes of both groups fall in the range of $75,000 - $100,000. However, the average household income for those who changed is about $64, 234, slightly lower than those who did not change ($73, 614). In addition, household income of respondents that changed behavior is more likely to fall in the range of $25,000-45,000 (25.3 percent).

Figure 38 shows the comparison of household income change from 2001 to 2003. More than half (57.7 percent) of respondent who did not change behavior reported no change in income level, and only about a third (33.6 percent) of those who changed behavior did so. Interestingly enough, about a third (32.8 percent) of those who changed behavior reported that their income went down significantly, which could be a reason why they changed travel behavior.

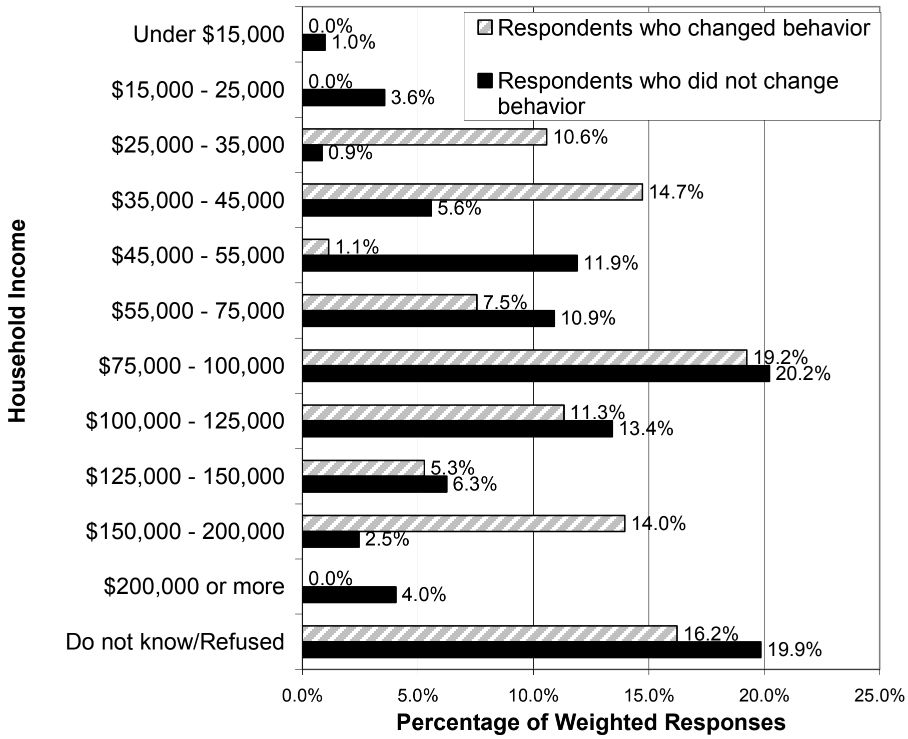

Figure 37. Comparison of household income distributions

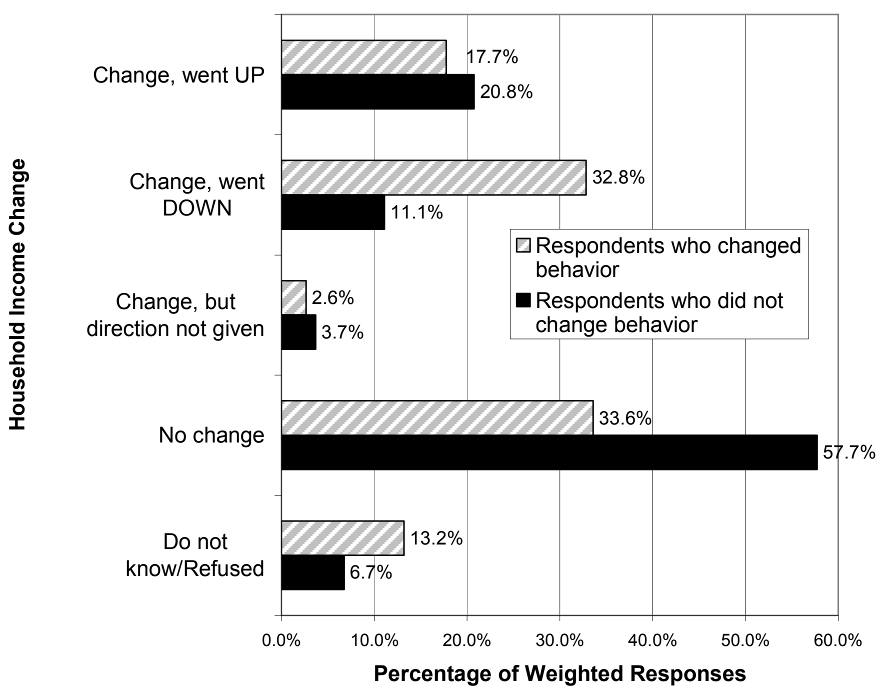

Figure 38. Comparison of household income change between 2001 and 2003

Table 45 and Table 46 show the comparisons of household structure and car ownership, both groups exhibit similar pattern of household structure, although the auto ownership of those who changed behavior is slightly higher than the others.

Table 45. Comparison of household structure

Household structure	Respondents who changed behavior	Respondents who did not change
Number of adults	**Average: 2.0**	**Average: 2.0**
1	28.7%	26.2%
2	44.2%	54.2%
3+	18.1%	17.6%
Do not know/Refused	9.1%	2.0%
Number of licensed drivers	**Average: 1.9**	**Average: 1.9**
1	32.1%	31.3%
2	48.3%	49.8%
3+	10.6%	16.9%
Do not know/Refused	9.1%	2.0%
Number of children	**Average: 0.9**	**Average: 0.7**
0	45.7%	55.8%
1	21.1%	20.6%
2	16.2%	15.4%
3+	7.9%	6.1%
Do not know/Refused	9.1%	2.0%

Table 46. Comparison of car ownership

Car ownership	Respondents who changed behavior	Respondents who did not change
Number of cars in household	Average: 1.9	Average: 2.1
0	0.0%	1.5%
1	29.4%	21.8%
2	49.8%	51.5%
3+	11.7%	23.0%
Do not know/Refused	9.1%	2.2%
Among the respondents reporting car ownership:		
Fewer cars than licensed drivers	7.5%	13.8%
Cars >= licensed drivers	92.5%	86.2%

In terms of work status, more than 70 percent of both groups are employed full-time. It was also found that, 46.5 percent of respondents who changed behavior could work at home while only 28.0 percent of respondents who did not change behavior could do so; and that respondents who changed behavior tend not to work outside the home (14.7 percent vs. 2.8 percent for those who did not change behavior). Conceptually, this makes sense, because respondents who do not work outside the home or could work at home are more flexible in terms of time of travel, and as a result, they are more likely to change travel behavior after time of day pricing.

Behavioral Changes Produced by the Time of Day Pricing Initiative

Respondents who reported behavior changes due to the time of day pricing initiative indicated multiple dimensions of response. Table 47 shows the detailed behavioral changes due to the time of day pricing initiative reported by 36 respondents. Table 48 summarizes the dimensions of travel behavior changes. Percentages in the first column are based on 265 weighted responses of behavioral changes and those in the second column are based on entire sample, i.e., 4044 weighted responses. The main reactions to time of day pricing include *increased car trips along alternate routes, decreased the frequency of travel on Turnpike, decreased weekday peak trips and decreased number of trips driving totally alone*. In addition, a group of individuals indicated they increased weekday peak trips.

Table 47. Reported behavioral changes

Respondent ID	User Type	Frequency on Turnpike	Usage f Carpool	Number of Trips Driving Totally Alone	Transit Use	Weekday Peak Trips	Weekday Off-Peak Trips	Weekend Trips	Number of Stops	Trips Along Alternate Routes	Got E-ZPass	Expansion Factor (trips/month)
2670	CU	I	S							I		15
1108	CU	I			D			D				1
3964	CU	D		I		I	I		I	I		16
4590	CU	D								I		30
4823	CU	D		D			D	D		I		30
4932	CU	D							I			5
4086	CU	D				D				I		20
4438	CU	D								D		20
4052	CU	D		D						I		22
628	CU	D		D	D	D				I		8
1378	CU	D			I					I		2
2766	CU	D								I		4
3104	CU	D							D	I		10
3647	CU	D			I	D		D		I		10
3810	CU	D		D		I				I	Y	3
4741	CU	D	I	D		D	D	I	D	I		1
4129	CU	D				D				I		20
2718	CU	D		D	I	D	D	D		I		2
1113	CU	D				D	I			D		5
2217	CU	D	S	D		D		D		I		3
2098	CU									I		3
2270	CU											2
4688	CU		S	I	I	I	I	I		I	Y	6
4145	CU				D	I						1
1263	CU				I							1
726	CU										Y	1
730	CU			D						I		4
825	CU											1
1834	CU			D		D		D				2
1893	CU									D		1
4020	CU				D			D				3
1470	CU									I		7
699	CU					D	D			D		2
3129	CU		D									2
2416	CU									I		1
3272	FU	D				I				I		1

Note: (1) CU stands for current regular user and FU stands for former regular user.
(2) I stands for Increased, D stands for Decreased, S stands for Started, and Y stands for Yes.
(3) The blank spaces indicated no change.

Table 48. Dimensions of behavioral changes

Dimensions of Change	%(1)	%(2)
Increased Trips Along Alternate Routes	82.3%	5.4%
Decreased Frequency on Turnpike	80.0%	5.2%
Decreased Number of Trips Driving Totally Alone	28.3%	1.9%
Decreased Weekday Peak Trips	27.5%	1.8%
Decreased Weekend Trips	19.2%	1.3%
Decreased Weekday Off-Peak Trips	13.2%	0.9%
Increased Weekday Peak Trips	10.2%	0.7%
Increased Weekday Off-Peak Trips	10.2%	0.7%
Decreased Trips Along Alternate Routes	10.6%	0.7%
Started or Increased Carpool	9.5%	0.6%
Increased Transit Use	7.9%	0.5%
Increased Number of Trips Driving Totally Alone	8.3%	0.5%
Increased Number of Stops	7.9%	0.5%
Increased Frequency on Turnpike	6.0%	0.4%
Decreased Transit Use	4.9%	0.3%
Decreased Number of Stops	4.2%	0.3%
Increased Weekend Trips	2.6%	0.2%
Got E-ZPass	3.8%	0.2%
Decreased Carpool	0.8%	0.1%

Note: (1) Percentages are based on 265 weighted responses of behavioral changes.
(2) Percentages are based on entire sample--4044 weighted responses.
(3) Peak hours: 7:00-9:00 AM, 4:30-6:30 PM during weekdays and all hours during weekends (based on time of entry). [69]
(4) Respondents reported multiple changes; therefore the percentages do not add up to 100 percent.

Most of respondents who reported behavioral changes because of time of day pricing indicated multiple changes. Table 49 and Table 50 show the major and minor two-dimension combinations of changes. Percentages in the first column are based on 265 weighted responses of behavioral changes and those in the second column are based on entire sample (4044 weighted responses). It is clear that the most cited combinations are *decreased frequency on Turnpike* plus either used other routes more often, or drove with other people, or traveled during weekday off-peak or weekend more often. It was also found that the most cited three-dimension combination of changes was decreased frequency on Turnpike, *increased trips along alternate routes and decreased number of trips driving totally alone* (1.7 percent of entire sample). The second most cited three-dimension combination of changes was *decreased frequency on Turnpike*, *increased trips along alternate routes*, and *decreased weekday peak trips* (1.6 percent of entire sample).

Table 49. Major combinations of behavioral changes

Combination of Behavioral Changes	% (1)	% (2)
Decreased Frequency on Turnpike + Increased Trips Along Alternate Routes + other changes	68.3%	4.5%
Decreased Number of Trips Driving Totally Alone + Increased Trips Along Alternate Routes + other changes	27.5%	1.8%
Decreased Frequency on Turnpike + Decreased Number of Trips Driving Totally Alone + other changes	26.0%	1.7%
Decreased Frequency on Turnpike + Decreased Weekday Peak Trips + other changes	26.0%	1.7%
Decreased Weekday Peak Trips + Increased Trips Along Alternate Routes + other changes	24.1%	1.6%

Note: (1) Percentages are based on 265 weighted responses. (2) Percentages are based on 4044 weighted responses.

Table 50. Minor combinations of behavioral changes

Combination of Behavioral Changes	% (2)	Combination of Behavioral Changes	% (1)	% (2)	% (2)
Decreased Frequency on Turnpike + Decreased Weekend Trips+…	1.1%	Decreased No of Trips Driving Alone + Decreased Transit Use+…	3.4%	0.2%	1.1%
Decreased Weekend Trips + Increased Trips Along Alternate Routes+…	1.1%	Increased Weekday Peak Trips + Got E-ZPass+…	3.4%	0.2%	1.1%
Decreased Weekday Peak Trips + Decreased Weekend Trips+…	1.0%	Increased Weekend Trips + Increased Trips on Alternate Routes	2.6%	0.2%	1.0%
Decreased Frequency on Turnpike + Decreased Weekday Off-Peak Trips+…	0.8%	Started Using Carpool + Decreased Weekend Trips+…	1.1%	0.1%	0.8%
Decreased Weekday Off-Peak Trips + Increased Trips Along Alternate Routes+…	0.8%	Decreased Frequency on Turnpike + Got E-ZPass +…	1.1%	0.1%	0.8%
Decreased No of Trips Driving Alone + Decreased Weekday Off-Peak Trips+…	0.8%	Started Using Carpool + Decreased Weekday Peak Trips+…	1.1%	0.1%	0.8%
Started Using Carpool + Increased Trips Along Alternate Routes+…	0.8%	Increased Carpool + Increased Trips Along Alternate Routes+…	0.4%	0.0%	0.8%
Decreased Weekday Peak Trips + Increased Trips Along Alternate Routes+…	0.7%	Increased Weekend Trips + Decreased Number of Stops+…	0.4%	0.0%	0.7%
Decreased Weekday Peak Trips + Decreased Weekday Off-Peak Trips+...	0.7%	Increased Carpool + Decreased Weekday Off-Peak Trips+…	0.4%	0.0%	0.7%
Decreased Number of Trips Driving Alone + Decreased Weekday Peak Trips + …	0.7%	Decreased No of Trips Driving Alone + Decreased No of Stops+…	0.4%	0.0%	0.7%
Increased Weekday Peak Trips + Increased Trips Along Alternate Routes+…	0.6%	Increased Carpool + Decreased Weekday Peak Trips+…	0.4%	0.0%	0.6%
Decreased Frequency on Turnpike + Increased Number of Stops+…	0.5%	Increased Carpool + Increased Weekend Trips+…	0.4%	0.0%	0.5%
Increased Transit Use + Increased Trips Along Alternate Routes+…	0.5%	Decreased Weekday Peak Trips + Decreased Number of Stops+…	0.4%	0.0%	0.5%
Decreased Transit Use + Decreased Weekday Peak Trips+…	0.5%	Decreased Weekday Off-Peak Trips + Decreased Number of Stops+…	0.4%	0.0%	0.5%
Decreased Weekday Peak Trips + Increased Weekday Off-Peak Trips+…	0.4%	Increased Carpool + Decreased Number of Trips Driving Alone+…	0.4%	0.0%	0.4%
Decreased Frequency on Turnpike + Decreased Number of Stops+…	0.3%	Increased Carpool + Decreased Number of Stops+…	0.4%	0.0%	0.3%
Decreased Number of Stops + Increased Trips Along Alternate Routes+…	0.3%				0.3%

Note: (1) Percentages are based on 265 weighted responses. (2) Percentages are based on 4044 weighted responses.

E-ZPASS USAGE AND AWARENESS OF TOLL DISCOUNT PROGRAMS

The main purpose of this section is to gain insight into users' attitude towards using E-ZPass, and to get an idea of their awareness of time of day pricing. This is important because the time of day pricing discounts are only available to E-ZPass users. For that reason, encouraging the use of E-ZPass is a necessary condition for the success of the time of day pricing initiative. The questions in this section can be categorized into six topics: use of E-ZPass, awareness of the toll discount programs, reasons for not using E-ZPass, who pays for E-ZPass, advantages and disadvantages of E-ZPass, and suggestions for improving the E-ZPass system. The percentages and the corresponding analyses in this section are based on 4044 weighted responses, among which 2588 are from 303 E-ZPass users and 1456 are from 210 cash users.

Use of E-ZPass

The majority of respondents (64.0 percent) said that they currently have an E-ZPass tag. Out of this group, only 41.6 percent have been using E-ZPass for four or more years. As Table 51 shows, the number of users getting E-ZPass over the years has consistently increased. Although this coincides with the implementation of time of day pricing, further research needs to be done to determine the causes of the increased E-ZPass usage.

Table 51. Number of years with an E-ZPass tag

Number of Years	Weighted Responses	Percentage
1	270	10.4%
2	569	22.0%
3	588	22.7%
4	413	16.0%
5	336	13.0%
6	94	3.6%
7	71	2.7%
8	81	3.1%
9	0	0.0%
10	81	3.1%
Do not know/Refused	85	3.3%
Total	**2588**	**100.0%**

Awareness of Toll Discount Programs

Table 52 below details users' awareness of discounts by categories. The majority of respondents (61.0 percent) were not aware of any discounts on the New Jersey Turnpike, this group of respondents and those who heard of discounts but do not know specifics are less likely to change travel behavior because of their poor awareness. Only 10.5 percent were aware of discounts associated with the time of travel.

Table 52. Awareness of toll discounts

Answer	Weighted Responses	Percentage
Not aware of any discounts	2465	61.0%
Heard of discounts but do not know specifics	450	11.1%
General discounts	448	11.1%
Time of day/off-peak use	426	10.5%
Frequent use of Staten Island bridges	257	6.4%
Carpool	109	2.7%
Total	**4044**	**--**

Note: This question accepts multiple options; therefore, the total percentage is greater than 100 percent.

Reasons for Not Using E-ZPass

The survey instrument included questions about why cash users do not use E-ZPass. The survey also asked to rank them as either major, minor, or not a reason for not using E-ZPass. Table 53 summarizes their answers which based on 1456 weighted responses from cash users.

Table 53. Reasons for not using E-ZPass

Reason	Major Reason	Minor Reason	Not a Reason	Do not know/Refused	Total
Wouldn't use it enough	37.8%	22.9%	36.3%	3.1%	100.0%
Afraid of being overcharged or fined	35.5%	16.9%	42.7%	4.9%	100.0%
Disclosure of personal information	26.5%	21.8%	46.6%	5.0%	100.0%
Never thought about it	21.0%	23.2%	49.8%	6.0%	100.0%
Won't save me money	20.4%	18.6%	49.0%	12.0%	100.0%
Discounts are not large enough	23.8%	14.8%	45.4%	15.9%	100.0%
Won't save me time	17.2%	18.1%	57.3%	7.4%	100.0%
Don't know where to get it	12.8%	17.4%	63.9%	5.9%	100.0%
Too much trouble to get one	7.8%	27.1%	57.9%	7.1%	100.0%
Too expensive to get one	8.3%	20.0%	55.8%	15.9%	100.0%
Seems complicated to use	7.5%	18.5%	68.0%	6.0%	100.0%

Note: The percentages are based on 1456 weighted responses of cash users.

Two of these reasons stand out from the rest. The first is that user think they *would not use the tag enough* to make it a worthwhile decision (37.8 percent of users mentioned it as a major reason for not getting E-ZPass, and 22.9 percent said that this was a minor reason). Being *afraid of being overcharged or fined* in the case that the device does not work properly was mentioned by about 52 percent of individuals (35.5 percent major reason, 16.9 percent minor). Another reason mentioned by 48.3 percent of respondents is being *afraid of giving out personal information*. 44.2 percent mentioned *never thought about it*, 39.0 percent mentioned *it won't save money* and 38.6 percent mentioned *discounts not big enough* as a reason.

Respondents were also asked if they always use their E-ZPass tag for trips on the New Jersey Turnpike. The results showed that approximately 98 percent of all E-ZPass users actually use their tags every time when they go through the Turnpike. The two percent that does not use it all the time said that they sometimes forget to bring the tags with them on their trip, or that they only use the tags when they do not have cash to pay for the toll.

Who Pays for the E-ZPass Account

Although most respondents said that they pay their own E-ZPass account, a small group said that their account was paid by their employer or a family member. The results are summarized in Table 54.

Table 54. Who pays for E-ZPass account

Answer	Weighted Responses	Percentage
Self	2004	77.4%
Family member	281	10.9%
Employer	272	10.5%
Self and employer	20	0.8%
Do not know/Refused	11	0.4%
Total	**2588**	**100.0%**

As the table shows, approximately 21 percent of users do not pay their own E-ZPass account. This group is likely to be less responsive to toll changes through the day given that they do not pay. It should also be noted that although only 10.5 percent of users had their account paid by their employers, some companies give their employees money to cover travel expenses, which might have not been included in this 10.5 percent.

Advantages and Disadvantages of E-ZPass

The survey instrument included questions to identify advantages and disadvantages of E-ZPass. Respondents were able to state more than one reason. Table 55 presents a statistical breakdown of their responses.

Table 55. Reasons for liking the E-ZPass system

Answer	Weighted Responses	Percentage
Saves time / quicker	2055	79.4%
Do not need to carry cash	321	12.4%
No interaction with toll collector	197	7.6%
Saves money / cheaper than cash toll	189	7.3%
Less stressful	97	3.7%
Just easier	92	3.6%
Safer	69	2.7%
Nothing in particular	55	2.1%
Can use it for other toll roads	38	1.5%
Like the itemized statement / no receipts	21	0.8%
Total	**2588**	**--**

Note: This question accepts multiple options; therefore, the total percentage is greater than 100 percent.

The vast majority of respondents (79.4 percent) said that saving time was the main reason for them to decide to use E-ZPass. Other reasons included the fact that users do not need to carry cash (12.4 percent), not having to interact with toll collectors (7.6 percent), and the system being less stressful (3.7 percent). It should be noted that only 7.3 percent of respondents mentioned monetary savings as their reason for using E-ZPass.

E-ZPass users were also asked what they disliked about the system. Again, they were able to give multiple reasons just as with the previous case. These results are summarized in Table 56.

Table 56. Reasons for disliking the E-ZPass system

Answer	Weighted Responses	Percentage
Nothing in particular	1136	43.9%
Hard to find / get to E-ZPass booths	286	11.1%
Monthly fee	284	11.0%
Toll not any faster, still traffic	258	10.0%
Have to slow down for toll	216	8.3%
Tag does not always work	138	5.3%
Hard to keep track of how much I spend	104	4.0%
Too complicated to use	96	3.7%
Afraid of being overcharged	82	3.2%
You get fined if tag does not work	66	2.6%
Afraid it will not work, will not be read	56	2.2%
Afraid of giving personal information	46	1.8%
Do not want to tie up money	16	0.6%
Total	**2588**	**--**

Note: This question accepts multiple options; therefore, the total percentage is greater than 100 percent.

The results show that 43.9 percent of the respondents were currently satisfied with the way that the system works, which means that the majority had different reasons for not liking the system. Some of the major reasons include that the toll booths were hard to get to (11.1 percent); having to pay the monthly fee (11.0 percent); others thought that the process was not any faster given that they had to still wait for traffic (10.0 percent); and several users stated that they still have to slow down in order to get through the booth (8.3 percent).

Suggestions for Improvement of the E-ZPass System

Finally, participants were asked to give some suggestions for improving the E-ZPass system. Table 57 summarizes their suggestions.

Table 57. Suggestions for improving the E-ZPass system

Answer	Weighted Responses	Percentage
No, nothing in particular	1297	32.1%
High speed toll lanes	598	14.8%
Make E-ZPass lanes separate, quicker	557	13.8%
Give a discount for use	307	7.6%
Give a BIGGER discount for use	309	7.6%
Better public relationship, communication	179	4.4%
Get rid of monthly fees	144	3.6%
Make it easier to get a tag	136	3.4%
Make sure info is not used for tracking	112	2.8%
Get rid of pre-payment	78	1.9%
Better customer service	74	1.8%
Expand use to other venues	24	0.6%
Do not know\Cannot recall\No answer\Refused	534	13.2%
Total	**4044**	**--**

Note: This question accepts multiple options; therefore, the total percentage is greater than 100 percent.

Suggestions for improvement of the system were very diverse, however three major groups stood out. The first one is comprised of those users that think the system works fine the way it is (32.1 percent). The second group represents the respondents that want a faster service (28.6 percent combined). These users suggested either high speed toll lanes or separate E-ZPass lanes so that they do not get mixed with the cash users and therefore move quicker. The third group wanted to receive either a discount or a bigger discount for using E-ZPass (15.2 percent). It should be noted that 43.9 percent of this group however, were not aware of any toll discounts available to them.

CHARACTERISTICS OF CURRENT USERS' MOST RECENT CAR TRIP

In this section, data about the respondent's most recent trip through the Turnpike is analyzed. The target respondents are those current regular users of the New Jersey Turnpike who made their most recent trips less than one year ago (450 respondents). These respondents account for 3540 car trips/month (2570 work related car trips/month, 552 recreation/shopping trips/month, and 418 other trips/month), which is the basis of the following analysis. The information includes trip purpose, frequency, day of travel, departure and arrival times, time of travel flexibility, and payment type. The characteristics of these most recent car trips are analyzed in this section.

The data is discussed in two parts: the first one deals with general aspects of most recent car trips made by current regular users; the second part analyzes the costs associated with the most recent trip through the turnpike, mainly tolls and parking.

Trip Attributes

Most respondents (92.1 percent) made their most recent trip less than a month before the survey was conducted, 77.8 percent made their most recent car trips just the week before. This is important given that their responses are likely to be more accurate. The respondents reported making this trip approximately eight times per month on average. The trip frequency reported by each user was used to weigh their responses to estimate the total number of car trips made.

As shown in Table 58, the vast majority of most recent car trips (73.6 percent) were made for work, either commuting to work (54.1 percent) or traveling for job (19.6 percent). The next major category was recreation/shopping trips, which made up for 15.6 percent of all trips. Other trip purposes included family/friend visits (5.1 percent), school trips (3.7 percent), doctor appointments (1.3 percent), and airport trips (0.6 percent).

The distribution of trip purposes by day suggests that users commuting to work make a significantly larger amount of trips on Fridays than any other day. It is important to note that work related trips (commuting to work or traveling for the job) dominate every day of the week except for Sunday, when most trips are made for recreation/shopping purposes.

Table 58. Trip purpose vs. day of the week

Trip Purpose vs. Day of Travel	Mon	Tues	Wed	Thurs	Fri	Sat	Sun	Total	Percentage of Weighted Responses
Commute to Work	187	221	306	255	663	119	17	1768	**54.1%**
Travel for job	100	120	130	60	150	70	10	640	**19.6%**
Recreation/shopping	27	45	45	63	96	156	78	510	**15.6%**
Visit family or friends	8	20	16	12	28	56	28	168	**5.1%**
School	8	16	24	16	40	16	0	120	**3.7%**
Doctor or other appointment	4	0	4	16	4	8	8	44	**1.3%**
Airport	0	3	0	9	0	9	0	21	**0.6%**
Total	334	425	525	431	981	434	141	3271	**100.0%**
Percentage (%)	**10.2**	**13.0**	**16.1**	**13.2**	**30.0**	**13.3**	**4.3**	**100.0**	

Table 58 also shows an uneven distribution of the number of trips by day of the week. There is a significant peak on Fridays (30.0 percent of trips), and a smaller one on Wednesdays (16.1 percent). Monday is slightly slower than the rest of the work week, making up for 10.2 percent of trips, which was expected given that people are coming off the weekend and are likely to do fewer recreation/shopping trips, as well as job travel. Tuesday, Thursday and Saturday each make up for approximately 13 percent. The difference is that on Saturdays there is a significant drop in work related trips, which is substituted by an increase in recreational trips. On Sundays, there is an overall decrease in trips of all purposes; hence it only makes up for 4.3 percent of the weekly trips.

Using the data provided by the participants about the time at which they enter and exit the Turnpike, the average travel time through the Turnpike was estimated to be slightly more than 57 minutes, which makes up for two-thirds of the average door to door travel time (85 minutes). Using the toll schedule from the New Jersey Turnpike for passenger cars (Peak hours: 7:00-9:00 AM and 4:30-6:30 PM during weekdays and all hours during weekends), it was found that approximately 62 percent of all respondents travel in the off-peak periods. (69) Table 59 and Table 60 show the split of peak and off-peak travel by trip purpose and by time of travel. The difference between travel times for different trip purposes is very pronounced, as shown in Table 59, 42.1 percent of the first three trip purposes (work commute, job travel and school) travel during peak hours, compared to only 23.8 percent of all other trip purposes. This difference is also marked between weekdays and weekends (41.4 percent vs. 27.1 percent) in Table 60.

Table 59. Trip purpose vs. time of travel

Trip Purpose vs. Day of Travel	Weighted Responses			Peak Percentage
	AM Peak	PM Peak	Off-Peak	
1. Commute to Work	595	221	1054	43.6%
2. Travel for job	190	70	430	37.7%
3. School	16	40	72	43.8%
4. Recreation/shopping	75	51	384	24.7%
5. Airport	3	3	18	25.0%
6. Doctor or other appointment	8	4	32	27.3%
7. Visit family or friends	28	4	128	20.0%
Total	**915**	**393**	**2118**	**38.2%**
Percentage	**26.7%**	**11.5%**	**61.8%**	
Combined 1-3	**801**	**331**	**1556**	**42.1%**
Combined 4-7	**114**	**62**	**562**	**23.8%**

Table 60. Trip day vs. time of travel

Day vs. Time of Travel	Weighted Responses			Peak Percentage
	AM Peak	PM Peak	Off-Peak	
Weekdays	834	292	1593	**41.4%**
Weekends	105	101	555	**27.1%**
Total	939	393	2148	**38.3%**
Percentage	**27.0%**	**11.3%**	**61.7%**	3480

When asked why they chose to travel at the time, only 0.4 percent of the current regular users said that they did so to take advantage of cheaper tolls (Table 61). Most users did so due to their work schedule (51.6 percent), to avoid congestion (22.0 percent), or to make an appointment (16.1 percent). These numbers, along with the impact of time of day pricing on travel behaviors presented in the previous section suggest that people are insensitive to the time of day pricing toll structure.

Table 61. Reasons for time of travel

Answer	Weighted Responses	Percentage
Work schedule	1826	51.6%
To avoid congestion	779	22.0%
To make an appointment	571	16.1%
Out of habit / What I usually do	118	3.3%
So I could return at a certain time	64	1.8%
Cheaper toll	14	0.4%
Easier or cheaper parking available	13	0.4%
No answer	155	4.4%
Total	**3540**	**100.0%**

The survey included questions about time of travel flexibility which indicate how late or early a traveler can depart from his/her origin (departure flexibility) or arrive at his/her destination (arrival flexibility). Time of travel flexibility is a key variable in studying current regular users' trip attributes because it measures how feasible it is for the respondents to shift time of travel. The overall finding is that current regular users do not have much flexibility to shift their time of travel. The details are discussed below.

As shown in Table 62, current regular users can depart 16.6 minutes later and 17.5 earlier than their desired departure time on average. Meanwhile, the reported arrival flexibility is 13.7 minutes later and 15.9 minutes earlier than the desired arrival time on average. The relatively low average flexibility indicates that current regular users do not have much flexibility to shift their current time of travel.

Among the three categories of trips in Table 62, work related trips are the least flexible group, followed by trips with other purposes and then recreation/shopping trips on average. The average flexibility of work related trips is around 15 minutes while the average flexibilities of recreation/shopping trips and other trips are about 19 minutes and 20 minutes respectively. This result is expected due to the tight work schedules. Another pattern revealed by Table 62 is that the average flexibility of late arrival or departure is always less than the one of early arrival or departure. This tells that people always try to avoid being late no matter what purpose the car trips are made for.

Table 62. Average travel time flexibility for current users (unit: minutes)

	Trip Type			
	Work related	Recreation/shopping	Other	All
Late departure	15.3	21.0	19.2	16.6
Early departure	16.3	21.5	19.5	17.5
Late arrival	12.0	18.8	17.2	13.7
Early arrival	14.2	21.6	18.8	15.9

Figure 39 through Figure 42 show the distributions of travel flexibility in terms of late/early departure flexibility and late/early arrival flexibility by type of trips. Consistent with the findings from the average flexibility, these figures tell that current regular users do not have much flexibility to change their current time of travel. Only around 10 percent of current regular users reported more than half hour flexibility. This group of current users could be the target of the time of day pricing initiative since they have the flexibility to shift to off-peak periods.

As can be seen, the most significant group of respondents is the one comprised by individuals that reported no flexibility at all. Compared with recreation/shopping trips, work related trips are more likely to have no flexibility at all. Meanwhile, it can also be observed that current regular users reported more flexibility for being early than being late for both departure and arrival, which again revealed respondents' willingness to avoid being late.

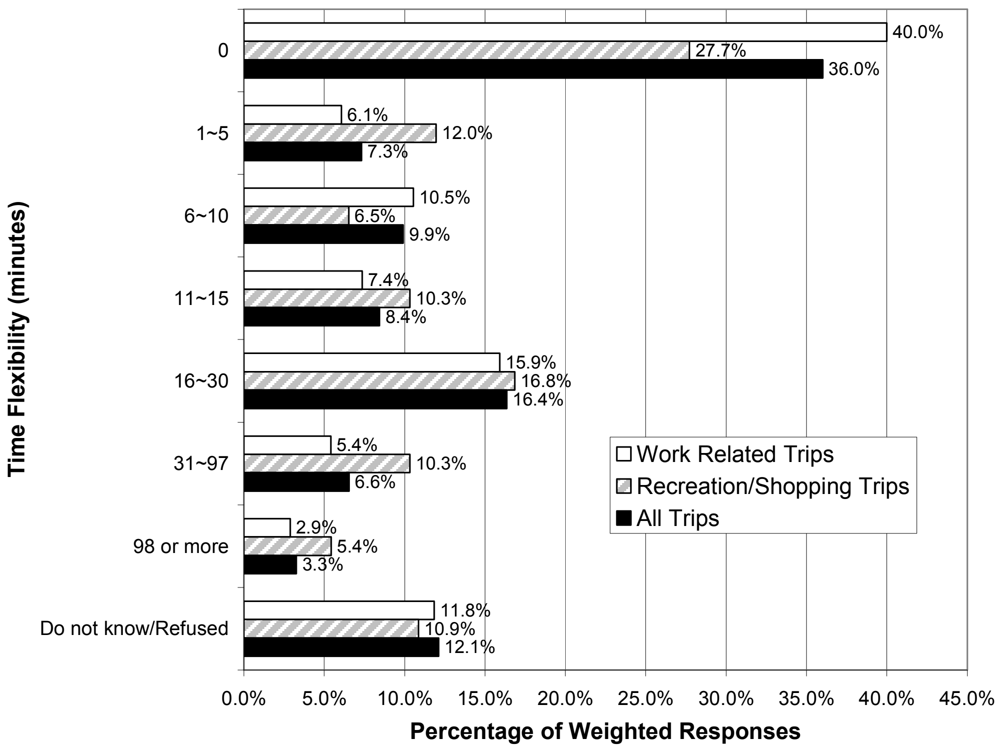

Figure 39. Departure flexibility for current users (late departure)

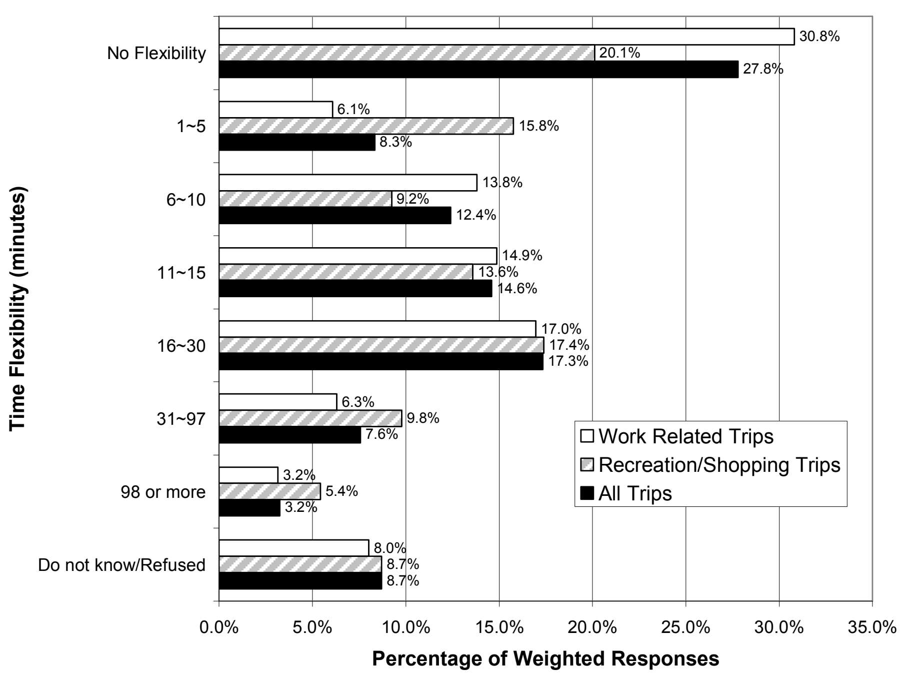

Figure 40. Departure flexibility for current users (early departure)

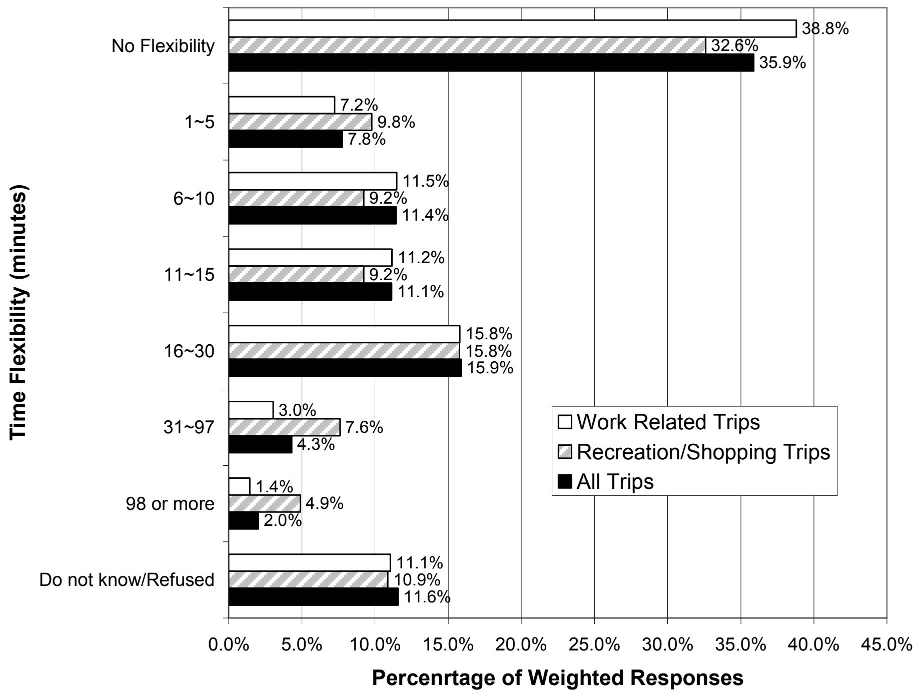

Figure 41. Arrival flexibility for current users (late arrival)

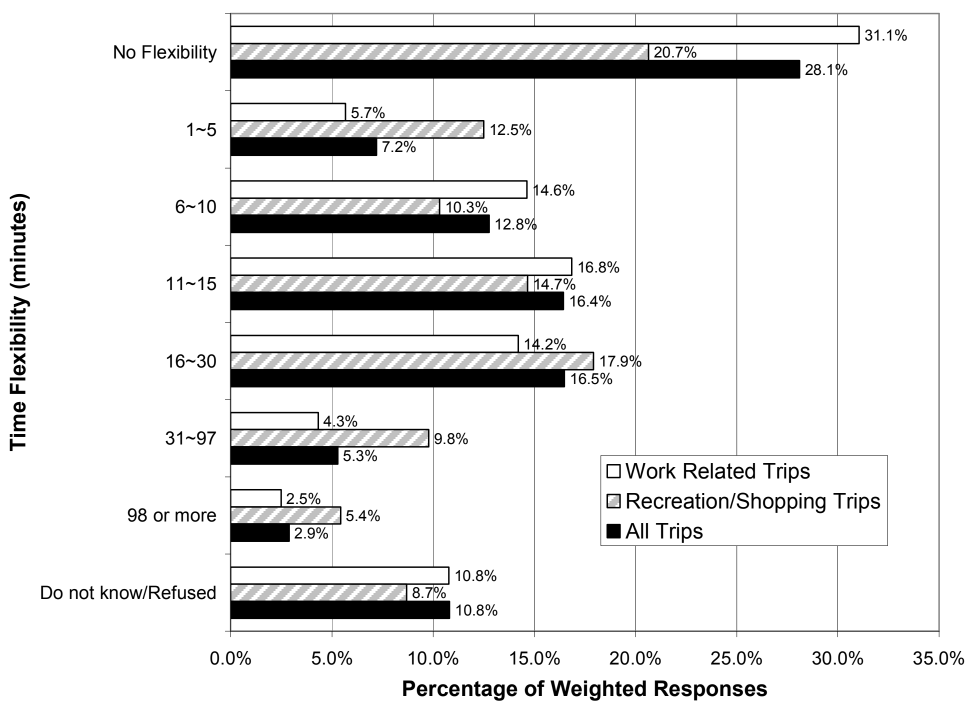

Figure 42. Arrival flexibility for current users (early arrival)

Travel Costs

Travel costs are a very important factor that affects people's travel behavior. For that reason, the survey asked current regular users how much they paid in parking and tolls. This section discusses the key findings.

Parking Expenses

As shown in Table 63, 77.3 percent of the respondents had free parking available to them and that, overall, 88.8 percent of respondents did not pay for parking (either free, or someone else paid); while only 8.7 percent paid by themselves. The group that paid parking (either by themselves or shared) paid $10.14 on average for their last trip.

Table 63. Parking payment

Parking payment	Weighted Responses	Percentage
Parking was free	2738	77.3%
Employer paid	358	10.1%
Self	307	8.7%
Other paid	50	1.4%
Shared by passengers	39	1.1%
Do not know/Refused	48	1.4%
Total	**3540**	**100.0%**

Toll Costs

The respondents indicated that they paid, in average, $1.84 in tolls at the Turnpike during their last trip; and that 80.1 percent of current regular users paid less than $3.00. About two-thirds of them (64.9 percent) paid the tolls with E-ZPass. It is also important to know that 68.7 percent of all trips were made alone while the remaining trips were made with at least one companion. The average number of persons in the car, including the driver, is 1.52.

As shown in Table 64, more than a quarter of respondents (27.2 percent) indicated using other toll facilities during their trips. 19.5 percent of current regular users said they used the Garden State Parkway while others reported using the Pennsylvania Turnpike (1.6 percent), the Lincoln Tunnel (1.4 percent), the Holland Tunnel (0.8 percent), and the Delaware Memorial Bridge (0.6 percent). A few also reported using George Washington Bridge, and the Goethals Bridge. As an average, users thought that their trip would have cost $15.97 on average had they done it by transit, a figure significantly larger than the tolls they are currently paying. The results also showed that approximately 11.9 percent have to travel by car given that transit is not available for their trips.

Table 64. Use of other toll facilities

Other Toll Facilities Used	Weighted Responses	Percentage
Do not use other toll facilities	2577	72.8%
Garden State Parkway	689	19.5%
Pennsylvania Turnpike	57	1.6%
Lincoln Tunnel	51	1.4%
Holland Tunnel	27	0.8%
Delaware Memorial Bridge	23	0.6%
Goethals Bridge	7	0.2%
George Washington Bridge	3	0.1%
Do not know/Refused	106	3.0%
Total	**3540**	**100.0%**

CHARACTERISTICS OF FORMER USERS' MOST RECENT TRIP

The target respondents for this section are those who no longer travel through the New Jersey Turnpike by car on a regular basis, but still travel to the same destination by an alternate route or by public transit. This section discusses the key findings pertaining to this group of users. It is important to highlight that, because of the relatively small number of observations in this subgroup, the results in this section must be interpreted and used with caution. There were 30 respondents, accounting for 240 weighted responses after expansion and representing 5.9 percent of the entire weighted sample, who reported being regular users of the toll facilities by car during past three years but have already switched to transit or to other routes. However, only 25 respondents, accounting for 200 weighted responses reported their trip attributes. The 200 weighted responses are the basis of the following analysis.

The analyses conducted are reported in two different subsections: The first subsection focuses on the characteristics of the most recent trips made by former regular users (e.g., trip purposes, time of travel and travel time frequency), and the second one analyzes travel costs.

The questions in this section are similar to those in the most recent car trip for current regular users. For comparison purposes, the analyses in this section follow the same outline as the section of the current regular users' most recent trips.

Trip Attributes

The trip purpose distribution for former regular users is different than that for current regular users. More than half of former regular users (56.8 percent) made their trips for recreation/shopping purposes, as shown in Table 65. Work related trips (commuting to work or traveling for the job) made up 20.7 percent of trips, while family/friend visits made up 15 percent. The other seven percent was distributed between doctor appointments (5.2 percent), and school trips (1.9 percent).

Table 65. Trip purpose vs. day of the week

Trip Purpose	Weighted Responses								Percentage
	Mon	Tues	Wed	Thurs	Fri	Sat	Sun	Total	
Commute to work	8	0	0	0	16	0	0	24	15.5%
Travel for job	0	0	0	0	0	8	0	8	5.2%
School	0	0	3	0	0	0	0	3	1.9%
Recreation/shopping	0	4	0	4	32	32	16	88	56.8%
Doctor or other appointment	0	0	0	0	0	8	0	8	5.2%
Visit family or friends	0	0	0	0	8	8	8	24	15.5%
Total	**8**	**4**	**3**	**4**	**56**	**56**	**24**	**155**	
Percentage	**5.2%**	**2.6%**	**1.9%**	**2.6%**	**36.1%**	**36.1%**	**15.5%**		

Table 65 also shows the temporal distributions of trips by trip purpose. The distribution of trips by day varies significantly from that of current regular users. The busiest days are Friday (same as current users' car trips) and Saturday, each making up for 36.1 percent of the total trips. Sunday accounted for 15.5 percent of the trips, while only 12.3 percent of the trips took place between Monday and Thursday. This distribution can be explained by the fact that most trips (57 percent) were made for recreational purposes, therefore they were more likely to be made on weekends. However, as noted earlier, these results may be a reflection of the small size of the former-regular-user sample.

On average, the average door-to-door travel time for former regular users' most recent trips was estimated to be approximately 100 minutes, which is 15 minutes more than the one for current regular users. Using the New Jersey Turnpike's definition of the peak hour for passenger cars (i.e., 7:00-9:00 AM and 4:30-6:30 PM during weekdays and all hours during weekends), it was found that approximately 76.0 percent of all respondents travel in the off-peak period. [69] Table 66 and Table 67 show the split of peak and off-peak trips by trip purpose and day of the week. The difference between travel times for different trip purposes is very pronounced, 50.0 percent of trip purposes 1-3 (work commute, job travel and school) travel during peak hours, compared to only 15.8 percent of all other trip purposes. This difference is also marked between weekdays and weekends (30.8 percent vs. 20.0 percent) as shown in Table 67.

Table 66. Trip purpose vs. time of travel

Trip Purpose vs. Day of Travel	Weighted Responses			Peak Percentage
	AM Peak	PM Peak	Off-Peak	
1.Commute to Work	16	0	8	66.7%
2.Travel for job	0	0	16	0.0%
3.School	8	0	0	100.0%
4.Recreation/shopping	24	0	96	20.0%
5.Doctor or other appointment	0	0	8	0.0%
6.Visit family or friends	0	0	24	0.0%
Total	**48**	**0**	**152**	**24.0%**
Percentage	**24.0%**	**0.0%**	**76.0%**	
Combined 1-3	**24**	**0**	**24**	**50.0%**
Combined 4-6	**24**	**0**	**128**	**15.8%**

Table 67. Trip day vs. time of travel

Day of Week vs. Time of Day	Weighted Responses			Peak Percentage
	AM Peak	PM Peak	Off-Peak	
Weekdays	32	0	72	30.8%
Weekends	16	0	64	20.0%
Total	**48**	**0**	**136**	**26.1%**

When asked why they chose to travel at the time, none of the former regular users said that they did so to take advantage of cheaper tolls (Table 68). Most users did so to avoid congestion (40.0 percent), to make an appointment (24.0 percent) or due to their work schedule (16.0 percent). Others mentioned that they travel at that time out of habit (8.0 percent), to return at a certain time (4.0 percent) or to find easier/cheaper parking (4.0 percent). Again, this reinforces the idea that most people are insensitive to small toll changes.

Table 68. Reasons for time of travel

Answer	Weighted Responses	Percentage
To Avoid Congestion	80	40.0%
To Make an Appointment	48	24.0%
Work Schedule	32	16.0%
Out of Habit / What I Usually Do	16	8.0%
So I could return at a certain time	8	4.0%
Easier or Cheaper Parking Available	8	4.0%
Cheaper Toll	0	0.0%
No Answer	8	4.0%
Total	**200**	**100.0%**

Table 69 shows the mean values for the travel flexibility for former regular users. In general, the respondents reported having more flexibility for recreation/shopping trips than work related trips, and even a higher flexibility for other trips (airport, doctor, or family visit trips). On average, the flexibility window of work related trips is around 10 minutes, while that of recreation/shopping trips is around 20 minutes. Other trip purposes had an average flexibility of roughly 30 minutes to about an hour. The average flexibility for other trip purposes is extremely high, which could be a reflection of the small sample of former regular users and the insignificant proportion of trips with other purposes among the total trips made by former regular users. Another pattern is that the reported flexibility in terms of late departure or arrival is always less than the one of early departure or arrival, no matter what purposes the trips were made for. Consistent with the previous findings from current regular users, this result reveals respondents' unwillingness to be late.

Table 70 shows the distribution of travel flexibility. The most significant group of former regular users is always those who reported no flexibility at all for both late/early departure and late/early arrival. Meanwhile, work related trips are more likely to have no flexibility than recreation/shopping trips, which makes sense since work related trips are tighter in schedule than recreation/shopping trips in general. Meanwhile, for each category of flexibility, only around 10 percent of former regular users reported more than half hour flexibility. All these findings indicate that former regular users, similar as current regular users, do not have much flexibility to change their current time of travel.

Table 69. Average travel time flexibility for former users (unit: minutes)

	Trip Type			
	Work related	**Recreation/shopping**	**Other**	**All**
Late departure	9.0	12.8	11.7	11.6
Early departure	11.3	20.7	52.7	24.1
Late arrival	6.0	12.8	25.0	13.5
Early arrival	11.3	13.6	64.0	19.0

Table 70. Distributions of travel flexibility for former users

Time Flexibility (minutes)	0	1~5	6~10	11~15	16~30	31~97	98 or more	Do not know/ Refused	Based on Weighted Responses
Late Departure									
Work Related Trips	60.0%	0.0%	0.0%	20.0%	20.0%	0.0%	0.0%	0.0%	40
Recreation/Shopping Trips	33.3%	13.3%	0.0%	6.7%	13.3%	6.7%	0.0%	26.7%	120
All Trips	36.0%	12.0%	0.0%	8.0%	16.0%	4.0%	0.0%	24.0%	200
Early Departure									
Work Related Trips	40.0%	0.0%	0.0%	20.0%	20.0%	0.0%	0.0%	20.0%	40
Recreation/Shopping Trips	13.3%	20.0%	6.7%	0.0%	13.3%	13.3%	0.0%	33.3%	120
All Trips	16.0%	12.0%	4.0%	4.0%	20.0%	8.0%	4.0%	32.0%	200
Late Arrival									
Work Related Trips	80.0%	0.0%	0.0%	0.0%	20.0%	0.0%	0.0%	0.0%	40
Recreation/Shopping Trips	40.0%	20.0%	0.0%	0.0%	6.7%	13.3%	0.0%	20.0%	120
All Trips	44.0%	12.0%	0.0%	0.0%	16.0%	12.0%	0.0%	16.0%	200
Early Arrival									
Work Related Trips	40.0%	0.0%	0.0%	20.0%	20.0%	0.0%	0.0%	20.0%	40
Recreation/Shopping Trips	13.3%	26.7%	6.7%	6.7%	6.7%	13.3%	0.0%	26.7%	120

Note: All trips include work related trips, recreation/shopping trips and other trips.

Travel Costs

The average travel cost for the most recent trips by former regular users was $5.60. 61.1 percent of former regular users paid $5.00 dollars or less for their trips while about 27.8 percent said that they paid somewhere between $6.00 and $10.00, and 11.11 percent paid more than $10.00. Meanwhile, the average cost they thought the corresponding car trips would cost them is about $7.56, which is only about $2.00 more than the average cost of their trips.

CONCLUSION

The analyses conducted are based on 513 complete passenger surveys collected during the period mid June - mid July, 2004. The following provides a brief summary of the key findings from the descriptive analyses (percentages shown are with respect to the total number of trips made by the users):

Demographics Section

The typical respondent was a middle-aged white male with education and household income level above the average. The households captured in the survey correspond to relatively small families with 2.2 adults and 0.8 children on average, with an average number of licensed drivers of 2.1 drivers per family. The distribution of licensed drivers follows the same pattern as the distribution of adults in the household. 53.5 percent of the respondents reported the number of licensed drivers in household is two, 21.7 percent reported three and more, and 24.8 percent reported only one. 55.0 percent of the respondents reported having no children in the household, 21.4 percent reported one, while 23.6 percent reported having two or more children (see Table 38). The average number of cars in all surveyed households was 2.1. 24.0 percent of the respondents reported owning one car, 47.8 percent reported owning two cars, 27.8 percent said that they have three or more vehicles, and only one percent said that they do not have a vehicle in their home (see Table 39).

The median household income for respondents was approximately $82,000 per year, which is significantly higher than the state median income for 2003 ($55,932). [68]

Consistent with the household income, over 80 percent of households have at least as many cars as licensed drivers (see Table 39). The high car ownership among these respondents may imply that they represent a significant portion of the total traffic through the New Jersey Turnpike. Furthermore, the relatively high household income, considered a determinant of price elasticity, suggests that these individuals are inelastic towards small changes in tolls or other travel costs.

Impacts of the 2000 Time of Day Pricing Initiative

The survey found that 36 respondents changed their travel behavior because of time of day pricing program, which account for 7.0 percent of individuals and 6.6 percent of car trips once weighted by trip frequency (see Table 42). The main reasons for not changing travel behavior include *no flexibility* (40.2 percent) and *my choice, I go when I want to go* (32.3 percent) (see Table 44). Unfortunately this group reflects too small a sample upon which to base any meaningful conclusions about demographics or behavioral choices. The sample size confirms that the time of day pricing had little effect on travelers' choice.

It was found that respondents who changed behavior are more likely to be females (42.6 percent vs. 34.9 percent for those who did not change), with relatively higher education levels, less likely to be White (58.9 percent vs. 70.2 percent) or African-Americans (3.4 percent vs. 8.3 percent), and more likely to be Hispanic (27.2 percent vs. 12.6 percent). The average household income for those who changed their behavior is about $64, 234, which is slightly lower than those who did not change ($73, 614). More than half (57.7 percent) of respondent who did not change behavior reported no change of household income from 2001 to 2003, and only about a third (33.6 percent) of those who changed behavior did so. Interestingly enough, about a third (32.8 percent) of those who changed behavior reported that their income went down significantly, which could be a reason why they changed travel behavior (see Figure 35 through Figure 38).

In terms of work status, it was found that 46.5 percent of respondents who changed behavior could work at home while only 28.0 percent of respondents who did not change behavior could do so; and that respondents who changed behavior tend not to work outside the home (14.7 percent vs. 2.8 percent for those who did not change behavior). Conceptually this makes sense, because respondents who do not work outside the home or could work at home are more flexible in terms of time of travel, and as a result, they are more likely to change travel behavior after time of day pricing.

Respondents who reported behavior changes due to the time of day pricing initiative indicated multiple dimensions of response. The main reactions to time of day pricing include *increased car trips along alternate routes* (5.4 percent of entire sample), *decreased the frequency of travel on Turnpike* (5.2 percent), *decreased number of trips driving totally alone* (1.9 percent) and *decreased weekday peak trips* (1.8 percent). In addition, a group of individuals indicated they *decreased weekend trips* (1.3 percent) (see Table 48).

Most of respondents who reported behavioral changes because of time of day pricing indicated multiple changes. The most cited combinations of changes are: *decreased frequency on Turnpike and increased trips along alternate routes* (4.5 percent of entire sample), *decreased number of trips driving totally alone and increased trips along alternate routes* (1.8 percent), *decreased frequency on Turnpike and decreased number of trips driving totally alone* (1.7 percent), *decreased frequency on Turnpike and decreased weekday peak trips* (1.7 percent), *and decreased weekday peak trips and increased trips along alternate routes* (1.6 percent) (see Table 49).

E-ZPass Usage and Awareness of Toll Discount Programs

The survey found 303 E-ZPass users (2588 weighted responses) and 210 cash users (1456 weighted responses). Although the majority of respondents (64.0 percent) are E-ZPass users, this high level of E-ZPass usage does not translate into a corresponding high level of awareness of the toll discount programs, as one may expect. The majority of respondents (61.0 percent) were *not aware of any discounts on the New Jersey Turnpike*, this group of respondents and those who *heard of discounts but do not know specifics* (11.1 percent) are less likely to change travel behavior because of their poor awareness. Only 10.5 percent were aware of discounts associated with the time of travel (see Table 52).

The main reasons for not using E-ZPass include *would not use the tag enough* (60.7 percent), *afraid of being overcharged or fined* (52.4 percent), *afraid of giving out personal information* (48.3 percent), *never thought about it* (44.2 percent), mentioned it *won't save money* (39.0 percent), and *discounts not big enough as a reason* (38.6 percent), among others (see Table 53).

The vast majority of E-ZPass users (79.4 percent) identified saving time was the key advantage of the system. Other reasons included the fact that users *do not need to carry cash* (12.4 percent), *not having to interact with toll collectors* (7.6 percent), and *the system being less stressful* (3.7 percent). It should be noted that only 7.3 percent of respondents mentioned monetary savings (see Table 55). The main reasons that E-ZPass users disliked about the system include toll booths were hard to get to (11.1 percent), having to pay the monthly fee (11.0 percent), and the process was not any faster given that they had to still wait for traffic (10.0 percent) (see Table 56). The most important suggestions for improvement of the system include high speed toll lanes or separate E-ZPass lanes (28.6 percent), and a discount or a bigger discount for using E-ZPass (15.2 percent) (see Table 57).

Characteristics of Most Recent Trip for Current Regular Users

The most recent car trips made by current regular users tend to have the following attributes:

- The vast majority of most recent car trips (73.6 percent) were made for work, either commuting to work (54.1 percent) or traveling for job (19.6 percent).

- The distribution of trip purposes by day suggests that work related trips (commuting to work or traveling for the job) dominate every day of the week except for Sunday, when most trips are made for recreation/shopping purposes (see Table 58).
- Off-peak trips are the dominant ones. Approximately 62 percent of the current regular users reported making their most recent trips during off-peak periods (the New Jersey Turnpike defined peak hours as: 7:00-9:00 A.M. and 4:30-6:30 P.M. during weekdays and all hours during weekends) (see Table 59). [69]
- Compared with recreation/shopping trips, work related trips are more likely to be made during peak hours (see Table 59).
- Current regular users traveled at that time mainly to adapt to their work schedule or avoid congestion rather than to take advantage of cheaper tolls, which suggest that people may be insensitive to the time of day pricing toll structure (see Table 61).
- The average travel time flexibility and the distribution of the reported flexibility both indicate that current regular users do not have much flexibility to shift their current time of travel. Only around 10 percent of current of current regular users reported more than half hour flexibility (see Table 62 and Figure 39 through Figure 42).

Characteristics of Most Recent Trip for Former Users

25 former regular users reported their most recent trips' attributes. These respondents account for 200 car trips/month, which is basis of the following analysis. These former regular users no longer travel through the New Jersey Turnpike toll facilities by car on a regular basis but instead use transit through it or switched to other routes. Due to the small number of observations in this subgroup, the results in this section must be interpreted and used with caution.

The most recent trips made by former regular users have the following attributes:

- Different from current regular users that tended to make work related trips, more than half of former regular users (56.8 percent) made their trips for recreation/shopping purposes (see Table 65).
- A higher proportion of former regular users (76.0 percent) reported traveling during off-peak periods than current regular users; however, this pattern varies by trip purpose, most of work related trips or school trips were made during peak periods while it is reverse for recreation/shopping trips (see Table 66).
- Similar as current regular users, former regular users traveled at that time to avoid congestion or to make an appointment rather than to take advantage of cheaper tolls (see Table 68).
- Former regular users also reported relatively little travel time flexibility, which indicates that they do not have much flexibility to change their current time of travel (see Table 69 and Table 70).

CHAPTER V - ECONOMIC VALUE OF TRAVEL TIME SAVINGS AT THE NJ TURNPIKE FACILITIES

INTRODUCTION

The success of the time of day pricing policies highly depends on how the users evaluate their travel time savings and amount of tolls they pay. To this extent, value of travel time (VOT) is crucial in understanding commuters' travel behavior. Knowing the VOT of users is also important to determine an individual's willingness to pay or to accept trip costs and the factors affecting his/her route and mode choices in response to the travel costs. By introducing user heterogeneity (i.e. user specific properties like travel and socio economic characteristics), VOT can be incorporated into a route and mode choice behavior model, and the tradeoff between cost and time in response to toll changes can be explained more accurately.

VOT, in the context of the time of day pricing is defined as the ratio between the marginal utility of travel time and the marginal utility of travel cost. In this chapter, first a user specific econometric utility model is developed to estimate a user specific value of travel time formulation. Then, using this utility function, user specific VOT functions are calculated. The econometric utility function and VOT function incorporate user heterogeneity into the model by considering both socio-economic and trip related factors.

In the following sections, first a comprehensive literature review of the previous studies which estimated VOT using different methods is presented. Then, a brief discussion of data sources and the proposed methodology are provided. Next, econometric utility models are derived. These models are then used to calculate VOT functions for the New Jersey Turnpike users. In the last section, conclusions and discussions are presented.

LITERATURE REVIEW

In the literature, there are three major methodologies used to estimate the value of travel time in the context of user behavior models developed for time of day pricing applications. These are:

(1) Assumption of discrete VOT values based on previous studies

(2) Development and estimation of discrete choice models

(3) Use of time allocation models

The first type of methodology uses discrete values that are determined based on previous studies or as a percentage of income levels. Boardman [67], after investigating 32 previous studies, concluded that the value of commuting time is 51 percent of the hourly wage rate. Ferrari [70], while determining the optimum toll level which divided the transportation cost burden between motorists and public financing, assumed a normal distribution for monetary value of travel time, with mean (VOT) and variance ($0.3VOT^2$), where VOT was taken as 100, 200 and 300 lire/min ($4.2/hr, $8.4/hr, $12.6/hr). Table 71 gives a brief summary of the previously conducted studies and the corresponding VOT values. It should be mentioned that, some of the studies provided VOT values in different currencies than U.S. dollars. Therefore, in order to compare these VOT values, they are all converted to 2004 dollar units using the currency rate in year 2004.

Table 71 VOT example, estimates

Study	Source	VOT
Moons et al. [71]	Hague Consulting Group, SP-RP Surveys	$5.7/hr (leisure trip)
Parry et al.[72]	% of wage rate	$13/h (62% of wage rate)
Nakamura et al.[73]	Purvis (1997), Bay Area	$9.65/h (46% of wage rate)
De Palma et al. [74]	Previous studies	$17.67/hr (private mode) $11.31/hr (public mode)
Yang et al.[75]	Discrete set of VOTs	$7.69/hr – $15.39/hr
Safirova et al. [76]	% of wage rate	$3.24/hr - $20.59/hr
Shaffer et al.[77]	New Earnings Survey (2003)	$17/h (working) $6.32/h (non-working)

In the second type of approach, discrete choice models were developed, based on revealed or stated preference data, and the value of travel time was calculated as the ratio of travel time to the travel cost. The parameters used to estimate route/departure choice models included both socio-economic factors (such as income, gender, education); and travel specific factors (such as travel time, toll and travel cost). The reviews and comparison of the stated preference vs. revealed preference (RP) data indicated that VOT values obtained from stated preference data was almost always the half of the one obtained from revealed preference data, and implied VOT values showed no clear pattern depending on the different route choice models.[78,79] Based on the comparison of the estimated values of time obtained using stated and revealed preference data, Ghosh [78] claimed that the significant difference between the estimates was due to the ignored unobserved heterogeneity in RP models, and incorporated heterogeneity into the model by estimating the model at two different points in time namely, morning and afternoon. Table 72 shows the underlying model, study area, and the calculated VOT values for corresponding studies.

Table 72 VOT estimation based on Methodology 2

Study	Area	Model	VOT
Leurent [80]	Marseilles, France	RP, Binary Logit	$12/hr
Algers et al. [79]	Sweden	SP, Mixed Logit	$7.96/hr
Hensher [81]	Australia	SP, heteroscedastic Logit	$6.34/hr-$10.2/hr
Calfee et al. [82]	Michigan	SP, Multinomial Logit	$4/hr
Ghosh [78]	I-15, San Diego	RP, Conditional Logit	$22/hr (morning)
Sullivan [8]	SR 91, California	RP, Multinomial Logit	$8-$16/hr
Small et al.[83]	SR 91, California	RP, Multinomial Logit	$13-$16/hr
Hultkrantz et al.[84]	Sweden	SP, Probit	$6.43/hr

In the majority of the studies mentioned above, an econometric modeling approach for the estimation of the utility function for route/departure choices is not employed. Moreover, the calculated VOT is not user specific. Furthermore, the developed models are mostly mode choice models, and they do not incorporate the travel related preferences such as departure time which becomes very important for time of day pricing applications.

With the development of time allocation models [85,86, 87], time and budget constraints were included in the model estimation processes. Bates [88], Gonzalez [89], Jiang et al.[90], and Jara-Diaz et al.[91] further analyzed time allocation models in order to investigate the travel choice behavior, and role of constraints in the utility maximization process. In these models, the utility of a specific mode or route was maximized under budget and time constraints. The utility function was either assumed to be linearly dependent on travel time and travel cost [90] or linearly approximated using the Cobb Douglass form of utility [91]. Then, value of travel time was estimated based on the Lagrangian mathematical programming. Jara-Diaz [94] further investigated the time allocation model and proposed a model that considered the technical relations between consumption and time assigned to activities for both related to leisure and work at the same time. In his study, Jara-Diaz [94] added constraints like minimum time and goods required to accomplish an activity, and concluded that the VOT assigned to leisure activities and work related activities were not equal due to the variations in goods consumption. Jiang et al. [92] introduced functional forms for marginal utilities and used time allocation framework in order to describe the representative utility of the discrete choice model. Blayac et al. [93] included the new constraints included by Jara-Diaz [94] to the optimization model, and relaxed the constant marginal utility assumption and proposed a particular derivation process of representative utility function based on DeSerpa's time allocation framework and developed a functional form for value of travel time depending on income, available time, price and travel time of the selected mode. Then, Blayac et al. [95] introduced nonlinearity of price, travel time and available time into the model estimation using Box-Cox transforms.

DATA SOURCES

The data utilized in the value of travel time estimation process were obtained from the traveler surveys conducted during a 6 six weeks period that spans between the beginning of June and the middle of July, 2004. Rutgers University's Eagleton Institute was in charge of this data collection effort.

The data were collected by means of a single state random sample using random digit telephone calls based on computer aided telephone interviews. The target population was defined as "all individuals who have used the NJ Turnpike on a regular basis (at least once per week) during the last four years", i.e., since the first phase of the time of day pricing program. The data set contained 513 complete observations. Among them, 483 respondents (94.2 percent) were current regular users, and 30 respondents (5.8 percent) were former regular users. All respondents reside in New Jersey.

The survey participants were asked in detail about their most recent trips in the morning and afternoon peak. The questions included origin and destination, travel time, toll amount, travel purpose, mode (alone or carpool), departure time, desired arrival time, actual arrival time, and deviation from the desired arrival time (early/late arrival) of each trip, as well as the questions on socio economic characteristics such as; income level, education level, employment type, age and gender. The details of the traveler survey questions may be found in Appendix 4.

The econometric utility model was derived based on the data obtained from current regular NJ Turnpike users forming a set of 483 data points. After eliminating the data points with missing travel or socio-economic characteristics information, the data set used for the model estimation had 292 valid points. Out of these 292 data points, 166 (57 percent) of them were work trips, and 126 (43 percent) of them were leisure trips. Since work and leisure trips have their own specific properties, the model estimation was done separately for both types of trips. Compared to other similar studies, size of the data set used in the estimation process is large enough to obtain statistically reliable results.

METHODOLOGY

The methodology used to estimate the user specific VOT formulation has two main steps, (1) derivation of user specific utility function and (2) calculation of VOT formulation based on the derived utility function. The specific steps of the proposed methodology can be summarized as follows.

1. Derivation of a user specific utility function of the time of day choices using DeSerpa's time allocation theory [85] and the idea of relaxing constant marginal utility assumption developed by Blayac [93]. The classical optimization models used to derive utility functions were extended by introducing additional constraints specific to time of day choices.
2. Derivation of user specific VOT functions as the ratio between the marginal utility of travel time (derivative of utility function with respect to travel time) and the marginal utility of travel cost (derivative of utility function with respect to travel cost).
3. Estimation of VOT functions regarding the time of day choices of the NJ Turnpike users using the travel survey data.

UTILITY FUNCTION ESTIMATION

As stated in the methodology section, calculation of the user specific VOT functions requires derivation and estimation of utility functions. Travel demand analysis regarding the route or time of day choices (peak or off-peak period) is based on the idea that each traveler maximizes some unobserved quantity called utility. This utility represents the relative desirability of the available alternatives. In this section the user specific utility function was derived extending the time allocation theory developed by DeSerpa [85], and the utility maximization problem proposed by Blayac [93].

Time allocation theory, first developed by Becker [86], was based on the time and market commodities required for consumption of basic commodities. These basic commodities defined the utility function. The maximization of this utility function was represented as a constrained optimization problem, where the constraints were the income and available time (like 24 hours a day) constraints. Then, DeSerpa [85] extended this optimization problem by developing a utility function dependent on all goods and all time periods, and by adding technological constraints. These constraints introduced the idea of the minimum time requirement to perform an activity. Within this framework, DeSerpa defined the VOT as the value of extending the time period allocated to an activity.

Since the main purpose of this chapter is to investigate the time of day choices of the NJ Turnpike users as a result of the time of day pricing program, De Serpa's time allocation model needs to be extended with additional variables and constraints to represent this special travel behavior. These new variables and constraints included to the model were related to the trip purpose, travel time, departure time, desired arrival time, actual arrival time and amount of early/late arrival.

The details of the proposed constrained optimization problem can be found in Appendix 5. The objective function of the optimization problem represents an unknown user specific utility function as a function of travel time, time spent to perform other activities, travel cost, cost of other activities, income, available time, departure time and penalties associated with early/late arrival. The first constraint (Equation 41b – Appendix 5) stands for available income constraint, such that the total income is allocated between the travel costs and cost of consumption of goods other than travel. Whereas, second constraint (Equation 41c – Appendix 5) which determines the allocation of available time ensures that individuals allocate their total time between work related activities, trip related activities and leisure activities. The third constraint (Equation 41d – Appendix 5) states that each period of choice (pre-peak, peak or post-peak) has its minimal time requirement. The rest of the constraints (Equation 41e-41h – Appendix 5), are related to the available early and late arrival times, such that users can either arrive early or late to their destination, and they arrive to their destination point within the maximum early/late arrival flexibility.

It should be mentioned that the utility function in the proposed optimization model does not have a specific formulation. In order to determine the parameters of this utility function, the utility maximization approach proposed by Blayac [93] and Jiang et al.[92] was adopted. The main logic of these models is based on the relaxation of marginal utilities; i.e. marginal utility of a specific parameter in the utility function is assumed to be variable, not constant, in contrast it is assumed that it varies depending on travel related parameters. Using this logic, user heterogeneity can be incorporated and user specific VOT functions can be calculated.

In order to derive utility models for the choice of the time of day, Lagrangian of the constrained utility maximization problem was calculated. Then, each marginal utility multiplier was approximated by applying the first order Taylor's Expansion theorem around the model parameters. Utility of a specific period was then derived based on the integral marginal utilities. The detailed discussion of the methodology and the derivation of user specific utility functions can be found in Appendix 5.

After the estimation process the following utility function shown in Equation (1) was derived. Equation (6) shows that the utility of a specific period "*i*" (*i* refers to the period of travel choice of a specific user which can be pre-peak, peak or post-peak period) increases with increasing income and decreasing travel time, travel cost, deviation from desired arrival, and departure times.

$$\begin{aligned} V_i = {} & a_1 R - a_2 R\overline{t_i} - a_3 R t_{oi} - a_4 \overline{t_i} p_i - a_5 p_i - a_6 t_{oi} p_i - a_7 \overline{t_i} - a_8 t_{oi} \overline{t_i} - a_9 t_{oi} - a_{10} \Delta_i \\ & - a_{11} p_i^2 - a_{12} \overline{t_i}^2 - a_{13} t_{oi}^2 - a_{16} p_i \Delta_i - a_{17} \overline{t_i} \Delta_i - a_{18} R p_i \end{aligned} \qquad (6)$$

where;

V= Utility function

i = period of travel choice index (pre-peak, mid-peak and post-peak periods)

R= income level (in thousands of dollars)

t_{oi} = (desired arrival time) – (departure time to travel on period i) (in hours)

p_i = cost of travel on period/route i (in dollars)

Δ_i = deviation from desired arrival time when period *i* is selected (in hours)

$\overline{t_i}$ = minimum time requirement to travel on period *i* (in hours)

DERIVATION OF THE USER SPECIFIC VOT FUNCTIONS

After estimating the parameters of the user specific utility function, the value of travel time of a specific period can be calculated as the ratio of partial derivative with respect to minimal travel time and partial derivative with respect to travel cost. Equation (7) depicts the corresponding VOT formulation. This equation shows that apart from travel time, travel cost and income, departure time and the difference between early/late time and the desired arrival time influence the VOT of the individuals. When these equations are compared with the model developed by Blayac et al. [93], it can be concluded that the signs of variables that are common to both models are the same. However, it is clear that departure and arrival times have significant effect on the behavior of the period of travel choice as a result of time of day pricing.

$$\frac{\partial V_i / \partial \overline{t_i}}{\partial V_i / \partial p_i} = \frac{(2\alpha_2)R - 2\alpha_2 p_i - 2\sigma_2 T + \tilde{\varepsilon}_o - 2b_2 t_{oi} - \varepsilon_1 \overline{t_i} - b_2 \Delta_i}{(-2\alpha_1)R - 2\alpha_2 \overline{t_i} - \tilde{\alpha}_o - 2\sigma_1 T - 2b_1 t_{oi} + \alpha_1 p_i + b_1 \Delta_i^e} \quad (7)$$

NJ TURNPIKE USERS'S UTILITY MODELS FOR THE CHOICE OF TRAVEL PERIOD

After the derivation of the econometric model for user specific utility and VOT functions, the estimated models were employed to investigate the choices of the New Jersey Turnpike users. For each trip purpose (work and leisure), the variables can be categorized into two parts, namely trip related variables (travel time toll, departure time, desired arrival time, early/late arrival amount, distance traveled at the NJ Turnpike) and traveler related variables (E-ZPass ownership, education level, age, income and occupation). Table 73 shows the definition of the variables included for both trip types.

Table 73 Definition of the independent variables

Variable	Description
time	Travel time in minutes, given time of day, destination
toll	Toll paid per occupancy, in dollars
early	Amount of early arrival time
late	Amount of late arrival time
Des.arr.time	Desired arrival time
distance	distance traveled at the NJ Turnpike
income	Income level
age	Age
female	1 if female, 0 otherwise
education	1, if the user has at least bachelor degree, 0 otherwise
employment	1, if the user is manager or professional, 0 otherwise
E-ZPass	1 if the user owns E-ZPass tag, 0 otherwise

Since the surveys were conducted to understand the user behavior regarding E-ZPass usage and selection of different periods of travel, such as pre-peak, peak and post-peak periods, the model was estimated for three different period choices. Time of day pricing is only applicable to E-ZPass users, therefore qualification for a toll discount at off-peak periods is fully determined by having E-ZPass tag or not. To observe the relative effects of getting E-ZPass tag for the chosen period, nested logit model was estimated for both work and leisure trips. In this type of model, the model regarding transponder choice (E-ZPass or cash) was derived in the first nest, and then in the second nest, conditional on the transponder ownership choice, utility model for the period of travel choice was estimated. Tree structure developed for each trip type is shown in Figure 43. Depending on the trip purpose, probability of selecting a specific time period-transponder ownership is calculated based on joint probability of obtaining an E-ZPass tag or not and choice of travel period. Each probability function has a logit distribution. The detailed mathematical formulation of nested logit models are provided in Appendix 5.

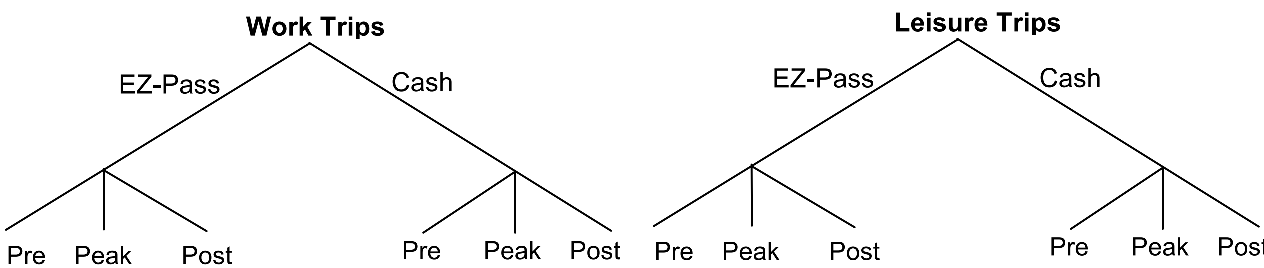

Figure 43 Nested logit tree for transponder and period choice

The parameters to be included in each nest of the utility model were determined based on their relative effects on transponder ownership and choice of travel period. Since traveler related parameters such as employment status, education level, age and gender directly affect the choice of transponder ownership, these parameters were included in the first nest, where the user decides whether to get an E-ZPass tag or not. Likewise, since trip related parameters such as travel time, toll level, early/late arrival and departure time affect the period of travel choice conditional on the selection of the EZ-Pass tag, these parameters were included in the second nest where the user decides on his/her period of travel at the NJ Turnpike.

Since the toll amount for cash users is the same for all periods, in order to investigate the individual and combined effects of toll levels on the user choice, the nested logit for cash users was estimated by first including and then excluding toll related parameters. Cash users pay the same amount of toll irrespective of the time of day, therefore toll related parameters were found to be irrelevant in terms of period of travel choice of cash users and these parameters reduced the model fitness. To this extent, in the final estimation toll related parameters were excluded from the cash users' utility models.

Using the nested logit model described above, 4 different kinds of econometric models were estimated depending on the trip purpose and choice of transponder ownership. The results for the estimated models are given in Table 74 through Table 77. The utility functions of each period and transponder choice are shown after each corresponding table.

Table 74 Estimation results for the nested logit model for work trips and E-ZPass choice

E-ZPass			
2nd nest			
	pre* (1)	peak** (2)	post*** (3)
Toll	-0.25	-0.24	-0.29
travel time	-0.22	-0.48	-0.34
Early	-0.18	-0.11	-
Late	-	-	-0.13
Tollsq	-0.24	-0.16	-0.15
Timesq	-0.45	-0.44	-0.31
Distance	-0.122	-0.11	-0.13
Income	0.064	0.05	0.07
des. Arr. time	-0.23	-0.18	-0.24
Time*income	-0.15	-0.14	-0.14
toll*time	-0.15	-0.2	-0.26
Time*des.arr.time	-	-0.3	-0.13
1st nest			
	pre (1)	peak (2)	post (3)
Age	0.05	0.04	0.05
Female	0.55	0.55	0.58
Employment	0.58	0.54	0.31
Education	-0.86	-1.02	-0.969
Inclusive parameters			
E-ZPass	0.57	0.38	0.66
Cash	0.22	0.45	0.44
Goodness of fit, r^2	0.23	0.27	0.40

*pre: 6-7A.M. and 3:30-4.30P.M.

**peak: 7-9A.M. and 4:30-6:30P.M ***post: 9-10A.M., and 6:30-7:30P.M

$$V_{11} = 0.064R - 0.15\overline{t_{11}}R - 0.106\overline{t_{11}}p_{11} - 0.25p_{11} - 0.22\overline{t_{11}} - 0.23t_{o11} - 0.18\Delta_{11}^{early} - 0.25p_{11}^2 - 0.45\overline{t_{11}}^2 - 0.122d_{11} + 0.58TR * employment + 0.05TR * age - 0.86TR * education + 0.55TR * female \quad (8)$$

$$V_{12} = 0.05R - 0.14R\overline{t_{12}} - 0.2\overline{t_{12}}p_{12} - 0.24p_{12} - 0.48\overline{t_{12}} - 0.18t_{o12} - 0.11\Delta_{12}^{early} - 0.16p_{12}^2 - 0.44\overline{t_{12}}^2 - 0.11d_{12} - 0.3\overline{t_{12}}t_{o12} + 0.54TR * employment + 0.04TR * age - 1.02TR * education + 0.55TR * female \quad (9)$$

$$V_{13} = 0.07R - 0.139R\overline{t_{13}} - 0.26\overline{t_{13}}p_{13} - 0.29p_{13} - 0.34\overline{t_{13}} - 0.24t_{o13} - 0.13\Delta_{13}^{late} - 0.15p_{13}^2 - 0.31\overline{t_{13}}^2 - 0.13d_{13} - 0.13\overline{t_{13}}t_{o13} + 0.31TR * employment + 0.05TR * age - 0.969TR * education + 0.58TR * female \quad (10)$$

Table 75 Estimation results for the nested logit model for work trips and cash choice

Cash			
2^{nd} nest			
	pre (1)	**peak (2)**	**post (3)**
Time	-0.35	-0.39	-0.39
Late	0.26	-0.24	-0.19
Timesq	0.25	-0.35	-0.17
Distance	-0.08	-0.09	-0.07
Income	0.08	0.08	0.1
Des.arr.time	-0.22	-0.12	-0.24
time*des.arr.time	-0.15	-0.26	-0.14
2^{nd} nest			
	pre (1)	**peak (2)**	**post (3)**
Female	-0.52	-0.52	-0.57
Employment	-0.34	-0.42	-0.72
Education	1.54	0.91	1.33
Age	-0.05	-0.05	-0.05
Inclusive Parameters			
E-ZPass	0.63	0.38	0.57
Cash	0.14	0.1	0.18
r-squared	0.38	0.35	0.36

$$V_{11} = 0.08R - 0.35\overline{t_{11}} - 0.22t_{o11} - 0.26\Delta_{11}^{late} - 0.25\overline{t_{11}}^2 - 0.08d_{11} - 0.15\overline{t_{11}}t_{o11} - 0.34TR * employment - 0.05TR * age + 1.54TR * education - 0.52TR * female \quad (11)$$

$$V_{12} = 0.08R - 0.39\overline{t_{12}} - 0.12t_{o12} - 0.24\Delta_{12}^{late} - 0.35\overline{t_{12}}^2 - 0.09d_{12} - 0.26\overline{t_{12}}t_{12} - 0.42TR * employment - 0.05TR * age + 0.91TR * education - 0.52TR * female \quad (12)$$

$$V_{13} = 0.1R - 0.39\overline{t_{13}} - 0.24t_{o13} - 0.19\Delta_{13}^{late} - 0.17\overline{t_{13}}^2 - 0.07d_{13} - 0.14\overline{t_{13}}t_{o13} - 0.72TR * employment - 0.05TR * age + 1.33TR * education - 0.57TR * female \quad (13)$$

Table 76 Estimation results for the nested logit model for leisure trips and E-ZPass choice

E-ZPass			
2nd nest			
	pre (1)	**peak (2)**	**post (3)**
Toll	-0.31	-0.2	-0.23
travel time	-0.44	-0.5	-0.53
Early	-	-0.32	-
Late	-	-	-0.13
Tollsq	-0.12	-0.28	-0.19
Timesq	-0.25	-0.59	-0.46
Income	0.082	0.058	0.08
Des. arr. Time	-0.34	-0.23	-0.16
time*income	-0.18	-0.2	-0.15
toll*time	-0.1	-0.15	-0.18
time*des.arr.time	-	-0.15	-0.43
1st nest			
	pre (1)	**peak (2)**	**post (3)**
Age	0.05	0.05	0.06
Female	0.39	0.36	0.46
Education	0.88	0.99	1.14
Inclusive parameters			
E-ZPass	0.77	0.71	0.31
Cash	0.69	0.56	0.251
Goodness of fit, r^2	0.28	0.26	0.27

$$V_{21} = 0.082R - 0.18R\overline{t_{21}} - 0.1\overline{t_{21}}p_{21} - 0.31p_{21} - 0.44\overline{t_{21}} - 0.34t_{o21} - 0.12p_{21}^2 - 0.25\overline{t_{21}}^2 - 0.21d_{21} + 0.05TR*age + 0.88TR*education + 0.39TR*female \quad (14)$$

$$V_{22} = 0.058R - 0.2R\overline{t_{22}} - 0.15\overline{t_{22}}p_{22} - 0.2p_{22} - 0.5\overline{t_{22}} - 0.23t_{o22} - 0.32\Delta_{22}^{early} - 0.28p_{22}^2 - 0.59\overline{t_{22}}^2 - 0.15\overline{t_{22}}t_{o22} + 0.05TR*age + 0.99TR*education + 0.36TR*female \quad (15)$$

$$V_{23} = 0.08R - 0.15R\overline{t_{23}} - 0.18\overline{t_{23}}p_{23} - 0.23p_{23} - 0.53\overline{t_{23}} - 0.16t_{o23} - 0.13\Delta_{23}^{late} - 0.19p_{23}^2 - 0.46\overline{t_{23}}^2 - 0.43\overline{t_{23}}t_{o23} + 0.06TR*age + 1.14TR*education + 0.46TR*female \quad (16)$$

Table 77 Estimation results for the nested logit model for leisure trips and cash choice

Cash			
2nd nest			
	pre (1)	**peak (2)**	**post (3)**
Time	-0.3	-0.37	-0.25
Late	-0.47	-0.24	-0.44
Timesq	-0.33	-0.3	-0.17
Income	0.063	0.064	0.094
Des.arr.time	-0.41	-0.26	-0.18
time*des.arr.time	-	-	-0.46
1st nest			
	pre (1)	**peak (2)**	**post (3)**
Age	-0.057	-0.054	-0.05
Female	-0.23	-0.23	-0.29
Education	-1.21	-1.15	-1.03
Inclusive Parameters			
E-ZPass	0.3	0.82	0.34
Cash	0.2	0.53	0.1
Goodness of fit, r^2	0.29	0.27	0.32

$$V_{21} = 0.063\,R - 0.3\overline{t_{21}} - 0.41 t_{o21} - 0.33\,\overline{t_{21}}^2 - 0.47\,\Delta_{21}^{late} - 0.057\,TR * age - 1.21 TR * education - 0.23\,TR * female \tag{17}$$

$$V_{22} = 0.064\,R - 0.37\,\overline{t_{22}} - 0.26\,t_{o22} - 0.24\,\Delta_{22}^{late} - 0.3\overline{t_{22}}^2 - 0.054\,TR * age - 1.15\,TR * education - 0.23\,TR * female \tag{18}$$

$$V_{23} = 0.094\,R - 0.25\overline{t_{23}} - 0.18 t_{o23} - 0.17\overline{t_{23}}^2 - 0.46\overline{t_{23}} t_{o23} - 0.44\,\Delta_{23}^{late} - 0.05 TR * age - 1.03 TR * education - 0.29 TR * female \tag{19}$$

Summary of Results

Equations 8-19 show that combined transponder-period choice is highly influenced by the individual and combined effects of toll level (only for E-ZPass users), travel time, income level, distance traveled at the NJ Turnpike, desired arrival time, deviation from desired arrival time, age, gender, education level and employment status. In most of the previous studies, investigating the user behavior as a result of time of day pricing applications, the utility functions were estimated based on route or mode choice. Therefore, in these studies departure time related parameters were no included in the choice models. However, in this chapter, it is observed that for time of day pricing, departure/arrival time related parameters have a statistically significant effect on the period choice. The detailed explanation of the impacts of these parameters can be summarized as follows:

- For each trip type, the probability of getting E-ZPass is higher for female commuters. This probability increases as the age of the user increases.
- For work trips, having managerial occupation increases the probability of getting E-ZPass.
- As the education level increases users prefer to get E-ZPass for leisure related trips.
- For each combined transponder-period choice, individual and combined effects of travel time, desired arrival time, distance traveled on the NJ Turnpike, and income level are found to be highly significant in selecting the period to travel.
- For E-ZPass users, toll amount is also found to be a significant factor in selecting the period of travel. On the other hand, for cash users, excluding the variables regarding the toll amount, improves the model's goodness of fit for each trip type and period choice.
- For E-ZPass users making a work related trip, amount of early arrival is more significant compared to the amount of late arrival. On the other hand, for cash users, late arrival is found to be statistically significant in period choice for work related trips, while early arrival has no statistical significance on their choice of travel period. The reason for this difference may be due to the characteristics of these users. As it is observed from the survey results, most of the users using E-ZPass arrive early at work. On the other hand, the data points for cash users are considerably less compared to E-ZPass users, and most of them arrive late at work, which may bias the estimation results.
- For cash users making leisure trips, early arrival is not statistically significant, while late arrival is found to be significant factor in terms of period choice. Furthermore, the coefficient of late arrival is smaller for peak period users compared to peak shoulder users.

- For E-ZPass users making a leisure trip, early arrival is statistically significant only for peak periods and insignificant for other periods. On the other hand, late arrival is not statistically significant for either period choice.
- The possible explanation for the statistical insignificance of early/late arrival on the period choice for leisure trips is that travelers are expected to be more flexible than commuters making work trips. Also, as it is observed from the surveys, more than half of the users do not have a strict arrival time constraint for leisure trips. Therefore, there is no specific early/late arrival consideration for leisure trips.
- For cash users the coefficients regarding the travel time related variables are higher compared to the coefficients obtained for E-ZPass users, for most of the period choices.

VOT FUNCTIONS FOR PERIOD OF TRAVEL CHOICES

After estimating the utility model parameters for each trip purpose, choice of transponder ownership and choice of travel period, the user specific VOT functions were calculated using the proposed methodology briefly described in "Derivation of the User Specific VOT Function" section. It should be mentioned that for cash users, toll related parameters are found to be statistically insignificant. Thus, VOT functions were calculated only for E-ZPass users. Table 78 presents the VOT functions and mean VOT values for each estimated model.

Table 78 VOT functions and mean VOT values for each model (EZ-Pass)

trip purpose	period	VOT Function	Mean VOT
Work (1)	pre* (1)	$\frac{\partial V_{11} / \partial \overline{t_{11}}}{\partial V_{11} / \partial p_{11}} = \frac{-0.106 p_{11} - 0.9\overline{t_{11}} - 0.15R - 0.22}{-0.106\overline{t_{11}} - 0.5 p_{11} - 0.25}$	\$16.72/hr
	peak** (2)	$\frac{\partial V_{12} / \partial \overline{t_{12}}}{\partial V_{12} / \partial p_{12}} = \frac{-0.2 p_{12} - 0.88\overline{t_{12}} - 0.3 t_{o12} - 0.14R - 0.48}{-0.2\overline{t_{12}} - 0.32 p_{12} - 0.24}$	\$19.72/hr
	post*** (3)	$\frac{\partial V_{13} / \partial \overline{t_{13}}}{\partial V_{13} / \partial p_{13}} = \frac{-0.26 p_{13} - 0.62\overline{t_{13}} - 0.13 t_{o13} - 0.139R - 0.34}{-0.26\overline{t_{13}} - 0.3 p_{13} - 0.29}$	\$17.35/hr
Leisure (2)	pre* (1)	$\frac{\partial V_{21} / \partial \overline{t_{21}}}{\partial V_{21} / \partial p_{21}} = \frac{-0.1 p_{21} - 0.5\overline{t_{21}} - 0.18R - 0.44}{-0.1\overline{t_{21}} - 0.24 p_{21} - 0.31}$	\$17.03/hr
	peak** (2)	$\frac{\partial V_{22} / \partial \overline{t_{22}}}{\partial V_{22} / \partial p_{22}} = \frac{-0.15 p_{22} - 1.08\overline{t_{22}} - 0.15 t_{o22} - 0.2R - 0.7}{-0.15\overline{t_{22}} - 0.56 p_{22} - 0.2}$	\$17.16/hr
	post*** (3)	$\frac{\partial V_{23} / \partial \overline{t_{23}}}{\partial V_{23} / \partial p_{23}} = \frac{-0.18 p_{23} - 0.92\overline{t_{23}} - 0.15R - 0.43 t_{o23} - 0.53}{-0.18\overline{t_{23}} - 0.38 p_{23} - 0.23}$	\$15.33/hr

*pre: 6-7A.M. and 3:30-4.30P.M.

**peak: 7-9A.M. and 4:30-6:30P.M.

***post: 9-10A.M., and 6:30-7:30P.M

As it is observed in Table 78, VOT for a specific user is highly influenced by the trip purpose, period choice, income level, toll amount, travel time, and desired arrival time. Also, mean VOT values range between \$15/hr and \$20/hr depending on the selected period and trip type. The highest mean VOT value is observed for peak period travelers making work related trips, whereas the lowest mean VOT value is observed for post peak period travelers making a leisure trips. VOT values of work related trips are higher compared to leisure related trips, for both peak and post-peak travels. On the other hand, for pre-peak travel, mean VOT value of leisure trips is slightly higher than mean VOT value of work trips. Additionally, for each trip type peak period has the highest VOT value among other periods. When compared with previous studies mentioned in the Literature Review section, it is observed that the mean VOT values of the NJ Turnpike users are higher than those of users of other toll roads. The reason behind this difference can be due to several factors specific to the NJ Turnpike. First, for most of the studies there were several modes or free routes available to the users other than the toll road. Therefore, the proposed models were mostly mode/route choice models. In addition the toll differential between different periods was relatively high for other toll roads studied in the literature. However, as it was observed from the traveler surveys (Chapter IV) and traffic impact analysis (Chapter II) for the NJ Turnpike, there was no shift to the other routes or modes as a result of time-of-day pricing initiative. This can be mainly due to the lack of competitive route and mode choice alternatives for the NJ Turnpike users. In addition, the commuters traveling on the NJ Turnpike have relatively high income levels. These facility specific properties may have resulted in higher value of travel time values with respect to toll differentials and absolute value of the tolls. All these facility specific characteristics may have resulted in higher value of travel time values with respect to toll differentials and absolute value of the tolls.

CONCLUSION

The goal of this chapter was to develop a VOT formulation which, incorporates socio-economic and trip related factors of the NJ Turnpike users. DeSerpa's time allocation theory [85] was used as a basis and which was incorporated with the idea of relaxing the constant marginal utility assumption proposed by Blayac [93]. In order to fully consider the effects of time of day pricing on travel choice behavior, new constraints and variables were also included into the model. To summarize, travel time, travel cost, income level, trip purpose, departure time and early/late arrival factors were included into the constrained utility maximization problem. This formulation necessitated the estimation of utility functions for modeling users' period of travel choice behavior as a result time of day pricing.

Taking the Lagrangian of constrained utility maximization problem, each marginal utility multiplier was approximated by applying the first order Taylor's Expansion theorem around the model parameters. Utility of a specific period was derived based on marginal utilities. Then, the user specific VOT functions were formulated based on the ratio of partial derivative with respect to travel time and partial derivative with respect to travel cost.

The estimated functions show that in the presence of time of day pricing applications, VOT and utility of a specific period are influenced by desired arrival time of the trip and deviation from the desired arrival time, in addition to income, travel cost, travel time, and the socio-economic characteristics of the travelers. Furthermore, the estimated utility functions indicate that females, commuters with high income, and commuters with managerial occupations prefer to acquire E-ZPass rather than paying cash. For each trip type and transponder ownership choice, individual and combined effects of travel time, desired arrival time, distance traveled on the NJ Turnpike, and income levels are found to be highly significant in selecting the period of travel. For E-ZPass users, the toll amount is also found to be statistically significant in selecting the period of travel. On the other hand, for cash users, excluding the variables regarding the toll amount, improves the model accuracy by increasing the goodness-of-fit for each trip type and period. This shows that the model accurately captures the behavior of cash users who are not qualified for the discounts offered by the time of day pricing program. Also, for leisure trips the amount of early/late arrival is found to be statistically insignificant for most of the period choices, possibly due to the fact that for leisure trips, users are more flexible. For cash users, the coefficients regarding the travel time related variables are higher compared to the coefficients estimated for EZ-Pass users.

After estimating the model parameters for each trip type, transponder ownership choice, and period of travel choice, the user specific VOT function is estimated. The results indicate that VOT for a specific user is highly influenced by the trip purpose, period of travel choice, income level, toll amount, travel time, and desired arrival time. Besides, mean VOT values calculated using VOT functions for E-ZPass users range between $15/hr and $20/hr, depending on the selected period and trip type. The highest mean VOT value is observed for peak period travelers making work related trips, whereas the lowest mean VOT value is observed for post peak period travelers making leisure trips. VOT values of work related trips are found to be higher compared to leisure related trips, for peak and post-peak travel. Besides, for each trip purpose, peak period has the highest VOT value among the other periods, whereas the magnitude of VOT values for peak shoulder periods changes depending on trip type.

The next chapter focuses on the elasticity of demand in terms of toll and travel time changes. The elasticity estimation process is applied to each combined transponder-period choice and trip purpose.

CHAPTER VI - DEMAND ELASTICITY AT THE NJ TURNPIKE FACILITIES

INTRODUCTION

One of the methodologies used to determine the efficiency and optimal design of time of day pricing policies is to investigate the relationship between toll amount and traffic demand [(100)]. In this chapter, this specific relationship was investigated by estimating the elasticity of traffic demand at the NJ Turnpike with respect to toll changes.

The elasticity of traffic demand with respect to toll changes is calculated as the percentage change in quantity demanded in response to one percent change in price. The elasticity of traffic demand is expected to be negative, i.e., a price increase in the facility would result in a reduction in the traffic. Demand is said to be "price-elastic" if the absolute value of the elasticity of the traffic demand with respect to price changes is greater than one, i.e., a price change elicits a more than proportionate change in the quantity demanded. A "price-inelastic" demand has a less than proportionate response in the quantity demanded to a price change, i.e., an elasticity between 0 and -1.0. Transportation demand elasticity with respect to toll changes tends to be inelastic, since it is a derived demand. [(101)]

This chapter has three sections. The next section provides review of the previous studies. In the analysis part, the elasticity of traffic demand with respect to toll changes is estimated, based on the nested logit model developed and estimated in Chapter 5. Different elasticity values are calculated based on the time of day choices and trip purposes. After presenting the results and discussions, concluding remarks are given in the last section. Appendix 6 presents the mathematical derivation of elasticities.

LITERATURE REVIEW

In the literature, traffic demand elasticity with respect to toll levels is calculated based on two methodologies. In the first methodology, traffic counts before and after the toll increase are calculated. Then, elasticity of traffic demand is calculated as the ratio of percentage change in the traffic to the percentage change in the toll level.

May [102] conducted an overall comparison of different elasticity studies and calculated an average of -0.45 for the demand elasticity with respect to toll levels. Mauchan et al. [103] estimated the elasticity of traffic level for bridges and motorways in UK. Based on the analysis conducted using traffic counts, it was shown that elasticity values for a bridge located in Southampton ranged between -0.21 and -0.36 for peak hours, and between -0.14 and -0.29 for off-peak hours. Similarly, from the simulation model developed for the motorways located in West Yorkshire, it was shown that the whole motorway had an elasticity value of -0.40, whereas the intercity motorway's elasticity was -0.25.

Harvey [104] investigated the impacts of toll levels on a bridge in San Francisco, California area by estimating the toll elasticities for automobiles using traffic counts before and after the toll changes. The analysis results indicated an average value of -0.1. The study performed by Hirshman [105] for the New York area bridge and tunnel toll elasticities for automobiles indicated an average value of -0.1. Mekky [106] analyzed Toronto, Canada's Highway 407 and calculated the elasticity values in a similar way to Harvey [104] by using traffic counts. However, elasticity values were found to be much higher compared to other studies, with a value of -4.0. Arentze et al.[107] used a public survey to determine traveler response to congestion pricing incentives in Netherlands. The price elasticity of overall vehicle travel was found to vary from -0.13 to -0.19, and from -0.35 to -0.39, depending on the selected route and time of day.

URS Consultants [108] developed a set of elasticity factors for each crossing of the Triborough Bridge and Tunnel Authority (TBTA) in New York, depending on the updates of previously derived factors and the analysis of the traffic data for periods before and after the toll increases. The estimated short term elasticity values were between -0.085 and -0.386. Long term elasticity values were between -0.33 and -1.307.

In the second type of methodology, first a demand function based on a discrete choice model is estimated. Then, elasticity values are calculated using the derivative of this demand function with respect to toll level.

Yan et al. [109] developed route choice models for SR 91 toll road in California by estimating logit models based on traveler surveys. The estimation of elasticities with respect to different toll levels was accomplished by using the sample enumeration method, where the weighted average of individual probabilities obtained from logit models was used for enumeration. The estimated elasticity values for the SR 91 Express lanes were between -0.7 and -1.0 depending on the time of day. On the other hand, estimated demand elasticity values for the Lee County, Florida value pricing project, where the drivers crossing the two bridges with variable tolls in 1999, were much lower. [110] Elasticity of traffic demand was derived from the logit models estimated based on the travel survey data. The elasticity values were between -0.05 and -0.36 depending on the time of day. In Matas et al. [111], the elasticities of demand for tolled motorways in Spain were analyzed and the demand equation was estimated using a panel data set, taking into account the dynamic effects of economic activity. Kockelman [112] derived a nested logit model using Texas travel survey data for Austin area. Estimated demand elasticities with respect to travel price were found to be between -0.022 and -0.22. Abdelwahab [113] estimated the mode choice elasticities for the intercity freight transport market based on probit models. The price elasticities of truck choice probabilities were found to vary from -0.749 to -2.525.

In Table 79, a summary of demand elasticity values with respect to toll levels is shown. The table shows the study area and the elasticity values at different time periods for passenger cars.

Table 79 Elasticity of traffic demand with respect to toll levels, passenger cars

Source	Location – Type	Elasticity Value
May[102]	literature review of number of previous studies	-0.45 (Average)
Oum et al [101]	Southampton, UK - bridges	(-0.21) – (-0.36) (peak) (-0.14) – (-0.29) (off-peak)
Harvey [104]	San Francisco, USA – bridges	-0.1 (average)
Cain et al. [114]	Lee County Florida, USA -bridges	(-0.03) (post-peak p.m.) (-0.36) (pre-peak a.m.)
Burris et al. [110]	Lee County Florida, USA –bridge (early morning discount period)	-0.42 (1998) -0.11 (2002)
Mauchan et al. [103]	West Yorkshire, UK - motorway	-0.4 (whole motorway) -0.25 (intercity motorway)
Matas et al.[111]	Spain – toll motorways	(-0.21) – (-0.83)
Mekky [106]	Toronto Highway 407	-4.0
Arentze et al.[107]	Netherlands – motorways	(-0.13) – (-0.19) (route) (-0.35) – (-0.39) (time of day)
Yan et al.[109]	SR 91, USA - motorway	(-0.7) – (-1.0) (time of day)
Kockelman et al. [112]	Austin, Texas, USA - motorways	(-0.022) – (-0.22)

ELASTICITY ESTIMATION USING NESTED LOGIT MODELS

The basic concept of demand elasticity is defined as the percent change in demand as a response to percent change in price. The equation for the elasticity is given below:

$$E = \frac{\Delta D}{\Delta p} * \frac{p}{D} \qquad (20)$$

where,

E: Elasticity of traffic demand with respect to price

ΔQ: Change in traffic demand after price change (%)

ΔP: Change in price (%)

Q: traffic demand before price change (volume/hr)

P: Price before change ($)

When elasticity values are estimated using discrete choice models, the direct demand elasticity represents the responsiveness of a user's probability of choosing a time of day for travel to a change in the toll level. In the case of nested logit model, a user specific elasticity function, depending on the choice of period and the trip purpose, is given by the following equation:

$$E_{p_{ni}}^{P_{ni}} = \frac{\partial P_{ni}}{\partial p_{ni}} \bullet \frac{p_{ni}}{P_{ni}} \qquad (21)$$

where;

i=Index for choice of travel period (1 = pre-peak, 2 = peak, 3 = post-peak)

k = Index for transponder ownership choice (1 = E-ZPass, 2 = Cash)

n = Index for individual user (n=1,…N) (N=166 for work trips) (N=126 for leisure trips)

P_{ni} = Probability of selecting travel period i for individual n

p_{ni} = Variable for toll amount ($)

Given the formulation of the nested logit model, the elasticity of the probability of selecting transponder-period combination (P_{ni}) with respect to toll amount (p_{nik}), can be calculated using Equation 21. Since the variables attributed to the transponder choice (Please refer to Chapter V for detailed description of variables attributed to transponder choice) do not include any variables regarding the toll amount paid, these variables were considered as constants in the calculation of the derivative of the probability function with respect to toll amount. For simplification purposes, only the final result of the derived elasticity function is presented in this section. The detailed derivation of the elasticity function is given in Appendix 6.

In practice, the measures of interest are the mean elasticity values, rather than the user specific disaggregate elasticity values. The mean of the disaggregate elasticities of each period can be calculated as the weighted average of the user specific elasticities, using the probabilities as weights. [113] The formulation for the mean elasticity $\left(E_{p_i}^{P_i}\right)$ is given by:

$$\overline{E_{p_i}^{P_i}} = \frac{\sum_{n=1}^{N} P_{ni} E_{p_{ni}}^{P_{ni}}}{\sum_{n=1}^{N} P_{ni}} \tag{22}$$

Table 80 summarizes the user specific elasticity functions and the corresponding mean elasticity values. As it is observed from Table 80, elasticity functions are different for each selected time period (pre-peak, peak and post-peak periods) and for each trip purpose (work and leisure). Besides, elasticity of a specific user is affected by the toll level, travel time and probability of selecting a time period (pre-peak, peak or post-peak periods). Mean elasticity values calculated based on the user specific elasticity functions indicate that elasticity of traffic demand with respect to toll amount is very low, i.e. demand is very inelastic with respect to toll changes. Additionally, elasticity values for work trips are lower compared to the elasticity values for leisure trips. Moreover, elasticity values for peak periods are lower compared to elasticity values for peak shoulders.

The estimated elasticities range between -0.06 and -0.08 for peak period users (7-9A.M. and 4:30-6:30P.M.), and between -0.11 and -0.18 for peak shoulder users (6-7A.M., 9-10A.M., 3:30-4.30P.M.and 6:30-7:30P.M.), depending on the trip purpose. In terms of the impacts on traffic levels, these elasticities mean that 10 percent increase in peak toll levels (the level of increase on January 1, 2003) would result in a decrease in peak period traffic ranging between 0.6 percent and 0.8 percent depending on trip purpose. Similarly, five percent increase in off-peak toll levels (the level of increase on January 1, 2003) would result in a decrease in peak shoulder period traffic ranging between 0.55 percent and 0.9 percent depending on the trip purpose. These very low elasticity values are consistent with the traffic impact analysis results, indicating that the second phase of the time of day pricing program did not have a statistical significant impact on the travel patterns of the NJ Turnpike users.

Table 80 Estimated elasticity functions and mean elasticity values

trip purpose	period	Elasticity Function	Mean Elasticity
Work (1)	Pre (1)*	$E_{p_{n1}}^{P_{n1}} = \left[(1-P_{n1}) + (1-P_{n1/C_1})\left(\frac{1}{\rho_{11}}-1\right)\right] \bullet \left(-0.106\overline{t_{n11}} - 0.5p_{n11} - 0.25\right)p_{n11}$	-0.108
	Peak (2)**	$E_{p_{n2}}^{P_{n2}} = \left[(1-P_{n2}) + (1-P_{n2/C_1})\left(\frac{1}{\rho_{21}}-1\right)\right] \bullet \left(-0.2\overline{t_{n21}} - 0.32p_{n21} - 0.24\right)p_{n21}$	-0.06
	Post (3)***	$E_{p_{n3}}^{P_{n3}} = \left[(1-P_{n3}) + (1-P_{n3/C_1})\left(\frac{1}{\rho_{31}}-1\right)\right] \bullet \left(\frac{-0.26\overline{t_{n31}} - 0.3p_{n31} - 0.29}{\rho_{31}}\right)p_{n31}$	-0.11
leisure (2)	Pre (1)*	$E_{p_{n1}}^{P_{n1}} = \left[(1-P_{n1}) + (1-P_{n1/C_1})\left(\frac{1}{\rho_{11}}-1\right)\right] \bullet \left(\frac{-0.1\overline{t_{n11}} - 0.24p_{n11} - 0.31}{\rho_{11}}\right)p_{n11}$	-0.18
	Peak (2)**	$E_{p_{n2}}^{P_{n2}} = \left[(1-P_{n2}) + (1-P_{n2/C_1})\left(\frac{1}{\rho_{21}}-1\right)\right] \bullet \left(\frac{-0.15\overline{t_{n2}} - 0.56p_{n2} - 0.2}{\rho_{21}}\right)p_{n21}$	-0.08
	Post (3)***	$E_{p_{n3}}^{P_{n3}} = \left[(1-P_{n3}) + (1-P_{n3/C_1})\left(\frac{1}{\rho_{31}}-1\right)\right] \bullet \left(\frac{-0.18\overline{t_{n31}} - 0.38p_{n31} - 0.23}{\rho_{31}}\right)p_{n31}$	-0.14

*pre: 6-7A.M. and 3:30-4.30P.M.
**peak: 7-9A.M. and 4:30-6:30P.M.
***post: 9-10A.M., and 6:30-7:30P.M

When compared to similar time of day pricing studies, it is observed that the elasticity values for the NJ Turnpike users are lower compared to most of other toll facilities in the U.S. On the other hand, the relative magnitude of elasticity values for peak/peak-shoulder period and work/leisure trips is similar to the results of other similar studies, suggesting that work trips and peak period trips tend to have lower elasticity values compared to off-peak period trips and leisure trips.

CONCLUSION

In this chapter, the efficiency of the time of day pricing policy implemented at the NJ Turnpike is evaluated by estimating the elasticity of traffic demand with respect to toll changes.

Elasticity values are calculated using nested logit models estimated for each time period and trip purpose, where each elasticity value represents the responsiveness of a user's probability of choosing a time of day for travel to a change in the value of toll level.

In this chapter, two kinds of elasticity values are estimated using traveler survey data. In the first part, user specific elasticity functions are derived from the nested logit models estimated in the previous chapter. Then, in the second part, average elasticity values are calculated using the user specific elasticity functions.

From the elasticity estimation process the following results are obtained:

- The user specific elasticity functions exhibit differences for each time period selected and for each trip purpose.
- Elasticity of a specific user is affected by the toll level, travel time, and probability of selecting a specific time period.
- Average elasticity of traffic demand with respect to the toll is found to be very inelastic.
- The elasticities are found to range between -0.06 and -0.08 for peak period users (7-9A.M. and 4:30-6:30P.M.), and between -0.11 and -0.18 for peak shoulder users (6-7A.M., 9-10A.M., 3:30-4.30P.M.and 6:30-7:30P.M.) depending on trip type.
- In terms of the impacts on traffic levels, these elasticities indicate that 10 percent increase in peak toll levels (the level of increase on January 1, 2003) would result in a decrease in peak period traffic ranging between 0.6 percent and 0.8 percent depending on trip purpose. Similarly, a 5 percent increase in off-peak toll levels (the level of increase on January 1, 2003) would result in a decrease in peak shoulder period traffic ranging between 0.55 percent and 0.9 percent depending on trip purpose. These very low elasticity values are consistent with the traffic impact analysis results, indicating that the second phase of the time of day pricing program did not have a statistical significant impact on the travel patterns of the NJ Turnpike users.
- Elasticity values for work trips are lower compared to elasticity values for leisure trips.
- Elasticity values for peak periods are lower compared to elasticity values for peak shoulders.

- The elasticity values for the NJ Turnpike users are lower compared to the elasticity values of users of most of the other toll facilities in U.S.
- The relative magnitude of elasticity values for peak/peak-shoulder period and work/leisure trips is similar compared to other similar studies, suggesting that work trips and peak period trips tend to have lower elasticity values compared to off-peak period trips and leisure trips.

CHAPTER VII – MEDIA AND DECISION MAKERS' REACTIONS TO THE TIME OF DAY PRICING INTIATIVE

INTRODUCTION

The purpose pf this chapter is to analyze the NJ Turnpike users' behavioral changes as a consequence of the implementation of value pricing. The Alan M. Voorhees Transportation Center at Rutgers University's Edward J. Bloustein School of Planning and Public Policy has undertaken a descriptive analysis of the decision-making process to gauge the acceptability of the value pricing program to opinion leaders and decision makers before and after implementation of the new toll schedule.[1] Two themes are explored in examining the acceptability of the NJ Turnpike Authority's value pricing program to opinion leaders and decision makers:

> 1) How the NJ Turnpike Authority implemented its value pricing program, how the media portrayed the NJ Turnpike Authority's implementation strategy, and how various stakeholders perceived the NJ Turnpike Authority's implementation strategy;
>
> 2) How the NJ Turnpike Authority, the media, and the various stakeholders used the term value pricing and the extent to which they differentiated between the term value pricing and various other terms, such as variable pricing, congestion pricing, and peak period pricing.

In this report each of the two themes are examined separately and then drawn together in the conclusion. At the outset the context of the NJ Turnpike Authority's value pricing program is provided. Thereafter, each theme is examined from the perspective of the NJ Turnpike Authority, the printed media's coverage of the value pricing program, and the acceptability of the value pricing program to selected stakeholders. The examination of the NJ Turnpike Authority is based on interviews with officials of the NJ Turnpike

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[1] A similar analysis examining the value pricing program of the Port Authority of New York and New Jersey was conducted by NYU's Wagner Rudin Center for Transportation Policy and Management. The wording in this paragraph is borrowed from the draft report of that study, dated October 27, 2003.

Authority[2] and the NJ Department of Transportation (NJDOT)[3]. The media analysis included a web search of printed articles relating to the value pricing program. Relevant articles were found in *The Star Ledger*, *The Record*, *The New York Times*, *The Courier News,* and *The Press of Atlantic City*. The analysis of the responses of selected stakeholders includes interviews with representatives of the New Jersey Motor Truck Association, the New Jersey Automobile Club, the Regional Plan Association, and the Tri-State Transportation Campaign. In the concluding section, the observations of this analysis is compared with those reported in the study of the Port Authority of New York and New Jersey's value pricing initiative and make policy recommendations.

CONTEXT: NJ TURNPIKE AUTHORITY'S VALUE PRICING PROGRAM

On January 25, 2000, the Board of Commissioners of the New Jersey Turnpike Authority adopted a Long-Term Financing Plan, one element of which was the value pricing initiative. The Plan included three major elements [(115)]

- A 5-year Capital Construction Plan, which included, among others, a new interchange in Secaucus to improve traffic movement in the Meadowlands and to support a proposed major commercial development associated with the Secaucus Junction rail station, major bridge deck repairs, the relocation of interchange 1, construction of an east-west extension of Route 92 from Route 1 in South Brunswick to Interchange 8A, and extensive service area renovations;

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[2] Phone interviews with Edward Gross on January 30, 2004, and September 13, 2004. Mr. Gross who was the Executive Director of the NJ Turnpike Authority at the time the value pricing program was introduced, provided the reasoning for the value pricing program and details of the strategy he adopted to implement the program.

Personal interview January 20, 2004, with Robert Dale, Director of Operations, and Jerry Kraft, Traffic Engineer, Design and Planning, at the NJ Turnpike Authority who provided background information on the value pricing program.

[3] Phone interview February 9, 2004, with James Weinstein, the Commissioner of the NJDOT during this period who provided information from the perspective of state government.

- A toll increase to fund the Capital Program, and the introduction of Value Pricing; and
- A new bond issue totaling more than $1.8 billion.

The implementation of the value pricing program was dependent on the introduction of an electronic toll system to replace the manual collection of tolls. Already in 1997, the NJ Turnpike Authority had committed to implement an electronic toll collection system (E-ZPass). However, the introduction of E-ZPass had been delayed, so that the NJ Turnpike Authority was the last of the region's toll agencies to implement it.

When establishing a toll schedule for the combined introduction of E-ZPass and value pricing, the NJ Turnpike Authority leadership felt compelled to offer an E-ZPass discount as an incentive to attract drivers to use E-ZPass. The region's other toll authorities had instituted an E-ZPass discount when they introduced electronic toll collection. According to Edward Gross, the Executive Director of the NJ Turnpike Authority at the time, an E-ZPass discount was necessary, despite the fact that it had become clear that the driving public did not need incentives, such as an E-ZPass discount, to enroll in the E-ZPass program.

The toll schedule for NJ Turnpike passenger cars drivers has three pricing rates—cash, E-ZPass peak period and weekend, and E-ZPass off-peak period (see Table 81). Passenger car E-ZPass users receive a discount off the cash price. The value pricing element, available only to E-ZPass users, distinguishes between the peak period and the off peak period. Tolls for passenger car E-ZPass users are lower during the off peak weekday periods than during the peak morning (7 A.M. to 9 A.M.) and peak evening (4:30 P.M. to 6:30 P.M.) weekday periods. On weekends the E-ZPass discount is in place, and tolls are the same as those during the peak weekday periods. Tractor trailers E-ZPass users also received a discount. However, truckers were not included in the value pricing program and, thus, they do not receive a weekday off peak period discount. But, truckers using E-ZPass can receive an off peak volume discount if they are enrolled in the E-ZPass Post-paid Commercial Account Plan.

The first toll increase went into effect on September 30, 2000, and the second on January 1, 2003. The differences in the toll rates between cash, E-ZPass peak and E-ZPass off peak, and the percentage increase in rates in September 2000 and January 2003 are shown in Table 81. Two examples are shown for passenger cars: one for a more or less typical trip on the NJ Turnpike between Interchanges 11 and 16, and the second for a trip along the full length of the NJ Turnpike from Interchanges 1 to 18. As of September 30, 2000, after the first toll increase, irrespective of the time of day, passenger car drivers paying cash who drove between Interchanges 11 and 16 were charged $2.05, a 20 percent increase over the prior toll of $1.70. Passenger car E-ZPass users who drove during the morning and evening peak periods and on weekends were charged $1.85, an increase of 8 percent over the prior toll of $1.70. However, tolls were not increased for passenger car E-ZPass users who drove during the off peak weekday periods; they were charged $1.70, a $0.15 saving over the E-ZPass peak period and a $0.35 saving over the cash charge.

The second toll hike was implemented on January 1, 2003. The toll for passenger car drivers who drove between Interchanges 11 and 16 and paid cash increased by $0.35 to $2.40, an increase of 17 percent. The toll for E-ZPass peak period users increased by $0.20 to $2.05, an increase of 10 percent. The toll for E-ZPass off peak users increased by $0.10 to $1.80, an increase of 5 percent. The price differential for E-ZPass users between the peak and off peak periods grew from $0.15 to $0.25, and the price differential in the off peak period between cash and E-ZPass users increased from $0.35 to $0.60.

Table 81 Toll rates ($) and percentage increases for passenger cars

Toll	Interchanges	1991	Percentage Increase	October 2000	Percentage Increase	January 2003
Cash	11 to 16	$1.70	20%	$2.05	17%	$2.40
	1 to 18	$4.60		$5.50		$6.45
E-ZPass Peak & Weekend	11 to 16	–	8%	$1.85	10%	$2.05
	1 to 18	–		$4.95		$5.45
E-ZPass Off Peak	11 to 16	–	0%	$1.70	5%	$1.80
	1 to 18	–		$4.60		$4.85

Source: NJ Turnpike Authority

Note: The peak periods are from 7 A.M. to 9 A.M. and from 4:30 P.M. to 6:30 P.M.

IMPLEMENTATION STRATEGY

The NJ Turnpike Authority

Edward Gross believes that the value pricing program at the NJ Turnpike Authority, which was his initiative, was successfully implemented—"the real sleeper was variable pricing and this may have been the number one accomplishment of the (long term financing plan) program." Mr. Gross stressed that, although the value pricing program was only one element of the Long Term Financing Plan, it was a crucial component with goals which were independent both of the other elements of the Long Term Financing Plan and the introduction of E-ZPass.

Mr. Gross initiated the value pricing program because he believed that the NJ Turnpike Authority needed to develop innovative marketing strategies that would reduce the flow of traffic during the congested peak periods of the day. He explained that eighteen hours a day, Monday to Friday, the NJ Turnpike is underutilized. However, as traffic flow increases over time, it will not be possible to build sufficient new highway capacity to meet the rise in demand. He believed that value pricing is a marketing tool that can be used to reduce traffic flows during the congested peak periods. By providing the traveling public a lower toll option if they used the NJ Turnpike during the off peak periods, traffic diversions to the off peak periods would occur, thereby reducing congestion during the peak periods.

Since the NJ Turnpike Authority was the first toll authority in the country to introduce value pricing, Mr. Gross wanted to make sure that the program would be introduced successfully. He adopted a set of strategies designed to buffer it from criticism. One was to present the E-ZPass off peak period pricing at a zero percent increase. Mr. Gross thinks that the zero percent increase was a good strategy which created strong marketing appeal. He believes that this strategy diluted public opposition to the value pricing element of the financial program. Second, Mr. Gross was sensitive to the size of the price differential between the peak and the off peak periods at the program's inception and decided that the price difference between the peak and off peak periods should not be significant. He believed that the price differential should be big enough to show there was a difference, but not so large as to create opposition to the program. He reasoned that a significant price differential ran the risk that the public would reject the program. On the other hand, he recognized that initially the price differential would not be big enough to persuade significant numbers of drivers to change their travel behavior. He considered it more important to get the concept in place and to introduce the notion of value pricing to the driving public. Over time, Mr. Gross foresaw that the price differential could be deepened.

Mr. Gross felt that in the period after the NJ Turnpike Authority adopted the Long Term Financial Plan, the media focused primarily on the capital program, the toll increases, the introduction of E-ZPass, and not on the value pricing element. This suited Mr. Gross, because he considered the value pricing program controversial. His principal strategy was to convince state government of the need for the capital program and to demonstrate that there would be a real infrastructure improvement which would benefit the public.

Much of the initial criticism of the program was based on the claim that drivers do not have the flexibility to change their peak period travel behavior and, thus, would be penalized for driving in the peak period. Mr. Gross understood that not every peak period trip could be avoided; however, value pricing was an option which would allow some drivers to choose the times they used to drive on the NJ Turnpike. He believed it was no different from the airline industry where it is not always possible to get the best price because sometimes a traveler needs to be at a destination at a specific time.

Mr. Gross engaged all the major interest groups before the value pricing program was implemented. He met with the truckers who responded that they did not see any benefit for them in a value pricing program, because their work schedules did not allow them to change their travel behavior. Despite the trucking industry's position, Mr. Gross claimed that surveys done by the NJ Turnpike Authority showed that at least 75 percent of the truckers had the flexibility to adjust their travel schedule and, thus, benefit from an off peak period discount. The trucking association was not convinced and asked that truckers receive only an E-ZPass discount. So, the NJ Turnpike Authority decided not to implement a value pricing program for truckers.

Another group that opposed the value pricing program was the Automobile Club of New Jersey. They used the 'no choice' claim that peak period drivers do not have the flexibility to alter their travel schedule and, thus, would be penalized by the higher toll charged for driving during the peak period.

Despite the opposition of the truckers and Automobile Club of New Jersey to the value pricing program, these two groups did not stir up public opposition to the program. Mr. Gross received strong support from the Tri-State Transportation Campaign, an organization that often opposed the NJ Turnpike Authority's positions on other highway matters. Mr. Gross encountered no meaningful opposition from the State Legislature. Packages explaining the value pricing program were sent to members of both chambers. Mr. Gross does not recall going to any briefings.

NJ Department of Transportation

James Weinstein commended Edward Gross' vision and effort in developing the value pricing idea and in implementing the value pricing program. Mr. Weinstein explained that the value pricing policy was instituted because it had become necessary to "flatten out the peak and put people who were making discretionary trips out of the peak period." Reducing peak period traffic would have positive ramifications for reducing congestion and improving the environment. Although Mr. Weinstein had initially been skeptical of the value pricing idea, Mr. Gross convinced him that it was a good idea and that it could be implemented. Mr. Weinstein accepted the notion that drivers should pay to use the existing highway capacity, because it is constrained.

Mr. Weinstein explained that Mr. Gross laid the ground work for the program, and that the NJ Turnpike Authority did all the work in presenting the program to the various constituents and interested parties. The NJ DOT had no part in the process. Mr. Weinstein pointed out that the environmental community's support for the E-ZPass and value pricing programs was important, because it allowed the NJ Turnpike Authority to implement its capital program. Mr. Gross did not make the mistake which the NJ Turnpike Authority had made in 1991 when its large toll increases (70 percent for car drivers and 100 percent for truckers) were met with widespread opposition from the trucking industry which then diverted truck traffic to the state roadways in retribution for the toll increase. State government was kept fully apprised of the program and its implementation was carried out in coordination with Governor Whitman's office. Mr. Weinstein believes that "this was as smooth a toll increase as you are going to see."

Media Coverage

This section focuses on the written media's portrayal, in articles and editorial comments, of the value pricing implementation strategy as it relates to the NJ Turnpike Authority, state government, various stakeholders, and the general public, including coverage of the public hearings. It also considers whether the media's coverage of the value pricing implementation strategy incorporated the disparate views of opinion leaders, decision-makers and the general public. A web-based search for articles from the printed media found that there were at least 19 articles in *The Star Ledger*, 19 articles in *The Record*, nine articles in *The New York Times*, three articles in *The Courier News*, and four articles in *The Press of Atlantic City* that included references to the NJ Turnpike Authority's value pricing program. The majority of the articles preceded the first toll increase at the end of September 2000 (18 articles in *The Star Ledger*, 16 articles in *The Record*, seven articles in *The New York Times*, two articles in *The Courier News*, and three articles in *The Press of Atlantic City*); the second toll increase of January 2003, when the value pricing program was deepened, received sparse coverage.

The written media provided comprehensive coverage of the NJ Turnpike Authority's long term financing program, focusing on all the elements of the program—the toll increases, the financial plan, the introduction of E-ZPass, and the value pricing initiative. For the most part, coverage of the value pricing element was discussed either together with other elements of the long term financial plan or with the pending introduction of E-ZPass; it was seldom the focus of an entire article. Only 4 articles in *The Star Ledger*, 5 articles in *The Record*, and 1 article in *The Press of Atlantic City* dealt at length with the value pricing element.

<u>The NJ Turnpike Authority</u>

Officials of the NJ Turnpike Authority who were quoted in the printed media portrayed the value pricing initiative as a modest and fair program intended to encourage off peak driving rather than to penalize those who drive in the peak period. In June 1998, when the value pricing program was first mentioned, both *The Star Ledger* and *The Record* in articles devoted entirely to the value pricing idea, reported that John Haley Jr., the Transportation Commissioner, emphasized off peak toll discounts rather than rush-hour toll hikes[(116)] Edward Gross was quoted as saying that "the idea is to create a better balance of traffic," and that the NJ Turnpike Authority was investigating how many drivers have the flexibility to change their motoring hours[(117)].

The value pricing initiative was raised again one year later when the same themes were picked up, although in the interim a number of articles appeared in *The Star Ledger, The New York Times*, and *The Record* dealing with possible toll hikes by the NJ Turnpike Authority to fund construction projects. In June 1999, *The Star Ledger* and *The Record,* in articles devoted entirely to the value pricing idea, again quoted Mr. Gross as saying that there was a need to create a better balance of traffic. *The Record* also reported that Mr. Gross conceded that the value pricing program would penalize truckers and, thus, would be implemented for cars only. He explained that car drivers have more flexibility in their travel schedules than truckers [(118)]. The NJ Turnpike Authority's modest program was also raised in *The Star Ledger* which quoted Mr. Gross as saying that "our initial program will be modest. I want the public to get comfortable with different prices at different times of day."[(119)]

The next set of articles referencing the value pricing element appeared in both *The Star Ledger* and *The Record* in November 1999. These articles focused on the NJ Turnpike Authority's proposal to increase tolls as part of its financial plan; the value pricing element received limited attention. Discussion of the value pricing element stressed the 'fairness' of the program and the value that off peak period car drivers would derive. *The Star Ledger* quoted Mr. Gross as conceding that while the variable pricing program was controversial, it was fair and that the difference was not so large as to penalize motorists who must travel during peak times. These drivers would benefit from less traffic during the peak periods, because the off peak toll discount would encourage others to change their drive times [(120)]. In *The Record*, Mr. Gross was quoted as relating the value pricing program to the larger financial plan: "we need to do things differently, be creative and to some extent controversial, but if you do it right, you can support the infrastructure and meet the demand for the next 20 years."[(121)] Both papers also quoted Mr. Weinstein: "if this works as we believe it will, and it helps alleviate congestion, I would suggest … the small increase (in tolls for E-ZPass users) would be more than paid for by the time and aggravation saved."[(122)]

In the months immediately after November 1999, the printed media's coverage focused on the approval process for the NJ Turnpike Authority's financial plan. These included the public hearings, the meetings of the commissioners of the NJ Turnpike Authority and the position of the Governor at the time, Christie Whitman. *The Star Ledger* also reported that the E-ZPass program was behind schedule and that this would delay the implementation of the toll hikes [(123)]. Although there were some references to the value pricing element during this period, there was no coverage of the NJ Turnpike Authority's value pricing implementation strategy until September 2000, just prior to the first toll increase.

With the concurrent implementation of E-ZPass, the September articles focused on explaining the new travel arrangements that would be necessary because of the implementation of E-ZPass system and the responses to the pending toll increases. Reference to the value pricing element once again highlighted the modest introduction of the program. *The New York Times* quoted Mr. Gross for the first time: "we're very excited about this new feature and we hope the public agrees that this will make everyone's life easier."[(124)] Mr. Gross was also quoted in *The Star Ledger*: "I embarked on a very modest beginning for value pricing because I wanted the public to become acquainted with the program and the way it works, I wanted the public to get to like the program. It's true, the greater the differential in price, the more effective value pricing is, but the greater the differential, the greater the potential for problems with gaining public acceptance."[(125)] Media coverage in the printed media of the value pricing element essentially ceased after October 2000, until just prior to the second toll hike.

Before the second toll increase, a new Governor took office, James McGreevy, as well as a new Commissioner of Transportation and a new Executive Director of the NJ Turnpike Authority. Despite the fact that the value pricing differential grew in the second toll increase, of the few articles that appeared either just prior to the second toll hike in January 2003, or immediately thereafter, none referred explicitly to the value pricing element. The articles in *The Star Ledger*, *The Record* and *The New York Times* focused on the price hike. Typical of the article headings was one from *The Record* of

December 29, 2002—"Trips on turnpike will get costlier: Second of 2 hikes takes effect New Year's."(125) The only reference to the value pricing element is a phrase stating that "the rate increases vary according to time of day and other factors." Explanations for varying the toll price by time of day no longer referred to the value pricing program but, instead, described the price variations as an attempt to encourage the use of E-ZPass. For example, Jamie Fox, the Transportation Commissioner at the time, was quoted in *The Star Ledger* as saying that "it's always good policy to encourage more people to use E-ZPass because it eases congestion and reduces pollution." (126) Another example of the NJ Turnpike Authority's position was a quotation in *The New York Times* by Joe Orlando, the spokesperson for the NJ Turnpike Authority. Explaining that the higher rate increase for cash paying drivers was intended to help ease traffic flows, Mr. Orlando was quoted as saying that "that was the original plan: to drive people to E-ZPass."(127)

Editorial Opinion

The written media's view of the NJ Turnpike Authority's value pricing program can be assessed from a number of editorial opinions that were written in *The Star Ledger* and *The Record*. Initially both *The Star Ledger* and *The Record* raised questions about the program. However, once the program was about to be implemented, both newspapers effectively endorsed the value pricing element.

In July 1999, an editorial in *The Star Ledger* questioned the variable pricing plan which would create off-peak discounts rather than rush-hour hikes. "If this is the way to go, show us. Demonstrate, without equivocation that this is a good deal for all Garden State residents. Show us that research demonstrates this is a good thing for New Jersey."(128) An editorial in *The Record* in November 1999, while stating that the use of E-ZPass discounts should alleviate backup at the toll booths, raised similar questions: "If the purpose is to reduce rush hour traffic, why should trucks pay the same during peak and non-peak hours? … Is it fair for drivers of cars using E-ZPass to have to pay more during rush hours, when many have no alternative but to drive at that time?"(129)

In December 1999, however, *The Star Ledger* had a more accepting tone: "There will be no initial fare hike, and a smaller one down the pike, for E-ZPass users who make their trips during the off peak hours. That might help unclog the road during rush hours."(130) *The Record* was even stronger in its support: "the plan, including the variable-pricing component, seems well-designed and doable."(131) And, in September 2000, just prior to the implementation of the value pricing program, *The Record* endorsed the initiative: "the concept makes all the sense in the world. You expect to pay a higher rent for a cottage at the shore in July and August than in June or September. …."(132)

Stakeholders Representation

The printed media covered the respective positions of various stakeholders, quoting from both supporters and critics of the value pricing initiative. For the most part, quotations from both supporters and critics did not deviate from their preconceived position on value pricing. Occasionally, critics received more coverage than supporters, probably because the media sought their responses to the position of the NJ Turnpike Authority and the NJ DOT.

Responses typical of the critics of the value pricing initiative were those voiced by Steve Carrellas, head of the state chapter of the National Motorists Association, and by Pam Fisher, a lobbyist for the New Jersey Automobile Club. In June 1999, when the value pricing program was first publicized, *The Record* quoted Mr. Carrellas as saying that "calling it value pricing makes it seem more like a benefit than a punishment. But really it's a punishment."(133) Ms. Fisher was quoted in *The New York Times* as saying that she was apprehensive about congestion pricing: "nobody gets in their car and thinks this is a peak or nonpeak hour. Most people who are working don't have that flexibility. So it is kind of discriminatory against people who can't adjust their work schedules."(134)

Responses typical of the supporters of the value pricing initiative were those voiced by Janine Bauer, the executive director of the Tri-State Transportation Campaign at the time, and by Jeffrey Zupan, a senior fellow at the Regional Plan Association. Ms. Bauer was quoted as saying that “value pricing will benefit motorists by reducing traffic.” She said that even the modest price difference should result in a decrease in rush-hour traffic.[135] In response to an article in *The New York Times*, that raised reservations about the initiative, Mr. Zupan acknowledged that “what the New Jersey Turnpike is doing is very timid, but then again, it’s a toehold.”[136] On another occasion, *The Star Ledger* made a more general comment, noting the backing the value pricing initiative received from groups that support mass transit and other environmentally friendly transportation strategies, such as the Tri-State Transportation Campaign, Sierra Club, and the New Jersey Association of Railroad Passengers.[137]

One stakeholder whose position seemed to undergo change over time was the New Jersey Motor Truck Association. Initially, the media reported the opposition of the New Jersey Motor Truck Association to the value pricing initiative. In November 1999, *The Record* quoted Sam Cunninghame, the executive director of the New Jersey Motor Truck Association: “the producers and users set the schedules and we have to deliver when they say.”[138] However, in an article a few days later *The Record* noted that the “financial plan got warm reviews from the New Jersey Motor Truck Association, the New Jersey Alliance for Action, and the Regional Planning Association.”[139] By the time the value pricing initiative was about to be implemented, Mr. Cunninghame seemed to have toned down his opposition: “with the volume discount and the E-ZPass discount, the increase should not be that much of a problem for the trucks.”[140]

Both *The Star Ledger* and *The Record* publicized the opposition the initiative received from Democrats in state government. The headline in *The Record* in November made it clear that the two parties were on opposing sides on this issue.[140] *The Star Ledger* quoted Senate Minority Leader Richard J. Codey (D-Essex) as saying that the idea is fundamentally flawed: “the problem is, people who are forced to use the Turnpike to go to and from work are going to be penalized. That’s wrong. It’s regressive and it’s not good public policy.” As a counterpoint, they also quoted Alex DeCroce (R-Morris) who dismissed the Democratic criticism. He intimated that he was inclined to support both the hikes in general and variable pricing.[141] In September 2000, immediately prior to the implementation of the value pricing initiative, the opposition of the Democrats, especially to the variable pricing for off peak drivers was noted in *The Star Ledger*.(142)

Public Response

As *The Record* noted, the value pricing initiative may have been the most controversial of all the components of the plan, yet public opposition, for the most part, was muted. (143) The public's subdued response to The NJ Turnpike Authority's financial plan, of which the value pricing initiative was one element, was succinctly captured by Joe Malinconico of *The Star Ledger*. Immediately before the value pricing program was to be implemented, he wrote that few people were fuming over the planned toll increase because:

"…. this year there has been little organized opposition and no sign of a backlash. There are a lot of reasons for the absence of outrage. This year's increase is not as large as the 1991 hike, and the public is more resigned. An anti-toll citizens' group has focused its attention on the Garden State Parkway. The economy is strong and the Turnpike Authority has sold the hike as a way of paying for $917 million in capital improvements. In addition, the blow will be softened by the simultaneous debut of E-ZPass and a new off peak discount program."(144)

The Star Ledger periodically reported on random interviews they conducted with drivers on the NJ Turnpike who expressed dissatisfaction or opposition to the value pricing initiative. However, the printed media also reported that value pricing program was generally well received at the four public hearings that were held (two hearings in East Brunswick, one in Teaneck, and one in Mount Laurel): "the plan (financial) was largely supported during public hearings last month, but prompted some mixed reviews from drivers, environmentalists, and local officials."(145)

In June 1999, when the value pricing program was first publicized, *The Star Ledger* reported that "several drivers interviewed yesterday at the Turnpike's Thomas Edison Service Area in Woodbridge weren't so enthusiastic. ....many people don't have control over when they can drive, and have to travel during rush hours."(146) In November of that year, *The Star Ledger* again interviewed random drivers, reporting that "most motorists interviewed yesterday at the Turnpike's Thomas Edison Service Area in Woodbridge panned the idea of an increase. And several said they thought variable pricing was unfair."(147)

Of the four public hearings that were held, *The Record* reported briefly on the Teaneck hearing and *The New York Times* reported briefly on the Mount Laurel hearing. *The Record* noted that about 50 people attended the public hearing held in Teaneck: "reviews in Teaneck were decidedly mixed, ranging from bitter disapproval to impassioned support."(148) *The New York Times* reported that the majority of the people who attended the public hearing in Mount Laurel supported the increase. Only 12 of the 50 people who attended opposed the proposal.(148) *The Star Ledger* made no mention of public hearings.

There was very little coverage of the public's response at the time of the second increase in January 2003. *The Star Ledger* reported that "news of the upcoming Turnpike toll increase angered some motorists. The toll hike has not generated any opposition from various transportation watchdog organizations."(149) *The Record* reported that ".. it's catching motorists by surprise because it was approved nearly three years ago. But a lot of people, it seems, forgot about the second one."(149)

Selected Stakeholders' Perspectives

A number of telephone interviews were conducted with representatives of various stakeholder organizations that are active in regional transportation matters—the New Jersey Motor Truck Association, the New Jersey Automobile Club, the Regional Plan Association, and the Tri-State Transportation Campaign. Interviewees were asked to respond to questions dealing with their views on the NJ Turnpike Authority's value pricing program and the extent to which they participated in the implementation process.[4]

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[4] The same stakeholders interviewed in the NYU study were interviewed for this study, although it was not necessarily the same person who was interviewed.

New Jersey Motor Truck Association

Although the trucking industry was not affected by the NJ Turnpike Authority's value pricing program, Gail Toth, Executive Director of the New Jersey Motor Truck Association, explained why the truckers preferred not to participate in the value pricing program.[5] Ms. Toth claimed that the truckers have no control over when they use the NJ Turnpike—"we have to be on the road when customers want us." The result is that truck deliveries, in most cases, are not possible during the off peak periods in New Jersey. In addition, Ms. Toth maintained that the E-ZPass off peak period discount was not large enough to make it worthwhile for truckers to buy into the value pricing program. The costs of administering E-ZPass statements are greater than the savings that accrue from an E-ZPass discount.

Ms. Toth viewed the value pricing program "as another way to charge the trucking industry more money." She complained that the toll increases were introduced at a time when the economy was in decline and truckers were facing difficult circumstances. Because of the toll increases, truckers were forced off the NJ Turnpike and on to inner roads, such as Route 1. This was not in the best interest of the state. The truckers would prefer a significant volume discount (e.g. a 20 percent discount for volume users) as an incentive to use the NJ Turnpike rather than other state roads. Ms. Toth also felt that it was not fair that the revenue from the increase in tolls is used to pay for infrastructure improvements that do not directly benefit truckers. As an example, she pointed out that truckers are not allowed to use the Garden State Parkway, yet some of the revenue from the tolls on the NJ Turnpike will be used to repair the Driscoll Bridge. If there was to be real value in the value pricing program, then the truck lanes on the NJ Turnpike should be restricted to trucks and buses. Private cars should not be permitted in the truck lanes.

[5] Telephone interview February 6, 2004.

Despite her objections to the toll raises and the value of the value pricing program to truckers, Ms. Toth commended the operations of the NJ Turnpike Authority. She said that the NJ Turnpike is a better managed roadway system than any other system in the bi-state area. Since the toll hike in 1991, the NJ Turnpike Authority has tried its best to accommodate truckers; for example, it has provided cheaper diesel fuel, more food vendors, expanded parking slots at rest areas, and generally improved facilities for truckers. Ms Toth also pointed out that the smaller toll increases, such as those imposed in September 2000, and January 2003, which were implemented incrementally, were more accommodating than the 100 percent toll hike of 1991.

New Jersey Automobile Club

Pam Fisher, Vice-President, Public Affairs for the New Jersey Automobile Club, explained the reasoning behind the New Jersey Automobile Club's opposition to the NJ Turnpike Authority's value pricing program.[6] Ms. Fisher contended that value pricing "is not fair and appropriate transportation policy." Many drivers don't have control over their time of travel. Because they pay more in the peak period than in the off peak period, value pricing serves as a deterrent rather than as the incentive it should be. In Ms. Fisher's opinion, a fairer system would be one in which everyone pays the same toll irrespective of the time of day, but receives a discount for using E-ZPass. The discount provides the incentive for drivers to use E-ZPass. The New Jersey Automobile Club would support this approach because E-ZPass usage improves traffic flows.

Ms. Fisher said that the New Jersey Automobile Club has become more receptive to the use of value pricing programs. They are willing to examine programs on a case by case basis. Ms. Fisher pointed out that the Automobile Association of America has endorsed some of the value pricing schemes being used in California; for example, where the added roadway capacity gives drivers the choice to either pay more to use the uncongested new road or to use the existing congested road at no cost. The New Jersey Automobile Club, however, objects to the NJ Turnpike Authority's approach

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[6] Telephone interview February 5, 2004.

which instituted a value pricing program on an existing highway that does not provide a quicker alternative at a higher price.

Ms. Fisher does not recall that the NJ Turnpike Authority consulted with the New Jersey Automobile Club before it implemented the value pricing program. All that was left for the New Jersey Automobile Club to do was to deal with the NJ Turnpike Authority's decision to go ahead with the value pricing program. There are four New Jersey Automobile Clubs and it is possible that one of the clubs did respond to the NJ Turnpike Authority's decision. The New Jersey Automobile Club supports the position of the truckers that they should be given a discount for using the NJ Turnpike. Truckers need an incentive to use the NJ Turnpike in order to keep them off other state roads.

The New Jersey Automobile Club conducted extensive member outreach at the time the NJ Turnpike Authority announced its intention to implement the value pricing program. It informed its members that the New Jersey Automobile Club was not a supporter of the value pricing program, although they did tell members that they supported the E-ZPass system and discounts for E-ZPass users.

Regional Planning Association

Jeffrey Zupan, Senior Fellow for Transportation at the Regional Plan Association (RPA) said that the RPA has long been a proponent of congestion pricing.[7] The Third Regional Plan recommended the adoption of varying price by time of day using electronic tolls as a way to reduce traffic flows during the congested periods of the day. Mr. Zupan is gratified that the NJ Turnpike Authority implemented a value pricing program, albeit a little timidly. His only criticism is that the difference between the peak and off peak periods was not large enough, although he did note that after the second toll increase in January 2003, the differential grew larger (from 8 percent to 14 percent).

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[7] Telephone interview February 11, 2004.

Mr. Zupan was generally impressed with the NJ Turnpike Authority's implementation strategy. In his words, "it was a soft sell." According to Mr. Zupan, Mr. Gross believed in the value pricing concept, he succeeded in getting it implemented, and "we should be thankful to him." Mr. Gross did not want to make waves and was successful in bringing "the program in under the radar screen." Mr Zupan maintains that while it is true that the value pricing program discriminates against those people who have no choice but to travel during the peak period, this is the price these drivers need to pay to make use of peak capacity. It is a question of demand and supply. By shifting people off the peak, it will make it less necessary to expand the transportation infrastructure. The cost savings will ultimately benefit all drivers.

Mr. Zupan pointed out that the NJ Turnpike Authority has an advantage over both the Port Authority of New York and New Jersey and the Garden State Parkway in that its users are so diffused that there is no easily organized opposition to its toll increases. Only the truckers are easily organized. Mr. Zupan expressed doubt that drivers really notice the small differences in tolls between the peak and off peak periods. In addition, since the toll is charged to the driver's E-ZPass account and not paid out of pocket, drivers are even less likely to be cognizant of the premium they are being charged for driving in the peak.

Mr Zupan thinks that the NJ Turnpike Authority should make a greater effort to notify the public that driving in the peak period costs more than in the off peak period. He endorses an idea, originally proposed by Janine Bauer, formally Executive Director of the Tri-State Transportation Campaign, that peak period drivers should be told as they pass through the toll station that they could have saved money had they made the trip during the off peak period. For example, an overhead flashing sign could indicate the amount the driver would have saved if the trip had been made in the off peak period. If the saving is hidden from the public, then the cost differential is not going to have the desired impact of diverting traffic to the off peak period.

Tri-State Transportation Campaign

Jonathan Orcutt, the Executive Director of the Tri-State Transportation Campaign, commended the "bravery" of the NJ Turnpike Authority for being the first to introduce a road pricing program in the region.[8] He believes that by being the first in the region, the NJ Turnpike Authority's value pricing program paved the way for the Port Authority of New York and New Jersey to subsequently introduce its value pricing program at the trans-Hudson bridges and tunnels. Together the actions of these two agencies are responsible for "a significant experiment in road pricing on the East Coast".

Mr. Orcutt thinks that the NJ Turnpike Authority did a good job in promoting the value pricing program: "they got their message out." He believes that although some of the effectiveness of the implementation strategy may have been lost in the concurrent toll increase, the politics of the region are such that a value pricing program can only be successfully introduced in the context of a toll increase. Mr. Gross adopted the correct strategy when he convinced state government of the need for a capital program that would provide infrastructure improvements to the NJ Turnpike. The public would not have bought into the value pricing program if the value pricing implementation strategy had focused on convincing the public that it would reduce congestion.

The Tri-State Transportation Campaign actively campaigned for a value pricing program. At the time that the NJ Turnpike Authority was considering a toll increase, members of the Tri-State Transportation Campaign met with the Commissioner of Transportation at the time, James Weinstein, and proposed to him that the NJ Turnpike Authority use the toll increase as an opportunity to introduce value pricing in the region. Mr. Orcutt believes that Mr. Weinstein accepted their argument.

Mr. Orcutt believes that the purpose of the NJ Turnpike Authority's value pricing program was not to move every driver out of the peak period, but to persuade a small percentage of drivers to shift to the off peak period. In this way, some improvement in

[8] Telephone interview October 7, 2004.

peak travel flows would occur. Unlike a flat toll increase, the value pricing program provides a benefit for everybody. Those drivers who are able to shift to the off peak period receive a toll discount, while those who continue to drive in the peak period encounter either less traffic or, at least, peak period traffic conditions that are not getting worse.

Mr. Orcutt pointed out that there is a drawback with the E-ZPass system in that E-ZPass users are less sensitive to the price signal because E-ZPass statements do not point out the savings received for traveling in the off peak period. He feels that the NJ Turnpike Authority should make greater effort to demonstrate to E-ZPass users the benefits of driving in the off peak period. They could also do a better job advertising the value pricing program.

Terminology

In evaluating the acceptability of the NJ Turnpike Authority's value pricing program to opinion leaders and decision makers, it is also necessary to examine how the NJ Turnpike Authority described the term value pricing and the extent to which the NJ Turnpike Authority differentiated between the term value pricing and various other pricing policies. The media's and stakeholders' understanding of the concept of value pricing as expressed in media coverage and stakeholder responses in the interviews are likely to be a function of the NJ Turnpike Authority's clarity in defining its preferred term. Successful marketing of a value pricing program requires a distinct brand image which the driving public understands and accepts.

A number of different terms are used to describe road pricing programs—value pricing, variable pricing (differential pricing), congestion pricing, dynamic pricing, and time of day pricing. Each pricing program is defined differently and, thus, has different implications. Value pricing implies that a choice exists between a congested and less congested roadway, "the idea being that one has the opportunity to pay to get extra value".[(150)] Variable pricing (differential pricing) is time of day pricing and tolls that vary by other factors like facility location, season, day of week, or air quality impact.[(151)] In the case of congestion pricing, drivers are charged "a fee that varies with the level of traffic on a congested roadway."[151] Dynamic pricing is similar to variable pricing; however, tolls vary in response to changing congestion levels, rather than following a fixed schedule as in variable pricing.[151] Time of day pricing implies "facility tolls that vary by time of day in response to varying congestion levels. Typically, such tolls are higher during peak periods when congestion is most severe."[151]

NJ Turnpike Authority

Edward Gross explained that he tried to be consistent in the term he used when talking to the media or making public presentations about the pricing program because he realized that each of the different terms—value pricing, variable pricing and congestion pricing—implied something different. His preference was to use the term variable pricing because it is the "more neutral" of the three terms. Variable pricing "gives the traveling public the option to use the Turnpike in a less congested period at a lower toll." Mr. Gross was reluctant to use either value pricing or congestion pricing. He felt that value pricing suggested that "at certain times a driver would not receive value," while congestion pricing suggested that "there was a penalty for driving in the peak period when conditions were congested."

Despite Mr. Gross' preference for the term variable pricing, the NJ Turnpike Authority was not consistent in its use of a term to describe its pricing initiative. In its official publications, the NJ Turnpike Authority used both variable and value pricing. In its 1999 Annual Report, the NJ Turnpike Authority used the term variable pricing, which it defined as "an innovative traffic management tool (that) encourages motorists who do not need to travel during peak hours to modify their behavior, and to travel during off peak hours when the road is underutilized. In return, the toll adjustment is reduced or eliminated."[152] In its 2000 Annual Report, the term value pricing was used. It was defined as providing "an incentive for motorists who do not need to travel during the peak hours, to take advantage of the less congested off peak periods and pay a reduced toll."[153]

NJ Department of Transportation

Mr. Weinstein could not recall which of the three terms—value pricing, congestion pricing, or variable pricing—was used to describe the NJ Turnpike Authority's pricing program. While he thought the three terms could be used interchangeably, he felt that variable pricing is "a pretty black and white way of describing it."

Media Coverage

The written media was undifferentiating in its use of the different terms to describe the NJ Turnpike Authority's pricing initiative. There is little evidence that Mr. Gross' preference for the term variable pricing was adopted by the media in its coverage. The media did not distinguish between the four terms they used to describe the NJ Turnpike Authority's pricing initiative—value pricing, variable pricing, congestion pricing, and off peak pricing. Sometimes, a reporter used more than one term in the same article to describe the pricing initiative and, sometimes, the same reporter used one term in one article and a different term in another article to describe the pricing initiative. The media's lack of differentiation between value pricing, variable pricing, congestion pricing, and off peak pricing meant that one definition was applied to the three terms. However, from one article to the next the definition was not consistent. Thus, by September 2000, when the NJ Turnpike Authority's pricing policy program was implemented, the four terms were being used interchangeably and their meanings were not consistent from one article to the next.

When the NJ Turnpike Authority's intention to introduce a pricing policy for the Turnpike was first mentioned in June 1998, Paul Wyckoff, in an article in *The Star Ledger,* used the terms congestion pricing and value pricing to describe the program. He wrote that "the New Jersey Turnpike Authority is considering a plan … ..called 'congestion pricing' or 'value pricing'[(154)] In an article in June of the following year, Mr. Wyckoff quotes Mr. Gross as saying that "someday, when the Turnpike is prepared to adjust its toll, it will be prepared to introduce meaningful variable pricing," the purpose of which, "is to encourage better use of the off-commuter hours and create a better balance of traffic."[(155)] Notwithstanding Mr. Gross' use of the term variable pricing, Mr. Wyckoff in the next paragraph equates the term variable pricing with value pricing and congestion pricing. He writes that "changing the tolls according to the time of day – a system also known as value or congestion pricing … ."[155] Then, in November of 1999, in an article describing the NJ Turnpike Authority's plan to introduce toll hikes in 2001, Mr. Wyckoff wrote that a system of variable pricing will be created for E-ZPass users.[155] But, in January 2000, Mr. Wyckoff reverted to using the term value pricing as the story headline notes "…. but E-ZPass users will get significant discounts, and the plan makes the Turnpike the first major toll road in the country to offer value pricing, …."[156]

Not only did Paul Wyckoff's coverage in *The Star Ledger* not distinguish between value pricing, variable pricing or congestion pricing, he was also not consistent in his definitions of the various pricing programs. In a June 1998 article, when he first reported on the NJ Turnpike's Authority's consideration of the pricing initiative, Mr. Wyckoff defined both congestion pricing and value pricing in the same way. He wrote that they "…. tailor pricing to the time of day, one that could charge higher tolls during periods of heavy highway congestion or a few bucks less during off peak hours."[157] In a June 1999 article, however, Mr. Wyckoff broadened the definition of value pricing to include the benefits that accrue from the system: "…. as a way to spread out traffic, without the cost and environmental challenges of building new highways."[157] This definition underscores the social value not the personal value that will be derived from the benefits to the system.

After the introduction of the value pricing program in September 2000, the terms value variable, congestion, and off peak pricing were no longer used in articles in *The Star Ledger*. A December 2000 article used the term 'E-ZPass discounts': "The Turnpike also offered discounts for drivers with electronic tolls when it began E-ZPass operation in September, in tandem with a toll hike."[158] Similar language was used in a December 2002 article immediately prior to the second toll hike in January 2003: "for the second time in three years, the New Jersey Turnpike Authority is raising its tolls, imposing an increase that goes into effect Wednesday and expands the highway's discount for E-ZPass."[159]

Coverage in *The New York Times* was equally undiscriminating in the choice of terms, using both congestion pricing and variable pricing to describe the NJ Turnpike Authority's pricing initiative. David Halbfinger, in a November 1999 article outlining the proposed toll increases on the NJ Turnpike, used the term congestion pricing: "the new toll structure, if adopted, would constitute the largest introduction yet of what is known as congestion pricing, …" Mr. Halbfinger's definition of congestion pricing as a toll structure "… in which rush-hour road space is treated as a scarce commodity and priced accordingly .." may be consistent with idea of congestion pricing. However, it is not consistent with Mr. Gross' preference not to use a term that suggests penalizing the driver for driving during the peak period.(160) In a September 2000 article a few weeks prior to the introduction of the NJ Turnpike Authority's pricing initiative, Andrew Jacobs used the term variable pricing: " …. it (E-ZPass) allows the turnpike to become the nation's first major highway to use so-called variable pricing."(161) His definition of variable pricing as a "system that rewards drivers who avoid rush hour by charging them lower tolls,"(162) is similar to the definition preferred by Mr. Gross.

Interestingly, in two articles in *The New York Times*, the first on the day the first toll increase went into effect and the second two days thereafter, the words value (or variable or congestion) pricing are not referenced.(163,164) Although the first of the two articles mentioned that the higher tolls were intended to increase travel during the off peak period when the NJ Turnpike's capacity is under utilized, it does not assign a term to the pricing initiative.(165)

Articles in *The Record* also do not differentiate between the three terms—value pricing, variable pricing and congestion pricing. *The Record* was the first of the region's newspapers to write about the possibility of a new pricing system for New Jersey's three highways (NJ Turnpike, Garden State Parkway, and the Atlantic City Expressway). In its initial articles, the term congestion pricing is used. Already in 1995, Frank Wilson, the Commissioner of Department of Transportation at the time, referred to this new system as congestion pricing. He is quoted as saying that "…'congestion pricing' may be implemented, under which tolls are higher during the rush hour and lower during the off peak hours."[166] In June 1998, the term congestion pricing is again used when the Commissioner of Transportation at that time, John Haley, is reported to have said that congestion pricing should take the form of discounted off peak travel rather than higher rush-hour tolls.[167] Whereas Mr. Wilson's notion of congestion pricing emphasized higher tolls during the rush hour, Mr. Haley stressed the discount that would be received for traveling in the off peak period.

Once the pricing initiative of the NJ Turnpike Authority became specific, articles in *The Record* used the different terms interchangeably. In a June 1999 article, Doug Most equated value pricing and congestion pricing when he wrote that "the goal of value pricing, also known as congestion pricing, is to offer an incentive to use the highway at a less busy time, reducing traffic and shortening backups at toll barriers."[168] Mr. Most's definition is similar to the one preferred by Mr. Gross, but no mention is made of the term variable pricing, which Mr. Gross preferred. In fact, in this article Mr. Most attributed the term value pricing to Mr. Gross: "whenever the turnpike deems it's appropriate for a toll adjustment, we can expect value pricing."[169] Subsequent articles, also used the terms value and congestion pricing interchangeably. However, the day before the toll increases were to take effect, Pat Gilbert, who in earlier articles used both value pricing and congestion pricing, referred to the system as variable pricing: "… and an unprecedented variable-pricing system are put into place."[170]

The lack of coordination on which term was to be used in describing the pricing program is also seen in quotes attributed to Mr. Weinstein. *The Record* quoted Mr. Weinstein using the term value pricing: "Not a lot of us have discretion in when we can go to work. But if we can get people out of the mix during those peak hours, an 8 percent increase could be well worth it. That's why it's called value pricing."[171]

Selected Stakeholders' Perspectives

Although Ms. Toth, of the New Jersey Motor Truck Association, acknowledged that the goal of the pricing program was to encourage drivers to use the off peak period, from her perspective, irrespective of the term, the consequence was that the cost of driving for truckers was going to increase. Ms. Fisher, of the Automobile Club of New Jersey, mentioned that the different terms are very similar. Congestion pricing has sanctioning overtones and variable pricing is similar to congestion pricing but is based on when you can travel. Ms. Fisher associated value pricing with new roadways such as those built in California where new capacity was added. Drivers have a choice between paying a toll to use the new roadway or to driving on the older highway at no cost.

Mr. Zupan, of the Regional Planning Association, explained that there is a problem with the terminology because no single phrase captures the full meaning. Value pricing means a driver pays more in order to receive greater value. Congestion pricing indicates the reason for instituting the program, which is to relieve congestion. Mr. Zupan prefers a longer explanation which he uses when explaining the concept to lay public. He uses the term variable time of day pricing and explains that the idea is to encourage some people to switch to a less congested period. On the other hand, Mr. Orcutt, of the Tri-State Transportation Campaign, does not distinguish between the different terms. For Mr. Orcutt, what is important is that a price signal is used to modulate traffic flows and to shift traffic from the peak to the off peak periods. This is true of all the road pricing tools irrespective of the actual term used.

CONCLUSION

Operationally, the NJ Turnpike Authority's value pricing was successfully introduced with minimal opposition from the public or various stakeholders. As Mr. Gross noted, "the real sleeper was variable pricing and this may have been the number one accomplishment of the (long term financing plan) program." However, the question whether the value pricing element was, in fact, the number one accomplishment of the Authority's long term financing program, as Mr. Gross noted, requires evaluation. Specifically, the question needs to be asked whether the price differentials of the value pricing program succeeded in their goal to shift traffic from the peak to the off-peak period.

The NJ Turnpike Authority's value pricing program was packaged within a larger package—a toll increase, an investment plan and the introduction of E-ZPass with pricing discounts for users. (Mr. Gross noted that the E-ZPass discount may not have been necessary. However, because all the other metropolitan area toll authorities that had implemented an E-ZPass system prior to the NJ Turnpike Authority had included it, he was also obliged to do so.) Although the value pricing initiative was potentially the most controversial element in the overall packages, it shared media attention with the toll increase and the introduction of E-ZPass, thereby diluting its impact on the public. This action, no doubt, was not unintentional on the part of the NJ Turnpike Authority. By making value pricing the 'sleeper' of the long term financing plan, the NJ Turnpike Authority chose to forego a major initiative to educate opinion leaders, decision makers and the general public on the 'value' of the value pricing initiative.

In comparison, the introduction of the E-ZPass program received much attention and media focus. E-ZPass usage increased steadily and approximately 70 percent of all NJ Turnpike users subscribe to E-ZPass. In early 2002, when the administration changed both at the NJ Turnpike Authority and the NJ Department of Transportation, the thrust of the pricing program was reframed as an E-ZPass discount and the value pricing program was given little publicity. Now the NJ Turnpike Authority has decided to eliminate the E-ZPass discount.

Before and after disaggregate analysis of NJ Turnpike Authority traffic toll data for the period October 2002 to March 2003, three months before and three months after the second stage of the value pricing program, showed that a little more than half of E-ZPass users preferred the peak period even although tolls were higher.[9] Their

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[9] This information is taken from the larger study which analyzed users' behavioral changes as a consequence of the implementation of value pricing. See: Ozbay, Kaan, Ozlem Yanmaz-Tuzel, and Jose Holguin-Veras, "Analysis of the Observed Behavior of Users to Value Pricing and Travel time: The New Jersey Turnpike Case," Paper presented at the Annual TRB Conference in Washington D.C., January, 2005.

preference for peak period travel seems to indicate that minimization of travel times and avoiding congestion were more important for E-ZPass users than the cost saving from the lower off-peak toll. The small price differential of the value pricing program, within the overall cost of most NJ Turnpike trips, does not appear to have induced a significant shift from the peak to the off-peak period.

Based on the larger study findings that travel time differences between different periods had more affect on user behavior than toll prices, it might be desirable to replace the value pricing program based on a price differential between the peak and off-peak periods with a true value pricing program that asks motorists to pay a premium for a speedier, more reliable service. One approach would be to charge a premium for use of the E-ZPass Express lanes that have been and will be introduced on both the NJ Turnpike and the Garden State Parkway. This approach would be in accord with user preferences and also generate higher revenue.

CHAPTER VIII- COMPARATIVE ANALYSES OF TOLL POLICIES IN THE U.S.

INTRODUCTION

Since Vickrey's seminal work [172] road pricing has been increasingly recognized as an important transportation demand management tool that leads to an optimal allocation of resources. The potential role of road pricing for both demand management and revenue generation has led to multiyear federal initiatives in the United States (US) aimed at increasing the level of implementation of road pricing and other forms of market based mechanisms, referred to in the U.S. as Time of Day Pricing. There is compelling evidence that shows indeed that collecting tolls on public roads lead to better maintained roads, where new roadway capacity is built sooner. On congested roads, collecting tolls has proven to allocate the demand more efficiently, reducing the amount of traffic on the highly demanded roads. In a context in which the relative importance of the fuel tax—that for decades has funded road construction and capacity improvements in the US—is declining, road pricing is likely to have an increasing role as a revenue generation tool, though it is realistic to assume that its role will be limited to the links with the heaviest traffic.

It is also clear that in order for road pricing to fulfill its role, as either a transportation demand management tool and/or a revenue generation mechanism, the actual tolls have to be set in accordance with economic theory. Theoretically, one can compute the optimal or fair toll rates by computing the marginal costs produced by vehicles. Vickrey [172] and Small [173], among others, state that the difference between the average cost and the marginal cost curves at a given traffic flow level reflects the optimal tolls. A fundamental principle is that the tolls for each vehicle type should be proportional to the impacts it produces. Since each vehicle type produces different amount of externalities (e.g., congestion, pollution) the marginal costs should be computed for each vehicle class. In the ideal condition, an optimal toll should take into consideration the entire set of conditions at each facility. This necessitates taking into account the nature of the underlying cost functions, particularly the marginal cost function, which is a reflection of the vehicular capacity, vehicle mix, congestion levels, pavement conditions, among other factors; and the corresponding demand patterns (e.g., traffic levels, price elasticities). Since these variables change with time of day, it follows that an ideal road pricing scheme should be dynamic, so that it is able to adjust tolls as traffic conditions change. Another important factor in reality is the toll authority's unique objectives.

At last count, there are 334 toll facilities in the U.S., which is probably the largest number of toll facilities in the world These facilities represent a wide range of conditions, from hyper-congested facilities in large metropolitan areas such as New York City; to toll highways in rural areas. The toll structures are equally diverse, ranging from multi-tier price structures with frequent user discount, carpool discounts, time of day discounts, and the like; to simpler structures in which the only differentiation is made on the basis of the number of axles per vehicle. The toll rates are typically set by the agencies that operate or own the toll facilities. The rules or formulas by which these tolls are determined are not generally available to the public, though it is safe to say that toll decisions are made taking into account technical considerations, as well as the all important criterion of political acceptability. However, data on toll rates and how they change by vehicle types and some other attributes are readily available.

Although it is not possible to study toll policy at individual facilities, by analyzing the overall patterns of tolls one could have a general understanding of the salient aspects of toll policies across the US. The aim of this chapter is to analyze toll data from various facilities across the US to gain insights into the overall factors affecting the toll rates, to identify any common features among toll agencies across the entire US. The literature review conducted confirmed that this is the first time such research has been conducted. The contributions of such research could be important, because it could be the first step toward an analysis of the efficiency of current toll policies, though computing optimal tolls is beyond the scope of this chapter.

The toll data are collected from various toll facilities across the US. A total of 334 toll facilities were identified, among which a random sample with 83 observations was selected. The toll data for the sample, which include toll rates for passenger cars, buses, and three different truck types, were assembled mainly from the available information on the web sites of various toll agencies. The dataset includes different kinds of facilities: 40 bridges, 35 highways, and 8 tunnels. About 70 percent of these facilities have some form of electronic toll collection (ETC) system. The dataset also includes the ETC toll rates for these facilities.

To understand the key features of the toll policy in the US, several references were examined. The history of toll policies on highways and bridges and the benefits from toll collection are discussed in CBO [(174)]. The document argues that collecting tolls on public roads and bridges resulted in a more efficient allocation of resources compared with the past when the policies were against toll collection. The Federal Highway Cost Allocation Study [(175)] and its 2000 addendum [(176)] give an overview of the highway related costs each vehicle type produces and the actual cost that were allocated to different vehicle types. Levinson and Gillen [(177)] also analyze all of the possible costs related to intercity highway transportation by each vehicle type in detail.

The next section provides a brief description of the data collection method which is followed by the descriptive analysis of the dataset. Following section presents the estimated models that explore the important factors that affect the toll rates. Finally, the conclusions are provided in the last section.

DATA COLLECTION

The first step in the research was to assemble a comprehensive list of all toll facilities in the U.S. Two main sources were used for that purpose: a report by Federal Highway Administration [(178)]; and a website that provides a list of toll authorities [(179)]. Table 82 shows the breakdown of all 334 different toll facilities that were identified. A random sample of 83 toll facilities was drawn from this population for a detailed data collection process. The authors identified a number of key attributes to be collected for each one of these observations: toll amount, vehicle type, facility type, payment method, time of travel (if toll rates change by time of the day), trip distance (if applicable), and geographic location. All these attributes and the notation adopted in the paper to denote these attributes are shown in Table 83.

Table 82. The population of identified toll facilities

Facility Type	Number of toll facilities	% of total facilities	Number with ETC	% with ETC
Bridge	177	53.00	55	31.07
Highway	143	42.81	85	59.44
Tunnel	13	3.89	9	69.23
Bridge/Tunnel	1	0.30	0	0.00
Total	334	100	149	44.61

Table 83. Attributes for data collection

Characteristic	Variable Name	Definition
Facility Type	DB	Bridge
	DT	Tunnel
	DH	Highway
Vehicle Type	DMC	Motorcycle
	DCP	Carpool
	DPC	Passenger Car
	DBUS	Bus
	DSUT	Single Unit Truck (small truck 2 axles)
	DST	Semi trailer (truck 5 axles)
	DLCV	Large Combination vehicle (large truck 6 axles)
Distance of Travel	DIST	Distance Traveled (for highway)
Method of Payment	DC	Cash Toll
	DETC	ETC Toll
Discount Programs	DFREQ	Frequent User Discount
	DHOV	High Occupancy Vehicle Discount
Travel Time	DALL	Toll is same throughout the day
	DOP	Off-Peak Discount Rate
	DAP	AM and PM Peak Rates
	DON	Overnight Discount Rate
Geographic Location	NE	North East
	SE	South East
	MW	Mid West
	SW	South West
	W	West
Other	TD	Toll Direction
	PC_SUT	Passenger Car and Single Unit Truck with same rate

Note: variables starting with “D” are binary variable, equal to one if they meet the corresponding definition.

Most of the toll data were collected from the websites of the toll agencies. In some instances, when the required information was not available on the websites or when there were major ambiguities with the data provided on the websites, the toll agencies were contacted by telephone to gather the information needed. Since several toll agencies among the 83 observations do not have a website at all, obtaining data became prohibitive for these toll facilities. These were replaced by new observations drawn from the master list of toll facilities. Among the 83 final observations, there were 40 bridges, 35 highways, and 8 tunnels. About 70 percent of these facilities had some form of an electronic toll collection (ETC) system. 49.5 percent of the observations were from Northeast, 14.5 percent of the observations were from Southeast, also 14.5 percent from Southwest and the West. The remaining 7.2 were of the observations were from the Midwest. The regions were defined according to the Portrait of the USA [180], and are as shown in Figure 44.

Figure 44. Map of USA, regional breakdown [180]

During the data collection process, some difficulties were encountered. First, different toll agencies have different ways of classifying vehicles. For example, some facilities collect tolls based on the number of axles (in this case a passenger car and a small truck pay the same toll), whereas some others specify toll rates based on the vehicle type (e.g., passenger car, small truck, bus, etc.). To solve this problem, data were collected only for seven vehicle types defined according to the FHWA vehicle classification. Another problem was related to finding the distance corresponding to the tolls charged on highways. Some of the websites provided all the distances between exists and the corresponding toll rates; while other websites have toll calculators that prompt for the entry and exit name and estimate the mileage and the toll amount. However, for some highways the distance had to be calculated by making measurements on maps. There are also several highways where toll rates are not dependent on the distance traveled. On these facilities, tolls are collected in several locations, and the same toll rates apply to all vehicles that pass through these locations. For all highways in the dataset, four toll rates collected: rates for the maximum distance; rates for the minimum distance; and rates for two randomly selected distances. Once the data for the various vehicle types and ranges of distance are organized and assemble, a data set with 1284 observations, from 83 different facilities, is obtained. This is the data set that is used for modeling and analyses purposes described in the following sections.

DESCRIPTIVE ANALYSIS

Table 84, Table 85 and Table 86 summarize the average, maximum and minimum tolls by vehicle type and payment type for highways, bridges, and tunnels, respectively. From these statistics, it can be observed that generally the ETC toll rates are lower than cash tolls, which indicates that ETC users are given discounts. Compared to cash and ETC tolls, amount of tolls being paid under the frequent user plan are significantly lower. For example, average frequent user toll is 55 cents on bridges for passenger cars whereas the corresponding ETC toll is $2.23 and cash toll $2.58. In the sampled toll facilities, frequent user plans are available to motorcycles, passenger cars, single unit trucks, and buses on highways; while such plans are available to only motorcycles and passenger cars on the bridges.

Table 84. Average, max and min toll rates for highways (cents per mile)

Vehicle Type	Payment Types								
	Cash			ETC			Frequent User		
	Average	Max	Min	Average	Max	Min	Average	Max	Min
Motorcycle	$0.23	$1.00	$0.03	$0.21	$0.90	$0.03	2	2	2
Passenger Car	$0.09	$1.00	-	$0.09	$0.90	-	6	10	2
Carpool	$0.06	$0.06	$0.06	$0.06	$0.06	$0.06	N/A	N/A	N/A
Buses with 2-axles	$0.10	$1.00	-	$0.10	$0.90	-	1	1	1
Single Unit Truck (2 axles)	$0.10	$1.00	-	$0.10	$0.90	-	1	1	1
Semi Trailer (5 axles)	$0.33	$2.50	-	$0.31	$2.25	-	N/A	N/A	N/A
Large Combination Vehicle (6 axles)	$0.40	$2.50	-	$0.38	$2.70	-	N/A	N/A	N/A

Table 85. Average, max and min toll rates for bridges

Vehicle Type	Payment Types								
	Cash			ETC			Frequent User		
	Average	Max	Min	Average	Max	Min	Average	Max	Min
Motorcycle	$1.81	$5.00	-	$1.48	$4.00	-	$0.46	$ 4.00	-
Passenger Car	$2.58	$8.00	$0.50	$2.23	$7.00	$0.50	$0.54	$ 7.00	$0.50
Carpool	$0.17	$0.30	-	$0.17	$0.30	-	N/A	N/A	N/A
Buses with 2-axles	$3.54	$16.00	-	$3.08	$12.80	-	N/A	N/A	N/A
Single Unit Truck (2 axles)	$4.72	$16.00	$0.50	$4.08	$12.80	$0.50	N/A	N/A	N/A
Semi Trailer (5 axles)	$13.64	$44.00	$1.50	$11.95	$35.20	$1.50	N/A	N/A	N/A
Large Combination Vehicle (6 axles)	$16.24	$44.00	$1.80	$14.51	$41.60	$1.80	N/A	N/A	N/A

Table 86. Average, max and min toll rates for tunnels

Vehicle Type	Payment Types								
	Cash			ETC			Frequent User		
	Average	Max	Min	Average	Max	Min	Average	Max	Min
Motorcycle	$3.38	$5.00	$1.75	$2.63	$4.00	$1.75	N/A	N/A	N/A
Passenger Car	$3.50	$6.00	$1.00	$2.93	$5.00	$1.00	$0.40	$0.40	$0.40
Carpool	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Buses with 2-axles	$3.69	$ 8.00	$1.00	$3.18	$6.40	$1.00	N/A	N/A	N/A
Single Unit Truck (2 axles)	$7.03	$12.00	$1.00	$5.76	$12.00	$1.00	N/A	N/A	N/A
Semi Trailer (5 axles)	$20.29	$30.00	$4.00	$16.53	$30.00	$4.00	N/A	N/A	N/A
Large Combination Vehicle (6 axles)	$24.29	$30.00	$5.00	$15.94	$36.00	$3.00	N/A	N/A	N/A

As expected, smaller vehicles pay lower tolls than larger vehicles. For example, average tolls paid by semi trailers with five axles are about 3 to 4 times larger than those paid by single unit trucks with two axles. Buses pay relatively small tolls, usually of the same order of magnitude as passenger car tolls. The lowest tolls are being paid by those subscribed to carpooling programs. As explained in the report by FHWA [(175)], the low carpool and bus tolls could be attributed to the interest to increase the use of these modes of transportation.

The highest cash toll on highways for passenger cars is charged on Interstate-15 in San Diego, California, which is 50 cents per mile for a total of 8 miles (note: the $1 per mile in Table 84 maximum cash toll column is for only 1 mile on Adams Avenue parkway in Utah). The highest toll on bridges for passenger cars is $8 at the Verrazano Narrows Bridge in New York City. The highest toll on tunnels for passenger cars is $6 per trip at Holland Tunnel also in New York City.

As shown in Table 84, the minimum cash tolls on highways are zero for all vehicle types except for motorcycles. On some highways no toll is charged if the distance between the entry and exit points is very short. Some bridges, on the other hand, charge no toll for motorcycles, carpools, and buses, but charge a toll for all other vehicle types. Finally, there are no zero tolls for any vehicle types on the tunnels within the dataset.

Although it is widely accepted that dynamic tolls are more efficient, the statistics of the sampled facilities shows that although 70 percent of the facilities have ETC systems, only 6 percent of them have road pricing programs with tolls that vary according to time of day. These are, for the most part, found in large metropolitan areas. This is taken as an indication that toll policies throughout the United States are not at their most efficient.

The data show that tolls seem low when compared with the available estimates of marginal costs, estimated by Levinson and Gillen [(177)] to be $0.52 per vehicle mile traveled on intercity highways. Yet, looking at average cash toll column in Table 84, it is observed that even the toll rate for large combination vehicle on highways is not charged that high. Part of the explanation is that some of the costs are paid by vehicles in form of taxes; and that, simply, the current tolls are not charged up to the marginal cost and thus give another indication that current toll policies are not most efficient.

MODELING RESULTS

In this section, ordinary least-squares regression is used to investigate the factors affecting the toll charges. The toll dataset described above is transformed into a format where the response variable is the amount of toll and the explanatory variables are binary values (with the exception of distance for highway facilities) characterizing the attributes listed in Table 83 corresponding to this toll amount. There are 1284 observations in this dataset which were used in the regression analysis. A number of regression models were estimated, and the best models, which are statistically significant and conceptually valid, are presented here. Two models that have different implications are presented in Table 87. These models are developed to analyze the systematic effects.

Linear models based on traffic and operational characteristics

Model 1

Model 1 is shown in Table 87. This model has an adjusted R-square value of 0.72, which means this model explained about 72 percent of the total variance in the dependent variable, which is quite acceptable. The model is a function of several characteristics including: facility type, vehicle type, distance of travel, discount programs, time of travel and geographic locations.

Table 87. Results for Model 1 and 2

Characteristic	Variable Name	Definition	Model 1		Model 2	
			Coefficient	t-value	Coefficient	t-value
Intercept	Constant		4.232	8.079	3.714	6.786
Facility Type	DB	If a bridge equal to 1	3.988	11.263		
	DT	If a tunnel equal to 1	5.378	10.462		
Vehicle Type	DMC	If motorcycle equal to 1	-3.167	-6.221	-2.093	-4.004
	DST	If semi trailer equal to 1	2.307	4.884	2.878	6.590
	DLCV	If large combination vehicle equal to 1	3.061	6.432	5.015	9.218
Distance of Travel	DIST	Distance traveled on highway.	0.190	24.716	0.084	17.629
Discount Program	FREQ	If frequent user toll equal to 1	-1.477	-2.435		
Time of Travel	DALL	If tolls are same at all times equal to 1	-3.664	-7.537	-3.234	-6.319
	DOP	If off-peak toll equal to 1	-1.525	-2.526	-1.608	-2.504
Interaction variables	DB_C	Interaction term DB*DC			3.554	9.237
	DT_C	Interaction term DT*DC			5.905	8.955
	DB_ETC	Interaction term DB*DETC			3.783	8.873
	DT_ETC	Interaction term DT*DETC			4.335	5.952
	DBUS_ETC_D	Interaction term DBUS*DETC*DIST			-0.026	-2.582
	DPC_ETC_D	Interaction term DPC*DETC*DIST			-0.032	-3.140
	DSUT_ETC_D	Interaction term DSUT*DETC*DIST			-0.026	-2.497
	DLCV_ETC_D	Interaction term DLCV*DETC*DIST			0.074	6.889
	DPC_D	Interaction term DPC*DIST	-0.138	-13.863		
	DBUS_D	Interaction term DBUS*DIST	-0.132	-13.325		
	DSUT_D	Interaction term DSUT*DIST	-0.132	-13.320		
	DPC_NE	Interaction term DPC*NE	-2.877	-6.005	-2.234	-4.695
	DCP_NE	Interaction term DCP*NE	-3.573	-2.875	-3.116	-2.359
	DBUS_NE	Interaction term DBUS*NE	-1.643	-3.220	-1.478	-2.786
	DST_NE	Interaction term DST*NE	5.565	8.217	5.498	8.038
	DLCV_NE	Interaction term LCV*NE	7.194	10.504	5.763	7.614
	DPC_MW	Interaction term DPC*MW	-1.964	-1.845		
	DLCV_SW	Interaction term LCV*SW			-2.001	-2.618
	DBUS_W	Interaction term DBUS*W	-1.757	-1.790		
	DST_NE_D	Interaction term DST*NE*DIST	-0.144	-9.844	-0.039	-2.802
	DLCV_NE_D	Interaction term DLCV*NE*DIST	-0.147	-9.258	-0.077	-4.896
	DST_SE_D	Interaction term DST*SE*DIST	-0.031	-2.834	0.073	7.816
	DST_SW_D	Interaction term DST*SW*DIST	-0.082	-2.867		
	DLCV_SW_D	Interaction term DLCV*SW*DIST	-0.077	-2.795		
	DPC_W_D	Interaction term DPC*W*DIST	0.156	3.133	0.148	2.805
	DBUS_W_D	Interaction term DBUS*W*DIST	0.206	3.545	0.145	2.752
	DSUT_W_D	Interaction term DSUT*W*DIST	0.153	3.076	0.147	2.791
	DST_W_D	Interaction term DST*W*DIST	0.535	10.397	0.631	11.740
	DLCV_W_D	Interaction term DLCV*W*DIST	0.715	14.039	0.731	13.397
Other	C_SUT	If car and Single Unit Truck has the same toll rate then 1, 0 otherwise.	-1.034	-2.881	-1.172	-3.172
F-Value			110.700		96.010	
Adjusted R-squared			0.720		0.682	

In general terms, a positive coefficient indicates a direct relationship between the variable in question and the toll; while a negative coefficient indicates the opposite. The toll will add or deduct by the amount in the coefficient if the variable is binary, and will increase by the amount in the coefficient if the variable increases by one unit if the variable is continuous (distance). The coefficient of the constant (intercept) represents the toll rate when none of the binary variables are true and distance is equal to zero.

Model 1 as presented in Table 87 has an intercept of 4.232. As already discussed, when none of the binary variables are true, and the distance is equal to zero, the toll rate will be $4.232. The coefficient for the bridge facility is $3.988 and for the tunnel facility is $5.378. They indicate that tunnels have a higher fixed toll than bridges, and bridges in turn have a higher fixed toll than highways. The coefficients for the three vehicle types are -3.167 for motorcycle, 2.307 for semi trailer, and 3.061 for large combination vehicle. These three coefficients meant that motorcycle compared to all other vehicle types have the lowest fixed toll, carpool, passenger car, bus and single unit truck have no fixed toll, while semi trailer and large combination vehicles are the vehicle types with the highest fixed toll. The coefficient of the frequent user variable has a value of -1.477 meaning that frequent users, in general, get a discount.

Two types of time of travel time variables were included in the estimation. DALL is equal to one if the tolls are the same during all time of the day; while DOP is equal to one, if there is an off peak discount. The two times of travel variables, travel during any time of the day and travel during off peak have coefficients -3.664 and -1.525 respectively. The fact that travel during any time of the day have a higher discount than off-peak discount is because the facilities that have time of day pricing programs are in large metropolitan area (as pointed out in the descriptive analysis) where demand is probably very high during peak time. For those facilities even though there is a discount in toll when vehicles are traveling in the off-peak, the off-peak toll is still higher than other facilities where demand is much lower. The last variable in Table 87, the binary variable for car and single unit truck has the same toll, has coefficient -1.034. A likely explanation of this coefficient is that in general when single unit truck is charged at the same rate as the passenger car, the toll booths are probably less congested and thus charge a lower toll.

To look at how toll rates differ in different geographic locations, the vehicle types were interacted with the geographic variables. There were seven of these interaction variables and their coefficient are as presented in Table 87 showed that in the Northeast region, while the fixed toll for passenger car and carpool were at the lowest, the semi trailer and the large combination vehicle pay the highest fixed tolls. The coefficient also showed that buses have the lowest fixed tolls in West and Northeast region, while passenger car also pay low fixed toll in the Midwest. Another finding from the interaction of those two types of variables was that the carpool programs only exist in Northeast among the sampled facilities.

The distance variable has a coefficient of 0.190, though this is not the only coefficient that describes the variable toll. To find out the other components of the variable toll, one must take into account the interaction variables between distance and binary variables. The coefficients of the three vehicle type and distance interaction variables in Table 87 show that these three vehicle types pay the lowest toll per vehicle mile traveled on highways, and all other vehicle types pay 19 cent per mile on highways. This information is still not enough, since highway facilities must have different policies in different regions. To investigate further, the vehicle type and distance variables are interacted with the geographic location variables. To be clearer on their effects, they are reorganized and presented in Equation (1) below. It was found that although semi trailers and large combination vehicles pay the highest fixed toll on highway facilities in the Northeast, they actually pay the lowest toll per vehicle mile traveled in the Northeast compared with all the other regions. Southwest was another region where those two vehicle types pay the lowest toll per vehicle mile traveled on highway facilities. In Equation (23) it was also found that all vehicle types except for motorcycle pay a higher toll per vehicle mile traveled on the highways in the West than all other regions.

$$\begin{aligned} Toll = ... + 0.190DIST(1 - 0.757\delta_{ST\_NE} - 0.772\delta_{LCV\_NE} - 0.163\delta_{ST\_SE} - 0.431\delta_{ST\_SW} \\ - 0.404\delta_{LCV\_SW} + 0.819\delta_{PC\_W} + 1.080\delta_{BS\_W} + 0.803\delta_{SUT\_W} + 2.808\delta_{ST\_W} + 3.753\delta_{LCV\_W}) \end{aligned} \quad (23)$$

Model 2

Since it was not possible to include the ETC, vehicle type and distance interaction variables in the first model due to their correlations with the vehicle type and distance interaction variables, another model was developed to include those interaction variables. Model 2 is presented in Table 87. The new model has an adjusted R-square value equal to 0.682. The model is a function of similar variables as in Model 1. The important differences between Model 1 and Model 2 are that in Model 2 the facility types were interacted with the two payment types, and the vehicle types were interacted with ETC and distance variables.

The newly introduced interaction variables in Model 2, facility type and payment type interaction terms resulted in a higher coefficient for ETC toll on bridges (3.785) than cash toll on bridges (3.554). It showed the same behavior as in the descriptive analysis. It is because although ETC tolls result in a discount from the cash tolls, the bridge facilities that provide ETC discount actually charge higher toll rates than other facilities. As for the sampled tunnel facilities, since there are only 8 facilities studied, Model 2 showed the expected behavior, that the coefficient for cash toll on tunnels (5.905) is higher than the ETC toll on tunnels (4.335).

The results of Model 2 regarding the interactions between vehicle type and facility location are summarized in Equation (24) for convenience of study. The equation showed that passenger cars pay the smallest ETC toll followed by bus and followed by single unit truck, and the large combination vehicle pays the largest ETC toll. It is as expected from the previous discussion in the descriptive analysis. Also in addition to Model 1, in Model 2 there was an additional interaction term that indicated that large combination vehicle pay the lowest fixed toll on facilities in the Southwest.

$$Toll = ... + 0.084DIST(1 - .310\delta_{BUS\_ETC} - 0.381\delta_{PC\_ETC} - .310\delta_{SUT\_ETC} + 0.881\delta_{LCV\_ETC}) \qquad (24)$$

Although Model 2 has showed some additional features from Model 1, the two models are in general very similar and the adjusted r-square values were very close. It revealed that ETC toll policies are in general very similar to the cash toll policies.

Outliers from the models

There are a total of 74 outliers in the dataset from the first model and 87 outliers from the second model. The outliers were identified as cases that do not fit the pattern of tolls in the United States. They were not removed as an attempt to find the best models for the entire dataset. Table 88 provides the breakdown of these outliers by the characteristics of the facilities and vehicles for Model 1 and Model 2. Table 88 is ranked with respect to the number of outliers in descending order of importance, and it only presented those variables which make up 10 percent or more of the total outliers in either of the models. The outliers of both models are mostly of the same characteristics.

Table 88. Outliers

Characteristic	Variable Name	Definition	Number of Outliers			
			Model 1		Model 2	
			Number of Outliers	% make of total outlier for this characteristic	Number of Outliers	% make of total outlier for this characteristic
Facility Type	DB	Bridge	27	36.49	29	33.33
	DB_C	DB*DC	20	27.03	20	22.99
	DB_ETC	DB*DETC	7	9.46	9	10.34
	DH	Highway	25	33.78	32	36.78
	DH_C	DH*DC	15	20.27	18	20.69
	DH_ETC	DH*DETC	10	13.51	14	16.09
	DT	Tunnel	22	29.73	26	29.89
	DT_C	DT*DC	14	18.92	18	20.69
	DT_ETC	DT*DETC	8	10.81	8	9.20
Vehicle Type	DLCV	Large Combinational Vehicle (large truck 6 axles)	43	58.11	52	59.77
	DST	Semi Trailer (truck 5 axles)	28	37.84	29	33.33
Distance of travel	DIST	Distance Traveled (for highway)	25	33.78	32	36.78
Method of Payment	DC	Cash Toll	49	66.22	56	64.37
	DETC	ETC Toll	25	33.78	31	35.63
Time of Travel	DALL	Toll is same whole day	32	43.24	50	57.47
	DAP	AM and PM Peak Rate	21	28.38	18	20.69
	DOP	Off-Peak Discount Rate	17	22.97	15	17.24
Geographic Location	NE	Northeast	69	93.24	71	81.61
	SE	Southeast	0	0.00	10	11.49
Interaction Variable (veh. type & geographic location)	DLCV_NE	DLCV*NE	39	52.70	40	45.98
	DST_NE	DST*NE	27	36.49	29	33.33
Interaction Variable (vehicle type and distance)	DLCV_D	DLCV*DIST	13	17.57	19	21.84
	DST_D	DST*DIST	10	13.51	9	10.34
Interaction Variable (vehicle type, geographic location and distance)	DLCV_NE_D	DLCV*NE*DIST	12	16.22	10	11.49
	DST_NE_D	DST*NE*DIST	9	12.16	9	10.34
Interaction Variable (vehicle type & ETC)	DLCV_ETC	DLCV*DETC	14	18.92	18	20.69
	DST_ETC	DST*DETC	11	14.86	11	12.64
Interaction Variable (vehicle type, ETC & distance)	DLCV_ETC_D	DLCV*DETC*DIST	6	8.11	9	10.34
Other	TD	Toll Direction	47	63.51	55	63.22
	PC_SUT	Passenger Car and Small Truck with same rate	12	16.22	24	27.59

Here are some of the findings:

1. There are more cash toll outliers than ETC toll outliers on bridge, highway and tunnel facilities. Since most of the data were cash tolls, it means ETC tolls fits into cash toll pattern very well. In some cases where the facility is in high demand, the cash toll is very high (result in outlying case), but the ETC is lower and fits into the general pattern better.
2. Almost all of the outliers are from two vehicle types: semi trailers (5 axle trucks), and large combination vehicle (6 axle trucks). With almost 60 percent of the total outliers from large combination vehicles and about 35 percent of the total outliers from semi trailers.
3. Model 2 resulted in more outliers with respect to distance than Model 1. Model 2 included vehicle types, distance and ETC interaction variables where as Model 1 included only vehicle type and distance interaction variable. The make up of the data included 60 percent of cash tolls and 40 percent of ETC tolls. Therefore, the extra outliers with respect to distance in Model 2 might be because the pattern of cash rates with respect to distance was not considered.
4. With respect to geographic location, most of the outliers are in the Northeast region (around 70 percent). When tracked down it was found that most of the outliers are over charged rates in the New York City area.
5. In model 2, 11.5 percent of the outliers came from the Southeast, while none from that category in the first model. It shows that the toll policies in the Southeast region does not fit the overall ETC pattern in the United States that well, but fit into the overall pattern better.
6. The several binary variables that had a reduction in outliers are time of travel variables DOP and DAP. It shows that the off-peak and A.M. and P.M. peak hours have a systematic ETC pattern. When introducing ETC interaction variables, the reduction in outliers for the following variables: DPC_NE_D, DBS_NE_D, DLCV_NE_D show that the ETC highway tolls for the passenger car, bus, and large vehicle in the Northeast

region are more systematic. (Some of the variables may not be presented in Table 88 since they account for less than 10 percent of the total make up of outliers.)

CONCLUSIONS

The first and probably the most important conclusion is that tolls across the US follow a systematic pattern, i.e., the one captured by the regression models.

The analysis of the toll data of selected 83 facilities has resulted in some expected results as well as several interesting findings. From the descriptive analysis, it was found that: (a) frequent user tolls when offered are lower than both cash and ETC tolls; (b) smaller vehicles pay lower tolls than larger vehicles; (c) buses and carpool pay relatively low tolls compared to other vehicle types of the same category; (d) the highest tolls are charged on facilities in large metropolitan areas; (e) facilities that provide ETC services in general charge higher cash toll than those that do not; (f) at those facilities that provide ETC services, ETC tolls are usually lower than cash tolls; (g) only 6 percent of the sampled facilities have time of day pricing programs, it is an indication that toll is not charged at an optimal level; (h) these time of day pricing programs only take place in large metropolitan areas; and (i) comparing the marginal cost per vehicle mile traveled on highways estimated by Levinson and Gillen [(177)] and the average tolls per vehicle mile traveled on sampled highway facilities has again showed that current highway tolls may not be the most efficient.

The important findings from the regression analysis were: (a) toll and the toll characteristics could be explained by a linear relationship; (b) tunnel tolls are higher than bridge tolls; (c) frequent users and off-peak users receive a discount; (d) among the sampled facilities only those in the Northeast have carpool programs; (e) passenger car tolls on the bridge and tunnel facilities are lowest in the Northeast, they also pay the lowest fixed toll on highway facilities in the Northeast; (f) in the Northeast, bridges and tunnels charge the highest semi trailer and large combinational vehicle tolls, they also charge the highest fixed toll for highways; (g) bus tolls on the bridges and tunnels are lowest in the West and Northeast, they also charge the lowest fixed toll on highway facilities in the West and Northeast; (h) toll per vehicle mile traveled (variable toll) on highways of all vehicle types are at the highest in the West; (i) although highway facilities in the Northeast charge the highest fixed semi trailer and large combinational vehicles toll among all other regions, the toll per vehicle mile traveled (variable toll) is charged at the lowest; (j) outliers of the regression analysis are mostly due to the high tolls charged to trucks on facilities near/in large metropolitan area; and (k) the two models shows that cash toll policies and ETC toll policies are in general very similar.

As mentioned in the data collection section, the data was limited by the unavailability of toll data from many of the smaller facilities, and the large dimension of characteristics in which the sampled facilities used to collect the tolls. In the study the first problem was resolved by collecting toll data from most of the large facilities, and the second problem was resolved by observing only the most often appeared characteristics among the sampled facilities. By making those decisions, some important aspects of the toll policies in the United States may not be observed. In the future if it is possible, toll data from facilities with no readily available information should be collected and considered, and the characteristics which facilities collect toll by should be comprehensive.

This study is intended to lead to the analysis the efficiencies of current toll policies in the United States. One important element in optimizing the tolls as discussed in this document is the congestion toll. The optimal congestion toll could not be calculated without the traffic information on each facility. Since this research did not include traffic level in the modeling process, a better understanding of the efficiencies of the tolls could be gained in the future when such variable is included. Another way to study the efficiencies of the tolls is by simulating a cost function, and then comparing it with the current tolls to see if they are equivalent at a marginal level.

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APPENDIX 1. – ANALYSIS STEPS OF DISAGGREGATE LEVEL ANALYSIS

Part 1: Algorithm of Criteria 1

Step 1: Total daily traffic generated at an entry location "i" .For each month "*m*" and day type "*l*" denoted as D_i^{ml}: is determined as the summation of all the demands between all entry-exit pairs (*i,j*) for all time periods.

$$D_i^{ml} = \sum_j \sum_k d_{ijk}^{ml} \tag{25}$$

Step 2: Total daily traffic generated between an entry exit pair (i,j). For each month "*m*" and day type "*l*", denoted as, f_{ij}^{ml} is determined as the total daily traffic between an entry-exit pair (*i,j*) for all time periods.

$$f_{ij}^{ml} = \sum_k d_{ijk} \tag{26}$$

Step 3: Determine the number of the entry-exit pairs (*i,j*), N^{ml} , which satisfy Criteria 1 shown in Equation (6).

$$\frac{f_{ij}^{ml}}{D_i^{ml}} \geq 0.1 \tag{27}$$

Part 2: Algorithm of Criteria 2

Step 1: Determine the sub-period with the maximum hourly entry traffic for each month "*m*" and day type "*l*",

$$\max_{k \in S}\left(d_{ijk}^{ml} \right) \Rightarrow time\ period: k^* \tag{28}$$

where;

S= Set of sub-periods (*S*= {1, 2 …8} for weekdays and Fridays)

(S= {1, 2} for weekends)

k^*: The sub-period where the traffic is maximized

Step 2: determine the traffic demand between each entry-exit pair (*i,j*) observed at sub-period k^* for each month "*m*" and day type "*l*",. Determine the number of entry-exit pairs (*i,j*), M^{ml}, which satisfy Criteria 2 shown in equation 10.

$$d_{ijk*}^{ml} \geq 100 \quad veh/hr \tag{29}$$

Part 3: Analysis of periods with maximum hourly traffic

1. Determine k^* which is the time of sub-period that has maximum traffic flow between entry-exit pairs (*i,j*). Sub-period k^* is an input to steps 2 to 5.

$$\max_{k \in S}\left(d_{ijk}^{ml}\right) \Rightarrow time\ period: k* \tag{30}$$

2. Calculate ϕ_{k*}^{ml} : Proportion of exit-entry pairs (*i,j*) with maximum traffic flow at peak periods but less travel time compared to peak shoulders.

$$\phi_{k*}^{ml} = \frac{\sum_i \sum_j \xi_{ijk*}^{ml}}{N^{ml} + M^{ml}} \tag{31}$$

where;

$$\xi_{ijk*}^{ml} = \begin{cases} 1 & \text{if time period } k* \text{ for month } m \text{ and } (m+1) \text{ is both peak period with less travel time} \\ 0 & \text{otherwise} \end{cases}$$

N^{ml} : number of pairs satisfying Criteria 1

M^{ml} : number of pairs satisfying Criteria 2

3. Calculate r_{k*}^{ml} : Proportion of exit-entry pairs (*i,j*) with maximum traffic flow at peak shoulders but less travel time compared to peak periods.

$$r_{k*}^{ml} = \frac{\sum_i \sum_j e_{ijk*}^{ml}}{N^{ml} + M^{ml}} \tag{32}$$

where,

$$e_{ijk*}^{ml} = \begin{cases} 1 \text{ if traffic flow between pair } (i,j) \text{ is maximized on peak shoulder with less travel time} \\ 0 \text{ other wise} \end{cases}$$

4. Calculate a_{k*}^{ml} : Proportion of pairs (*i,j*) with maximum traffic flow and the highest travel time but either have travel time less than 15 minutes or that provide less than 10% time savings when a shift to sub-period with lower travel time occurs.

$$a_{k*}^{ml} = \frac{\sum_i \sum_j g_{ijk*}^{ml}}{N^{ml} + M^{ml}} \tag{33}$$

where,

$$g_{ijk*}^{ml} = \begin{cases} 1 \text{ if pair } (i,j) \text{ has travel time less than 15 min. or provides less than 10\% time saving} \\ 0 \text{ other wise} \end{cases}$$

5. Calculate d_{k*}^{ml} : Percentage of O-D pairs (*i,j*) with maximum traffic flow and the highest travel time but have travel time more than 15 minutes or they provide more than 10% time savings when a shift to a sub-period with lower travel time occurs.

$$d_{k*}^{ml} = \frac{\sum_i \sum_j f_{ijk*}^{ml}}{N^{ml} + M^{ml}} \tag{34}$$

where,

$$f_{ijk*}^{ml} = \begin{cases} 1 \text{ if pair } (i,j) \text{ has travel time more than 15 min. or provides more than 10\% time saving} \\ 0 \text{ other wise} \end{cases}$$

Part 4: Analysis of periods with maximum travel time

1. Determine k' which is the time of sub-period that has maximum travel time between an entry-exit pair (*i,j*). Sub-period *k'* is an input to steps 2 to 6.

$$\max_{k \in S}\left(t_{ijk}^{ml}\right) \Rightarrow time\ period : k' \qquad (35)$$

2. Calculate $P_{ijk'}^{ml}$: The percent share of traffic between pair (*i, j*) at sub-period "*k*" with respect to the total daily traffic between pairs (*i, j*).

$$P_{ijk'}^{ml} = \frac{d_{ijk'}^{ml}}{\sum_k d_{ijk}^{ml}} * 100 \qquad (36)$$

3. Calculate $\Delta_{ijk'}^{ml}$: Change in percent share of traffic between two consecutive months during sub-period "*k'* ".

$$\Delta_{ijk'}^{ml} = P_{ijk'}^{(m+1),l} - P_{ijk'}^{ml} \qquad (37)$$

4. Determine $\gamma_{k'}^{ml}$: Proportion of pairs (*i, j*) for which "$\Delta_{ijk'}^{ml}$" is negative during sub-period " *k'* ".

$$\gamma_{k'}^{ml} = \frac{\sum_i \sum_j \delta_{ijk'}^{ml}}{\sum_i \sum_j \Delta_{ijk'}^{ml}} * 100 \qquad (38)$$

where,

$$\delta_{ijk'}^{ml} = \begin{cases} 1 & \text{if } \Delta_{ijk'}^{ml} \text{ is negative} \\ 0 & \text{other wise} \end{cases}$$

5. Calculate $\vartheta_{k'}^{ml}$: Among the pairs (*i, j*) where "$\Delta_{ijk'}^{ml}$" is positive, proportion of pairs (*i,j*), which either have travel time less than 15 minutes or provide less than 10% travel time saving when a shift to other sub-periods occur.

$$\vartheta_{k'}^{ml} = \frac{\sum_i \sum_j \theta_{ijk'}^{ml}}{\left(\sum_i \sum_j \Delta_{ijk'}^{ml} - \sum_i \sum_j \delta_{ijk'}^{ml} \right)} * 100 \qquad (39)$$

where,

$$\theta_{ijk'}^{ml} = \begin{cases} 1 & \text{if pair } (i,j) \text{ has travel time less than 15 min. or provides less than 10\% time saving} \\ 0 & \text{other wise} \end{cases}$$

6. Calculate $\chi_{k'}^{ml}$: Among the pairs (*i,j*) where proportion of traffic during sub-period "*k'*" changed, proportion of pairs in which change is to or within peak periods.

$$\chi_{k'}^{ml} = \frac{\sum_i \sum_j \beta_{ijk'}^{ml}}{\sum_i \sum_j \Delta_{ijk'}^{ml}} \qquad (40)$$

where,

$$\beta_{ijk'}^{ml} = \begin{cases} 1 & \text{if time period } k' \text{ for month } (m+1) \text{ is peak period given that proportion at} \\ & \text{k' for month } (m) \text{ has changed} \\ 0 & \text{otherwise} \end{cases}$$

APPENDIX 2. – TOLL PLAZA DELAYS

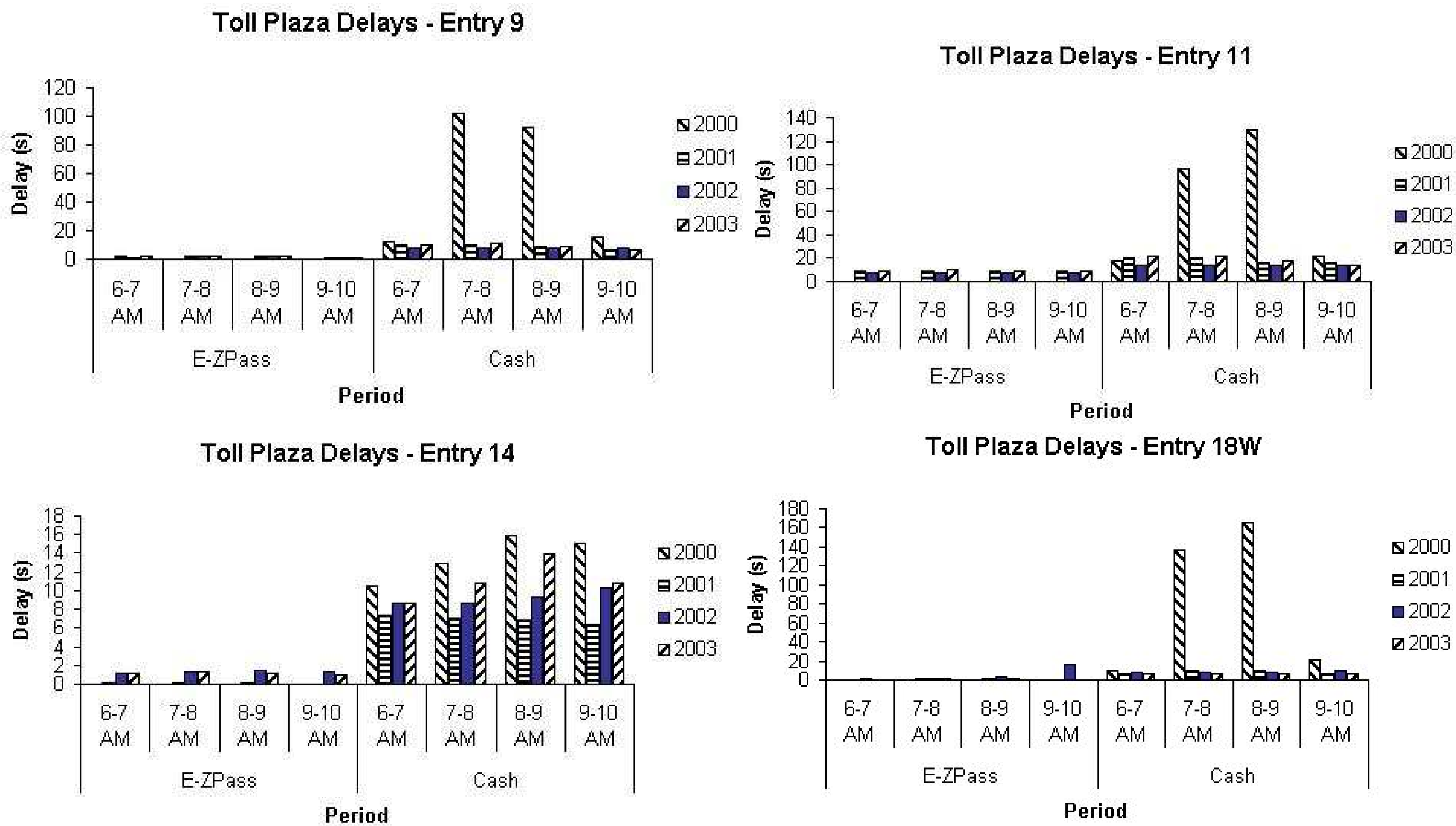

Figure 45. Distribution of delays at the entry toll plazas (9, 11, 14 and 18W) for various periods during the AM period

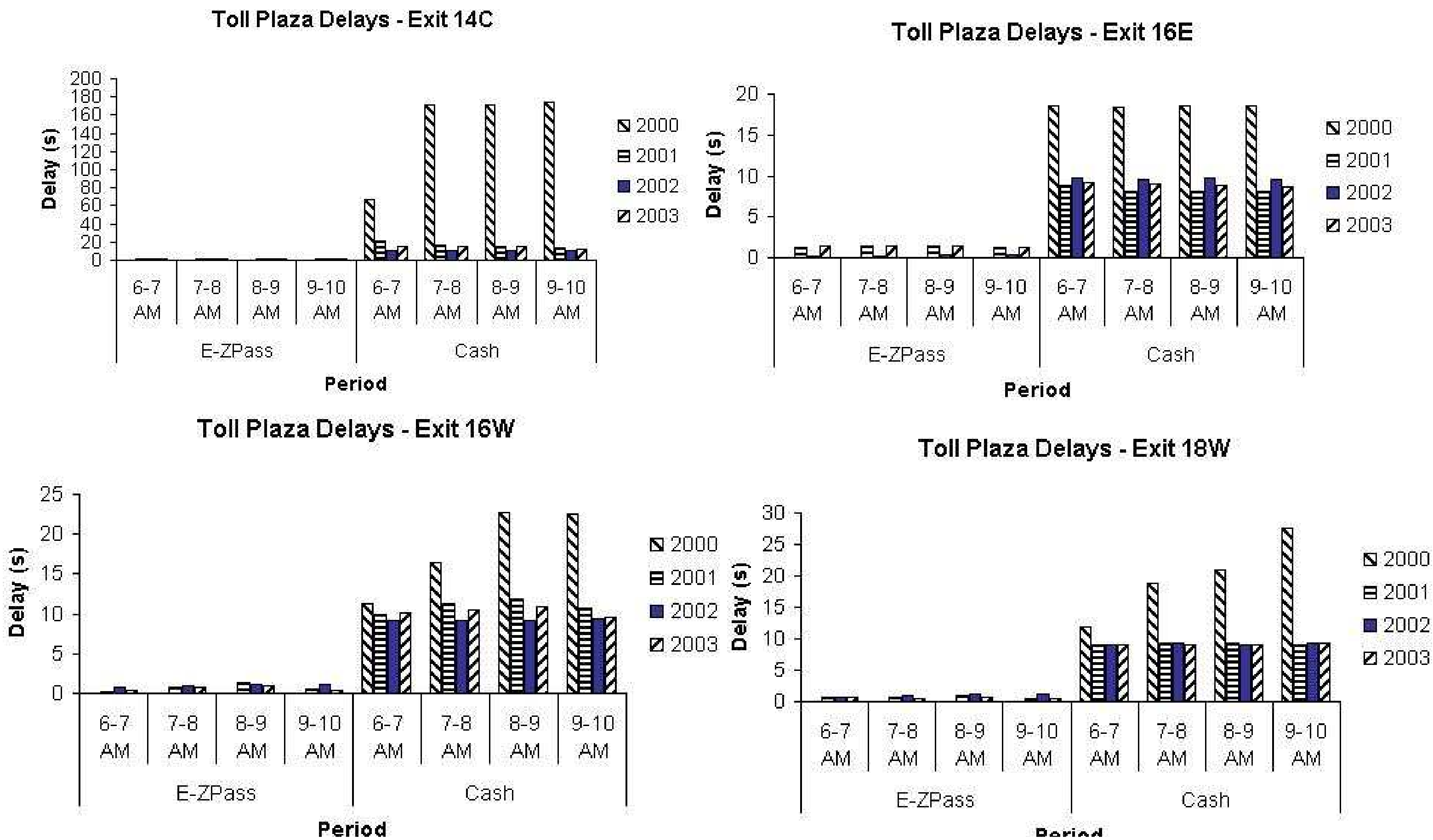

Figure 46. Distribution of delays at the exit toll plazas (14, 14C, 16E and 18W) for various periods during the AM period

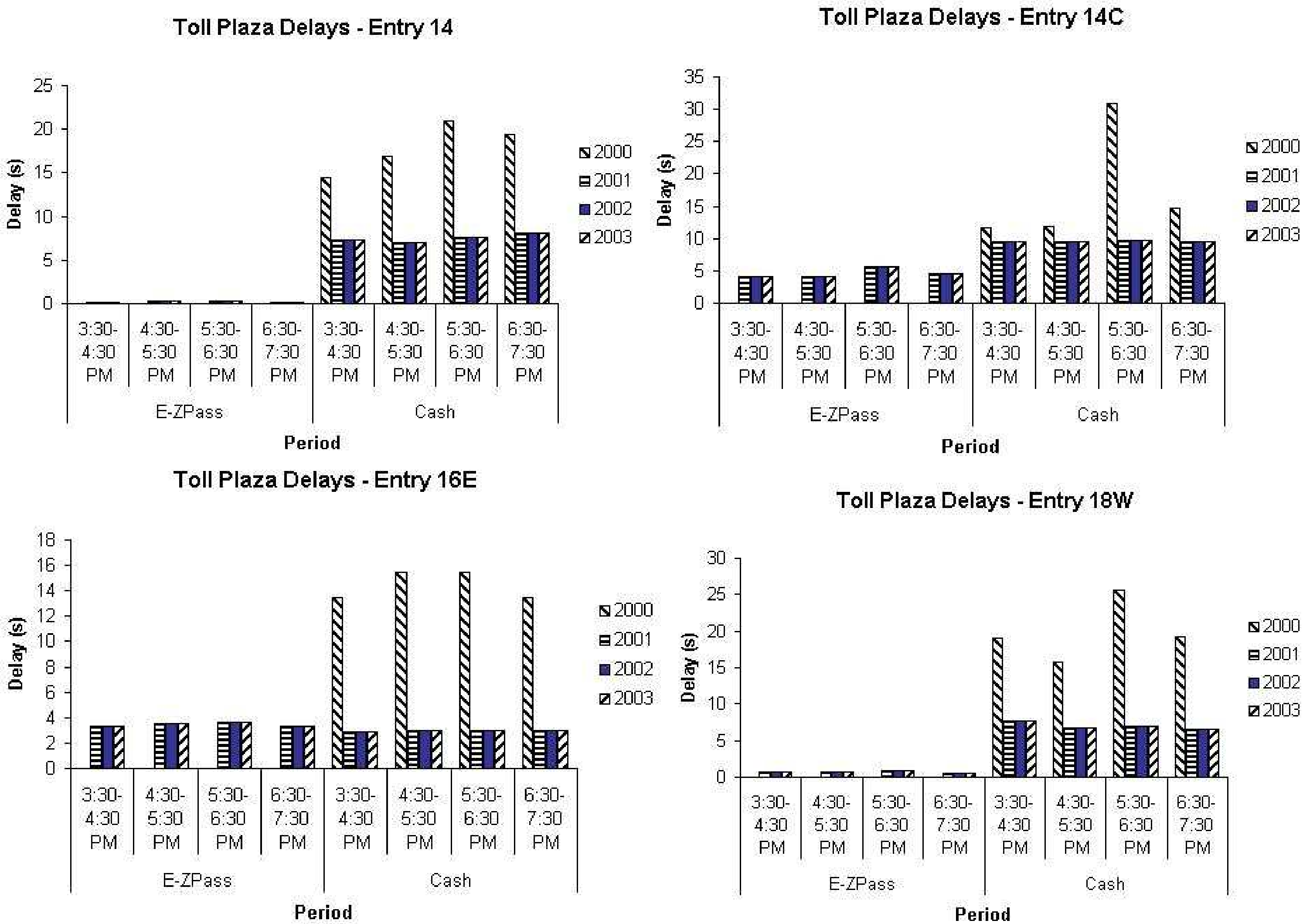

Figure 47. Distribution of delays at the entry toll plazas (14, 14C, 16E and 18W) for various periods during the PM period

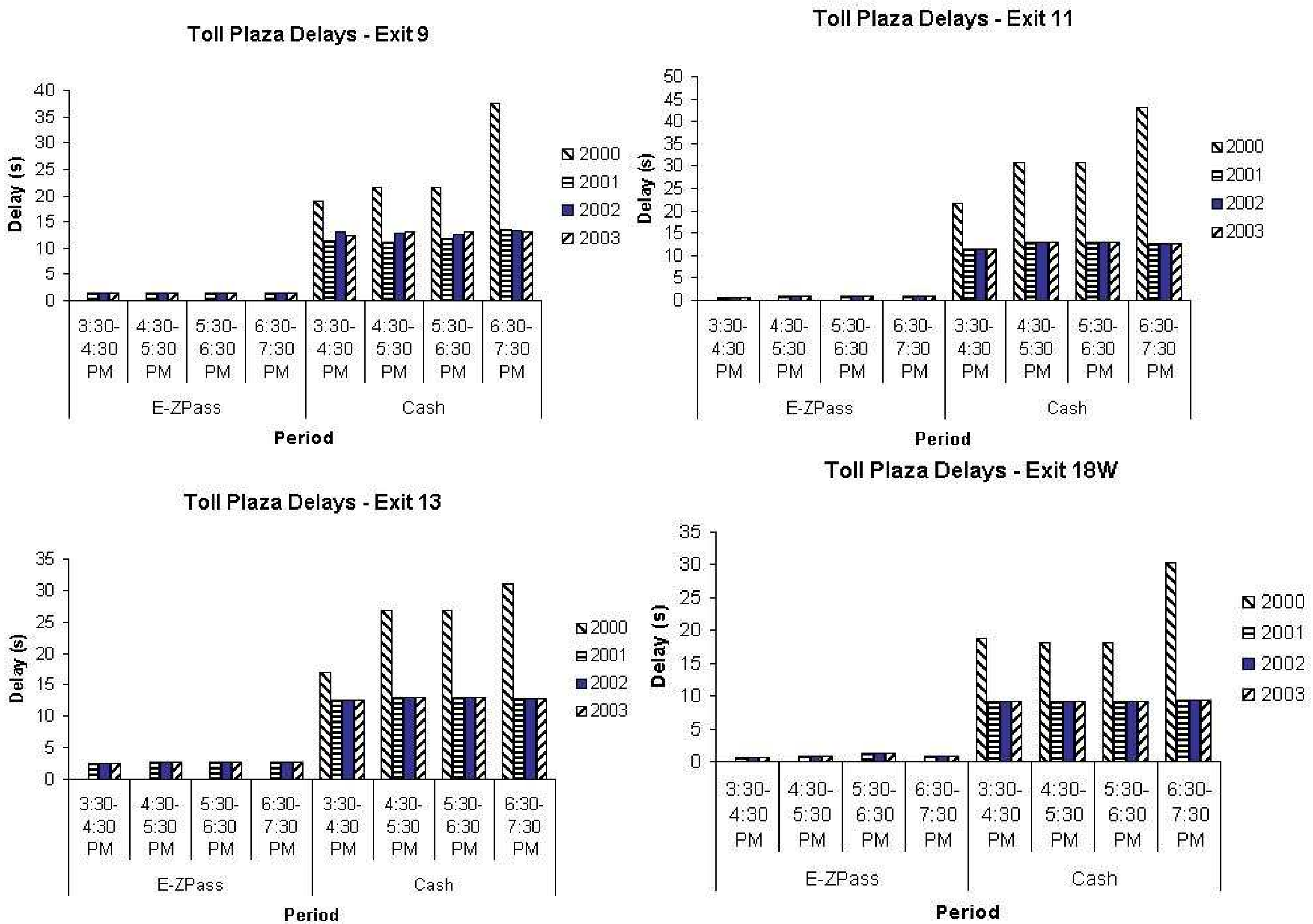

Figure 48. Distribution of delays at the entry toll plazas (9, 11, 13 and 18W) for various periods during the AM period

APPENDIX 3. – EMISSIONS AT TOLL PLAZAS

NOTE: The other pollutants are within 1-2% within that of HC and their respective graphs would appear very similar

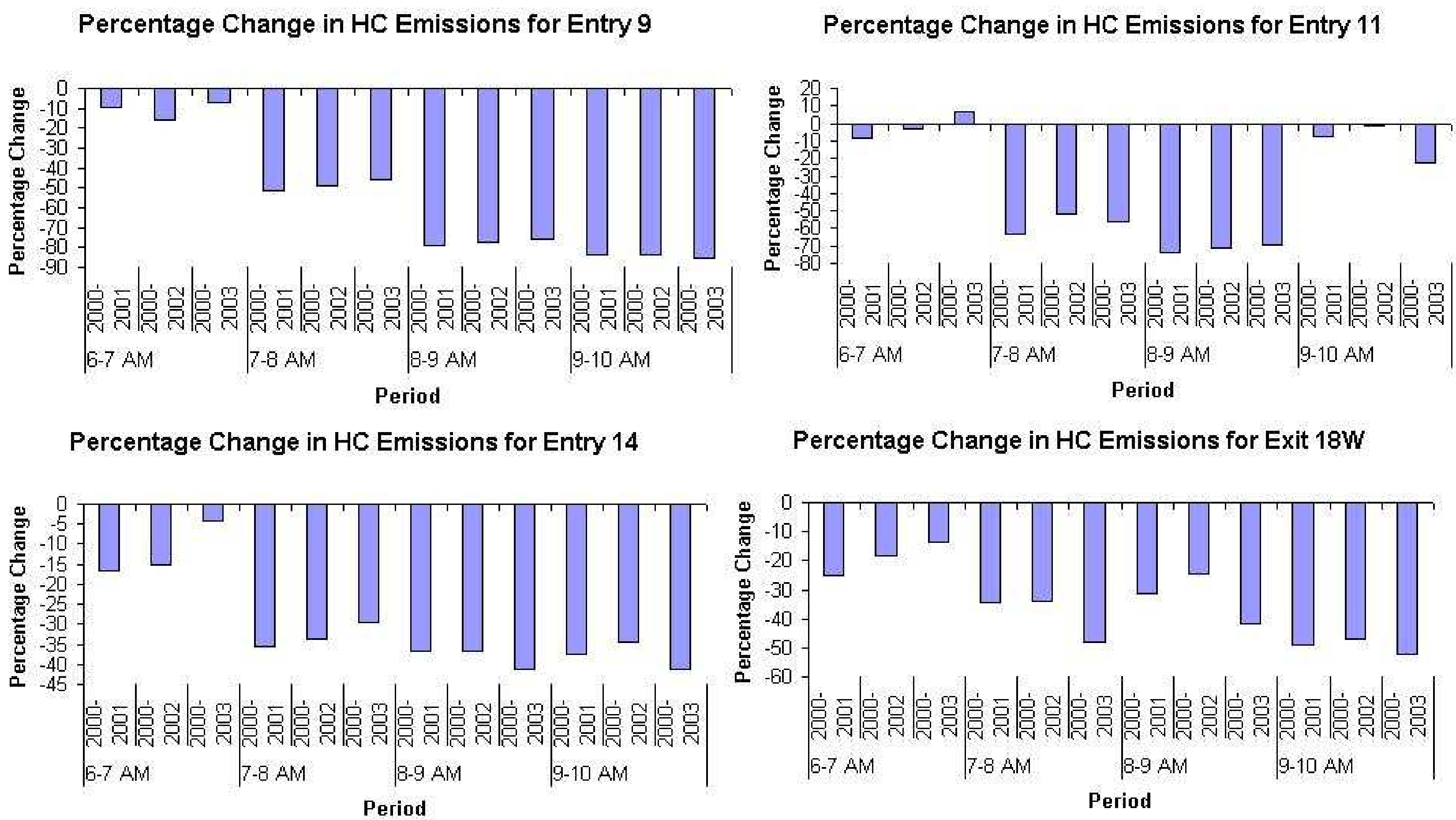

Figure 49. Percent change in emissions at the entry toll plazas (9, 11, 14) Exit 18W for various periods during the PM period

NOTE: The other pollutants are within 1-2% within that of HC and their respective graphs would appear very similar

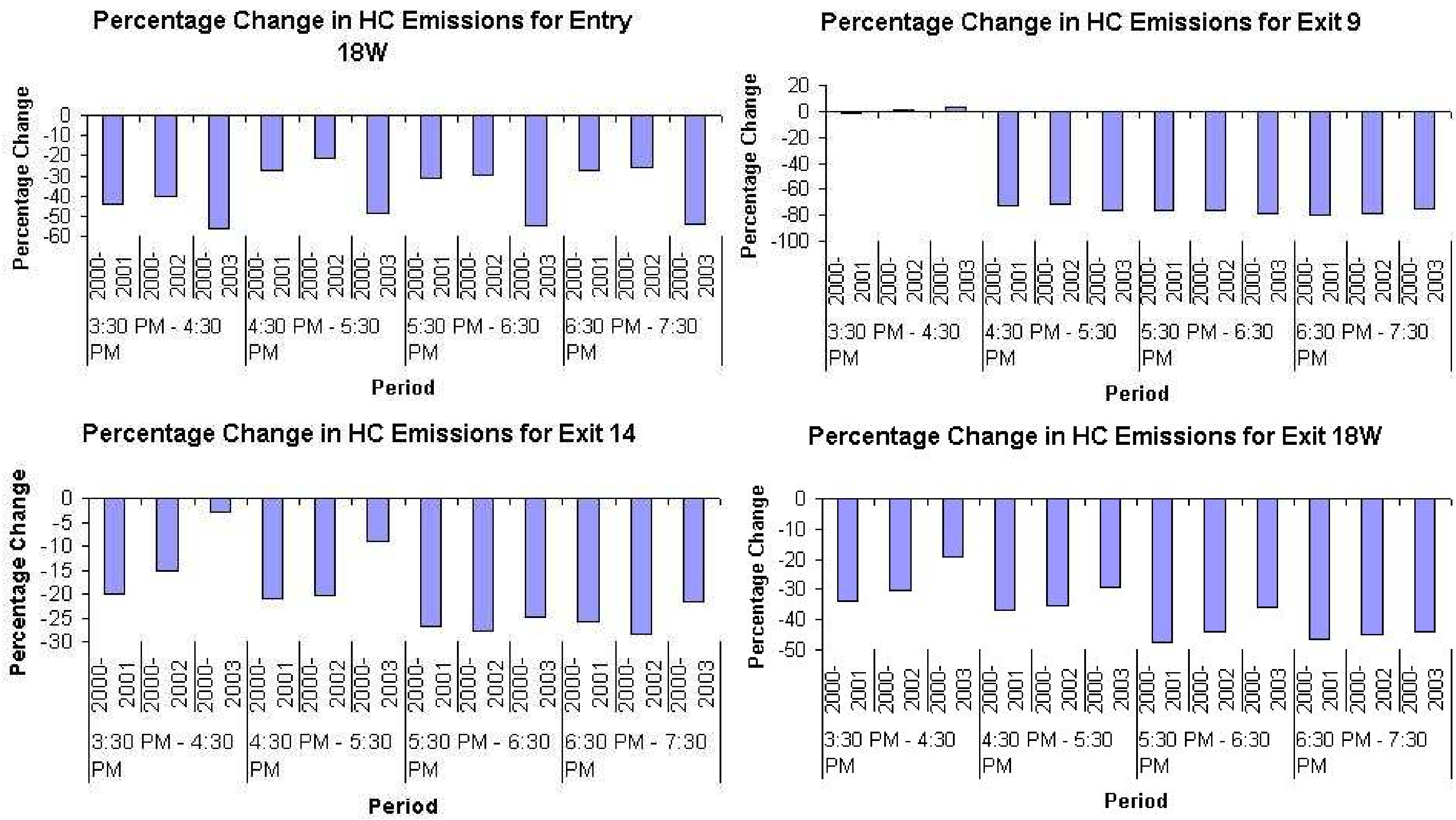

Figure 50. Percent change in emissions at the exit toll plazas (9, 14, 18W) Entry 18W for various periods during the PM period

APPENDIX 4. NEW JERSEY TURNPIKE AUTHORITY PASSENGER SURVEY

Hello, my name is _________________ (first and last name) I'm on the staff of the Eagleton Poll, and I'm taking a public opinion survey of New Jersey adults for Rutgers University.

I'd like to ask a few questions of the YOUNGEST MALE, 18 years of age or older, who is now at home. [IF NO MALE, ASK: May I please speak with the OLDEST FEMALE, 18 years of age or older, who is now at home?]

RESPONDENT ON PHONE: I'd like your views on toll roads and transportation in New Jersey ---- CONTINUE WITH QUESTIONNAIRE ----

IF NECESSARY: We are not selling anything, not asking for money, and all your answers will be completely confidential.

A. PANYNJ USER SCREEN

A1. Since we're asking about New Jersey travel, I'd like to start by asking you about toll facilities you may have used. First off, have you personally driven on any of the toll bridges or tunnels to cross the Hudson River in the past three years?

1. Yes >> CONTINUE WITH A2
2. No >>> ASK A1A
9. Don't Know >>> ASK A1A

A1a. Is there someone else in your household who has done this? [If needed: Driven across the Hudson in the past three years]

1. Yes >> Use new respondent/schedule callback
2. No >>> GO TO R1/Turnpike Screener

9. Don't Know >>> GO TO R1/Turnpike Screener

A2. Have you driven these on a regular basis – that is at least once a week for any period during the past three years? [IF "YES" ASK: Do you currently use these facilities on a regular basis?]

1. Yes, current regular user >> CONTINUE WITH A3
2. Was regular user in past three years >> ASK A2B
3. Not a regular user in past three years >>> ASK A2A
9. Don't Know >>> ASK A2A

A2A. Is there someone else in your household who has done this? [If needed: Driven across the Hudson at least once a week sometime during the past three years]

1. Yes >> Use new respondent/schedule callback
2. No >>> GO TO R1/Turnpike Screener
9. Don't Know/Ref >>> GO TO R1/Turnpike Screener

A2B. Do you still travel regularly across the Hudson River by bus, train, or ferry?

1. Yes >>> CONTINUE WITH A3
2. No >>> ASK A2C
9. Don't Know/Ref >>> GO TO R1/Turnpike Screener

A2C. Why did you decide to stop using the bridges and tunnels?

____________________________ Record verbatim

then GO TO R1/Turnpike Screener

OR IF Turnpike Quota Filled, SKIP TO MODULE Z

AND Keep in data file, but do not count toward quota

A3. Which bridges and tunnels [do/did] you use? [MULTIPLE RESPONSE – ACCEPT ALL MENTIONS BUT DO NOT READ LIST]

1. Holland Tunnel
2. Lincoln Tunnel
3. George Washington Bridge
4. Goethals Bridge
5. Bayonne Bridge
6. Outerbridge Crossing
7. Tappan Zee Bridge
8. Verrazano Narrows Bridge
9. Other, specify: ______________________
10. DK/Ref

[*****NOTE: RESPONDENT MUST GIVE RESPONSES 1-6 TO CONTINUE WITH SURVEY. If punch 1 through 6 not among mentions, skip to R1/Turnpike Screener.*****]

R. TP USER SCREEN

R1. Have you driven on the New Jersey Turnpike on a regular basis – that is at least once a week for any period during the past three years? [IF "YES" ASK: Do you currently use these facilities on a regular basis?]

1. Yes, current regular user >> CONTINUE WITH R2
2. Was regular user in past three years >> ASK R1B
3. Not a regular user in past three years >>> ASK R1A
9. Don't Know >>> ASK R1A

R1A. Is there someone else in your household who has done this? [If needed: Driven on the New Jersey Turnpike at least once a week sometime during the past three years]

1. Yes >> Use new respondent/schedule callback
2. No >>> THANK AND TERMINATE INTERVIEW, except if below
9. Don't Know >>> THANK AND TERMINATE INTERVIEW, except

Exception: IF R1A = 2 or 9 and A2B=2, ASK MODULE Z

AND Keep in data file, but do not count toward quota

R1B. Do you still travel regularly to the same basic destination by an alternate route or by public transit?

1. Yes >>> CONTINUE WITH R2
2. No >>> ASK R1C
9. Don't Know/Ref >>> THANK AND TERMINATE

R1C. Why did you decide to stop using the New Jersey Turnpike?

______________________________ Record verbatim

then SKIP TO MODULE Z

AND Keep in data file, but do not count toward quota

R2. For how many years have you been using the Turnpike on a regular basis?

__________ [Record number. 0=Less than 1 year, 99=DK/Ref]

R3. And overall, how satisfied are you with your trips on the Turnpike – very satisfied, somewhat satisfied, not too satisfied, or not at all satisfied?

1. Very satisfied
2. Somewhat satisfied
3. Not too satisfied
4. Not at all satisfied

9. DK/Ref

NOTE: IF CURRENT USER FROM R1 #1, PROCEED WITH SECTION S
IF PAST USER FROM R12B #1, SKIP AHEAD TO SECTION U

S. MOST RECENT TRIP

S1. In order to understand driving patterns better, I'd like ask you about the most recent trip where you drove on the New Jersey Turnpike. How long ago did you make this trip?

1. The past 7 days/week
2. The past month
3. The past year
4. Longer ago than 1 year >>> SKIP TO T1
9. DK/Ref >>> SKIP TO T1

S2. Was the main purpose of this trip to commute to your workplace, travel for your job, to get to school, for recreation or shopping, or for some other reason?

1. Commute to Work
2 Travel for job
3. School
4. Recreation/shopping
5. Other, specify: ____________________________
9. DK/ref

S3. And how many times per week do you typically make this trip?

____________ Code number. 0=Less than one, 99=DK/Ref

S4. What day of the week was the most recent trip?

1. Monday
2. Tuesday
3. Wednesday
4. Thursday
5. Friday
6. Saturday
7. Sunday
9. DK/Ref

S5. About what time of day did you ENTER the Turnpike?

_____ : _____ 1. am 2. pm 99. DK/ref

S5a. Why did you choose to leave at this time? [ACCEPT MULTIPLE RESPONSES. DO NOT READ LIST]

1. Work schedule
2. To avoid congestion
3. To make an appointment
4. Cheaper toll
5. Out of habit / what I usually do
6. So I could return at a certain time
7. Easier or cheaper parking availability
18. Other, specify: ___________________
19. No reason / DK/REF

S6. And what exit did you get on? [SINGLE RESPONSE]

1. 1 / Delaware Memorial Bridge
2. 2
3. 3
4. 4
5. 5
6. 6
7. 7
8. 7A
9. 8
10. 8A
11. 9
12. 10
13. 11
14. 12
15. 13
16. 13A
17. 14
18. 14A
19. 14B
20. 14C / Holland Tunnel
21. 15E
22. 15W
23. 16E
24. 16W / Lincoln Tunnel
25. 17
26. 18E
27. 18W
28. Other, specify: ____
29. DK/REF

S7. What time of day did you get OFF the Turnpike?

_____ : _____ 1. am 2. pm 99. DK/ref

S8. At what exit did you get off? [SINGLE RESPONSE]

1. 1 / Delaware Memorial Bridge
2. 2
3. 3
4. 4
5. 5
6. 6
7. 7
8. 7A
9. 8
10. 8A
11. 9
12. 10
13. 11
14. 12
15. 13
16. 13A
17. 14
18. 14A
19. 14B
20. 14C / Holland Tunnel
21. 15E
22. 15W
23. 16E
24. 16W / Lincoln Tunnel
25. 17
26. 18E
27. 18W
28. Other, specify: ____
29. DK/REF

S9. How much was the toll?

__________ Record in dollars and cents

S10. Did you use E.Z. Pass to pay the toll?

1. Yes
2. No
9. DK/ref

S11. And how many people were in the car, including yourself?

___________ Code number 8=8 or more, 9=DK/Ref

S12. Did you pay for parking on this trip, was the parking cost shared with other passengers, or did an employer or someone else pay for it?

1. Self >>ASK S12A
2. Shared by passengers >> ASK S12A
3. Employer paid
4. Other paid, specify: ________________
5. (VOL) Parking was free, on street, etc.
9. DK/REF

S12A. And what was [your/your share of the] parking cost?

_________ Record in dollars and cents

S13. What is the zip code where you started this trip?

________________ 98888=DK, 99999=Ref

S14. And what is the zip code of your final destination?

________________ 98888 = Unknown >> ASK for cross streets and city, 99999 = Ref

S15. What was the total travel time from door to door for this trip? Please include all non-Turnpike driving time as well.

___________ Code in minutes

S16. Did you make any stops along the way?

1. Yes
2. No
9. DK/ref

S17. What time were you supposed to be at your destination?

_____ : _____ 1. am 2. pm
98. No Specific time >>> SKIP TO S21
99. DK/ref >>> SKIP TO S21

S18. And did you arrive more than 10 minutes earlier or later than this time?

1. More than 10 minutes earlier >> ASK S19
2. More than 10 minutes later >> ASK S9
3. Arrived within 10 minutes of target time >>> SKIP TO S21
8. (VOL) never arrived at destination >>> SKIP TO S21
9. DK/Ref >>> SKIP TO S21

S19. How many minutes (early/late) were you?

__________ Code in minutes

S20. Did you specifically plan to be [early/late] when you left?

1. Yes
2. No
9. DK/Ref

S21. I'd just like to get some idea about your trip flexibility. How much LATER than your desired arrival time are you willing to arrive at your destination?

__________ Code in minutes, 0=None

S22. And how much EARLIER than your desired arrival time are you willing to arrive at your destination?

__________ Code in minutes, 0=None

S23. And now a few quick questions about your return trip. About what time of day did you ENTER the Turnpike for your return trip?

_____ : _____ 1. am 2. pm 99. DK/ref

100. DID NOT USE TURNPIKE FOR RETURN TRIP >> GO TO S28

S24. And what exit did you get on? [SINGLE RESPONSE]

1. 1 / Delaware Memorial Bridge	2. 2	4. 4
	3. 3	5. 5

6. 6
7. 7
8. 7A
9. 8
10. 8A
11. 9
12. 10
13. 11
14. 12
15. 13
16. 13A
17. 14
18. 14A
19. 14B
20. 14C / Holland Tunnel
21. 15E
22. 15W
23. 16E
24. 16W / Lincoln Tunnel
25. 17
26. 18E
27. 18W
28. Other, specify: ____
29. DK/REF

S25. What time of day did you get OFF the Turnpike?

_____ : _____ 1. am 2. pm 99. DK/ref

S26. At what exit did you get off? [SINGLE RESPONSE]

1. 1 / Delaware Memorial Bridge
2. 2
3. 3
4. 4
5. 5
6. 6
7. 7
8. 7A
9. 8
10. 8A
11. 9
12. 10
13. 11
14. 12
15. 13
16. 13A
17. 14
18. 14A
19. 14B
20. 14C / Holland Tunnel
21. 15E
22. 15W
23. 16E
24. 16W / Lincoln Tunnel
25. 17
26. 18E
27. 18W
28. Other, specify: ____
29. DK/REF

S27. And what was the total travel time from door to door for your return trip?

__________ Code in minutes

S28. Did you use any other toll facilities or toll roads during these trips?

1. Yes >> ASK S29
2. No >>> SKIP TO S30
9. DK/ref >>> SKIP TO S30

S29. What were they? [ACCEPT MULTIPLE RESPONSES. DO NOT READ LIST]

1. Holland Tunnel
2. Lincoln Tunnel
3. George Washington Bridge
4. Goethals Bridge
5. Bayonne Bridge
6. Outerbridge Crossing
7. Tappan Zee Bridge
8. Verrazano Narrows Bridge
9. Queens/Midtown Tunnel
10, Tri-Borough Bridge
11. Garden State Parkway
12. Pennsylvania Turnpike
18. Other, specify: ______________________
19. DK/Ref

S30. Thinking about your total round trip – what do you think the cost would have been if you went by public transit? [Note: cost is for respondent only]

________________ Record in dollars and cents

99. Don’t know

100. (VOL) Transit not available for this trip

T. REASONS FOR TOLL USE

T1. Thinking back, do you recall why you first started using the New Jersey Turnpike?

1. Gave answer: ________________ Record verbatim
2. Can't recall
9. DK/ref

T2. For the same type of trips that we have just been discussing, did you previously travel on a regular basis by public transit?

1. Yes, in past >>> ASK T3
2. (VOL) Yes, and still use it regularly now as well >>> SKIP TO U1
3. No >>> SKIP TO U1
9. DK/Ref >>> SKIP TO U1

T3. Why did you stop using transit? [ACCEPT MULTIPLE RESPONSES. DO NOT READ LIST]

1. Formed/joined a carpool
2. Transit is too expensive
3. Transit takes too long
4. Transit is uncomfortable
5. Transit is unsafe
6. Transit is inconvenient
7. Moved home
8. Family situation changed
9. Job relocated

10. Work situation/hours changed
11. Job requires me to have a car
97. Did not stop, still use it regularly
98. Other, specify: _________________
99. DK/ref

U. IMPACT OF 2000 TOLL INCREASE

[IF R2=4-98, ASK U1. ALL OTHERS GO TO V1]

U1. The tolls on the New Jersey Turnpike were raised just over three years ago in September 2000.

Do you recall this toll increase at all?

1. Yes >>> ASK U2
2. No >>> SKIP TO V1
9. DK/ref >>> SKIP TO V1

U2. Do you think the toll increase had any effect on traffic along the New Jersey Turnpike or not?

1. Yes
2. No >>> SKIP TO U4
9. DK/ref >>> SKIP TO U4

U3. Do you think traffic is now better or worse?

1. Better
2. Worse
3. (VOL) Combination, sometimes better/sometimes worse
9. DK/ref

U4. After the September 2000 toll increase some drivers may have made changes in the way they traveled on the Turnpike. This may include a change in the time they left, their route, whether they traveled by carpool or public transit, how long it took them to travel, and how often they made the trip.

Did the toll increase of September 2000 affect your own travel behavior in any way?

1. Yes >>> ASK U6
2. No >>> ASK U5
9. DK/ref >>> SKIP TO V1

[ASK U5 IF U4=2]

U5. What are the main reasons your travel behavior did not change? [MULTIPLE RESPONSE. DO NOT READ LIST]

1. Price difference not all that much/can afford it
2. Toll is paid by employer
3. Have no choice, no flexibility
4. My choice, I go when I want to go
8. Other, specify: ___________
9. DK/ref >>>>> ALL FROM U5 GO TO V1

[ASK U6ff IF U4=1]

RANDOMIZE UNITS: U6/6a/6b/6c, U7/U8, U9, U10, U11/U12, U13/13a/13b/13c, U14, U15, U16. ALWAYS ASK U17 LAST.

U6. Did you change how often you drove on the Turnpike because of the toll increase?

1. Yes >>> ASK U6a-c

2. No
9. DK/ref

U6a. How many trips did you make a week on average BEFORE the toll increase?

_____________ Record number , 99=DK/Ref

U6b. How many trips did you make a week on average AFTER the toll increase?

_____________ Record number, 99=DK/Ref

[IF 99/DK/REF TO U6a or U6b, ASK U6c:]

U6c. Was the number of trips you made after the increase more or less than before?

1. More
2. Less
9. DK/ref

U7. Did you start using or increase your use of carpooling because of the toll increase?

1. Started using carpools >>> SKIP TO U9
2. Increased use of carpools >>> SKIP TO U9
3. No, neither
9. DK/ref

U8. Did you stop using or decrease your use of carpooling because of the toll increase?

1. Stopped using carpools
2. Decreased use of carpools

3. No, neither
9. DK/ref

U9. Did the number of trips where you drove totally alone increase, decrease or stay about the same because of the toll increase?

1. Increased
2. Decreased
3. Stayed the same
9. DK/ref

U10. Did your number of trips using public transportation increase, decrease or stay about the same because of the toll increase?

1. Increased
2. Decreased
3. Stayed the same
9. DK/ref

U11. Did your number of trips driving during the weekday peak hours increase, decrease or stay about the same because of the toll increase?

1. Increased
2. Decreased
3. Stayed the same
9. DK/ref

U12. Did your number of trips driving during the weekend increase, decrease or stay about the same because of the toll increase?

1. Increased

2. Decreased
3. Stayed the same
9. DK/ref

U13. Did you change how many times you made stops during the trip because of the toll increase?

1. Yes >>> ASK U13a-c
2. No
9. DK/ref

U13a. How many stops did you make a week on average BEFORE the toll increase?

______________ Record number , 99=DK/Ref

U13b. How many stops did you make a week on average AFTER the toll increase?

______________ Record number, 99=DK/Ref

[IF 99/DK/REF TO U13a or U13b, ASK U13c:]
U13c. Was the number of stops you made after the increase more or less than before?

1. More
2. Less
9. DK/ref

U14. Did the number of trips you made driving on alternate routes to the Turnpike increase, decrease or stay about the same because of the toll increase?

1. Increased
2. Decreased

3. Stayed the same
9. DK/ref

U15. Did your trips on the Turnpike become longer, shorter or stay about the same because of the toll increase?

1. Became longer
2. Became shorter
3. Stayed the same
9. DK/ref

U16. Did you get an E-ZPass tag because of the toll increase or not?

1. Yes
2. No
9. DK/ref

U17. Did you make any other changes in your travel behavior because of the September 2000 toll increase?

1. Yes, specify : ____________________
2. No
9. DK/ref

V. E-ZPASS USE

[IF S9 EQ 1 or U16 EQ 1, Read intro: 'Just to confirm,"]
V1. Do you currently have an E-ZPass tag?

1. Yes >>> ASK V1a
2. No

9. DK/ref

V1a. For how many years have you had E-ZPass?

__________ [Record number. 0=Less than 1 year, 99=DK/Ref]

V2. Are you aware of any discounts that you can get using E-ZPass?

1. Yes >>> ASK V2a
2. No
9. DK/ref

V2a. What are they? [ACCEPT MULTIPLE RESPONSES. DO NOT READ LIST]

1. Time of day/off-peak use discounts
2. Carpool discounts
3. Discounts for frequent use of Goethels/Outerbridge/ Bayonne/Staten Island bridges
8. Other, specify: _____________
9. DK of specific discounts/ref

[IF V1=2/No, ASK V3. ALL OTHERS GO TO V4]

V3. There are a number of reasons why people don't have E-ZPass. For each one I read, tell me whether it is a major reason, minor reason, or not a reason for you. [ROTATE]

a. It really won't save me any time
b. It really won't save me any money
c. The discounts are not large enough
d. Wouldn't use it enough
e. It's too much trouble to get one

f. It's too expensive to get one

g. I don't want to give out personal information

h. Seems complicated to use

i. Afraid of being overcharged or fined if the tag doesn't work right

j. I just never really thought about getting it

k. I don't know where to get E-ZPass

Codes for V3a-k

1. Major reason 2. Minor reason 3. Not a reason 9. DK/ref

V3l. Are there any other specific reasons why you do not have E-ZPass?

1. Yes, specify: ___________________
2. No
9. DK/ref

[IF V1=1/Yes, ASK V4. ALL OTHERS GO TO V8]

V4. Do you always use E-ZPass for trips across the Hudson where you pay tolls?

1. Yes
2. No >>> ASK V4a
9. DK/ref

V4a. Why don't you use it all the time? [ACCEPT MULTIPLE RESPONSES. DO NOT READ LIST]

1. Want trip to be anonymous
2. Only use when I don't have cash
3. Can only use it for business trips
4. Can only use it for personal trips
5. Sometimes forget to bring it
6. Sometimes lose it

7. Other member of family has it
8. Not enough money in E-ZPass account
18. Other, specify: ____________________
19. DK/ref

V5. Who pays your E-ZPass account?

1. Self
2. Employer
3. Family member
8. Other, specify: _____________
9. DK/ref

V6. What do you like MOST about E-ZPass? [ACCEPT MULTIPLE RESPONSES. DO NOT READ LIST]

1. Saves time/quicker
2. Saves money, cheaper than cash toll
3. Don't need to carry cash
4. Don't need to interact with toll collector
5. Safer
6. Less stressful
7. Like the itemized statement/don't need to keep receipts
8. Can use it for parking
9. Can use it for other toll roads
17. Other, specify: _____________________
18. Nothing in particular
19. DK/ref

V7. Is there anything you don't like about E-ZPass?

1. Yes, specify: ________________ Record verbatim
2. No, nothing in particular
9. DK/ref

V8. Is there anything that could be done to make E-ZPass attractive to more people?

1. Yes, specify: ________________ Record verbatim
2. No, nothing in particular
9. DK/ref

W. FORMER TOLL USERS

[ASK SECTION W IF R1=2/R1B=1. ALL OTHERS GO TO SECTION X.]

W1. Earlier you stated that you previously used the Turnpike regularly, but now you use another route or transit more often. What is the main reason you switched? [ACCEPT MULTIPLE]

1. Gave answer, specify : ________________ Record verbatim
2. No specific reason
9. Can't recall/DK/ref

W2. Thinking about the most recent time you made the same basic trip that you used to make on the Turnpike -- How long ago did you make this trip?

1. The past 7 days/week
2. The past month
3. The past year
4. Longer ago than 1 year >>> SKIP TO X1
9. DK/Ref >>> SKIP TO X1

W3. Was the main purpose of this trip to commute to your workplace, travel for your job, to get to school, for recreation or shopping, or for some other reason?

1. Commute to Work
2 Travel for job
3. School
4. Recreation/shopping
5. Other, specify: ___________________________
9. DK/ref

W4. And how many times per week do you typically make this trip?

___________ Code number. 0=Less than one, 99=DK/Ref

W5. What day of the week was the most recent trip?

1. Monday
2. Tuesday
3. Wednesday
4. Thursday
5. Friday
6. Saturday
7. Sunday
9. DK/Ref

W6. Did you travel by car, train, PATH, bus, or ferry?
[ACCEPT MULTIPLE RESPONSES]

1. Car
2. Train
3. PATH

4. Bus
5. Ferry
8. Other, specify: ______________________
9. DK/Ref

W7. About what time of day did you start this trip?

_____ : _____ 1. am 2. pm 99. DK/ref

W8. Why did you choose to travel at this specific time?

1. Work schedule
2. To avoid congestion
3. To make an appointment
4. Cheaper toll
5. Out of habit / what I usually do
6. So I could return at a certain time
7. Easier or cheaper parking availability
18. Other, specify: ___________________
19. No reason / DK/REF

W9. What was the total travel time from door to door for the trip from New Jersey to New York?

__________ Code in minutes

W10. Did you make any stops along the way?

1. Yes
2. No
9. DK/ref

W11. What time were you supposed to be at your destination?

_____ : _____ 1. am 2. pm

98. No Specific time >>> SKIP TO W15

99. DK/ref >>> SKIP TO W15

W12. And did you arrive more than 10 minutes earlier or later than this time?

1. More than 10 minutes earlier >> ASK W13
2. More than 10 minutes later >> ASK W13
3. Arrived within 10 minutes of target time >>> SKIP TO W15
9. DK/Ref >>> SKIP TO W15

W13. How many minutes (early/late) were you?

__________ Code in minutes

W14. Did you specifically plan to be [early/late] when you left?

1. Yes
2. No
9. DK/Ref

W15. I'd just like to get some idea about your trip flexibility. How much LATER than your desired arrival time are you willing to arrive at your destination?

__________ Code in minutes, 0=None

W16. And how much EARLIER than your desired arrival time are you willing to arrive at your destination?

__________ Code in minutes, 0=None

W17. What is the zip code where you started this trip?

_______________ 98888=DK, 99999=Ref

W18. And what is the zip code of your final destination?

_______________ 98888 = Unknown >> ASK for cross streets and city
99999 = Ref

W19. And now thinking about your return trip – about what time of day did you start your return trip?

_____ : _____ 1. am 2. pm 99. DK/ref

W20. How much did this total trip cost you round-trip?

__________ Round to nearest dollar.
0=less than $1, 98=$98+99=DK/REF

W21. And how much do you think this trip would have cost you if you used the Turnpike?

__________ Round to nearest dollar.
0=less than $1, 98=$98+, 99=DK/REF

X. TOLL SCENARIO TESTS

X1. For research purposes, we're interested in finding out your reactions to different types of toll rates. I'm going to present you with some hypothetical situations and ask for your reaction. For our purposes, peak travel hours include the morning rush between 7 and 9 A.M. and the evening rush between 4:30 and 6:30 P.M. as well as weekend travel all day on Saturday or Sunday. Off-peak hours are all other times.

Would you have done anything differently during your most recent trip on the New Jersey Turnpike if the cash toll was [READ X], the peak hour E-ZPass toll was [READ Y] and the off-peak E-ZPass toll [READ Z]?

ROTATE:

Scenario	X read-in	Y read-in	Z read-in
A.	$1	$1	50 cents
B.	$4	$1	50 cents
C.	$8	$1	50 cents
D.	$4	$4	50 cents
E.	$8	$4	50 cents
F.	$4	$4	$1
G.	$8	$4	$1
H.	$4	$4	$2
I.	$8	$4	$2
J.	$8	$8	50 cents
K.	$8	$8	$1
L.	$8	$8	$2

<u>Conditions for which items in X1 get asked</u>

1. If peak hour/weekend E-ZPass user , ask A RANDOM 4 of scenarios A, B, C, E, F, G, H, I, J, K, and L (all but D)
2. If off-peak E-ZPass user , ask scenarios H, I, and L
3. If R1B=1 (alternate route), ask A RANDOM 4 of scenarios A, B, C, D, E, and J
4. If S10=2 or 9 (cash user), ASK A RANDOM 4 of scenarios A thru L

<u>Peak hour E-ZPass user</u>:

IF S10=1 and ((s4=6/7 and s5=any time) or (s4=1-5 and s5 is 7-9 am or 4:30-6:30 pm))

<u>OR</u> S10=1 and ((s4=6/7 and s23=any time) or (s4=1-5 and s23 is 7-9 am or 4:30-6:30 pm))

Off-Peak E-ZPass user:

IF S10=1 and (s4=1-5 and s5 is Midnight/12am-6:59 am or
9:01 am-4:29pm or 6:31-11:59pm)

AND S10=1 and (s4=1-5 and s23 is Midnight/12am-6:59 am or
9:01 am-4:29pm or 6:31-11:59pm)

Answer codes for X1A-L

1. Yes >>> ASK X2A-L as appropriate after each "Yes"
2. No
9. DK/ref

X2A-L. (For each yes, X1A through L:) What would you have done differently? [DO NOT READ LIST. ACCEPT MULIPLE RESPONSES]

1. Switched to off peak travel
2. Used alternate route
3. Used public transit (bus, train)
4. Not made this trip at all
5. Get E-ZPass
18. Other, specify: ________________________
19. Don't know

Y. PUBLIC OPINION

[RANDOMIZE Y1-4]

Y1. Now a few quick questions on your opinions. In general, do you feel it is fair or unfair to charge higher Turnpike tolls during peak travel periods?

1. Fair

2. Unfair
9. DK/ref

Y2. Do you feel it is fair or unfair to give discounts to E-ZPass users?

1. Fair
2. Unfair
9. DK/ref

Y3. Is it fair or unfair to give discounts to frequent peak-hour commuters?

1. Fair
2. Unfair
9. DK/ref

Y4. Is it fair or unfair to use Turnpike toll revenues to support public transit?

1. Fair
2. Unfair
9. DK/ref

Z. DEMOGRAPHICS

Just a few more questions so we can classify your answers.

Z1. What was the last grade in school you completed?

1. 8TH GRADE OR LESS
2. HIGH SCHOOL INCOMPLETE (GRADES 9, 10 AND 11)
3. HIGH SCHOOL COMPLETE (GRADE 12)
4. VOCATIONAL/TECHNICAL SCHOOL

5. SOME COLLEGE
6. JUNIOR COLLEGE GRADUATE (2 YEAR, ASSOCIATES DEGREE)
7. 4 YEAR COLLEGE GRADUATE (BACHELOR'S DEGREE)
8. GRADUATE WORK (MASTERS, LAW/MEDICAL SCHOOL, ETC.)
9. DK/REF

Z2. What was your age on your last birthday?

/ / / (CODE # OF YEARS, 99 = REFUSED)

Z2A. [IF REFUSED IN Z2, ASK:] Is it between...

1. 18 - 20
2. 21 - 24
3. 25 - 29
4. THIRTIES (30 - 39)
5. FORTIES (40 - 49)
6. FIFTIES (50 - 59)
7. 60 - 64
8. 65 OR OVER
9. NO ANSWER/REFUSED

Z3. Are you married, living with a partner, widowed, divorced, separated, or have you never been married?

1 Married
2 Living with a partner
3 Widowed
4 Divorced
5 Separated
6 Never married
9 Don't know

Z4. How many children under the age of 18 live in your household?

________ Code number 0-9, 8=8 or more, 9=DK/ref

Z5. Are you of Latino or Hispanic origin?

1 Yes
2 No
9 (VOL) Don't Know / Refused

Z6. And are you white, black or Asian?

1 White
2 Black
3 Asian
4 (VOL) Other, specify: ______________________
9 (VOL) Don't Know/Refused

Z7. Is your current working status employed full-time, employed part-time, retired, or not working outside the home?

1. Employed full-time >> Z8-9
2. Employed part-time >> ASK Z8-9
3. Retired >>> SKIP TO Z10
4. Not working outside the home >>> SKIP TO Z10
5. (VOL) Student >>> SKIP TO Z10
6 (VOL) Other, specify: ____________________ >>> SKIP TO Z10
9. DK/ref >>> SKIP TO Z10

Z8. What kind of work do you do – management, professional, office work, sales, technical, or something else?

1. Management/professional
2. Office work
3. Sales
4. Technical
5. Other, specify: ___________________
9. DK/ref

Z9. Does your job allow you to work at home at all?

1. Yes
2. No
9. DK/ref

Z10. How many vehicles are available for use by your household?

________ Code number 0-9, 8=8 or more, 9=DK/ref

Z11. In what county do you live?

< 1 > Atlantic

< 2 > Bergen

< 3 > Burlington

< 4 > Camden

< 5 > Cape May

< 6 > Cumberland

< 7 > Essex

< 8 > Gloucester

< 9 > Hudson

< 10 > Hunterdon

< 11 > Mercer

< 12 > Middlesex

< 13 > Monmouth

< 14 > Morris

< 15 > Ocean

< 16 > Passaic

< 17 > Salem

< 18 > Somerset

< 19 > Sussex

< 20 > Union

< 21 > Warren

< 22 > Don't know/REF

Z12. What is your zip code? /____/____/____/____/____/

(Range 07001 to 08904; DK/RF=99999)

Z13. So that we can group all answers, is your household's total annual income before taxes under $25,000; from $25,000 to just under $55,000; from $55,000 to just under $95,000; from $95,000 to just under $135,000; or $135,000 or more?

1. UNDER $25,000 >>> ASK Z13a
2. $25,000 -- $54,999 >>> ASK Z13b

3. $55,000 -- $94,999 >>> ASK Z13c
4. $95,000 -- $134,999 >>> ASK Z13d
    5. $135,000 OR MORE >>> GO TO Z14
8. DON'T KNOW >>> GO TO Z14
9. REF >>> GO TO Z14

Z13a. Is it under $15,000, or $15,000 to $25,000?

1. Under $15K
2. $15K-25K
9. DK/ref

Z13b. Is it under $35,000, $35,000 to just under $45,000, or $45,000 to $55,000?

1. Under $35K
2. $35K-45K
3. $45K-$55K
9. DK/ref

Z13c. Is it under $65,000, $65,000 to just under $75,000, $75,000 to $85,000, or $85,000 to $95,000?

1. Under $65K
2. $65K-75K
3. $75K-85K
4 $85K-95K
9. DK/ref

Z13d. Is it under $105,000, $105,000 to just under $115,000, $115,000 to $125,000, or $125,000 to $135,000?

1. Under $105K
2. $105K-115K
3. $115K-125K
4 $125K-135K
9. DK/ref

Z14. Did your household income change significantly from 2001 to 2003? [IF YES, ASK: Did it go up or go down?]

1. Change, went UP
2. Change, went DOWN
3. Change, but NA on direction
4. NO CHANGE
9. DK/ref

Z15. RESPONDENT SEX (from observation): 1. MALE 2. FEMALE

That is the end of the survey. You've been very helpful. Thank you very much for your participation.

APPENDIX 5. DERIVATION OF USER SPECIFIC UTILITY FUNCTION OPTIMIZATION MODEL BASED ON TIME ALLOCATION THEORY

$$Max \quad V\left(t, \overline{t_i}, p_i, p, T, R, \Delta^{early}, \Delta^{late}, t_{0i}\right) \tag{41a}$$

st

$$px + \sum_{i=1}^{r} d_i p_i - R = 0 \tag{41b}$$

$$t + \sum_{i=1}^{r} d_i t_i = T \tag{41c}$$

$$t_i \geq \overline{t_i} \tag{41d}$$

$$e_i\left(t_{0i} - t_i\right) = \Delta_i^{early} \tag{41e}$$

$$l_i\left(t_{0i} - t_i\right) = \Delta_i^{late} \tag{41f}$$

$$e_i \Delta_i^{early} \leq \Delta_{early}^{*} \tag{41g}$$

$$l_i \Delta_i^{late} \leq \Delta_{late}^{*} \tag{41h}$$

where;

V= Utility function

i = period choice index (pre-peak, mid-peak and post-peak periods)

R= income level (in thousands of dollars)

t = time spent in activities other than travel time (in hours)

t_i = travel time for selected period i (in hours)

t_{oi} = (desired arrival time) – (departure time to travel on period i) (in hours)

T = total available time (in hours)

p_i = cost of travel on period/route i (in dollars)

p = cost of goods other than travel (in dollars)

x = consumption of goods other than travel

d_i = 1, if period i is selected, 0 otherwise

e_i = 1, if early arrival is observed when period/route i is selected, 0 otherwise

l_i = 1, if late arrival is observed when route i is selected, 0 otherwise

Δ^{*}_{early} = flexibility in early arrival time (in hours)

Δ^{*}_{late} = flexibility in late arrival time (in hours)

Δ_i^{early} = early arrival time when period i is selected (in hours)

Δ_i^{late} = late arrival time when period i is selected (in hours)

$\bar{t}_i$ = minimum time requirement to travel on period/route i (in hours)

DERIVATION OF THE USER SPECIFIC UTILITY FUNCTIONS

The methodology used to derive the user specific utility functions can be summarized as follows;

1. Construction of Lagrangian of the constraint optimization problem for both early and late arrival cases in order to incorporate the model constraints into the objective function.
2. Calculation of the first derivative of the Lagrangian function using Envelope Theorem (96) in order to determine the functional forms of marginal utilities of different parameters such as travel time, toll level, income, desired arrival time, deviation from desired arrival time (early/late arrival) and maximum available time.
3. Application of the first order of Taylor Expansion with several variables (97) to determine the specific parameters of each marginal utility functions. The Taylor expansion is applied around the average point of marginal utilities of income, toll level, travel time, desired arrival time and amount of early/late arrival.
4. Derivation of econometric utility function based on the integral of sum of these marginal utilities.

Lagrangian of the Optimization Problem

The Lagrangian of this mathematical problem can be written as follows:

$$L = V + \lambda\left(R - px - \sum_{i=1}^{r} d_i p_i\right) + \mu\left(T - t - \sum_{i=1}^{r} d_i t_i\right) + \sum_{i=1}^{r} d_i k_i\left(\bar{t_i} - t_i\right) + \sum_{i=1}^{r} l_i d_i \vartheta_i\left(-t_i + t_{oi} + \Delta_i^{late}\right)$$
$$+ \sum_{i=1}^{r} e_i d_i \theta_i\left(-t_i + t_{oi} - \Delta_i^{early}\right) + \sum_{i=1}^{r} e_i \varpi_i\left(\Delta_i^{early} - \Delta_{early}^{*}\right) + \sum_{i=1}^{r} l_i\, \psi_i\left(\Delta_i^{late} - \Delta_{late}^{*}\right) + \rho_i\, \Delta_i^{early} + \varsigma_i \Delta_i^{late} \quad (42a)$$

$$k_i\left(t_i - \bar{t}_i\right) = 0 \quad (42b)$$

$$\theta_i\left(-t_i + t_{oi} - \Delta_i^{early}\right) = 0 \quad (42c)$$

$$\varphi_i\left(-t_i + t_{oi} + \Delta_i^{late}\right) = 0 \quad (42d)$$

$$\varpi_i\left(\Delta_i^{early} - \Delta_{early}^{*}\right) = 0 \quad (42e)$$

$$\psi_i\left(\Delta_i^{late} - \Delta_{late}^{*}\right) = 0 \quad (42f)$$

$$\rho_i\ \Delta_i^{early} = 0 \quad (42g)$$

$$\varsigma_i \Delta_i^{late} = 0 \quad (42h)$$

The Lagrange multiplier for income constraint, λ, represents the marginal utility of income, whereas multiplier for time constraint, μ, is the marginal utility of having an additional unit of time available. The multiplier, k_i, is the marginal utility of decreasing time requirements, and the other multipliers, ϑ_i, θ_i, ϖ_i, and ψ_i, are the marginal utility of arriving early/late obtained by reducing departure time and deviation from desired arrival time. The very existence of VOT indicates that the marginal utility of decreasing time requirement for a trip is positive, indicating that the third constraint is binding, and k_i is nonnegative. Since early and late arrivals can not be occurred at the same time two different cases should be considered for early and late arrival. In this study equal weight are given to early and late arrivals, therefore derivation process for each case is identical. For illustration purposes only the derivation of early arrival is provided. However, the derivation of late arrival can be done easily by just replacing the early arrival parameters with late arrival parameters.

If it is assumed that individuals prefer to arrive early (e_i=1, l_i=0, and ρ_i=0) within the available flexibility, then constraints regarding late arrival become redundant and since the user is within the flexible early arrival period the multiplier, ϖ_i , becomes zero. The corresponding Lagrangian of this particular mathematical model becomes as follows:

$$L = V + \lambda\left(R - px - \sum_{i=1}^{r} d_i p_i\right) + \mu\left(T - t - \sum_{i=1}^{r} d_i t_i\right) + \sum_{i=1}^{r} d_i k_i\left(\bar{t}_i - t_i\right) + \sum_{i=1}^{r} d_i \theta_i\left(-t_i + t_{oi} - \Delta_{early}\right) \tag{43}$$

The envelope theorem states that, the effect of a change in a parameter on the optimal value of the objective function is the partial derivative of the objective function with respect to the parameter, ignoring the effect of the change in the parameter on the choice variable.(96) Therefore following the envelope theorem the first order partial derivatives can be written as follows:

$$\frac{\partial V_i}{\partial R} = -\lambda \tag{44a}$$

$$\frac{\partial V_i}{\partial T} = -\mu \tag{44b}$$

$$\frac{\partial V_i}{\partial \bar{t}_i} = k_i d_i \tag{44c}$$

$$\frac{\partial V_i}{\partial p} = \lambda x \tag{44d}$$

$$\frac{\partial V_i}{\partial p_i} = d_i \lambda \tag{44e}$$

$$\frac{\partial V_i}{\partial t_{oi}} = -d_i \theta_i \tag{44f}$$

$$\frac{\partial V_i}{\partial \Delta_i^{early}} = d_i \theta_i \tag{44g}$$

The differentials for total utility (dV) and alternative specific utility (dV_i) are given in Equations (45) and (46). If it is assumed that, the prices of goods other than transportation are steady, then the derivative with respect to p becomes zero, and the final form of the differential for the utility function of each choice can be written as in Equation (47).

$$dV = \frac{\partial V}{\partial R} dR + \frac{\partial V}{\partial p} dp + \frac{\partial V}{\partial T} dT + \sum_{i=1}^{r} d_i \frac{\partial V}{\partial p_i} dp_i + \sum_{i=1}^{r} d_i \frac{\partial V}{\partial t_i} d\bar{t}_i + \sum_{i=1}^{r} d_i \frac{\partial V}{\partial \Delta_i^{early}} d\Delta_i^{early} \tag{45}$$

$$dV_i = \frac{\partial V}{\partial R} dR + \frac{\partial V}{\partial p} dp + \frac{\partial V}{\partial T} dT + \frac{\partial V}{\partial p_i} dp_i + \frac{\partial V}{\partial t_i} d\bar{t}_i + \frac{\partial V}{\partial t_{oi}} dt_{oi} + \frac{\partial V}{\partial \Delta_i^{early}} d\Delta_i^{early} \tag{46}$$

$$dV_i = \lambda(dp_i - dR) - \mu dT + k_i d\overline{t_i} - \theta_i\left(dt_{oi} - d\Delta_i^{early}\right) \tag{47}$$

Application of Taylor Expansion to the Marginal Utilities

Since first order conditions obtain from Envelope Theorem is a summary of Taylor's Expansion Theorem with several variables, Taylor expansion around average point of the marginal utilities, $\left(\overline{R}, \overline{p_i}, \overline{T}, \overline{\overline{t_i}}, \overline{t_{oi}}, \overline{\Delta_i^{early}}\right)$, is analyzed, assuming that each marginal utility parameter varies by all variables associated in the utility model, in order to develop an analytical expression for the utility function.

<u>Marginal Utility of Departure Time</u>

The multiplier, θ_i, in Equation 47, refers to the marginal utility of departure time. By relaxing the assumption of constant marginal utility, first order Taylor expansion is applied for the multiplier, θ_i. Equations (48a) through (48c) represent the derivation for this specific multiplier.

$$\frac{\partial V_i}{\partial\left(t_{oi} - \Delta_i^{early}\right)} = -\theta_i \approx -\left(b_o + \frac{\partial \theta_i}{\partial p_i}\left(p_i - \overline{p_i}\right) + \frac{\partial \theta_i}{\partial t_i}\left(\overline{t_i} - \overline{\overline{t_i}}\right) + \frac{\partial \theta_i}{\partial T}\left(T - \overline{T}\right) + \frac{\partial \theta_i}{\partial t_{oi}}\left(t_{oi} - \overline{t_{oi}}\right) + \frac{\partial \theta_i}{\partial R}\left(R - \overline{R}\right) + \frac{\partial \theta_i}{\partial \Delta_i^{early}}\left(\Delta_i^{early} - \overline{\Delta_i^{early}}\right)\right) \tag{48a}$$

$$-\theta_i \approx -b_o - b_1\left(p_i - \overline{p_i}\right) - (b_2)\left(\overline{t_i} - \overline{\overline{t_i}}\right) - b_4\left(T - \overline{T}\right) - b_3\left(t_{oi} - \overline{t_{oi}}\right) + b_1\left(R - \overline{R}\right) + b_4\left(t_L - \overline{t_L}\right) + b_3\left(\Delta_i^{early} - \overline{\Delta_i^{early}}\right) \tag{48b}$$

$$\approx \tilde{b}_o - b_1 p_i - b_2 \overline{t_i} - b_3 t_{oi} - b_4 T + b_1 R + b_3 \Delta_i^{early} \tag{48c}$$

where;

$$-\frac{\partial\theta_i}{\partial p_i} = \frac{\partial^2 V_i}{\partial\left(t_{oi} - \Delta_i^{early}\right)\partial p_i} = \frac{\partial\lambda}{\partial\left(t_{oi} - \Delta_i^{early}\right)} = -b_1$$

$$-\frac{\partial\theta_i}{\partial\bar{t}_i} = \frac{\partial^2 V_i}{\partial\left(t_{oi} - \Delta_i^{early}\right)\partial\bar{t}_i} = \frac{\partial k_i}{\partial\left(t_{oi} - \Delta_i^{early}\right)} = -b_2$$

$$-\frac{\partial\theta_i}{\partial\left(t_{oi} - \Delta_i^{early}\right)} = -\frac{\partial^2 V_i}{\partial\left(t_{oi} - \Delta_i^{early}\right)^2} = -b_3$$

$$-\frac{\partial\theta_i}{\partial T} = \frac{\partial^2 V_i}{\partial\left(t_{oi} - \Delta_i^{early}\right)\partial T} = -\frac{\partial\mu}{\partial\left(t_{oi} - \Delta_i^{early}\right)} = -b_4$$

$$-\frac{\partial\theta_i}{\partial R} = \frac{\partial^2 V_i}{\partial\left(t_{oi} - \Delta_i^{early}\right)\partial R} = -\frac{\partial\lambda}{\partial\left(t_{oi} - \Delta_i^{early}\right)} = b_1$$

$$\tilde{b}_o = -b_o + b_1\overline{p_i} + b_2\bar{\bar{t}}_i + b_3\overline{t_{oi}} + b_4\bar{T} - b_1\bar{R} - b_4\left(\overline{t_L}\right) - b_3\overline{\Delta_i^{early}}$$

Marginal Utility of Available Time

The multiplier, μ , in Equation 47, refers to the marginal utility of available time. Even if, the available time is fixed within a given period of time, the distribution of time between work/leisure activities and travel will affect the individual's utility. By relaxing the assumption of constant marginal utility, first order Taylor expansion is applied for the multiplier, θ_i . Equations (49a) through (49c) represent the derivation for this specific multiplier.

$$\frac{\partial V_i}{\partial T} = -\mu \approx -\left(\sigma_o + \frac{\partial\mu}{\partial p_i}\left(p_i - \overline{p_i}\right) + \frac{\partial\mu}{\partial\bar{t}_i}\left(\bar{t}_i - \bar{\bar{t}}_i\right) + \frac{\partial\mu}{\partial T}\left(T - \bar{T}\right) + \frac{\partial\mu}{\partial t_{oi}}\left(t_{oi} - \overline{t_{oi}}\right) + \frac{\partial\mu}{\partial R}\left(R - \bar{R}\right) + \frac{\partial\mu}{\partial\Delta_i^{early}}\left(\Delta_i^{early} - \overline{\Delta_i^{early}}\right)\right) \quad (49a)$$

$$-\mu \approx -\left(\sigma_o + \sigma_1\left(p_i - \overline{p_i}\right) + (\sigma_2)\left(\bar{t}_i - \bar{\bar{t}}_i\right) - \sigma_3\left(T - \bar{T}\right) + b_4\left(t_{oi} - \overline{t_{oi}}\right) - \sigma_1\left(R - \bar{R}\right) - b_4\left(\Delta_i^{early} - \overline{\Delta_i^{early}}\right)\right) \quad (49b)$$

$$\approx \tilde{\sigma}_o - \sigma_1 p - \sigma_2\bar{t}_i - b_4 t_{oi} + \sigma_3 T + \sigma_1 R + b_4\Delta_i^{early} \quad (49c)$$

where;

$$-\frac{\partial\mu}{\partial p_i} = \frac{\partial^2 V_i}{\partial T\partial p_i} = \frac{\partial\lambda}{\partial T} = -\sigma_1$$

$$-\frac{\partial\mu}{\partial\bar{t}_i} = \frac{\partial^2 V_i}{\partial T\partial\bar{t}_i} = \frac{\partial k_i}{\partial T} = -\sigma_2$$

$$-\frac{\partial \mu}{\partial t_{oi}} = \frac{\partial^2 V_i}{\partial t_{oi} \partial T} = \frac{\partial \theta_i}{\partial T} = -b_4$$

$$-\frac{\partial \mu}{\partial T} = \frac{\partial^2 V_i}{\partial T^2} = \sigma_3$$

$$-\frac{\partial \mu}{\partial R} = \frac{\partial^2 V_i}{\partial T \partial R} = -\frac{\partial \lambda}{\partial T} = \sigma_1$$

$$\frac{\partial \mu}{\partial \Delta_i^{early}} = \frac{\partial^2 V_i}{\partial T \partial \Delta_i^{early}} = \frac{\partial \theta_i}{\partial T} = -b_4$$

$$\tilde{\sigma}_o = -\sigma_o + \sigma_1 p_i + \sigma_2 \overline{\overline{t_i}} + b_4 \overline{t_{oi}} - \sigma_3 \overline{T} - \sigma_1 \overline{R} + b_4 \overline{\Delta_i^{early}}$$

Marginal Utility of Income

The multiplier, λ , in Equation 47, refers to the marginal utility of income. By relaxing the assumption of constant marginal utility, first order Taylor expansion is applied for the multiplier, θ_i . Equations (50a) through (50c) represent the derivation for this specific multiplier.

$$\frac{\partial V_i}{\partial (p_i - R)} = \lambda \approx \left(\alpha_o + \frac{\partial \lambda}{\partial p_i}\left(p_i - \overline{p_i}\right) + \frac{\partial \lambda}{\partial \overline{t_i}}\left(\overline{t_i} - \overline{\overline{t_i}}\right) + \frac{\partial \lambda}{\partial T}\left(T - \overline{T}\right) + \frac{\partial \lambda}{\partial t_{oi}}\left(t_{oi} - \overline{t_{oi}}\right) + \frac{\partial \lambda}{\partial R}\left(R - \overline{R}\right) + \frac{\partial \lambda}{\partial \Delta_i^{early}}\left(\Delta_i^{early} - \overline{\Delta_i^{early}}\right) \right) \tag{50a}$$

$$\lambda \approx \left(\alpha_o + \alpha_1\left(p_i - \overline{p_i}\right) - \left(\alpha_2\right)\left(\overline{t_i} - \overline{\overline{t_i}}\right) - \sigma_1\left(T - \overline{T}\right) - b_1\left(t_{oi} - \overline{t_{oi}}\right) - \alpha_1\left(R - \overline{R}\right) + b_1\left(\Delta_i^{early} - \overline{\Delta_i^{early}}\right) \right) \tag{50b}$$

$$\approx -\tilde{\alpha}_o + \alpha_1 p_i - \alpha_2 \overline{t_i} - b_1 t_{oi} - \sigma_1 T - \alpha_1 R + b_1 \Delta_i^{early} \tag{50c}$$

where;

$$\frac{\partial \lambda}{\partial (p_i - R)} = \frac{\partial^2 V_i}{\partial (p_i - R)^2} = \alpha_1$$

$$\frac{\partial \lambda}{\partial \overline{t_i}} = \frac{\partial^2 V_i}{\partial (p_i - R) \partial \overline{t_i}} = \frac{\partial k_i}{\partial (p_i - R)} = -\alpha_2$$

$$\frac{\partial \lambda}{\partial t_{oi}} = \frac{\partial^2 V}{\partial t_{oi} \partial (p_i - R)} = \frac{\partial \theta_i}{\partial (p_i - R)} = -b_1$$

$$\frac{\partial \lambda}{\partial T} = \frac{\partial^2 V_i}{\partial T \partial (p_i - R)} = -\frac{\partial \mu}{\partial (p_i - R)} = -\sigma_1$$

$$\frac{\partial \lambda}{\partial R} = \frac{\partial^2 V_i}{\partial (p_i - R) \partial R} = -\frac{\partial \lambda}{\partial (p_i - R)} = \alpha_1$$

$$\frac{\partial \lambda}{\partial \Delta_i^{early}} = \frac{\partial^2 V_i}{\partial (p_i - R)\partial \Delta_i^{early}} = \frac{\partial \theta_i}{\partial (p_i - R)} = b_1$$

$$-\tilde{\alpha}_o = \alpha_o - \alpha_1 p_i + \alpha_2 \bar{\bar{t}}_i + b_1 \overline{t_{oi}} + \sigma_1 \overline{T} + \alpha_1 \overline{R} - b_1 \overline{\Delta_i^{early}}$$

Marginal Utility of Travel Time

The multiplier, k_i, in Equation 47, refers to the marginal utility of minimal travel time. By relaxing the assumption of constant marginal utility, first order Taylor expansion is applied for the multiplier, k_i. Equations (51a) through (51c) represent the derivation for this specific multiplier.

$$\frac{\partial V_i}{\partial \bar{t}_i} = k_i \approx \left(\varepsilon_o + \frac{\partial k_i}{\partial p_i}\left(p_i - \overline{p_i}\right) + \frac{\partial k_i}{\partial \bar{t}_i}\left(\bar{t}_i - \bar{\bar{t}}_i\right) + \frac{\partial k_i}{\partial T}\left(T - \overline{T}\right) + \frac{\partial k_i}{\partial t_{oi}}\left(t_{oi} - \overline{t_{oi}}\right) + \frac{\partial k_i}{\partial t_w}\left(R - \overline{R}\right) + \frac{\partial k_i}{\partial \Delta_i^{early}}\left(\Delta_i^{early} - \overline{\Delta_i^{early}}\right)\right) \tag{51a}$$

$$k_i \approx \left(\varepsilon_o - \alpha_2\left(p_i - \overline{p_i}\right) - \varepsilon_1\left(\bar{t}_i - \bar{\bar{t}}_i\right) - \sigma_2\left(T - \overline{T}\right) - b_2\left(t_{oi} - \overline{t_{oi}}\right) + \alpha_2\left(R - \overline{R}\right) + b_2\left(\Delta_i^{early} - \overline{\Delta_i^{early}}\right)\right) \tag{51b}$$

$$\approx \tilde{\varepsilon}_o - \alpha_2 p_i - \varepsilon_1 \bar{t}_i - b_2 t_{oi} - \sigma_2 T + \alpha_2 R + b_2 \Delta_i^{early} \tag{51c}$$

where;

$$\frac{\partial k_i}{\partial p_i} = \frac{\partial^2 V_i}{\partial p_i \partial \bar{t}_i} = \frac{\partial \lambda}{\partial \bar{t}_i} = -\alpha_2$$

$$\frac{\partial k_i}{\partial \bar{t}_i} = \frac{\partial^2 V_i}{\partial \bar{t}_i^{\,2}} = -\varepsilon_1$$

$$\frac{\partial k_i}{\partial t_{oi}} = \frac{\partial^2 V_i}{\partial t_{oi} \partial \bar{t}_i} = -\frac{\partial \theta_i}{\partial \bar{t}_i} = -b_2$$

$$\frac{\partial k_i}{\partial T} = \frac{\partial^2 V_i}{\partial T \partial \bar{t}_i} = -\frac{\partial \mu}{\partial \bar{t}_i} = -\sigma_2$$

$$\frac{\partial k_i}{\partial R} = \frac{\partial^2 V_i}{\partial \bar{t}_i \partial R} = -\frac{\partial \lambda}{\partial \bar{t}_i} = \alpha_2$$

$$\frac{\partial k_i}{\partial \Delta_i^{early}} = \frac{\partial^2 V_i}{\partial \bar{t}_i \partial \Delta_i^{early}} = \frac{\partial \theta_i}{\partial \bar{t}_i} = b_2$$

$$\tilde{\varepsilon}_o = \varepsilon_o + \alpha_2 \overline{p_i} + \varepsilon_1 \bar{\bar{t}}_i + b_2 \overline{t_{oi}} + \sigma_2 \overline{T} - \alpha_2 \overline{R} - b_2 \overline{\Delta_i^{early}}$$

Based on the partial derivatives with respect to each variable the differential for a specific route/period can be obtained as the summation of all marginal utilities, which is represented in Equation (52a). By integrating the differential utility function with respect to appropriate variables utility function for route i is obtained and represented in Equation (52b).

$$\begin{aligned} dV_i &= \lambda(dp_i - dR) - \mu dT + k_i d\bar{t}_i - \theta_i\left(dt_{oi} - d\Delta_i^{early}\right) \\ &= \left(-\tilde{\alpha}_o + \alpha_1 p_i - \alpha_2 \bar{t}_i - b_1 t_{oi} - \sigma_1 T - \alpha_1 R + b_1 \Delta_i^{early}\right)(dp_i - dR) \\ &+ \left(\tilde{\sigma}_o - \sigma_1 p - \sigma_2 \bar{t}_i - b_4 t_{oi} + \sigma_3 T + \sigma_1 R - b_4 \Delta_i^{early}\right) dT \\ &+ \left(\tilde{\varepsilon}_o - \alpha_2 p_i - \varepsilon_1 \bar{t}_i - b_2 t_{oi} - \sigma_2 T + \alpha_2 R - b_2 \Delta_i^{early}\right) d\bar{t}_i \\ &+ \left(\tilde{b}_o - b_1 p_i - b_2 \bar{t}_i - b_3 t_{oi} - b_4 T + b_1 R + b_3 \Delta_i^{early}\right)\left(dt_{oi} - \Delta_i^{early}\right) \end{aligned} \quad (52a)$$

$$\begin{aligned} V_i &= \left(+\tilde{\alpha}_o + 2\sigma_1 T - b_1 \Delta_i^{early}\right) R - (2\alpha_1) R p_i + (2\alpha_2) R \bar{t}_i + (2b_1) R t_{oi} - 2\alpha_2 \bar{t}_i p_i + p_i\left(-\tilde{\alpha}_o - 2\sigma_1 T + b_1 \Delta_i^{early}\right) \\ &- 2b_1 t_{oi} p_i + \left(-2\sigma_2 T + \tilde{\varepsilon}_o - b_2 \Delta_i^{early}\right)\bar{t}_i - 2b_2 t_{oi} \bar{t}_i + \left(\tilde{b}_o - 2b_4 T + b_3 \Delta_i^{early}\right) t_{oi} - \left(b_4 T - \tilde{b}_0\right)\Delta_i^{early} \\ &+ \frac{\alpha_1}{2} p_i^2 - \frac{\varepsilon_1}{2} \bar{t}_i^{\,2} - \frac{b_3}{2} t_{oi}^2 + \frac{\alpha_1}{2} R^2 - \frac{b_3}{2}\left(\Delta_i^{early}\right)^2 \end{aligned} \quad (52b)$$

NESTED LOGIT MODEL FOR UTILITY MODELS

Depending on the selected trip purpose, probability of selecting a specific period and transponder is calculated based on the following equation. This equation calculates the joint probability of obtaining an E-ZPass tag and time of day choice. Each probability function has a logit distribution.

$$\begin{aligned} P_{ni} &= P_{ni \backslash C_k} P_{nC_k} \\ P_{ni} &= \frac{exp(\beta X_{ni} / \rho_k)}{\sum_{j \in B_i} exp(\beta X_{nj} / \rho_k)} \bullet \frac{exp(\rho_k I_{nk} + \alpha Y_{nk})}{\sum_{l=1}^{m} exp(\rho_k I_{nl} + \alpha Y_{nl})} \end{aligned} \quad (53)$$

where;

$$I_{nk} = \ln\left(\sum_{j \in C_k} \exp\left(X_{nj} / \rho_k\right)\right)$$

i=Index for choice of travel period (1 = pre-peak, 2 = peak, 3 = post-peak)

k = Index for transponder ownership choice (1 = E-ZPass, 2 = Cash)

n = Index for individual user (n=1,…N) (N=166 for work trips) (N=126 for leisure trips)

C_k = Set of transponder ownership choice (E-ZPass and cash)

P_{ni} = Probability of selecting travel period i for individual n

$P_{ni \backslash C_k}$ =Conditional probability of travel period i given that a transponder alternative k in nest C_k is chosen

P_{nC_k} = Marginal probability of choosing a transponder alternative in set C_k

β = Coefficients of the utility function for transponder-period combination

X_{ni} = Vector of variables included in the period choice model

m=Number of Transponder choice

ρ_k = Inclusive parameter for the transponder choice

α = Coefficients of the utility function for transponder choice

Y_{nk} = Vector of variables included in the transponder choice model

APPENDIX 6. DERIVATION OF USER SPECIFIC ELASTICITY FUNCTION

In the case of nested logit model, user specific elasticity function, depending on the period choice and trip purpose, is given by the following equation. Detailed estimation of the probability function (P_{nik}) can be found in previous chapter.

$$E_{p_{ni}}^{P_{ni}} = \frac{\partial P_{ni}}{\partial p_{ni}} \bullet \frac{p_{ni}}{P_{ni}} \tag{54}$$

$$E_{p_{ni}}^{P_{ni}} = \frac{p_{ni}}{P_{ni}} \bullet \left(\frac{\partial P_{ni/C_k}}{\partial p_{ni}} \bullet P_{C_k} + \frac{\partial P_{C_k}}{\partial p_{ni}} \bullet P_{ni/C_k} \right) \tag{55}$$

where;

i=Index for choice of travel period (1 = pre-peak, 2 = peak, 3 = post-peak)

k = Index for transponder ownership choice (1 = E-ZPass, 2 = Cash)

n = Index for individual user (n=1,…N) (N=166 for work trips) (N=126 for leisure trips)

P_{ni} = Probability of selecting transponder ownership k and travel period i for individual n

p_{ni} = Variable for toll amount ($)

C_k = Set of Transponder choice (E-Z Pass, or cash)

Derivative of the Conditional probability of choosing travel period *i* $\left(P_{ni \backslash C_k}\right)$

$$\frac{\partial P_{ni/C_k}}{\partial p_{ni}} = \frac{\partial}{\partial p_{ni}} \left(\frac{exp(\beta X_{ni} / \rho_k)}{\sum_{j \in C_k} exp(\beta X_{nj} / \rho_k)} \right) \tag{56}$$

$$\frac{\partial P_{ni/C_k}}{\partial p_{ni}} = \frac{\frac{\partial \beta X_{ni}}{\partial p_{ni}} \frac{1}{\rho_k} exp(\beta X_{ni} / \rho_k) \sum_{j \in C_k} exp(\beta X_{nj} / \rho_k) - exp(\beta X_{ni} / \rho_k) \frac{\partial \beta X_{ni}}{\partial p_{ni}} \frac{1}{\rho_k} exp(\beta X_{ni} / \rho_k)}{\left(\sum_{j \in C_k} exp(\beta X_{nj} / \rho_k) \right)^2} \tag{57}$$

$$\frac{\partial P_{ni/C_k}}{\partial p_{ni}} = \frac{\partial \beta X_{ni}}{\partial p_{ni}} \frac{1}{\rho_k} \left(\frac{exp(\beta X_{ni} / \rho_k)}{\sum_{j \in C_k} exp(\beta X_{nj} / \rho_k)} - \left(\frac{exp(\beta X_{ni} / \rho_k)}{\sum_{j \in C_k} exp(\beta X_{nj} / \rho_k)} \right)^2 \right) \quad (58)$$

$$\frac{\partial P_{ni/C_k}}{\partial p_{ni}} = \frac{\partial \beta X_{ni}}{\partial p_{ni}} \frac{P_{ni/C_k}}{\rho_k} \left(1 - P_{ni/C_k}\right) \quad (59)$$

Derivative of the Probability of Choosing Transponder Ownership *k* $\left(P_{C_k}\right)$

$$\frac{\partial P_{C_k}}{\partial p_{ni}} = \frac{exp(\rho_k I_{nk} + \alpha Y_{nk})}{\sum_{l=1}^{m} exp(\rho_k I_{nl} + \alpha Y_{nl})} \quad (60)$$

$$\frac{\partial P_{C_k}}{\partial p_{ni}} = \frac{\partial}{\partial p_{ni}} \left(\frac{exp(\rho_k I_{nk} + \alpha Y_{nk})}{\sum_{l=1}^{m} exp(\rho_k I_{nl} + \alpha Y_{nl})} \right) \quad (61)$$

$$\frac{\partial P_{C_k}}{\partial p_{ni}} = \frac{\rho_k \frac{\partial I_{nk}}{\partial p_{ni}} exp(\rho_k I_{nk} + \alpha Y_{nk}) \sum_{l=1}^{m} exp(\rho_k I_{nl} + \alpha Y_{nl}) - exp(\rho_k I_{nk} + \alpha Y_{nk}) \frac{\partial I_{nk}}{\partial p_{ni}} exp(\rho_k I_{nk} + \alpha Y_{nk})}{\left(\sum_{l=1}^{m} exp(\rho_k I_{nl} + \alpha Y_{nl}) \right)^2} \quad (62)$$

$$\frac{\partial P_{C_k}}{\partial p_{ni}} = \rho_k \frac{\partial I_{nk}}{\partial p_{ni}} \left(\frac{exp(\rho_k I_{nk} + \alpha Y_{nk})}{\sum_{l=1}^{m} exp(\rho_k I_{nl} + \alpha Y_{nl})} - \left(\frac{exp(\rho_k I_{nk} + \alpha Y_{nk})}{\sum_{l=1}^{m} exp(\rho_k I_{nl} + \alpha Y_{nl})} \right)^2 \right) \quad (63)$$

$$\frac{\partial P_{C_k}}{\partial p_{ni}} = \rho_k \frac{\partial I_{nk}}{\partial p_{ni}} P_{C_k} \left(1 - P_{C_k}\right) \quad (64)$$

Derivative of the Inclusive utility of nest *C*$_k$ $\left(I_{nk}\right)$

$$I_{nk} = ln\left(\sum_{j \in C_k} exp(X_{nj} / \rho_k) \right) \quad (65)$$

$$\frac{\partial I_{nk}}{\partial p_{ni}} = \frac{\partial}{\partial p_{ni}}\left(ln\left(\sum_{j \in C_k} exp\left(X_{nj} / \rho_k \right) \right) \right) \tag{66}$$

$$\frac{\partial I_{nk}}{\partial p_{ni}} = \left(\frac{\frac{\partial \beta X_{ni}}{\partial p_{ni}} \frac{1}{\rho_k} exp(\beta X_{ni} / \rho_k)}{\sum_{j \in C_k} exp\left(X_{nj} / \rho_k \right)} \right) \tag{67}$$

$$\frac{\partial I_{nk}}{\partial p_{ni}} = \frac{\partial \beta X_{ni}}{\partial p_{ni}} \frac{1}{\rho_k} \left(P_{ni / C_k} \right) \tag{68}$$

Joining Equations (55), (59), (64) and (68) the elasticity of demand with respect to toll changes can be derived as follows.

$$E_{p_{ni}}^{P_{ni}} = \frac{p_{ni}}{P_{ni}} \bullet \left(\frac{\partial \beta X_{ni}}{\partial p_{ni}} \frac{P_{ni / C_k}}{\rho_k} \left(1 - P_{ni / C_k} \right) \bullet P_{C_k} + \frac{\partial \beta X_{ni}}{\partial p_{ni}} \left(P_{ni / C_k} \right) P_{C_k} \left(1 - P_{C_k} \right) \bullet P_{ni / C_k} \right) \tag{69}$$

$$E_{p_{ni}}^{P_{ni}} = \frac{p_{ni}}{P_{ni}} \frac{\partial \beta X_{ni}}{\partial p_{ni}} \left(\frac{1}{\rho_k} P_{ni} \left(1 - P_{ni / C_k} \right) + P_{ni} P_{ni / C_k} \left(1 - P_{C_k} \right) \right) \tag{70}$$

$$E_{p_{ni}}^{P_{ni}} = p_{ni} \frac{\partial \beta X_{ni}}{\partial p_{ni}} \left(\frac{1}{\rho_k} \left(1 - P_{ni / C_k} \right) + P_{ni / C_k} \left(1 - \frac{P_{ni}}{P_{ni / C_k}} \right) \right) \tag{71}$$

$$E_{p_{ni}}^{P_{ni}} = p_{ni} \frac{\partial \beta X_{ni}}{\partial p_{ni}} \left(\frac{1}{\rho_k} \left(1 - P_{ni / C_k} \right) - \frac{\rho_k}{\rho_k} \left(1 - P_{ni / C_k} - 1 + P_{ni} \right) \right) \tag{72}$$

$$E_{p_{ni}}^{P_{ni}} = p_{ni} \frac{\partial \beta X_{ni}}{\partial p_{ni}} \left(\frac{1 - \rho_k}{\rho_k} \left(1 - P_{ni / C_k} \right) + \left(1 - P_{ni} \right) \right) \tag{73}$$

$$E_{p_{ni}}^{P_{ni}} = p_{ni} \frac{\partial \beta X_{ni}}{\partial p_{ni}} \left(\left(\frac{1}{\rho_k} - 1 \right) \left(1 - P_{ni / C_k} \right) + \left(1 - P_{ni} \right) \right) \tag{74}$$