Analysis of the Observed Behavior of Users to Value Pricing and Travel time: The New Jersey Turnpike Case

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ABSTRACT

In this paper, impacts of value pricing on traffic and travel times at NJ Turnpike were investigated. The shift in traffic between peak and off-peak periods were studied using before-after traffic data at both aggregate and disaggregate levels. Aggregate level analysis showed a shift in traffic to off-peak periods after the first stage of value pricing program, and a shift to peak periods after the second stage, but due to lack of detailed traffic and travel time data, it was not possible to draw reliable conclusions from the aggregate level analysis. Disaggregate level analysis was then conducted using traffic and travel time information for each pair of entry-exit locations along the NJ Turnpike between October 2002-March 2003, three months before and three months after the second stage of value pricing implementation. The vehicle-by-vehicle travel time analysis indicated that travel times were not always highest during peak periods. For instance, in 2003 for almost 40% of entry-exit pairs, higher travel times were observed during morning peak-shoulders. Additionally, the data showed that, 55% of users preferred peak periods with lower travel times and higher tolls instead of peak-shoulders with higher travel times but lower tolls, indicating that NJ Turnpike users were trying to avoid congestion rather than slightly higher tolls.
INTRODUCTION

Concepts such as value pricing, private toll roads and other forms of road pricing, aiming at changing travelers’ behavior, can be effective means of improving traffic and thus reducing various impacts of traffic congestion. However, successful implementation of pricing policies requires an understanding of user behavior and possible responses to these policies. NJ Turnpike, one of the most heavily used roadways in the country has recently implemented a new “value pricing program” (1). In September 2000, EZ-Pass Technology is introduced by NJ Turnpike Authority (NJTPK) along with the first stage of value pricing program. As part of this program, different toll levels are charged to users depending on time of day. In January 2003, toll levels for each time period and vehicle type are increased as the second stage of value pricing program. The percent increase in the toll amount and resulting toll amounts between entry-exit pair (1,18W), implemented as part of two stage program are shown in TABLE 1 to give the reader an idea of price differentials.

Most of the previous similar studies conduct before-after analysis and apply various statistical tests using aggregate traffic counts to investigate the impacts of value pricing. In all these studies hypothesis is that, under value pricing discount tolls would reduce peak-period traffic and this reduction in traffic will lead to reduced travel times during peak periods. Study conducted by (2), investigates impacts of value pricing implication in London considering only traffic to city center before and after congestion pricing. On the other hand, in the analysis performed by (3), impacts of I-15 Congestion Pricing Project on various traffic characteristics such as: traffic, delay and travel time are investigated, along the section of I-15 study corridor and the corresponding section of the I-8 control corridor, from December 1996 through December 1999. To accomplish this goal, travel time data collected for a single day using “floating car” method and traffic data aggregated for every fifteen minute periods along the study period are utilized. The performed analysis indicates that, dynamic FasTrak fee structure redistributed a portion of Express Lanes traffic from mid-peak to shoulders. A similar study performed by (4), investigates the impacts of Lee County’s variable pricing program on travel times on four bridges. Variable pricing is implemented on two bridges. Travel time data is collected similar to (3), using a vehicle that travels along predetermined routes at constant speed for two days of each month in the study period. However, due to small number of travel time runs, variability in travel-time speeds, and relatively uncongested roadways, whether change in travel time was attributable to variable pricing could not be determined. In (5), change in traffic conditions on SR91 corridor is investigated using traffic data collected from loop detectors before and after the opening of tolled lanes, concluding that travel times in peak hours are reduced after opening of tolled lanes.

Since traffic varies substantially depending on hours of the day, days of the week and months of the year, to analyze the impacts of value pricing on traffic, time-dependent factors should also be considered. (6) defines monthly adjustment factor as the ratio between monthly average daily traffic and annual average daily traffic and recommends to represent the actual patterns of monthly traffic by using inverse of the monthly adjustment factors. Whereas; (7) defines monthly adjustment factors as the ratio between flow on any month to the flow on a base month. During before-after study for A1 Willowburn to Denwick Improvement Scheme, traffic on October is taken as a base, and traffic is adjusted by calculating monthly adjustment factors. Besides, in (8), two assessment periods, are compared using same six-month of traffic data from subsequent years; to minimize potential bias due to seasonal variation during before-after study of Lee County variable pricing program. During the analysis of SR-91X Lanes, (9) conducts two-tailed-
t-tests comparing 1996, 1997 and 1998 annual average midweek traffic volume data, concluding that there is no seasonal variation in the SR-91 corridor traffic.

None of these studies incorporate traffic, travel time and value pricing implications using reliable disaggregate data, apart from one or two days of travel time data collected using “floating car” method. However, to understand travel behavior and response to value pricing, relationship between traffic, travel time and toll amount should be investigated carefully. The objective of this paper is to investigate the changes in traffic and travel time observed at each entry-exit pair of NJ Turnpike before and after the value pricing considering seasonal variations among months, and to determine the reasons of shift in traffic between peak and off-peak periods, if any, which can be either due to toll or travel time difference between periods. In order to accomplish this objective, before-after analyses are done using both aggregate and disaggregate level data and appropriate statistical tests are applied to determine the significance level of the observed changes.

In the next sections first, data sources and details of proposed methodology are discussed, then seasonal factor analysis, and impacts of value pricing implementations at aggregate and disaggregate levels are provided. Finally, in the last section conclusions and discussions are presented.

DATA DESCRIPTION

The extensive database used in this study, is obtained from (NJTPK) (1). Aggregate level data include (1) Average monthly traffic for peak and off-peak periods between October – December (1998, 1999, 2000, and 2002), and between January – June (1999, 2000, 2001, and 2003), (2) Daily traffic for each day of May and June (2000 and 2003) and (3) Hourly traffic between each entry-exit pairs for May 11, 2000, June 15, 2000, May 15, 2003 and June 12, 2003. Disaggregate level data include vehicle-by-vehicle entry/exit times and locations for each EZ-Pass vehicle, and toll paid by each vehicle for 6 months period between October 2002 and March 2003.

METHODOLOGY

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

1. Seasonal factor analysis is conducted using aggregate data between October 1998 and June 2000, to investigate sources of time-dependent variations.
2. Before-after analysis is conducted to determine the change in travelers’ behavior during peak and off-peak periods using average traffic before and after the toll change. Appropriate statistical significance tests are applied to determine the significance level of the changes in traffic.
3. The relationship between the change in traffic and travel time for different periods is investigated using vehicle-by-vehicle disaggregate data, to better understand the reasons of shift in traffic.

ANALYSIS OF SOURCES OF VARIATIONS

When traffic distribution is analyzed three kinds of variations should be considered:

(1) Factor_1: Temporal variations due to traffic fluctuations depending on time of day, days of the week and months of the year.
(2) Factor_2: Traffic fluctuations among years for a specific time period of a day due to the changes in toll amount, travel time, or demand.

(3) Other random errors: Fluctuations due to external factors difficult to capture such as, economic growth, and sampling errors.

The statistical model representing the traffic distribution can be given by (10):

\[ y_{ij} = \mu + \alpha_i + \beta_j + \epsilon_{ij} \]  

where:
\[ y_{ij} \]: Observed percent share at level \( i, j \)
\[ \mu \]: Mean of all observations \( y_{ij} \)
\[ \alpha_i \]: Effect of Factor_1 at level \( i \)
\[ \beta_j \]: Effect of Factor_2 at level \( j \)
\[ \epsilon_{ij} \]: Random error term

To fully determine the effects of these factors on traffic, two-way ANOVA test is employed by constructing a two-factor full factorial design without replications using data sets, shown in TABLE 2. To reduce the fluctuations (1) A.M./P.M. and peak/off-peak period traffics are investigated separately, (2) Years with fixed tolls and typical work days are selected, (3) Traffic is represented in terms of percentage share with respect to total daily traffic. Therefore Factor_1 represents seasonal variation among months, and Factor_2 represents yearly changes in traffic when everything else in the system is unchanged.

The percent share of each data type is calculated using Equation 2.

\[ \gamma_i = \frac{\sum M_j * 100}{\sum M_i} \]  

where:
\( i \): Time period index, \( i \) = A.M., P.M. peak, off-peak
\( j \): Month index, \( j \) = October, November,…June (for Set 1)
\[ j \] = October, November, December (for Set 2)

\[ \gamma_{ij} \]: Percent share of period \( i \) on month \( j \)
\[ M_i \]: Average traffic during period \( i \) on month \( j \)

The results of two-way ANOVA for each time period are represented in TABLE 3. Analysis results for Set-1 show that there exists a statistically significant seasonal variation among the months (Factor_1). On the other hand, changes in percent share of specific time periods with respect to total daily traffic (Factor_2) is statistically insignificant before 2000. However, data Set-2 indicates that, between first and second toll increase, there exists a statistically significant change in percent shares of peak and off-peak periods, even if the toll amount is fixed. To fully explain this change in user behavior, traffic for peak and off-peak hours is studied in the next
sections. Besides, fluctuations among consecutive months in data Set-2 are statistically insignificant. This may be due to the fact that in data Set-2, three consecutive months which have a similar trend are compared, whereas in Set-1 a wider range of months are compared. To further investigate fluctuations between consecutive months, monthly adjustment factors are calculated using the methodology proposed by (6). The seasonal factor analysis results indicate that:

1. Traffic on December, January and February is lower compared to traffic on other months.
2. Monthly adjustment factors between October and June, shown in Figure 1, are similar to each other for consecutive months. However, they become different for months further away from each other. This result supports the results obtained from the two-way ANOVA analysis.

AGGREGATE LEVEL BEFORE AND AFTER ANALYSIS

In this section, changes in traffic patterns for peak and off-peak periods after the both stages of value pricing implementations are investigated. Using the results obtained from the previous section, in aggregate level analysis, absolute and percentage shares of peak/off-peak period traffics are compared for same months between 1998-2003. The methodology can be summarized as follows.

1. Analysis of fluctuations in traffic among different days of the week
2. Analysis of changes in absolute and percent shares of AM./P.M. peak and off-peak periods traffic after the two value pricing implementations
3. Application of statistical tests to determine the significance level of these changes

The fluctuations among different days of the week are analyzed using daily traffic on each day of May and June (2000 and 2003). The results indicate that, traffic patterns are different for Monday through Thursday (14.5% of total weekly volume), Friday (17% of total weekly volume) and weekends (12.5% of total weekly volume). Since traffic exhibits significant differences for different days of the week, remainder of the analysis is conducted using typical work days. The data sets and results for changes in the absolute and percentage traffic are shown in TABLE 4. After first toll increase and introduction of EZ-Pass, between years 1999 and 2001, peak-period traffic increased at a lower rate compared to off-peak period traffic, supporting the results obtained in (11). Additionally, after first toll increase peak traffic percent share decreased, while percent share of off-peak traffic increased. On the other hand, after second toll increase, between years 2001 and 2003, peak period traffic has increased at a higher rate compared to off-peak traffic. Additionally, unlike the first toll increase the percent share of peak period traffic increased, while percent share of off-peak traffic decreased from year 2001 to year 2003.

In order to determine whether or not these changes in traffic between peak and off-peak periods after two toll changes are statistically significant, 1-tailed paired two-sample t-tests are conducted at 90% and 95% confidence levels (CL). In order to increase the sample size for the second toll change, two-sample t-test assuming unequal variances are applied to compare the time period between October 2000–June 2001 (nine data points) and time period January 2003–
March 2003 (three data points). The t-tests, applied separately for A.M./P.M. peak and off-peak periods, are based on the following hypothesis (10):

\[
H_0: (\mu_i)_{\text{before}} - (\mu_i)_{\text{after}} = 0 \\
H_1 : (\mu_i)_{\text{before}} - (\mu_i)_{\text{after}} > 0
\]

where;
\(\mu_i = \text{mean percent share of period } i, \quad i=1, 2, 3 \) (1=A.M.-peak, 2=P.M.-peak, 3=Off-peak)

The results of 1 tailed t-tests conducted at 90% and 95% CL, are shown in TABLE 4. After the first toll increase there is a statistically significant reduction in peak-period traffic percent share and a statistically significant increase in off-peak period traffic percent share. On the other hand, after the second toll increase, changes in percent shares are reversed. The peak period traffic percent share has increased, whereas off-peak traffic percent share has reduced. These changes are found to be statistically significant at 95% CL.

In summary, comparison of impacts of value pricing implementations at NJ Turnpike indicate that, response of users to the second toll increase is different from the response to the first toll increase. Between time periods after the first toll increase and the second toll increase, there is a significant increase in the percent share of peak period traffic. Therefore, given the small differential between peak and off-peak tolls, it is likely that change in percent share of peak and off-peak periods can be due to higher travel times rather than the toll differential.

Since travel time data for these time periods was not available, aggregate level analysis could not determine a reliable relationship between shift in traffic and congestion levels. Therefore we could not conclude that change in traffic between peak and off-peak periods is solely due to peak and off-peak toll differentials. In order to better identify source of the changes in traffic, third part of analysis is conducted at disaggregate level using vehicle-by-vehicle information obtained from NJTPK.

**DISAGGREGATE LEVEL BEFORE AND AFTER ANALYSIS**

In this section, vehicle-by-vehicle EZ-Pass traffic data, between October 2002 and March 2003, is analyzed. This period coincides with the second phase of the value pricing program. The database contains entry-exit locations, times and toll amount but does not contain any other vehicle data to ensure the privacy of users. Based on the information obtained from NJTPK (1), EZ-Pass users form 63% of total users for a typical day, and 88% of all EZ-Pass vehicles are passenger cars. During peak hours and peak shoulders, more than 90% of the vehicles are passenger cars with EZ-Pass. Since value pricing is only available to passenger cars with EZ-Pass, behavior of cash users is not directly affected from toll differentials. Thus, it can be assumed that EZ-Pass users are commuters who use NJ Turnpike on a regular basis and who are well aware of daily traffic conditions and variable tolls. This is the type of user preferred for this analysis since the ultimate goal is to understand the behavioral change of regular commuters who are eligible for toll discounts and familiar with the facility.

While conducting disaggregate analysis, a computer program is written in Matlab to sort out the individual vehicle data obtained from NJTPK with respect to entry times. Then, for totally 26 entry-exit pairs, two 26x26 matrices are created for each hour of the day, representing the traffic between entry-exit pairs, and travel times corresponding to that specific traffic. As presented in “Analysis of Sources of Variations” Section, monthly fluctuations between two consecutive months are negligible compared to fluctuations between months further away from each other.
Thus, to minimize the error due to seasonal variations, analysis is conducted by utilizing consecutive months. The shift in traffic and travel times are determined based on percentages not absolute values to incorporate the changes in traffic independent of toll increase and seasonal variations. Since traffic pattern for weekdays, Fridays and weekends are different, traffic and travel time values observed at 676 (26x26) entry-exit pair, are investigated separately for each day type. Each day is divided into 8 sub-periods for weekdays and Fridays in order to analyze the shift between peak periods and peak shoulders:

1. Pre-peak period (6:00A.M.–7:00A.M. and 15:30P.M.–16:30P.M.)
2. Peak-1 period (7:00A.M.–8:00A.M. and 16:30P.M.–17:30P.M.)
3. Peak-2 period (8:00A.M.–9:00A.M. and 17:30P.M.–18:30 P.M.)
4. Post-peak period (9:00A.M –10:00 A.M. and 18:30P.M.–19:30P.M.)

On the other hand, for weekends, since toll value is same for the whole day, each day is divided into 2 sub-periods:

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

Let “$d_{ij}^m$” and “$t_{ij}^m$” be the traffic and travel time between entry-exit pair $(i, j)$ at time “$k$” for month “$m$” during day “$l$” where:

$i$: Entry point index $i=1, 2,...26$
$j$: Exit point index $j=1, 2,...26$
$k$: Time of day index $k=1, 2,...24$
$m$: Month index $m=1, 2,...6$ (1: October, 2: November.....6: March)
$l$: Day type index $l=1, 2$ (1: Weekdays and Fridays, 2: Saturdays and Sundays)

For each month, two matrices representing total traffic and average travel time between each entry-exit pair for weekdays, Fridays, and weekends are constructed. Since some of these clusters are too small to be statistically significant and are not needed to be included in the analysis, EZ-Pass database is further clustered to develop clusters of vehicles that are large enough to be statistically significant. The following steps for consecutive months included in the analysis are implemented to obtain a useful data set.

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

   **Criteria 1:** Determine the exit location “$j$”, which forms at least 10% of total daily traffic, generated from a specific entry location “$i$”. If all entry-exit pairs were analyzed, percent changes at pairs with low traffic would be quite high even if absolute magnitudes of these changes are not important enough to affect overall traffic. Therefore, to reduce this bias, pairs forming the most significant share of total daily traffic are determined.

   The algorithm for this criterion first calculates total traffic for each entry point for every day of every month within the analysis set. Then, it calculates total daily traffic between every
entry-exit pair as the sum of traffic between each entry-exit pair for every time period. Finally it determines entry-exit pairs that satisfy Criteria 1 by calculating the ratio of total traffic between each entry-exit pair and total daily traffic generated at the entry location of each pair. The mathematical representation of this algorithm is presented in Appendix 1.

Criteria 2: Determine entry-exit pairs, \((i,j)\), which have at least 100 veh/hr of traffic demand during sub-periods This amount is approximately 10% of hourly traffic between an entry-exit pair during pre-specified sub-period. This criterion determines pairs that are highly utilized during sub-periods, and that have almost no traffic during off-peak periods. These pairs are responsible for most of the traffic during specific sub-periods even if they do not satisfy the first criterion. The logic of this criterion is presented in Appendix 2.

The data set determined based on these two criteria, represents approximately 80% of total flow observed on sub-periods.

After cleaning the data set, our main goal is to construct “before and after conditions” at NJ Turnpike and compare them. Before and after conditions are constructed based on traffic and travel times patterns observed before and after value pricing implementation. To achieve the above goal, disaggregate level analysis is conducted in two parts. In the first part, for each consecutive month “\(m\)” and day type “\(l\)”, periods with maximum hourly traffic is investigated by using the following steps.

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.

2. Calculate \(\phi^{ml}_{k^*}\): Proportion of exit-entry pairs \((i,j)\) with maximum traffic flow at peak periods but less travel time compared to peak shoulders.

3. Calculate \(r^{ml}_{k^*}\): Proportion of exit-entry pairs \((i,j)\) with maximum traffic flow at peak shoulders but less travel time compared to peak periods.

4. Calculate \(a^{ml}_{k^*}\): Proportion of pairs \((i,j)\) with maximum traffic flow and 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.

5. Calculate \(d^{ml}_{k^*}\): Proportion of pairs \((i,j)\) with maximum traffic flow at and highest travel time but have travel time more than 15 minutes or they provide more than 10% time savings when a shift to sub-period with lower travel time occurs.

After the analysis of sub-periods with maximum hourly traffic, periods with maximum travel time for each consecutive month “\(m\)” and day type “\(l\)”, are also studied using the following steps.

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 5.
2. Calculate $\Delta^m_{ijk}$: Change in percent share of traffic between two consecutive months during sub-period “$k$”. 

3. Determine $\chi^m_{k}$: Proportion of pairs $(i, j)$ for which “$\Delta^m_{ijk}$” is negative during sub-period “$k$”. 

4. Calculate $\beta^m_{k}$: Among the pairs $(i, j)$ where “$\Delta^m_{ijk}$” 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. 

5. Calculate $\chi^m_{k}$: 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. 

The analysis results conducted for consecutive months can be summarized as follows. Results are denoted as “R”. 

October-November, November-December, 2002:  

$R_B$ (1): For 50% of the pairs traffic is maximum at peak periods that have less travel time than peak shoulders (Column (1) in TABLE 5). 

$R_B$ (2): For 25% of the pairs traffic is maximum at peak shoulders that have less travel times than peak periods (Column (2) in TABLE 5). 

$R_B$ (3): For 10% of the pairs, traffic flow is maximum during sub-periods with highest travel time. These pairs either have travel times higher than 15 minutes, or they provide more than 10% travel time savings when a shift to other sub-periods occur (Column (4) in TABLE 5). 

$R_B$ (4): For almost 35% of the pairs there is a change in traffic for sub-periods with highest travel time (Column (5) in TABLE 5). 

$R_B$ (5): 67% of the pairs where traffic flow changed, traffic flow at sub-periods with highest travel time decreased (Column (6) in TABLE 5). 

$R_B$ (6): 80% of the pairs for which traffic flow increased, either have travel times less than 15 minutes or provide less than 10% time savings when a shift to other sub-periods occur (Column (7) in TABLE 5). 

$R_B$ (7): Almost 65% of changes in departure time are to or within peak periods (Column (8) in TABLE 5). 

December-January, January – February, 2003:  

$R_F1$ (1): For 45% of the pairs traffic is maximum at peak periods that have less travel time than peak shoulders (Column (1) in TABLE 5). 

$R_F1$ (2): For 23% of the pairs traffic is maximum at peak shoulders that have less travel times than peak periods (Column (2) in TABLE 5). 

$R_F1$ (3): For 18% of the pairs, traffic flow is maximum during sub-periods with highest travel time. These pairs either have travel times higher than 15 minutes, or they provide more than 10% travel time savings when a shift to other sub-periods occur (Column (4) in TABLE 5). 

$R_F1$ (4): For almost 42% of the pairs there is a change in traffic for sub-periods with highest travel
time (Column (5) in TABLE 5).

R_{F1} (5): 65% of the pairs where traffic flow changed, traffic flow at sub-periods with highest travel time decreased (Column (6) in TABLE 5).

R_{F1} (6): 69% of the pairs for which traffic flow increased, either have travel times less than 15 minutes or provide less than 10% time savings when a shift to other sub-periods occur (Column (7) in TABLE 5).

R_{F1} (7): Almost 65% of changes in departure time are to or within peak periods (Column (8) in TABLE 5).

February-March 2003:

R_{F2} (1): For 53% of the pairs traffic is maximum at peak periods that have less travel time than peak shoulders (Column (1) in TABLE 5).

R_{F2} (2): For 20% of the pairs traffic is maximum at peak shoulders that have less travel times than peak periods (Column (2) in TABLE 5).

R_{F2} (3): For 16% of the pairs, traffic flow is maximum during sub-periods with highest travel time. These pairs either have travel times higher than 15 minutes, or they provide more than 10% travel time savings when a shift to other sub-periods occur (Column (4) in TABLE 5).

R_{F2} (4): For almost 40% of the pairs there is a change in traffic for sub-periods with highest travel time (Column (5) in TABLE 5).

R_{F2} (5): 65% of the pairs where traffic flow changed, traffic flow at sub-periods with highest travel time decreased (Column (6) in TABLE 5).

R_{F2} (6): 80% of the pairs for which traffic flow increased, either have travel times less than 15 minutes or provide less than 10% time savings when a shift to other sub-periods occur (Column (7) in TABLE 5).

R_{F2} (7): Almost 68% of changes in departure time are to or within peak periods (Column (8) in TABLE 5).

A similar pattern is observed for weekends, apart from the fact that, on weekends sample size is smaller, and smaller percent of travelers try to minimize their travel time and number of travelers who prefer not to change their travel periods is slightly more compared to weekdays. The reason for these slight differences between weekdays and weekends can be due to the fact that traffic flows on weekends are almost 25% lower than weekday traffic, and most of the travelers do not have a strict departure time constraints since most of the trips are not work related.

The analysis results indicate that, most of the users are found to prefer peak periods with lower travel times and higher tolls instead of peak-shoulders with higher travel times but lower tolls, indicating that NJ Turnpike users are trying to avoid congestion rather than slightly higher tolls. Besides, toll increase on January 2003 did not have a serious impact on traffic. Apart from some fluctuations on January and February, traffic conditions are found to be similar before and after the toll changes. Only difference between traffic conditions before and after the toll increase; on February-March 2003 the percentage of pairs with maximum traffic at peak periods but less travel time than peak shoulders increased after the toll increase (R_{F2}(1)). However the percentage of pairs with maximum traffic at peak shoulders but less travel time than peak periods decreased after the toll increase (R_{F2}(2)). Since this difference is counterintuitive in terms of purpose of
value pricing, it cannot be attributed to toll increase; it can only be explained by travel time
differences between peak periods and peak shoulders.

CONCLUSION

This paper has attempted to gain insights into the behavior of users as response to value pricing
and travel time fluctuations using reliable and accurate data sources. Among two different levels
of analysis, 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 value pricing. The details of the obtained results can be summarized as follows:

1. Traffic patterns are different among different months of the year. Traffic during winter
months is lower compared to traffic during summer months. Besides, traffic flows are
different among three different portions of a week namely, Monday through Thursday, Friday, and weekends. Fridays and weekends have the highest and lowest share of total
weekly traffic, respectively. This is shown using the ANOVA tests.

2. Aggregate level analysis conducted for the first stage of value pricing implementation
indicate that, rate of increase of peak period percent shares are lower than rate of increase
of off-peak period percent share. AM. and P.M. peak and off-peak hour traffic flows are
increased by 6%, 4% and 10% from 1999 to 2001, respectively. AM. and P.M peak
period percent shares have decreased by 1.7%, and 3.7%, respectively. Off-peak traffic
percent share has increased by 1.1% during the same time period. However after two
years, between January 2001–March 2001 and January 2003–March 2003, trend in traffic
is reversed. AM. and P.M. peak and off-peak traffics are increased by 15%, 10% and 9%
from 2001 to 2003, respectively. A.M. and P.M. peak percent shares for a typical week
day are increased by almost 17% and 14%, respectively. Off-peak period percent share is
decreased by almost 6% during the same time period. 1-tailed t-tests conducted for both
value pricing implementations indicate that, these changes in peak and off-peak period
percent shares are statistically significant. These changes among two stages of value
pricing implementation can be due to the first stage of the value pricing program which
might have encouraged commuters to shift to peak shoulders and in turn increased travel
times during these periods. However, due to lack of more detailed traffic and travel time
data at aggregate level, it is not possible to pinpoint the exact reason of this shift in
traffic.

3. From the disaggregate analysis it is observed that on weekdays and Fridays, before the
toll increase for almost 75% of entry-exit pairs, traffic is maximum at periods with less
travel time. Whereas for 10% of pairs traffic is maximum at periods with highest travel
time. After the toll increase on January 2003, between January and February, the
percentage of pairs for which traffic is maximum at periods with less travel time, are
dropped to 68%. And percentage of pairs for which the traffic is maximum at periods
with highest travel time increased to 18%. However, on March 2003, the corresponding
percentage values starts to come back to values observed before the toll increase. These
results indicate that most of the users choose to stay in periods with less travel time, and
the second toll increase did not have serious impact on NJ Turnpike traffic patterns.

4. A similar pattern is observed for weekends, apart from the fact that, on weekends sample
size is smaller, smaller percent of travelers try to minimize their travel time and number.
of travelers who prefer not to change their periods is slightly more compared to weekdays. The reason for these slight differences can be due to the fact that traffic on weekends is almost 25% lower than weekday traffic, and most of the travelers do not have a strict departure time constraints since most of the trips are not work related.

5. Overall, the disaggregate analysis, indicate that commuters at NJ Turnpike respond more to congestion (lower travel times) than slightly higher tolls. More specifically, most of the users prefer peak periods with less travel times and higher tolls instead of peak shoulders with higher travel times but less toll (TABLE 5).

6. In some of the empirical studies by (2, 3, 4, and 5) investigating the impacts of variable pricing on traffic using traffic counts, maximum traffic is observed during mid-peak periods, where the toll is higher and shift in traffic is always from mid-peak hours to peak shoulders. Unlike these studies, traffic at NJ Turnpike is more uniformly distributed between mid-peak hours and peak shoulders. Thus, maximum traffic is not always observed at mid-peak hours at NJ Turnpike.

7. Same studies conclude that discount tolls reduce peak-period traffic and this reduction in traffic leads to reduced travel times during peak periods. However, toll differences between peak and off-peak periods at NJTPK are quite small. Given these facility specific traffic conditions and small toll differences shown in TABLE 1, travel time differences between different periods are found to have more effect than toll differences on user behavior. This was an important finding specific to this study.

8. All of the aforementioned empirical studies also emphasized that lack of reliable travel time data had a negative and limiting effect on reliable statistical assessments of travel time changes due to the implementation of variable pricing policies. Thus, these studies conclude that individual and combined impact of toll and travel time differences on user behavior cannot be determined properly without reliable travel time data. The same problem is encountered in this study too when it is attempted to understand the change in traffic using aggregate data. However, disaggregate data enabled the research team to partially overcome this problem and to explain some of the reasons behind the change in traffic before and after the value pricing implementation. Thus, in order to fully understand the user response to value pricing implementations, disaggregate data which include detailed traffic, travel time and toll amount information at the same time is necessary.

Based on these conclusions, future research will attempt to develop an analytical demand function representing the relationship between cost namely, travel time and tolls, and demand. This demand function will be used to calculate the price elasticities for different sub-periods. Based on the same demand function relative effects of value of time and tolls on user behavior can also be studied. Finally, these results will be compared with the results which will be obtained from detailed traveler surveys being conducted by RPI/Rutgers research team.
ACKNOWLEDGEMENTS

The New Jersey Value Pricing Program is sponsored by the Federal Highway Administration, and New Jersey Department of Transportation. We would like to thank NJ Turnpike for their continuing support in obtaining the data and other related information used in this paper. This paper represents interim preliminary findings that have not been reviewed nor endorsed by the sponsors or any other agencies. The opinions and conclusions presented are the sole responsibility of the authors and do not reflect the views of sponsors and other participating agencies.

REFERENCES

1. New Jersey Turnpike Authority, 2003
APPENDIX 1

1. For each “m” and “l”, determine the total daily traffic, “$D_{ml}^m$”, generated from entry point “i” as the sum of all the traffic between each entry-exit pair for all time periods.

\[
D_{ml}^m = \sum_j \sum_k d_{iji}^{ml} \tag{1}
\]

2. For each “m” and “l”, determine the total daily traffic between pair (i,j), “$f_{ij}^m$”, as the sum of all such demands for all time periods, “k”.

\[
f_{ij}^m = \sum_k d_{ij} \tag{2}
\]

3. Determine the number of pairs (i,j), “$N_{ml}^m$”, which satisfy Criteria 1 shown in Equation (3).

\[
\frac{f_{ij}^m}{D_{ml}^m} \geq 0.1 \tag{3}
\]
APPENDIX 2

1. For each “m” and “l” determine the sub-period with the maximum hourly entry traffic.

\[
\max_{k \in S} \left( d_{ijkl}^{ml} \right) \Rightarrow \text{time period:} k^* \tag{1}
\]

where;

\( S \) = Set of sub-periods

(\( S = \{1, 2 \ldots 8\} \) for weekdays and Fridays)

(\( S = \{1, 2\} \) for weekends)

2. For each “m” and “l” determine the number of entry-exit pairs \((i,j)\), “\( M^m \)”, which satisfy Criteria 2 shown in Equation (2).

\[
d_{ijkl}^{ml} \geq 100 \text{ veh/hr} \tag{2}
\]
List of Tables and Figures

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FIGURE 1 Seasonal pattern for NJ Turnpike 23
### TABLE 1 History of NJ Turnpike Congestion Pricing Implementation (NJTPK, 2003)

<table>
<thead>
<tr>
<th>Toll</th>
<th>Passenger Cars</th>
<th>Tractor Trailers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cash all day</td>
<td>70 %</td>
<td>20% ($5.50)</td>
</tr>
<tr>
<td>EZ Pass peak</td>
<td>-</td>
<td>8% ($4.95)</td>
</tr>
<tr>
<td>EZ Pass off peak</td>
<td>-</td>
<td>0% ($4.60)</td>
</tr>
<tr>
<td>EZ Pass (all weekend)</td>
<td>-</td>
<td>8% ($4.95)</td>
</tr>
</tbody>
</table>

The percentage values represent the percentage of increase in the toll amount.
The values in parentheses represent the toll amount between pairs (1,18W).
<table>
<thead>
<tr>
<th>Data set</th>
<th>Compared Time Periods</th>
<th>Type of Data</th>
</tr>
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<tr>
<td>Set 1</td>
<td>October 1998 – June 1999</td>
<td>A.M. peak percent share</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P.M. peak percent share</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Off-peak percent share</td>
</tr>
<tr>
<td>Set 1</td>
<td>October 1999 – June 2000</td>
<td>A.M. peak percent share</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P.M. peak percent Share</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Off-peak percent share</td>
</tr>
<tr>
<td>Set 2</td>
<td>October 2001 – December 2001</td>
<td>A.M. peak percent share</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P.M. peak percent Share</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Off-peak percent share</td>
</tr>
<tr>
<td>Set 2</td>
<td>October 2002 – December 2002</td>
<td>A.M. peak percent share</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P.M. peak percent Share</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Off-peak percent share</td>
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</tbody>
</table>
### TABLE 3 Two-way ANOVA Results for Sources of Variation

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<tr>
<th>Data set</th>
<th>Time Period</th>
<th>Source of Variation</th>
<th>Mean Square Error</th>
<th>Computed F</th>
<th>F-critical</th>
<th>Significance</th>
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<td></td>
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<td>Factor_1</td>
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<td>13.44</td>
<td>5.32</td>
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<tr>
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<td>Factor_2</td>
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<td></td>
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<td>Factor_1</td>
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<td>18.9</td>
<td>5.32</td>
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<td>1.9</td>
<td>3.44</td>
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<td></td>
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<td>Random Error</td>
<td>0.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td></td>
<td>A.M.</td>
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<td>19.00</td>
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<td>18.51</td>
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<td>-</td>
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<td>19.00</td>
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<td></td>
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<td>20.95</td>
<td>18.51</td>
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<td>0.4</td>
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<td>Factor_1</td>
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<td>2.92</td>
<td>19.00</td>
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<td></td>
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<td>2.38</td>
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TABLE 4 Results for Aggregate Level Analysis

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<th>toll change</th>
<th>Data Set</th>
<th>Absolute</th>
<th>Percent Share</th>
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<td>Mean</td>
<td>Mean change (%)</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Mean</td>
<td>change (%)</td>
</tr>
<tr>
<td>A.M.</td>
<td>1st</td>
<td>Oct 98 - June 00</td>
<td>86477</td>
<td>6.27</td>
</tr>
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<td></td>
<td></td>
<td>Oct 00 - June 01</td>
<td>91900</td>
<td>13.83</td>
</tr>
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<td></td>
<td></td>
<td>Oct 99 - June 00</td>
<td>86843</td>
<td>13.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oct 00 - June 01</td>
<td>91900</td>
<td>13.83</td>
</tr>
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<td></td>
<td>2nd</td>
<td>Jan 01 - March 01</td>
<td>92446</td>
<td>14.93</td>
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<td></td>
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<td>Jan 03 – March 03</td>
<td>106295</td>
<td>16.83</td>
</tr>
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<td>Oct 00 - June 01</td>
<td>91900</td>
<td>15.67</td>
</tr>
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<td></td>
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<td>Jan 03 – March 03</td>
<td>106295</td>
<td>16.83</td>
</tr>
<tr>
<td>P.M.</td>
<td>1st</td>
<td>Oct 98 - June 00</td>
<td>91495</td>
<td>4.17</td>
</tr>
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<td>Oct 00 - June 01</td>
<td>95310</td>
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<td></td>
<td>Oct 99 - June 00</td>
<td>92301</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Oct 00 - June 01</td>
<td>95310</td>
<td>14.33</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>Jan 01 - March 01</td>
<td>93530</td>
<td>9.84</td>
</tr>
<tr>
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<td>Jan 03 – March 03</td>
<td>102738</td>
<td>16.55</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oct 00 - June 01</td>
<td>95310</td>
<td>14.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jan 03 – March 03</td>
<td>102738</td>
<td>16.55</td>
</tr>
<tr>
<td>off peak</td>
<td>1st</td>
<td>Oct 98 - June 00</td>
<td>437104</td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oct 00 - June 01</td>
<td>478332</td>
<td>71.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oct 99 - June 00</td>
<td>454601</td>
<td>5.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oct 00 - June 01</td>
<td>478332</td>
<td>71.84</td>
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<td></td>
<td>2nd</td>
<td>Jan 01 - March 01</td>
<td>455416</td>
<td>8.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jan 03 – March 03</td>
<td>495684</td>
<td>66.62</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oct 00 - June 01</td>
<td>478332</td>
<td>71.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jan 03 – March 03</td>
<td>495684</td>
<td>66.62</td>
</tr>
</tbody>
</table>

*t_{critical} = 1.4 (90% CL), **t_{critical} = 1.86(95% CL), ***t_{critical} = 2.92 (95% CL), ****t_{critical} = 2.35 (95% CL)
**TABLE 5 User Responses to Value Pricing and Travel Times on Different Days of the Week**

<table>
<thead>
<tr>
<th>Day type</th>
<th>Time-Period</th>
<th>( N_{ml} + M_{ml} )</th>
<th>( \varphi_{ml}^{k*} )</th>
<th>( r_{k*}^{ml} )</th>
<th>( a_{k*}^{ml} )</th>
<th>( d_{k*}^{ml} )</th>
<th>( \Delta_{k}^{ml} )</th>
<th>( \gamma_{k}^{ml} )</th>
<th>( \sigma_{ml}^{\forall} )</th>
<th>( \chi_{k}^{ml} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekdays</td>
<td>Oct, 2002 – Nov, 2002</td>
<td>323</td>
<td>48% 25% 17% 10%</td>
<td>38% 67% 88% 74%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nov, 2002 – Dec, 2002</td>
<td>324</td>
<td>49% 27% 14% 10%</td>
<td>33% 67% 76% 73%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dec, 2002 – Jan, 2003</td>
<td>365</td>
<td>45% 23% 18% 14%</td>
<td>41% 65% 69% 61%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jan, 2003 – Feb, 2003</td>
<td>324</td>
<td>43% 23% 16% 18%</td>
<td>43% 73% 7% 64%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Feb, 2003 – Mar, 2003</td>
<td>349</td>
<td>53% 20% 16% 11%</td>
<td>40% 80% 87% 68%</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Fridays</td>
<td>Oct, 2002 – Nov, 2002</td>
<td>345</td>
<td>64% 15% 10% 11%</td>
<td>39% 70% 63% 72%</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Nov, 2002 – Dec, 2002</td>
<td>324</td>
<td>67% 18% 5% 20%</td>
<td>37% 81% 66% 75%</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dec, 2002 – Jan, 2003</td>
<td>308</td>
<td>51% 19% 13% 13%</td>
<td>41% 67% 61% 69%</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Jan, 2003 – Feb, 2003</td>
<td>313</td>
<td>58% 18% 11% 13%</td>
<td>44% 72% 65% 71%</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td>Feb, 2003 – Mar, 2003</td>
<td>345</td>
<td>63% 16% 6% 15%</td>
<td>35% 83% 70% 75%</td>
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<tr>
<td>Saturdays</td>
<td>Oct, 2002 – Nov, 2002</td>
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<td>- - -</td>
<td>40% 61% 60% -</td>
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<td></td>
<td>Nov, 2002 – Dec, 2002</td>
<td>295</td>
<td>- - -</td>
<td>42% 62% 59% -</td>
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<td></td>
<td>Dec, 2002 – Jan, 2003</td>
<td>286</td>
<td>- - -</td>
<td>46% 58% 57% -</td>
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<td></td>
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<tr>
<td></td>
<td>Jan, 2003 – Feb, 2003</td>
<td>279</td>
<td>- - -</td>
<td>45% 57% 55% -</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>Feb, 2003 – Mar, 2003</td>
<td>305</td>
<td>- - -</td>
<td>42% 60% 58% -</td>
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<tr>
<td>Sundays</td>
<td>Oct, 2002 – Nov, 2002</td>
<td>328</td>
<td>- - -</td>
<td>42% 66% 62% -</td>
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</tr>
<tr>
<td></td>
<td>Nov, 2002 – Dec, 2002</td>
<td>314</td>
<td>- - -</td>
<td>37% 61% 57% -</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>Dec, 2002 – Jan, 2003</td>
<td>324</td>
<td>- - -</td>
<td>48% 55% 51% -</td>
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<td></td>
<td>Jan, 2003 – Feb, 2003</td>
<td>316</td>
<td>- - -</td>
<td>40% 53% 59% -</td>
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<tr>
<td></td>
<td>Feb, 2003 – Mar, 2003</td>
<td>290</td>
<td>- - -</td>
<td>36% 57% 61% -</td>
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</table>

- \( k' \): Time of sub-period, where traffic between an entry-exit pair \((i, j)\) is observed to be maximum.
- \( \varphi_{ml}^{k*} \): Proportion of exit-entry pairs \((i, j)\) where sub-period \( "k" \) are peak periods with less travel time compared to peak shoulders.
- \( r_{k*}^{ml} \): Proportion of exit-entry pairs \((i, j)\) where sub-period \( "k" \) are peak shoulders with less travel time compared to peak periods.
- \( a_{k*}^{ml} \): Proportion of pairs \((i, j)\) where sub-period \( "k" \) are periods with higher travel time which either have travel time less than 15 minutes or that provide less than 10% time saving compared to periods with lower travel time.
- \( d_{k*}^{ml} \): Proportion of pairs \((i, j)\) where sub-period \( "k" \) are at periods with higher travel time. These periods either have travel time more than 15 minutes or they provide more than 10% time saving when a shift to sub-period with lower travel time occurs.
- \( \Delta_{ijk}^{ml} \): Change in percent share of traffic between two consecutive months during sub-period \((k')\).
- \( \gamma_{k}^{ml} \): Proportion of pairs \((i, j)\) for which \( \Delta_{ijk}^{ml} \) is negative during sub-period \((k')\).
- \( \sigma_{ml}^{\forall} \): 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 periods occur.
- \( \chi_{k}^{ml} \): Among the pairs \((i, j)\) where proportion of traffic during sub-period \((k')\) has changed, proportion of pairs in which the change is to or within peak periods.
FIGURE 1 Seasonal pattern for NJ Turnpike

Seasonal Pattern for NJ Turnpike

monthly adjustment factor

Oct Nov Dec Jan Feb Mar Apr May Jun

month