An Integrated System Model for Evaluating the Impact of the Dynamic ICC Toll Policy on the Regional Network Mobility

The Pennsylvania State University ❖ University of Maryland
University of Virginia ❖ Virginia Polytechnic Institute and State University
West Virginia University

The Pennsylvania State University ❖ The Thomas D. Larson Pennsylvania Transportation Institute
Transportation Research Building ❖ University Park, Pennsylvania 16802-4710
Phone: 814-863-1909 ❖ Fax: 814-863-37073
www.pti.psu.edu/mautc

AN INTEGRATED SYSTEM MODEL FOR EVALUATING THE IMPACT OF THE DYNAMIC ICC TOLL POLICY ON THE REGIONAL NETWORK MOBILITY

FINAL REPORT

UMD-2009-09
DTRT07-G-0003

Prepared for

U.S. Department of Transportation
Research and Innovative Technology Administration

By

Dr. Gang Len Chang, Principal Investigator
Dr. Cinzia Cirillo, Co- Principal Investigator
Nayel R. J. Urena Serulle and Pratt Hetrakul, Graduate Research Assistant

Department of Civil & Environmental Engineering
1173 Glenn L. Martin Hall, Bldg #088
University of Maryland, College Park, MD 20742

December 2011

1. Report No. UMD-2009-09	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle An Integrated System Model for Evaluating the Impact of the Dynamic ICC Toll Policy on the Regional Network Mobility		**5. Report Date** December 2011 **6. Performing Organization Code**
7. Author(s) Dr. Gang Len Chang, Dr. Cinzia Cirillo, Nayel R. J. Urena Serulle and Pratt Hetrakul,		**8. Performing Organization Report No.**
9. Performing Organization Name and Address Department of Civil & Environmental Engineering 1173 Glenn L. Martin Hall, Bldg #088 University of Maryland, College Park, MD 20742		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** DTRT07-G-0003
12. Sponsoring Agency Name and Address US Department of Transportation Research & Innovative Technology Admin UTC Program, RDT-30 1200 New Jersey Ave., SE Washington, DC 20590		**13. Type of Report and Period Covered** Final 1/1/10 – 12/31/11 **14. Sponsoring Agency Code**
15. Supplementary Notes		

16. Abstract
Road pricing has been advocated as an efficient travel demand management to alleviate congestion since the seminal work by Pigou (1920) and Knight (1924) (see Lindsey, 2006, for recent reviews). More specifically, dynamic toll pricing has received greater interest among policy makers and public agencies due to its potential for lowering energy costs for society. Some analytical studies (e.g., Arnott et al., 1990) have found that dynamic toll pricing generally yield greater efficiency gains than static toll pricing because the former reduce queueing delays by altering travelers' departure times as well as routes.
The construction of the Inter-county Connector (ICC) has certainly offered the prospect of reducing travel time between the I-270 and I-95 corridors, and may potentially alleviate congestion on the I-270 and I-495. Given that the ICC relies on dynamic toll pricing scheme, its daily traffic volumes are governed by individual trip-makers' perceived time and cost saving in the term of value of travel time (VOT). Moreover, the ability to realistically capture trip-makers' responses to time-varying road charges in term of willingness to pay (WTP) for toll is essential for predicting network flows and network equilibrium assignment models. These behavioral characteristics of users vary across individuals. Therefore capturing the heterogeneity of users in this regard is critical in predicting the impact of dynamic pricing schemes (e.g., Lu et al., 2008).
This study proposes the model that enables practitioners to integrate user response to dynamic toll pricing. The analysis accounts for cost and time savings perceived by regional drivers and the users' response to time-varying road charges. More specifically, the study captures difference in behavioral characteristics of the willingness to pay (WTP) for toll across users socioeconomics and trip related characteristics such as time of day, and trip purpose. The analysis is expected to be useful for transportation agency responsible for the ICC operations.

17. Key Words	18. Distribution Statement
	No restrictions. This document is available from the National Technical Information Service, Springfield, VA 22161

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

TABLE OF CONTENTS

1. INTRODUCTION 1

2. PREVIOUS WORK ON VALUE OF TIME AND WILLINGNESS TO PAY 2

3. SURVEY DESIGN 4

3.1 Revealed Preference (RP) Questionnaire 4

3.1.1 Socioeconomic Information 5

3.1.2 Recent Trip Information 5

3.2 Stated Preference (SP) Questionnaire 6

4. DESCRIPTIVE STATISTICS 9

4.1 Socioeconomics Results 9

4.2 Trip Characteristics Results 12

5. MODELS AND RESULT 16

5.1 Model 1: Generic Willingness to Pay (WTP) 18

5.2 Model 2: Willingness to Pay (WTP) by Income Level. 18

5.3 Model 3: Willingness to Pay (WTP) by Trip Purpose 20

5.4 Model 4: Willingness to Pay (WTP) by Congestion Period 22

6. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS 25

REFERENCES 26

LIST OF FIGURES

Figure 1 Stated Preference Questionnaire 9

LIST OF TABLES

Table 1 Stated Preference Survey Design 8

Table 2 Socioeconomic Statistics 11

Table 3 Trip Characteristics Statistics 14

Table 4 Model 1 Result 18

Table 5 Willingness to Pay by Income Level 19

Table 6 Model 2 Result 20

Table 7 Willingness to Pay by Trip Purpose 21

Table 8 Model 3 Result 22

Table 9 Willingness to Pay by Congestion Period 23

Table 10 Model 4 Result 24

1. INTRODUCTION

Road pricing has been advocated as an efficient travel demand management to alleviate congestion since the seminal work by Pigou (1920) and Knight (1924) (see Lindsey, 2006, for recent reviews). More specifically, dynamic toll pricing has received greater interest among policy makers and public agencies due to its potential for lowering energy costs for society. Some analytical studies (e.g., Arnott et al., 1990) have found that dynamic toll pricing generally yield greater efficiency gains than static toll pricing because the former reduce queueing delays by altering travelers' departure times as well as routes.

The construction of the Inter-county Connector (ICC) has certainly offered the prospect of reducing travel time between the I-270 and I-95 corridors, and may potentially alleviate congestion on the I-270 and I-495. Given that the ICC relies on dynamic toll pricing scheme, its daily traffic volumes are governed by individual trip-makers' perceived time and cost saving in the term of value of travel time (VOT). Moreover, the ability to realistically capture trip-makers' responses to time-varying road charges in term of willingness to pay (WTP) for toll is essential for predicting network flows and network equilibrium assignment models. These behavioral characteristics of users vary across individuals. Therefore capturing the heterogeneity of users in this regard is critical in predicting the impact of dynamic pricing schemes (e.g., Lu et al., 2008).

This study proposes the model that enables practitioners to integrate user response to dynamic toll pricing. The analysis accounts for cost and time savings perceived by regional drivers and the users' response to time-varying road charges. More specifically, the study captures difference in behavioral characteristics of the willingness to pay (WTP) for toll across users socioeconomics and trip related characteristics such as time of day, and trip purpose. The analysis is expected to be useful for transportation agency responsible for the ICC operations.

2. PREVIOUS WORK ON VALUE OF TIME AND WILLINGNESS TO PAY

High occupancy toll (HOT) lanes are a special case of road pricing in that they refer to high occupancy vehicle (HOV) facilities that are open to lower-occupancy vehicles upon payment of a fee or toll (Goodman, Jurasin, Larwin, Orski, Turnbull, & Cunard, 1998). They can be characterized as a commodity that offers faster, safer and more reliable travel time for the drivers that are willing to pay to access it.

Currently, HOT lanes exist in several U.S. cities, and more are under construction or planned, such as Atlanta (GA), Austin (TX), Oakland (CA), and Washington (DC). As of 2010, existing HOT lanes include the following (Los Angeles County Metropolitan Transportation Authority, 2010):

- I-95 Express Toll Lanes in Miami, Florida (since 2008)
- SR-167 HOT Lanes Pilot in Seattle, Washington (since 2008)
- I-25 Express Lanes in Denver, Colorado (since 2006)
- I-15 Express Lanes Pilot in Salt Lake City, Utah (since 2006)
- I-394 in Minneapolis, Minnesota (since 2005, employs dynamic tolling)
- I-15 Express Lanes in San Diego, California (since 1998, employs dynamic tolling)
- HOT Lanes on the I-10 Katy Freeway and US-290 Northwest Freeway, Houston, Texas (since 1998)
- SR-91 Express Lanes in Orange County, California (since 1995)

The previous list supports to the notion that congestion pricing, and HOT lanes, is becoming a more attractive alternative for agencies to deal with: 1) high congestion levels and 2) underused HOV lanes. Nevertheless, the key question always is how much drivers are willing to pay to save time by avoiding congested roadways.

Lam and Small (2001) measured value of time (VOT) and value of reliability (VOR) using data on actual travel behavior in a real pricing context. In this study, they collected data from the toll highway State Route 91 (SR-91) drivers. SR-91 users face a choice between two parallel routes, one free but congested and the other with time-varying tolls. At the time of this study, high occupancy vehicles (3 plus occupants) paid half of the toll. The authors created several models with different variables' interaction and weight. Their proposed model yielded a VOT of $22.87 per hour, whereas one of the other reliable models estimated VOT as $16.37 per hour. Both VOT are estimates for congested travel.

Brownstone, et al. (2003) estimated willingness to pay to reduce travel time on a congested road. The approach uses RP data from the I-15 congestion pricing project in San Diego, collected over a two month period, in October and November 1998. They found that the average willingness to pay to reduce travel time of morning commuters is roughly $30 per hour. In addition, they explain that I-15 drivers mostly preoccupy about unexpected delays in their morning commute. As a result, they are willing to pay a higher than usual toll to avoid unusual congestion. Furthermore, the authors highlight the fact that the toll lanes along the I-15 are separated from the rest of the freeway, which may improve driving conditions and safety. As a result, this may affect the willingness to pay estimates by biasing the estimates upward.

Later on, Brownstone and Small (2005) compared their previous results. Their results from the SR91 and I-15 corridors based on RP lane-choice data almost always obtain median VOT of $20 to $40 per hour. They found that the VOT estimated using stated preference data (SP) are about half of the ones estimated using revealed preference (RP) data, SR-91 and I-15 respectively. They explain this by stating that: 1) people display time inconsistency in their actual behavior, but not in their hypothetical behavior (i.e. drivers make the higher-cost choice more often in real life than on hypothetical surveys); and 2) the difference is caused by systematic misperception of travel times (i.e., RP respondents overestimate their time saving). The authors then implemented sample weights in order to match the income and commute distance distribution of both facilities. This approach yielded similar VOT around $20 per hour for I-15 and SR-91.

More recently, Finkleman, Casello and Fu (2011) conducted a willingness to pay (WTP) study in the Greater Toronto Area, Ontario, Canada. Given that the study was performed in Canada, all monetary value related to it are in Canadian dollar. The study estimates WTP based on common trip and travelers' characteristics (i.e. travel time, income, trip distance, etc.) and introduces "trip urgency" as a factor. For this, they collected SP data of 255 Toronto residents. Their results indicate that under a trip condition of high urgency and high congestion level on parallel lanes, travelers are willing to pay $4.12 for 24 minute trip on the HOT lane, which equates to $10.3 per hour. On the other hand, for the least urgent trips, their WTP decreases to $0.58 for a 13 minute trip, which equates $2.7 per hour. As expected, they found that trip urgency plays a significant role on travelers' decision to pay for admission to the HOT lanes.

Literature on value of time for dynamic toll systems is scarce given the lack of facilities to perform this type of studies. In summary, the existing literature universally concludes that traveler's value of time and willingness to pay varies by the trip and driver characteristics. In addition, value of time is sensitive to geographic (i.e. regional) effects, as evidenced by the different values obtained in each study.

3. SURVEY DESIGN

The stated preference survey was conducted in the Maryland Capital Beltway (I-495) to capture response of the potential regional driver on the ICC in the presence of dynamic toll pricing. The questionnaire was designed as a web-based survey where the survey recruitment was conducted by flyer distributions at several exit locations of I-495. The sample population consisted of car drivers traveling on I-495 during weekday extended peak periods (8:00 AM - 11:00 AM and 3:30 PM. - 6:00 PM) on March 21-25, and May 23-27, 2011. A total of 200 respondents from a sample of 4,000 who received the flyers responded to the questionnaire which results in the overall response rate of 5%. Within the 200 responded surveys, 173 of the respondents completed the survey, which results in the effective sample size of 173 observations for the model estimation.

The questionnaire consists of two parts: revealed preference (RP) and stated preference (SP) questions. The description for each part of the survey is described as follows:

3.1 Revealed Preference (RP) Questionnaire

The revealed preference (RP) questionnaire consists of two sections: respondents' socioeconomics and recent trip information.

3.1.1 Socioeconomic Information

The purpose of this section is to investigate socioeconomic data of the potential HOT lane users in I-495. The respondent is asked to describe his/her socioeconomic information via the following constructs:

- Gender
- Age
- Household income range
- Education
- Occupation
- Number of worker per household
- Number of vehicle in the household
- Vehicle type most used by the respondent
- Number of years the vehicle owned
- ZIP code of work place

3.1.2 Recent Trip Information

The recent trip information gathers data about the respondent's most recent trip on I-495. The purpose of this section is to use respondent's experienced trip condition as the pivot point when designing the stated preference (SP) question. This ensures that the stated scenario in the SP part is realistic for each respondent. The respondent is asked to describe his/her most recent trip information on I-495 via the following constructs:

- Mode choice
- Number of passenger
- Trip purpose
- Departure time (DT)
- Arrival time (AT)
- Preferred departure time (PDT)
- Preferred arrival time (PAT)
- Total travel time in minutes (TT)
- Total trip distance in miles (D)

- Fuel cost (FC)
- Parking cost ($)
- Toll cost ($)
- Entry and exit ramp locations
- Shortest (TT min) and longest (TT max) travel time experienced on the whole trip in minutes
- Shortest (ST) and longest (LT) travel time experienced on the beltway in minutes
- Number of departure time alternatives respondents have considered
- Corresponded departure and arrival time for the alternative departure time
- Work starting/ending time, work schedule flexibility (whether can start work 30 minutes later)

3.2 Stated Preference (SP) Questionnaire

The stated preference (SP) portion of the survey aims at investigating traveler lane choice in response to time-of-day traffic condition and dynamic toll pricing scheme. It presents respondents with 7 scenarios of stated experiments on the lane choice alternatives. Given that a prevalent form of congestion pricing in the US is high-occupancy/toll (HOT) lanes, the dynamic toll pricing is introduced through the HOT lane alternative.

The game consists of three alternatives and four variables. These variables have the maximum of five levels of variation per alternative. Three alternatives presented to respondents are: (1) Solo driver on normal lane, (2) High Occupancy Toll (HOT) lane, and (3) High Occupancy Vehicle (HOV) lane. The variables included in the stated preference are: (1) Departure time, (2) Travel time range, (3) Fuel cost, and (4) Toll. These variables are designed to account for traffic conditions by time of day taking into account observed respondents' departure time where the peak period is defined as 8:00 AM. to10:00 AM., and 3:00 PM. to 7:00 PM. (Crunkleton, 2008). The description of the variables used in the survey is as follows:

1) Departure time: Departure time is pivoted from respondent's reported departure time in the RP part.

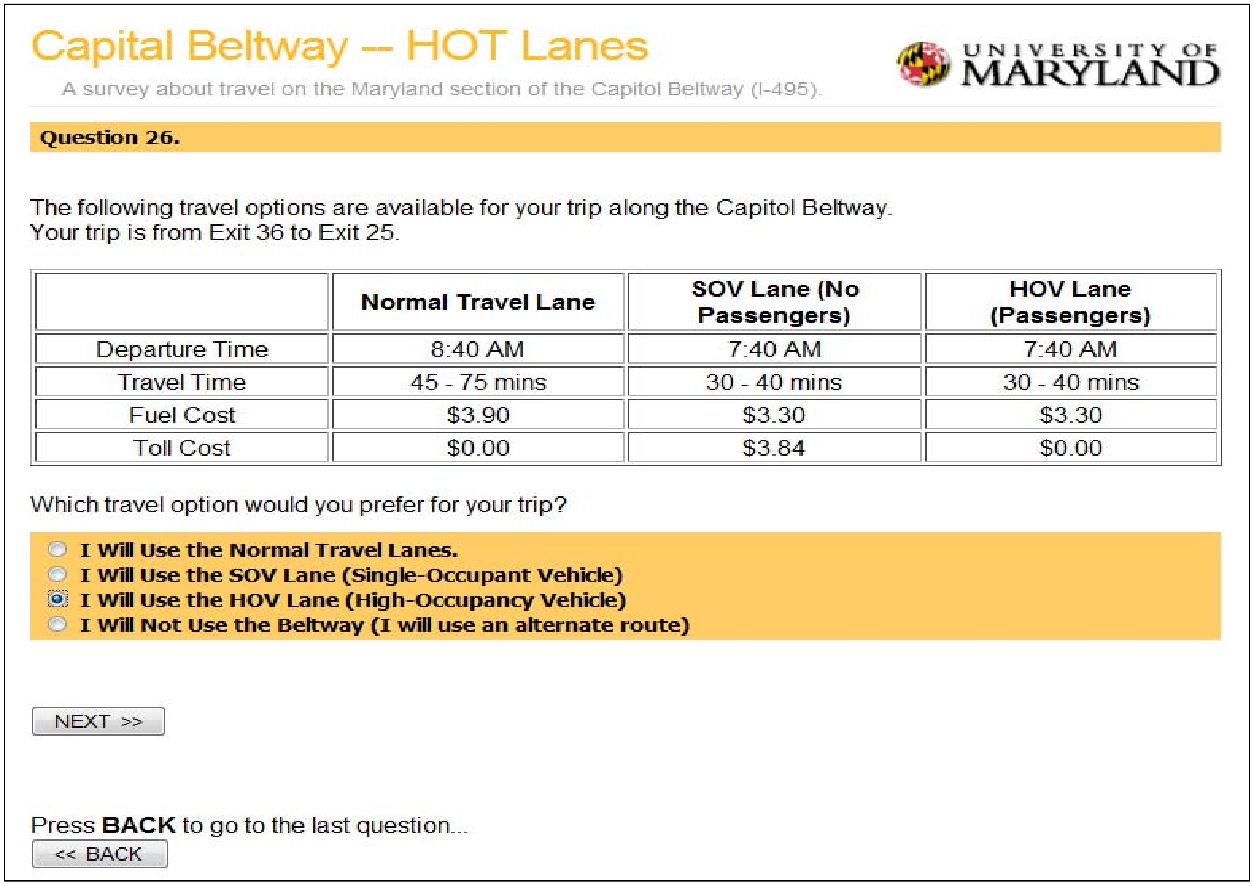
2) Total travel time range: This variable is designed to account for both time-of-day conditions based on the respondent's reported departure time and travel condition on toll lane. It is aimed at capturing travel time uncertainty.
3) Fuel cost: The fuel cost is designed to reflect higher expenses in the peak period and on the normal lane. The fuel cost is pivoted from the reported fuel cost in the RP part.
4) Toll cost: The toll cost is designed as a mileage based using the Intercounty Connector toll rates (MDTA, 2010). The toll rate for the HOT lane accounts varies depending on whether the respondents' reported departure time is in the peak or non-peak period.

The survey is designed with orthogonal design approach where numerical evaluations in a wide range of parameters values was undertaken to guarantee sufficient efficiency of the design. The pilot study, in combination with expert judgments, was also used to arrive at the final levels of attribute in the SP experiment. The questionnaire design of the stated preference survey is shown in Table 1.

Table 1 Stated Preference Survey Design

Variable	**Normal Lane**	**HOT Lane**	**HOV Lane (passengers >1)**
Departure time	DT-40min DT-20min DT DT+20min DT+40min	DT-40min DT-20min DT DT+20min DT+40min	DT-40min DT-20min DT DT+20min DT+40min
Total travel time range (minute)	**If DT in peak hour** TTmin+20 to TTmin+30; TTmin+20 to TTmin+40; TTmin+20 to TTmax; TTmin+20 to TTmin+45; TTmin+20 to TTmin+35; **If DT not in peak hour,** TTmin+10 to TTmin+20; TTmin+10 to TTmin+30; TTmin+10 to TTmax-10; TTmin+10 to TTmax-20; TTmin+10 to TTmax-30;	**If DT in peak hour** TTmin+10 to TTmin+20; TTmin+10 to TTmin+25; TTmin+10 to TTmin+30; TTmin+10 to TTmin+25; TTmin+10 to TTmin+20; **If DT not in peak hour,** TTmin+5 to TTmin+10; TTmin+5 to TTmin+15; TTmin+5 to TTmin+20; TTmin+5 to TTmin+15; TTmin+5 to TTmin+10;	**If DT in peak hour** TTmin+10 to TTmin+20; TTmin+10 to TTmin+25; TTmin+10 to TTmin+30; TTmin+10 to TTmin+25; TTmin+10 to TTmin+20; **If DT not in peak hour,** TTmin+5 to TTmin+10; TTmin+5 to TTmin+15; TTmin+5 to TTmin+20; TTmin+5 to TTmin+15; TTmin+5 to TTmin+10;
Fuel cost ($)	**If DT in peak hour** FC(1+10%) FC(1+20%) FC(1+30%) **If DT not in peak hour,** FC(1+10%) FC(1+15%) FC(1+20%)	**If DT in peak hour** FC FC(1+10%) FC(1+20%) **If DT not in peak hour,** FC FC(1+15%) FC(1+20%)	**If DT in peak hour** FC FC(1+10%) FC(1+20%) **If DT not in peak hour,** FC FC(1+15%) FC(1+20%)
Toll cost ($)	**0**	**If DT in peak hour** $0.3/mile*D $0.35/mile*D $0.4/mile*D $0.45/mile*D $0.5/mile*D **If DT not in peak hour,** $0.1/mile*D $0.15/mile*D $0.2/mile*D $0.25/mile*D $0.3/mile*D	**0**

Figure 1 shows the interface of the stated preference survey on the website.



Capital Beltway -- HOT Lanes

A survey about travel on the Maryland section of the Capitol Beltway (I-495).

UNIVERSITY OF MARYLAND

Question 26.

The following travel options are available for your trip along the Capitol Beltway.
Your trip is from Exit 36 to Exit 25.

	Normal Travel Lane	SOV Lane (No Passengers)	HOV Lane (Passengers)
Departure Time	8:40 AM	7:40 AM	7:40 AM
Travel Time	45 - 75 mins	30 - 40 mins	30 - 40 mins
Fuel Cost	$3.90	$3.30	$3.30
Toll Cost	$0.00	$3.84	$0.00

Which travel option would you prefer for your trip?

- I Will Use the Normal Travel Lanes.
- I Will Use the SOV Lane (Single-Occupant Vehicle)
- I Will Use the HOV Lane (High-Occupancy Vehicle)
- I Will Not Use the Beltway (I will use an alternate route)

NEXT >>

Press **BACK** to go to the last question...

<< BACK

Figure 1 Stated Preference Questionnaire

4. DESCRIPTIVE STATISTICS

A sample size of 173 completed surveys was collected. The respondent's characteristics are divided into two groups, socioeconomics and trip characteristics. The distribution of the sample is presented next.

4.1 Socioeconomics Results

Socioeconomic data was collected for the respondent's gender, age, education, and occupation; and the household's income, number of worker in the household, number of vehicle in the household, and others. The summary of socioeconomic statistics is shown in Table 2.

Gender Statistics show that 51% of respondents are male.

Age Respondents' ages are distributed with an average age of 43 and median age of 45. The youngest respondent is 19 and the oldest is 82.

Education Approximately 49% of the respondents are at a graduate or professional level. In addition, 34% of the respondents have a bachelor's degree and 8% have some college education. The remaining respondents are distributed almost uniformly across the other levels.

Occupation Approximately 46% of the respondents work for a private company, whereas 30% work for the government. Only 1.2% of the respondents are unemployed.

Income Approximately 32% of households have incomes above $150,000. Approximately 24% of households have incomes between $100,000 and $149,999. Similarly, 24% of households have income between $50,000 and $99,999. Around 10% of households have incomes less than $50,000 with the remaining households (9%) refusing to answer the question.

Number of workers in the household Only 2.3% of the sample have no worker in the household. Nearly 27% have 1 worker and 54% of households have 2 workers. Almost 8% of households have 3 workers, whereas 3.5 have 4 or more workers.

Number of vehicle per household Nearly 2% of households have no vehicles. On the other hand, 27% reported having 1 vehicle and 54% had 2 vehicles. 7.5% of households have 3 vehicles and 3.5% have 4 or more vehicles with the remaining households (6.4%) refusing to answer the question.

Table 2 Socioeconomic Statistics

Category	Case	Respondents	Percentage*
Gender	Male	77	45.00%
	Female	89	51.00%
Age	18-25	13	7.51%
	26-35	40	23.12%
	36-45	33	19.08%
	46-60	63	36.42%
	Greater than 60	15	8.67%
Education	Associate Degree	3	1.70%
	Bachelor Degree	59	34.10%
	Graduate or Professional Degree	84	48.60%
	High School Graduate	2	1.20%
	Less than High School	2	1.20%
	Some College	14	8.10%
Occupation	Faculty or School Staff	5	2.90%
	Retired	2	1.20%
	Self Employed	10	5.80%
	Student	8	4.60%
	Work for Private Company	80	46.20%
	Work for the Government	52	30.10%
	Unemployed	2	1.20%
	Other	6	3.50%
Household Income	Less than $50,000	18	10.40%
	$50,000-$99,999	41	23.70%
	$100,000-$149,999	42	24.28%
	Greater than $150,000	56	32.37%
Workers per household	0	4	2.31%
	1	46	26.59%
	2	93	53.76%
	3	13	7.51%
	4	2	1.16%
	Greater than 4	4	2.31%
Vehicle per household	0	4	2.31%
	1	46	26.59%
	2	93	53.76%
	3	13	7.51%
	4	2	1.16%
	Greater than 4	4	2.31%

* Travelers who skipped the answer are excluded from the statistics.

4.2 Trip Characteristics Results

Respondents were also asked about their trips, mainly focusing on the mode of transportation, number of passengers, different times and costs associated with the trip, distance traveled, and others. The summary of trip characteristic statistics is shown in Table 3.

Carpool. Approximately 17% of the respondents are carpool travelers.

Shared Expenses. Of the carpool travelers, 80% of them do not share fuel and parking expenses.

Number of Passengers. Of the carpool travelers, 60% and 23% of them have 1 passenger and 2 passengers respectively. The remaining have 3 or more passengers.

Travel Time. The average travel time of the respondents is 30 minutes, without considering the trips that took more than 2 hours. Around 29% of the respondents spent 15 minutes or less in their trip, whereas 41% spent between 16 and 30 minutes. Almost 15% spent between 31 and 45 minutes and nearly 7% took between 46 and 60 minutes. The remaining spent more than 60 minute to complete their trip.

Departure Time. The majority of the trips departed within peak hours (33% in AM peak and 32% in PM peak).

Distance Traveled. The average trip length is 23.4 miles. 41% of the respondents traveled between 20 and 40 miles, followed by 10 to 20 miles with 32%. Around 15% traveled less than 10 miles with the remaining traveling 40 miles or more.

Fuel Cost. On average, each respondent spent $6 on fuel. Most of the respondent (60%) spent between $2.5 and $10, whereas nearly 24% spent between 0 and $2.5. The remaining 15.6% is somewhat equivalently distributed among the other cost groups.

Parking Cost. The average parking cost is $0.96, without taking into consideration two respondents that combined paid $200 for parking. 85% of the respondents did not pay for parking, while 11% paid less than $10.

Toll Cost. The average toll cost is $0.24. 94% of the respondents did not pay for toll, while 3% paid less than $5. 1.7% paid between $5 and $10, with the remaining paying more than $10 in toll.

Shortest Trip Time. The majority of the respondents (56%) performed their shortest trip between 16 and 30 minutes. On the other hand, 14% took 15 minutes or less, while 21% took between 31 and 45 minutes. Only 6.4 % took between 46 and 60 minutes and the remaining needed more than 60 minutes to complete their trip.

Longest Trip Time. The average longest trip time is 93.5 minutes. Only 3% of respondents performed their longest trip in 15 minutes or less, while 4.6% needed between 16 and 30 minutes. The remaining respondents are somewhat equivalently distributed among the other time ranges.

Shortest Travel Time on Beltway. On average, respondents performed their shortest trip on the Beltway in 15 minutes. Nearly 46% of respondents traveled for 10 minutes or less, whereas approximately 39% needed between 11 and 20 minutes to complete their trip. 11% took between 21 and 30 minutes, and the remaining 4% needed more than 30 minutes.

Longest Travel Time on Beltway. On average, respondents performed their longest trip on the Beltway in 62 minutes. Nearly 9% of respondents traveled for 15 minutes or less, whereas approximately 7% needed more than 120 minutes to complete their trip. The remaining respondents are somewhat equivalently distributed among the other time ranges.

Table 3 Trip Characteristics Statistics

Category	Case	Respondents	Percentage*
Carpool	Carpool	30	17.30%
	Non-Carpool	143	82.70%
Travel Time (min)	0-15	50	28.9%
	16-30	71	41.0%
	31-45	25	14.5%
	46-60	11	6.4%
	Greater than 60	16	9.2%
Departure Time	Before 6 AM	4	2.4%
	6AM-8AM	30	17.8%
	8AM-10AM	55	32.5%
	10AM-12PM	9	5.3%
	12PM-2PM	8	4.7%
	2PM-4PM	10	5.9%
	4PM-7PM	54	32.0%
	After 7PM	3	1.8%
Distance Traveled (mile)	0-5	5	2.9%
	5-10	20	11.6%
	10-20	56	32.4%
	20-40	71	41.0%
	40-60	7	4.0%
	Greater than 60	13	7.5%
Fuel Cost	0-2.5	41	23.70%
	2.5-5	54	31.20%
	5-10	51	29.50%
	10-20	12	6.90%
	20-40	6	3.50%
	Greater than 40	9	5.20%
Parking Cost	0	147	85.00%
	0-5	10	5.80%
	5-10	9	5.20%
	10-20	5	2.90%
	Greater than 20	2	1.20%
Toll Cost	0	162	93.60%
	0-5	5	2.90%
	5-10	3	1.70%
	Greater than 10	3	1.70%
Minimum Freeway Travel Time (min)	0-10	79	45.70%
	11-20	68	39.30%
	21-30	19	11.00%

	31-45	3	1.70%
	Greater than 45	4	2.30%
Maximum Freeway Travel Time (min)	0-15	15	8.70%
	16-30	33	19.10%
	31-45	40	23.10%
	46-60	27	15.60%
	61-90	23	13.30%
	91-120	23	13.30%
	Greater than 120	12	6.90%

* Travelers who skipped the answer are excluded from the statistics.

5. MODELS AND RESULT

In this section, the information on traveler's socioeconomic and trip characteristics presented in section 4 are used for the model estimation, the variable definitions are as follows:

- The variable Time is the traveler's travel time in minutes.
- Trip time is divided into two groups:
  - PeakHr: dummy variable that takes the value of 1 if the trip takes place between peak hours (8-10 AM or 3-7 PM) and 0 otherwise.
  - OffPeakHr: dummy variable that takes the value of 1 if the trips takes place during off-peak hours and 0 otherwise.
- The variable Tc refers to the toll cost in US dollars.
- Carpool is a dummy variable that takes a value of 1 if the person carpools and 0 otherwise.
- Distance refers to the distance traveled in miles.
- Trip purpose in divided into four dummy variables which take the value of 1 if trip purpose is the same as the variable and 0 otherwise:
  - Hbw_sch: work or school related trip.
  - Hbsoc: social trip.
  - Hbshop: shopping trip.
  - Hbo: other trips.
- Traveler's age is divided into five dummy variables which take the value of 1 if age falls between the specified range and 0 otherwise:
  - AgeLess25
  - Age25to35
  - Age36to45
  - Age46to60
  - AgeMore60
- The education level is captured by 4 dummy variables which take the value of 1 if the education level is the same as the variable and 0 otherwise:
  - Somecollege

    - Ass_degr: represents associate degree.
    - Bach_degr: represents bachelor degree.
    - Gradprof_degr: represents a graduate or professional degree.
- Income refers to the household income level. These variables are represented as categorical values which range from 0 to 3 depending on whether the income is less than $50k, $50k-$100k, $100k-$150k, and more than $150k, respectively.
- Cars_per_hh represents the number of vehicles in the household.
- Traveler's occupation is divided into seven dummy variables which take the value of 1 if the occupation is the same as the variable and 0 otherwise:
    - Occ_other: refers to unrevealed or miscellaneous occupation.
    - Occ_facsch: refers to school faculty.
    - Occ_priv: refers to working for a private company.
    - Occ_self: refers to self employed.
    - Occ_ret: refers to retired.
    - Occ_stud: refers to student.
    - Occ_unemp: refers to unemployed.
    - Occ_gov: refers to working for the government.

The following significance levels are used in this study:

* Significant at the 10% level;

** Significant at the 5% level;

*** Significant at the 1% level.

5.1 Model 1: Generic Willingness to Pay (WTP)

To estimate the willingness to pay (WTP) toll to reduce travel time, a model is developed focusing on time and toll cost, see Table 4. The resulting willingness to pay is 12.93 $/hr, with a 95% confidence interval of [11.63 $/hr, 16.53 $/hr]. Notice that the variables time and toll cost are significant at the 1% level and the signs are in line with intuition.

Table 4 Model 1 Result

Scenario	Coef.	P>|z|				
Time	-0.0402***	0.0000				
Tc_	-0.1866***	0.0000				
Choice	**Normal Lane**		**HOT**		**HOV**	
	Coef.	P>|z|	Coef.	P>|z|	Coef.	P>|z|
_cons	Base Alternative		-0.8328***	0.000	-2.2371***	0.000
Log Likelihood:	-746.8564	**# obs:**	2682			
Wald Chi2(42):	52.56	**# cases:**	894			
Prob > Chi2:	0.0000	**# Alt:**	3			

5.2 Model 2: Willingness to Pay (WTP) by Income Level.

A second model is estimated to calculate the willingness to pay by income level, see Table 5. One would expect that the WTP monotonically increases by level of income. Nevertheless, the results indicate that it behaves in a u-shape manner, see Table 5. This could be explained by the fact that low income people's (less than $50,000) daily activities have an intense dependency on their strict work and personal schedules (e.g. they cannot afford to be late for work and risk losing it). On the other hand, although high income people (more than $150,000) may not have a fixed schedule, their daily activities may have a higher monetary value. It should be noticed that the estimated WTP for income level 2 is not significant at the 5% confidence level; hence it should not be considered as accurate.

Table 5 Willingness to Pay by Income Level

Level	HH Income	WTP ($/hour)	[95% Conf. Interval] ($/hour)	
0)	Less than 50K	16.03	19.61	7.22
1)	50 K – 100 K	11.03	12.17	8.21
2)	100 K – 150 K	5.59	8.31	(1.11)
3)	More than 150 K	17.67	16.70	20.05

Model 2 result is shown in Table 6. Toll cost and the interaction between time and income levels have expected signs and are significant at the 1% level, except for income level 2, which is significant at the 10% level. Moreover, all variables within the model are significant at the 5% level or less and have expected sign. As expected, travelers that carpool show preference to HOV lanes. The results indicate that travelers with longer trips would prefer HOT lanes, although it should be noticed that the difference between alternative’s coefficients is relatively small. Travelers with trip purpose home based office are the most likely to use HOT lanes. In addition, as age increases HOV preference monotonically decreases. On the other hand, as education level increases HOV preference increases as well. Self employed travelers prefer to use HOT lanes. This could be explained by assuming that self employed travelers have very unique and personal schedules that are difficult to match, compared to other occupations. In contrast, private employees prefer HOV lanes, which could be explain by the previous reasoning. As an overall, based on the constant, HOT is the least preferred alternative.

Table 6 Model 2 Result

Scenario	Coef.		P>|z|						
TimeInc0	-0.0600	***	0.008						
TimeInc1	-0.0413	***	0.001						
TimeInc2	-0.0209	*	0.079						
TimeInc3	-0.0662	***	0.000						
Tc_	-0.2247	***	0.000						
Choice	**Normal Lane**			**HOT**			**HOV**		
	Coef.		P>|z|	Coef.		P>|z|	Coef.		P>|z|
Carpool	Base alternative			-1.3632	***	0.002	4.6624	***	0.000
Distance				0.0181	***	0.007	0.0134	*	0.056
Hbw_sch				0.8956		0.104	-1.6864	**	0.010
Hbshop				1.6402	**	0.018	-15.8597		0.995
Hbo				2.0191	***	0.001	-1.0094		0.177
AgeLess25				1.2346	**	0.043	1.8416	*	0.051
Age25to35				0.8777	**	0.044	-1.0536		0.218
Age36to45				-0.1377		0.763	-2.6457	**	0.012
Age46to60				0.8177	**	0.048	-4.2467	***	0.000
Ass_degr				0.5587		0.717	-16.9022		0.993
Bach_degr				0.0694		0.893	-3.5681	***	0.001
Gradprof_degr				0.7716		0.134	-2.8665	***	0.004
Occ_other				-0.7082		0.580	5.7006	***	0.000
Occ_facsch				0.1477		0.789	-15.4865		0.997
Occ_priv				0.2417		0.252	2.7924	***	0.000
Occ_self				0.5596		0.228	-2.7975	*	0.075
Occ_ret				4.0022	***	0.001	-15.8858		0.994
Occ_stud				-0.3708		0.552	0.2612		0.845
Occ_unemp				-16.6141		0.998	1.4388		0.395
_cons				-3.3891	***	0.000	-0.3547		0.806
Log Likelihood:	-482.913	**# obs:**	2535						
Wald Chi2(43):	201.19	**# cases:**	845						
Prob > Chi2:	0.0000	**# Alt:**	3						

5.3 Model 3: Willingness to Pay (WTP) by Trip Purpose

The third model is estimated to calculate willingness to pay by trip purpose. The results are significant at the 5% level, except for willingness to pay for shopping trips, which is not significant. Hence, its value should not be taken into account. The resulting WTP's are presented in Table 7. Work and school related trips presented the lower WTP, whereas ‘Other’ trips presented the highest WTP. This result, although counterintuitive, is not uncommon. Several studies, such as Cirillo and Axhausen (2006) and Finkleman, Casello, and Fu (2011), have found that high urgency trips and shopping and leisure trips have higher WTP compared to work and school related trips.

Table 7 Willingness to Pay by Trip Purpose

Purpose	**Variable**	**WTP ($/hour)**	**[95% Conf. Interval] ($/hour)**	
Shopping	HBShop	10.35	18.64	(12.05)
Work or School	HBW_Sch	11.17	10.94	11.81
Other	HBO	22.95	24.20	19.56
Social	HBSoc	14.00	18.28	2.46

Model 3 result is shown in Table 8. Toll cost and the interaction between trip purposes and time have expected signs and are significant at the 1% level, except for social related trips, which is significant at the 5% level. Two new variables are included in this model, cars per household and income, both significant at the 5% level. The higher the number of vehicles in a household the lower their likelihood to select HOT lanes. This could be explained by the unwillingness of households to pay toll for each individual vehicle. In addition, travelers with high income prefer HOV lanes. Finally, all remaining variables follow the same pattern as the previous model.

Table 8 Model 3 Result

Scenario	Coef.		P>|z|						
Hbshop_time	-0.0362		0.229						
Hbw_sch_time	-0.0391	***	0.000						
Hbo_time	-0.0803	***	0.000						
Hbsoc_time	-0.0490	**	0.030						
Tc_	-0.2101	***	0.000						
Choice	**Normal Lane**			**HOT**			**HOV**		
	Coef.		P>|z|	Coef.		P>|z|	Coef.		P>|z|
Carpool	Base alternative			-1.3776	**	0.000	5.4282	***	0.000
Distance				0.0146	**	0.029	0.0083		0.227
AgeLess25				1.7300	***	0.006	3.0939	***	0.005
Age25to35				0.8626	*	0.055	-0.9282		0.310
Age36to45				-0.3380		0.469	-3.1690	***	0.003
Age46to60				0.7293	*	0.089	-4.9329	***	0.000
Ass_degr				0.9419		0.535	-20.5178		0.996
Bach_degr				0.5144		0.324	-4.9062	***	0.000
Gradprof_degr				1.0487	**	0.042	-4.4373	***	0.000
Occ_other				0.2340		0.853	7.6714	***	0.000
Occ_facsch				0.6741		0.215	-11.7820		0.991
Occ_priv				0.4453	**	0.035	3.2580	***	0.000
Occ_self				0.2687		0.531	-3.4877	**	0.036
Occ_ret				5.6679	***	0.000	-12.6054		0.985
Occ_stud				-0.0431		0.946	1.0704		0.430
Occ_unemp				-13.4859		0.995	2.0227		0.227
Cars_per_hh				-0.3110	**	0.010	0.2589		0.320
Income				0.5068	***	0.000	0.8817	***	0.004
_cons				-3.0976	***	0.000	-2.8879	**	0.044
Log Likelihood:	-483.647		**# obs:**	2535					
Wald Chi2(41):	199.22		**# cases:**	845					
Prob > Chi2:	0.0000		**# Alt:**	3					

5.4 Model 4: Willingness to Pay (WTP) by Congestion Period

The fourth model is estimated to calculate willingness to pay by congestion period (i.e. peak hour and off-peak hour). The results indicate that WTP for peak hour is less than for off-peak hours, see Table 9. As indicated in the previous models, non work and school related trips have higher willingness to pay. It is reasonable to assume that these trips take place during off-peak hours, hence the higher WTP for off-peak hour trips.

Table 9 Willingness to Pay by Congestion Period

Period	**WTP ($/hour)**	**[95% Conf. Interval] ($/hour)**	
Peak hour	$ 11.70	$ 11.33	$ 0.21
Off-peak hour	$ 13.62	$ 5.01	$ 0.21

Model 4 result is shown in Table 10. Toll cost and the interaction between congestion period and time have expected signs and are significant at the 1% level. All remaining variables follow the same pattern as the previous models.

Table 10 Model 4 Result

Scenario	Coef.		P>|z|					
TimePeakHr	-0.0441	***	0.000					
TimeOffPea~r	-0.0513	***	0.000					
Tc_	-0.2260	***	0.000					
Choice	**Normal Lane**			**HOT**			**HOV**		
	Coef.		P>|z|	Coef.		P>|z|	Coef.		P>|z|
Carpool	Base alternative			-1.4486	***	0.001	4.5737	***	0.000
Distance				0.0150	**	0.028	0.0100	*	0.158
Hbw_sch				0.7155		0.173	-1.4686	**	0.029
Hbshop				1.4166	**	0.035	-13.9082		0.991
Hbo				1.8882	***	0.001	-0.6460		0.406
AgeLess25				2.2025	***	0.001	2.8351	**	0.010
Age25to35				0.9784	**	0.028	-0.8992		0.316
Age36to45				-0.3358		0.469	-2.7133	***	0.009
Age46to60				0.6102		0.149	-4.6046	***	0.000
Ass_degr				0.8032		0.601	-15.9549		0.985
Bach_degr				0.1935		0.714	-4.0866	***	0.000
Gradprof_degr				0.7962		0.127	-3.4276	***	0.001
Income				0.5403	***	0.000	0.5777	*	0.066
Occ_other				0.1653		0.899	6.7651	***	0.000
Occ_facsch				0.6020		0.305	-13.5461		0.995
Occ_priv				0.4289	**	0.045	2.9825	***	0.000
Occ_self				0.5501		0.235	-2.9623	*	0.069
Occ_ret				4.5479	***	0.000	-14.1206		0.989
Occ_stud				0.1353		0.832	0.2559		0.855
Occ_unemp				-14.4932		0.995	1.8987		0.269
_cons				-4.3586	***	0.000	-1.1913		0.449
Log Likelihood:	-476.432		**# obs:**	2535					
Wald Chi2(43):	209.39		**# cases:**	845					
Prob > Chi2:	0.0000		**# Alt:**	3					

6. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

In this study, we propose the user response model to dynamic toll pricing. The modeling framework provides the willingness to pay toll to reduce travel time which varies across user socioeconomics and trip related characteristics such as time of day, and trip purpose. The data used for the analysis are based on the dedicated stated preference survey on the lane choice where attributes are travel time, toll cost, and fuel cost, all of which account for traffic condition by time of day.

Four models are proposed to calculate the willingness to pay toll to reduce travel time. The model considers the user choice of lane among 1) Normal lane, 2) HOT lane, and 3) HOV lane in the presence of dynamic toll pricing. Given that departure time is incorporated in the choice attributes, the model can determine not only change in lane choice in response to dynamic toll pricing, but also temporal shift toward less congested period. The model estimation results are in line with the expectation based on the previous studies. Apart from estimating the generic willingness to pay (WTP) for toll, the approach enables to account for different WTP by income level, trip purpose, and congestion period. Based on the results, the generic willingness to pay toll for travel time saving is 12.93 $/hour. The willingness to pay by income level ranges from 5.59 $/hour to 17.67 $/hour for household with $100,000-$149,999 income and greater than $150,000 income respectively. The willingness to pay by trip purpose ranges from 10.35 $/hour to 22.95 $/hour for the home based shopping and home based others respectively. Finally, the willingness to pay by congestion period is 11.70 $/hour in the peak hour and 13.62 $/hour in the off peak hour.

Future research extensions are suggested based on this modeling capability. For instance, the model can be integrated into a solution framework to find an optimal dynamic pricing scheme so as to alleviate congestion and social benefit. In addition, the data collected from this survey can incorporate stochastic travel condition based on travel time uncertainty. More importantly, the model calibrated from the data collected at the ICC facility when the system is fully operational will provide more representative behavioral characteristics of the ICC users.

REFERENCES

Arnott, R., de Palma, A., Lindsey, R., 1998. Recent developments in the bottleneck model. In: Button, Kenneth J., Verhoef, Erik T. (Eds.), Road Pricing, Traffic Congestion and the Environment: Issues of Efficiency and Social Feasibility, pp. 79–110.

Brownstone, D., & Small, K. (2005). Valuing Time and Reliability: Assessing the Evidencefrom Road Pricing Demonstrations. *Transportation Research Part A* , 279-293.

Brownstone, D., Ghosh, A., Golob, T. K., & Amelsfort, D. (2003). Drives' Willingness to Pay to Reduce Travel Time: Evidence from the San Diego I-15 Congestion Pricing Project. *Transportation Research Part A* , 373-387.

Cirillo, C., & Axhausen, K. (2006). Evidence on the Distribution of Values of Travel Time SAvings from a Six-week Diary. *Transportation Research Part A* , 444-457.

Crunkleton, J. (2008). Congestion Pricing for the Capital Beltway. *Master Thesis, University of Maryland, College Park* .

Finkleman, J., Casello, J., & Fu, L. (2011). Empirical Evidence from the Greater Toronto Area on the Acceptability and Impacts of HOT Lanes. *Transport Policy* , 814-824.

Goodall, N., & Smith, B. (2009). *Modeling Single Occupant Vehicle Behavior in High-Occupancy Toll (HOT) Facilities.* Charlottesville: University of Virginia Center for Transportation Studies.

Goodman, L., Jurasin, R., Larwin, T., Orski, C., Turnbull, K., & Cunard, R. (1998). High-Occupancy/Toll (HOT) Lanes and Value Pricing: A Preliminary Assesment. *ITE Journal* , 30-40.

Knight, F.H., 1924. Some fallacies in the interpretation of social cost. Quarterly Journal of Economics 38, 582–606.

Lam, T., & Small, K. (2001). The Value of Time and Reliability: Measurement from a Value Pricing Experiment. *Transportation Research E* , 231-251.

Lindsey, R., 2006. Do economists reach a conclusion on road pricing? The intellectual history of an idea. Econ Journal Watch 3, 292–379.

Los Angeles County Metropolitan Transportation Authority. (2010, January 15). *Hot Lanes in the U.S.* Retrieved December 15, 2011, from Metro: http://www.metro.net/projects/expresslanes/expresslanes_us/

Lu, C.-C., Mahmassani, H.S., Zhou, X., 2008. A bi-criterion dynamic user equilibrium traffic assignment model and solution algorithm for evaluating dynamic road pricing strategies. Transportation Research Part C 16 (4), 371–389.

Maryland Transportation Authority (MDTA). (2010). *Toll Rates Set for the First Segment of the ICC*. Retrieved from http://www.mdot.maryland.gov/News/2010/June2010/ICCtollrates-segment1.html.

Pigou, A.C., 1920. Wealth and Welfare. Macmillan, London.