



Empirical evidence from the Greater Toronto Area on the acceptability and impacts of HOT lanes

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ABSTRACT

This paper describes a study on willingness to pay (WTP) and public acceptability for High-Occupancy/Toll (HOT) lanes using empirical evidence from Toronto, Ontario, Canada. From a stated preference survey of more than 250 drivers, we estimate mean willingness to pay values under various trip conditions and for various traveler characteristics. The study provides statistically significant evidence on the relationships between willingness to pay and the improvement in travel speeds in HOT lanes, the length of the trip, and the urgency of on-time arrival. Furthermore, our study confirms several literature findings from previous studies on the relationship between travelers' willingness to pay and income as well as prior experience with HOT lanes. Some of the findings are qualitatively validated on the basis of the observed travel behavior in choosing tolled facilities over untolled facilities during periods of heightened congestion and urgency.

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1. Introduction

High-Occupancy/Toll (HOT) lanes are modern traffic management facilities that attempt to maximize the person-throughput of freeway lanes by balancing the capacity consumed by high-occupancy and single occupancy vehicles (HOVs and SOVs, respectively). Typically, HOVs are allowed into HOT lanes free of charge while SOVs are charged varying tolls thereby influencing demand and the facility's Level of Service (LOS).

HOT lanes have gained support from transportation professionals because of their purported throughput-maximizing characteristics and because HOT lanes have the potential to generate revenue from which additional transportation supply may be provided. The most commonly cited concerns about HOT lanes involve public unwillingness to pay for freeway travel, particularly where travel is currently not tolled. Further, concerns have been identified regarding the equity of HOT lanes. As the cost for

single-vehicle entry into HOT lanes rises, there may be a segment of society for whom the increased travel costs may present the greatest challenges and for whom alternatives – in terms of departure times, modes and paths – may be most limited.

The goals of the research are to understand and estimate quantitatively, through stated preference surveys, travelers' willingness to pay (WTP) as a function of trip characteristics (trip urgency, length, and travel speed), travelers' income levels, and previous exposure to tolled roadways. Moreover, the research allows us to assess travelers' willingness to carpool or use transit as a function of travelers' characteristics.

The research is conducted in Toronto, Ontario, Canada. This provides an interesting and unique contribution to the literature for several reasons. First, the Greater Toronto Area (GTA) produces nearly 45% of Provincial and 20% of Canada's Gross Domestic Product. As such, improving transportation efficiency in the region has enormous impacts on the GTA's and Canada's global economic competitiveness (OECD, 2009). Transportation planning in the GTA is now under the control of a regional agency – Metrolinx – that has identified the need to invest more than \$40B (CDN) in transportation infrastructure to accommodate growth by 2031. Given this order of magnitude of investment, assessing capacity-enhancing methods has particular value in the GTA. Finally, the region's main travel corridor is served by two parallel freeways—Provincial Highway 401 which is not tolled and Highway 407 which is tolled. The presence of these parallel freeways allows us to complement the stated preference results with travelers' revealed preferences.

Abbreviations: 400-series highways, Ontario Provincial limited access expressways; AADT, annual average daily traffic; BRT, bus rapid transit; GP lane, general purpose lane; GTA, Greater Toronto Area; HOT, High Occupancy/Toll; HOV, High Occupancy Vehicle; Hwy 407-ETR, Highway 407-electronic toll route; IVTTS, implied value of travel time savings; LOS, Level of Service; MTO, Ontario Ministry of Transportation; RP, revealed preference; SOV, single occupant vehicle; SP, stated preference (data gathering and analysis technique); TTS, travel time savings; VTTS, value of travel time savings; WTP, willingness to pay

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Table 1
Significant trip characteristic and driver factor indicators of WTP to escape congestion.

Item type	Item	Study
Trip characteristics	Trip distance	Burris and Appiah (2004); Ozbay et al. (2006) (travel time); Small et al. (2005)
	Highway speed	–
	Trip urgency/trip purpose	Senbil and Kitamura (2006); Li (2001); Davis et al. (2009); Burris and Appiah (2004); Ozbay et al. (2006)
Driver factors	Annual household income	Mastako et al. (1998); Ozbay et al. (2006); Li (2001); Davis et al. (2009); Small et al. (2005)
	Respondent age	Li (2001); Davis et al. (2009); Burris and Appiah (2004); Small et al. (2005)
	Respondent gender	Tested in Li (2001), not significant; Small et al. (2005)
	Limited access freeway travel frequency	Burris and Appiah (2004)
	Previous exposure to electronic tolling	–

Our results add additional evidence to the literature that willingness to pay is strongly influenced by trip characteristics, particularly trip urgency. We extend the literature by demonstrating that a commonly used metric for WTP, travel time savings, may have limitations in its application. Similarly, our results confirm previous work that suggests WTP depends heavily on income. While this raises equity questions, our data suggest that transit and carpooling have the potential to become travel alternatives to mitigate the equity concerns, particularly for younger respondents.

The remainder of the paper is structured as follows. We review the literature related to contemporary analyses of HOT lanes, concentrating on willingness to pay under various trip conditions as well as equity concerns. We then describe the Greater Toronto Area case context in more detail. We define our methodology, emphasizing the survey techniques and freeway data applied in this research. Next, we report our results and conclude with policy interpretation and suggestions for additional research.

1.1. Literature review

HOT-lanes have been implemented, planned or proposed in a number of US jurisdictions because HOT service is viewed as a solution to the underutilization of HOV-lane space, as a way to improve overall corridor mobility, and as a source of revenue that can be used for roadway, transit, or other improvements (Chu et al., 2007).

Studies of HOT lanes have typically concentrated on four areas. These are public acceptance of HOT lanes, the characteristics of trips and drivers which influence willingness to pay to avoid congestion, the equity impacts of HOT service, and appropriate statistical measures to compare WTP. Each of these categories of literature is reviewed here.

Ungemah and Collier (2007) present an excellent review of barriers and methods to overcome public opposition. The authors examined three US HOT lane projects – State Route (SR) 91 and Interstate (I)-15 in California, as well as I-394 in Minnesota – and determined that public opposition may be based on ideological grounds; travelers are unwilling to pay “additional taxes” for highway travel. Alternatively, travelers may fail to understand tolling if the toll rates or collection mechanisms are overly complicated. These obstacles are less tangible when tolls are implemented on newly constructed HOT lanes and when the public finds value in the proposed use of revenues generated. These authors identified a series of potential advocates – environmental groups, business leaders or transportation professionals – who can help build public support for HOT lanes. Finally, Ungemah and Collier showed that support for HOT lanes tends to increase after implementation. During the study period for I-15, 60% of respondents were undecided about the project. Seven

years later, after the project was operating, 66% of respondents approved.

Several trip characteristics and driver factors have been identified as significant indicators of willingness to pay to escape congestion (see Table 1). Stated preference surveys conducted by Senbil and Kitamura (2006), Davis et al. (2009), and Li (2001) identified trip urgency/trip purpose as a key determinant of WTP. For example, Burris and Appiah (2004) found that total trip length, perceived time savings, trip purpose, and frequency of travel in the observed corridor affected the Houston, Texas QuickRide/HOT program participation rates. As another example, Ozbay et al. (2006) identified trip purpose, desired arrival time, travel time, toll rate, and driver income as significant indicators of driver value of travel time savings (VTTS) along the New Jersey Turnpike.

In addition to trip characteristics, research has shown that WTP is informed by socio-demographic and other driver factors. A survey of Orange County, California's SR-91 HOT-lane users found that household income and age were important determinants of HOT-lane use while gender, trip length, trip frequency, household size, and household type did not significantly affect use (Li, 2001). A survey of SR-91 users completed by Mastako et al. (1998) found that household income significantly influenced HOT-lane use among two-occupant vehicle commuters, while household type significantly influenced HOT-lane use among SOV commuters.

Other work based on California's SR-91 was completed by Small et al. (2005). They used a combined stated preference (SP) and revealed preference (RP) dataset of SR-91 commuters derived from three surveys (2 RP, 1 SP) conducted in 1999–2000. Despite the different periods of analysis, travel(er) characteristics (time of travel, respondent demographics, and toll-lane proportion) were sufficiently similar in all surveys that the authors felt comfortable to combine them into a larger dataset.

From these data, the authors used econometric analysis and logit modelling to assess driver value of time (VOT) and value of reliability (VOR). The results confirmed the idea that toll prices significantly affect driver choice to use express lanes (elasticity –1.59). Heterogeneity in results was explained by controlling for a number of factors including income, distance of trip, gender, age, and household size. In both the SP and RP results, both the VOT and VOR parameters showed very high, unexplained variance.

Podgorski and Kockelman (2006) surveyed more than 2000 Texans in an effort to understand the public's priorities in addressing congestion through tolling. This widespread survey was conducted throughout the state's seven Census Metropolitan Statistical Areas (CMSAs)—with data collected in Houston, Dallas, San Antonio as well as less urbanized areas. Approximately 200 survey interviews were done in Spanish. The authors found that demographics and the residential locations of the respondents influenced the satisfaction with tolling. Older (but not retired) residents and residents new to their location were stronger



Fig. 1. Map of the Greater Toronto Area showing the location of Downtown Toronto, the region's limited access freeways (400-series highways), and Hwy 407-ETR.

supporters of tolling. Retired respondents were less supportive presumably due to the cost impacts while living on a fixed income. Residents of smaller urban areas tended to be more supportive of tolling than larger. The authors suggest that in smaller areas respondents may have been evaluating the concept of tolling, without genuinely believing that tolling may occur in their region.

As driver income has repeatedly been found to be a key indicator of HOT-lane use, the economic equity implications of HOT-lanes is a subject of considerable discussion in the literature (see Weinstein and Sciara (2004) for an overview of identified equity concerns). Briefly, the introduction of HOT lanes raises concerns that higher levels of service are provided only for those who have income to afford this mode of travel. Lower income travelers are unable to afford the higher quality of service or face a disproportionate economic impact. Other questions have been raised about spatial equality with certain regions deriving greater benefits within political limits (i.e. state government).

HOT-operations have similar benefits to HOV lanes. Both systems typically provide incentives to carpoolers, function as efficient corridors for bus rapid transit (BRT), and improve flow in all lanes. BRT systems operate in HOV lanes in many cities; currently, BRT service operates on Miami's I-95 HOT-lanes and is planned for the San Diego-area I-15 managed facilities (95-Express, 2010; SANDAG, 2010).

In terms of equity, HOT lanes are argued to have advantages over HOV lanes in that revenues generated may be used to cover the cost of existing infrastructure and to fund transportation investments that expand travel choices. Mowday (2006) argued that HOT-lanes are more equitable (horizontally) than other forms of road funding because those who choose to use the facilities pay directly for their construction and upkeep. Barker and Polzin (2004) investigated the costs and benefits of integrating HOT-lanes and BRT along the Capital Beltway in Northern Virginia—a congested, 14 mile, 8-lane urban freeway. The results of their simulations demonstrated greater impacts on mode choice – higher transit ridership presumably due to pricing signals – and greater revenue generation with BRT in HOT lanes versus BRT in HOV lanes.

Several HOT facilities act as funding sources for public transit (see Baker et al., 2008; Levine and Garb, 2002). Dahlgren (2002) as well as Yang and Huang (1999) studied the optimal pricing levels and the conditions under which HOT is preferable from a social welfare perspective to HOV or mixed use lanes.

To deal more directly with equity concerns innovative approaches to pricing have been proposed to reduce purchasing power disparities. Complex derived tolls could incorporate driver income, vehicle type, or fuel efficiency. Transportation agencies in Atlanta, Georgia have suggested a unique approach involving commuter credits for proposed HOT-lanes along the Northwest Expressway (I-85). The program would reward positive driving practices by allowing participants to accrue credits for driving during off-peak hours or in general purpose (GP)-lanes. Credits could then be redeemed for free HOT-lane trips when desired (Rountree et al., 2008).

Ultimately, a major goal of this study and others is to identify how roadway pricing may influence the behavior of travelers and, as a result, the performance of the transportation system. The literature has shown that a traveler's willingness to pay or elasticity of demand to price varies by the trip and driver characteristics shown in Table 1. The literature also suggests that WTP varies by geographic region. One common method of making comparisons across studies is to convert the WTP for trips of differing lengths, urgencies, etc., to a common measure defined as the "implied value of travel time savings" (IVTTS). In an IVTTS calculation, a hypothetical willingness to pay \$2.00 to save 20 min of travel time would convert to an IVTTS of \$6.00 per hour. Davis et al. (2009) report previous studies of WTP for various trip types and locations using IVTTS. We present our results in terms of IVTTS to demonstrate the consistency of our results with other published literature and to offer some words of caution about the widespread use of this statistic.

1.2. The Greater Toronto Area case study

The Greater Toronto Area is the largest metropolitan region in Canada. It consists of the City of Toronto and the surrounding Regional Municipalities of Durham, York, Peel, and Halton.

Currently the GTA and the nearby City of Hamilton have a population of over 6 million residents; this number is expected to reach 8.6 million by 2031 (Metrolinx/Greater Toronto Transportation Authority, 2008).

The region has an extensive multi-modal transportation network. Public transit is operated by eight separate agencies and includes commuter rail, express/long-distance bus routes, three subway corridors, and a multitude of local streetcar/Light Rail Transit (LRT) lines and bus routes. The GTA also has the busiest and most extensive freeway network in Canada comprised of both provincially funded and operated 400-series highways and municipal expressways. In 2006, Highway 401, the GTA's principle expressway, had an annual average daily traffic (AADT) count of 367,100 vehicles at a central screenline (MTO, 2006).

Highway 407-Express Toll Route (ETR) is a parallel, electronically tolled freeway that serves the GTA's auto-oriented northern suburbs. Tolling is conducted at access points by electronic transponders or video imaging. Toll rates vary based on distance travelled, time of day, and vehicle class. The GTA and the location of the region's limited access freeways are shown in Fig. 1. In recent years, the Province of Ontario has constructed a number of HOV lanes along 400-series highways. Additional HOV lanes are planned for the region. To date, no HOT lanes have been proposed.

2. Methods of analysis

As described in the introduction, the primary objective of this research is to develop an improved understanding on how travelers' WTP for and acceptability of HOT lanes are related to various factors such as trip attributes, traveler characteristics and travel environment. To address this objective, we conducted a mail-back survey within the Greater Toronto Area. We distributed 4000 surveys, 800 at five locations geographically distributed throughout the GTA. Locations were chosen based on a set of criteria that included: a range of distances from Toronto's central business district to represent both urban and suburban locations; sufficient proximity to a limited-access freeway; and mixed land uses from strictly commercial and retail to mixed use (commercial and

residential). A map showing the distribution locations is presented in Fig. 2. The surveys were left on the windshield of cars parked in various parking facilities within the distribution areas.

Of the 4000 surveys distributed, 255 were returned (6.4% response rate). The spatial distribution of the returned surveys was sufficiently dispersed to prevent obvious geographic bias. The number of returned surveys from distribution locations one through five were 67, 51, 55, 43, and 39, respectively.

To quantify the willingness to pay as a function of trip conditions, the survey asked respondents to indicate their WTP with varying:

1. *trip urgency*, defined as high urgency ("due at work or late for a scheduled activity") or low urgency ("driving to a recreational activity, driving to a scheduled activity when you have ample time to spare");
2. *travel speed*, defined as either high – 70 km/h – or low—30 km/h;
3. *travel distance*, defined as either a short trip – 15 km – or long—40 km.

From these three trip characteristics, we derived eight trip designations (2^3 combinations) and provided a graphic scale on which we asked respondents to indicate their WTP in each scenario. Sample questions (for trip designations V and VI, as identified in Table 2) are shown in Fig. 3 and the designations of all eight trip types analyzed are shown in Table 2. The hash marks

Table 2
Trip type designations.

Trip designation	Trip urgency	Trip speed (km/h)	Trip distance (km)
I	High	30	15
II	Low	30	15
III	High	70	15
IV	Low	70	15
V	High	30	40
VI	Low	30	40
VII	High	70	40
VIII	Low	70	40

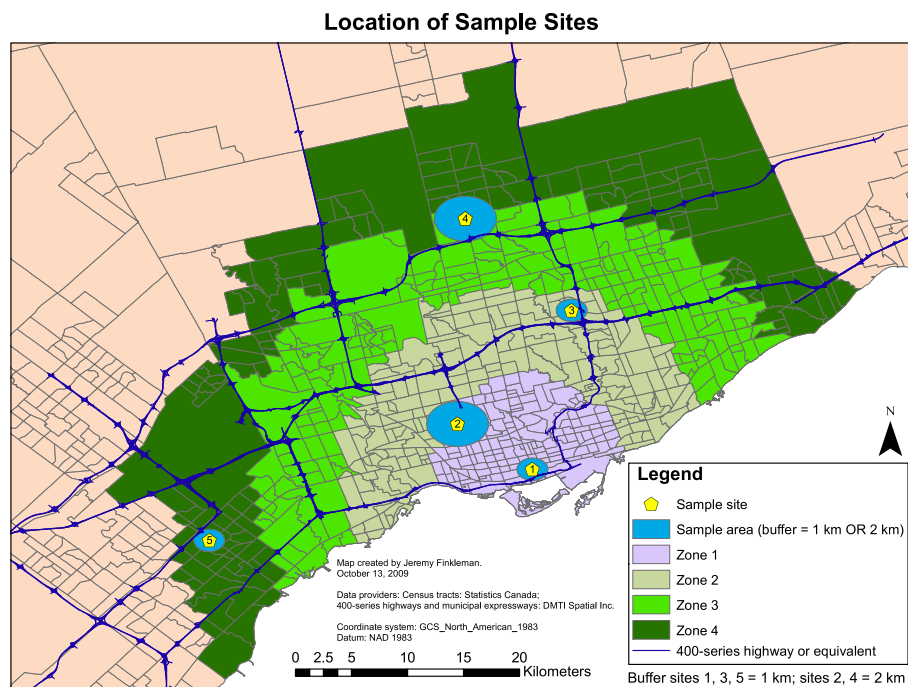


Fig. 2. Location of distribution areas.

Unfortunately today the freeway is heavily congested and moving at a speed of **30 km/h**. You know the road will not speed-up and you'll have to travel the full **40 km trip at 30 km/h** (a total trip time of **1 hour and 20 minutes**).

How much would you be willing to pay to entirely escape congestion and travel in parallel express toll lanes at a speed of 100 km/h?

Assuming **urgent** circumstances:

\$0 \$0.25 \$0.50 \$0.75 \$1.00 \$1.25 \$1.50 \$1.75 \$2.00 \$2.50 \$3.00 \$3.50 \$4.00 \$4.50 \$5.00 \$5.50 \$6 \$7 \$8 \$9 \$10

If greater than \$10, how much? (please write):

Assuming **non-urgent** circumstances:

\$0 \$0.25 \$0.50 \$0.75 \$1.00 \$1.25 \$1.50 \$1.75 \$2.00 \$2.50 \$3.00 \$3.50 \$4.00 \$4.50 \$5.00 \$5.50 \$6 \$7 \$8 \$9 \$10

If greater than \$10, how much? (please write):

Fig. 3. Sample survey questions.

on the continuous scale in Fig. 3 were used to draw respondents' attentions to places where the WTP scales changed. For example, left of the first hash marks, each tick on the scale represents a change of \$0.25; in the middle section each tick represents a change of \$0.50 and in the final section each tick represents a change of \$1.00.

In addition to understanding how trip characteristics influence WTP, we were also interested in understanding how household income affects travelers' acceptance of and WTP for HOT lanes. To this end, the survey asked respondents to indicate their average annual household income. Categories of income were listed from below \$20,000 to above \$140,000 in increments of \$20,000. An additional survey question was included to quantify prior Highway 407 exposure on mean willingness to pay for each trip type designation. Six categories were given for prior usage ranging from daily to never.

Finally, we asked respondents to indicate if the presence of HOT lanes that guarantee quality of service ("congestion free") would influence their willingness to carpool or use public transportation operating in these corridors. The responses to these two questions were binary—yes or no.

Our stated preference survey has several limitations. First, we ask drivers to assess their willingness to pay for roadway performance. We make no attempt to control for drivers' actual understanding of true travel costs—including auto ownership, insurance, depreciation, or the external costs of auto travel. Our results are likely biased by the fact that our survey distribution was only to auto users who presumably have already elected to pay the costs associated with auto travel. In interpreting our results, we are unable to comment on how the presence of enhanced facilities may reduce costs such that those who have elected not to travel may be inclined to make trips. Despite these limitations, our data collection method is consistent with other published research and we feel confident in our interpretation of results.

To conduct the revealed preference (RP) analysis, we collected travel volume data for various segments of both Highway 401 and Highway 407 over a period of five weeks in March and April, 2009. If we consider the two freeways as parallel alternatives, then one measure of willingness to pay is the percentage of total flow using the tolled facility. From the data collected, we are able to plot and analyze these proportions for different periods of time during which reasonable expectations of trip urgency can be made.

3. Stated preference results

From the survey instrument, we were able to determine respondents' willingness to pay for each trip designation and

Table 3
Willingness to pay for each trip designation.

Trip designation	Trip urgency	Trip speed (km/h)	Trip distance (km)	Mean WTP (CDNS)	Rank
I	High	30	15	\$3.06	2
II	Low	30	15	\$1.09	6
III	High	70	15	\$1.66	5
IV	Low	70	15	\$0.58	8
V	High	30	40	\$4.12	1
VI	Low	30	40	\$1.93	4
VII	High	70	40	\$2.34	3
VII	Low	70	40	\$0.96	7

respondents' demographics. We were also able to comment on how the presence of HOT lanes may influence respondents' propensity to use higher efficiency modes, particularly carpooling and transit. Each of these results is presented in subsequent sections.

3.1. Willingness to pay and trip conditions

We first analyzed respondents' mean willingness to pay for each trip designation defined in Table 2. The results of this analysis are shown in Table 3 and Fig. 4. The maximum stated values were for trip designation V—a high urgency trip of 40 km during which traffic is moving at 30 km/h. In this case, 86.2% of respondents indicated a willingness to pay with a mean WTP of \$4.12 and a standard deviation of \$3.83. As trip conditions improved, willingness to pay decreased. For trip designation VII – a high urgency, long trip but with acceptable highway speeds – respondents were willing to pay an average of \$1.93. In the extreme case – trip IV, a low urgency trip of 15 km at 70 km/h – only 37.7% of respondents were willing to pay and the mean WTP was \$0.58.

We were also interested in how trip conditions – urgency, speed, and distance – influence WTP. The importance of urgency on willingness to pay is also evident in Fig. 4, as four of the top five stated values of WTP are high urgency trips. Beyond this observation, we tested statistically the differences in means amongst each trip characteristic. The method we employed is as follows.

Because we were concerned about the dependence of responses within a single survey, we elected to compare trip characteristics across independent survey respondents. To this end, we randomly assigned each survey a number from one to eight corresponding to the trip designations presented above. To test the significance of urgency (high versus low) we selected

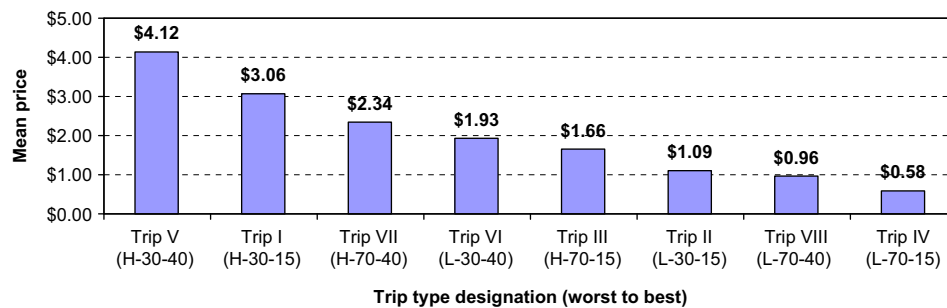


Fig. 4. WTP variation by trip designation.

Table 4

Statistical significance and effect of urgency, speed, and distance on WTP.

Dependent variable: WTP to escape congestion (\$)						
Trip characteristic	Type IV sum of squares	Df	Mean square	F	Sig.	η^2
Urgency	2.612	1	2.612	33.714	0.000	0.109
Speed	1.332	1	1.332	17.195	0.000	0.056
Distance	0.854	1	.854	11.029	0.001	0.036

surveys numbered I, III, V, and VII ($N=128$). On these surveys, we calculated the mean WTP for all four trips with high urgency. We repeated the process for surveys marked II, IV, VI, and VIII ($N=124$) and calculated the mean WTP for all trips with low urgency. We repeated the process for 30 and 70 km/h trip designations and for trip distance. We then compared those means using factorial ANOVA. The results are shown in Table 4.

Each variable is statistically significant at the 99% confidence level. The η^2 variable in Table 4 represents the amount of variance explained by each trip characteristic. As noted above, urgency has the strongest influence on WTP, followed by speed and distance. We also tested the interactions amongst these variables but found no statistically significant correlations.

In many previous WTP studies, respondents' willingness to pay is considered as a function of the number of minutes saved. While we did not directly ask respondents to indicate their WTP based on time savings, we are able to derive values from our results. In our survey, we suggested that the HOT lane would travel at a free-flow speed of 100 km/h. Based on the scenarios provided, we can compute the travel time savings for both speeds (30 and 70 km/h) and both trip distances (15 and 40 km).

In Fig. 5 we plot the mean WTP as a function of travel time savings for the two urgency cases. We then fit the two data series with power curves of the form:

$$WTP = \alpha TTS^\beta \quad (1)$$

where α , β = model parameters; and TTS = travel time savings in minutes.

The results shown in Fig. 5 demonstrate several important findings. First, the curves reinforce the importance of urgency on willingness to pay for travel time savings. In this case, our results suggest that to save 30 min of travel time, for example, a respondent would be willing to pay \$3.37 in high urgency situations but only \$1.41 in low urgency situations. These results are consistent with previous literature – shown in Table 5 – where WTP was higher for work trips versus non-work trips. We recognize that there may be a disconnect between travelers' perceptions of "urgent" trips and work trips in terms of WTP; certainly non-work trips may be urgent. We only make this correlation to compare our ranges of results with those previously

published. We tested the importance of urgency on WTP and found the results significant at the 99% confidence level.

Second, with our power formulation (Eq. (1)), the exponent represents elasticity of WTP with respect to travel time savings (e.g. with an exponent of 0.43, 1% increase in saving would lead to 0.43% increase in WTP). The calibrated models have an elasticity of less than 1.0, suggesting that WTP is inelastic with respect to travel times. Finally, our curves demonstrate that WTP is not a linear function of IVTTS. From Fig. 5, in an urgent situation the average WTP for 10 min of travel time savings was \$2.34. This equates to \$14.04 per hour. Again under urgent conditions, the average WTP for 20 min of travel time savings was \$3.06 or \$9.18 per hour. As such, our data suggest that care should be taken when using hourly IVTTS to assess WTP.

3.2. Willingness to pay and respondent characteristics

The literature (see for example Ungemah and Collier, 2007) indicates that, in previous HOT lane studies, public approval for the concept increased after implementation. The presumption in these studies is that approval increased because travelers were able to experience and to derive personal utility from the LOS provided by HOT lanes that exceeded the HOT charges. In the Toronto case, Highway 407 offers a similar opportunity. While the toll rate on Highway 407 does not vary in real time, it does offer a higher-cost travel alternative with significantly improved reliability relative to Highway 401.

Given this relationship, we tested the mean willingness to pay for those travelers who had previous exposure to Hwy 407 (at least one previous trip) compared to those who did not. As expected, the mean WTP was higher for every trip designation for those who had previous exposure to Hwy 407. The results are shown in Fig. 6.

The means were found to be significantly different at the 99% confidence interval for all trip types.

We next tested the correlation between respondents' annual household income level and WTP. In this case we divided annual income levels into three categories: below \$60,000; from \$60,000 to \$119,999; and \$120,000 and above. Of all returned surveys, 236 respondents indicated their income levels; the results were 60, 106, and 70 responses in the low, mid, and high categories, respectively. We computed the mean WTP of each income group for each trip designation. These results are shown in Fig. 7.

As expected, WTP increases as income levels rise. One-way ANOVA tests statistically demonstrated that the mean WTP is different amongst income groups at the 95% confidence interval for all trip designations except trip designation IV (the lowest willingness to pay trip). Using the results of the ANOVA tests, we can explain the relative importance of income in predicting WTP for each trip designation. These results are shown in Fig. 8. It is interesting to note that income has the weakest explanatory powers in extreme cases; when trip conditions are satisfactory

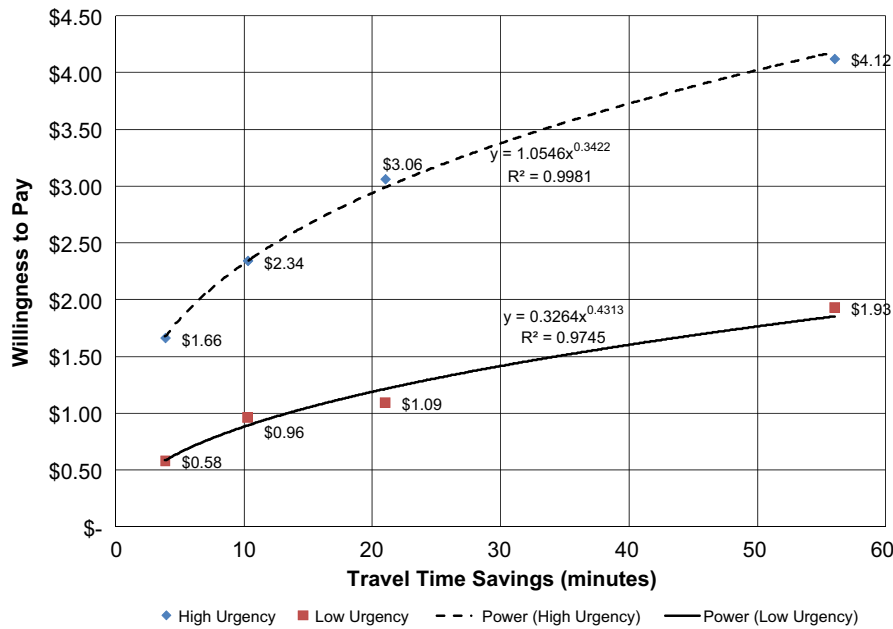


Fig. 5. Amount respondents were willing to pay for travel time saved.

Table 5
Implied VTTS from previous and current studies.
Source: Davis et al. (2009).

Facility (year of study)	Trip type	Implied VTTS
Hypothetical HOT lane—Indianapolis, IN (2008)	Work	\$3.63–\$6.60
Atlanta, GA Managed Lane Study (2008)	Non-work	\$2.17–\$5.00
Illinois East-West Tollway Variable Pricing Study (2007)	Weekday	\$9.06
	Peak	\$11.83–\$16.43
	Off-Peak	\$8.79–\$10.73
I-394 MnPass HOT lanes (2006)	AM	\$11.19–\$13.09
I-15 HOT lanes, San Diego, CA (2002)	Commute	\$9.63–\$11.34
Lee County, FL, Queue Jump (2002)	Weekday	\$5.64–\$6.24
SR 91 Express Toll Lanes (2002)	Weekday	\$5.21
	Peak	\$13.00–\$16.00
Hypothetical system in Greater Toronto Area (2010)	Urgent	\$5.00–\$14.00
	Non-urgent	\$2.00–\$6.00

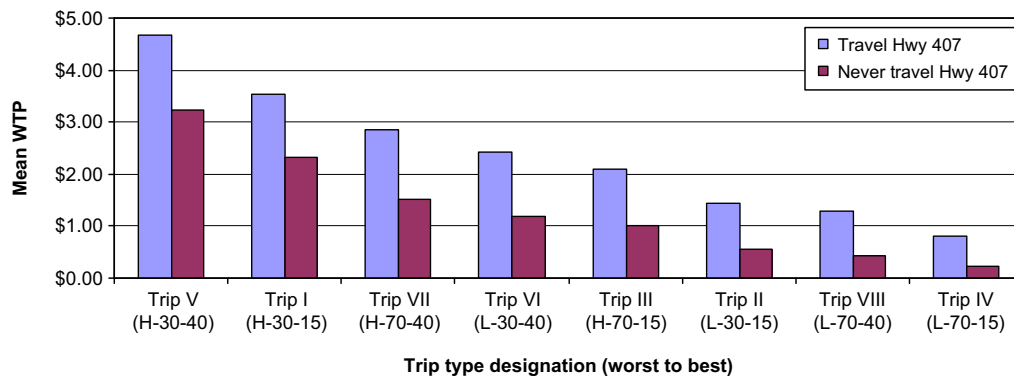


Fig. 6. WTP mean values of respondents with and without previous Hwy 407-ETR exposure per trip type designation.

(designations IV and VIII) or very poor (designations I or V), there is somewhat less difference in WTP across income levels. In mid-level trip conditions (designations II, III, VI, and VII), income levels help explain more of the variance amongst the means.

The direct tests of the relationships between both previous tolling exposure and income to WTP demonstrate statistically significant results. We were also curious as to the relationship between Hwy

407 exposure and income levels. Intuitively, one would expect a strong positive correlation between income and previous use of the electronic toll road. To test this hypothesis, we divided Highway 407 exposure into three categories: at least once per month (regular users), some previous experience but less frequently than monthly, and no previous experience. This relationship between income categories and Hwy 407 exposure is plotted in Fig. 9.

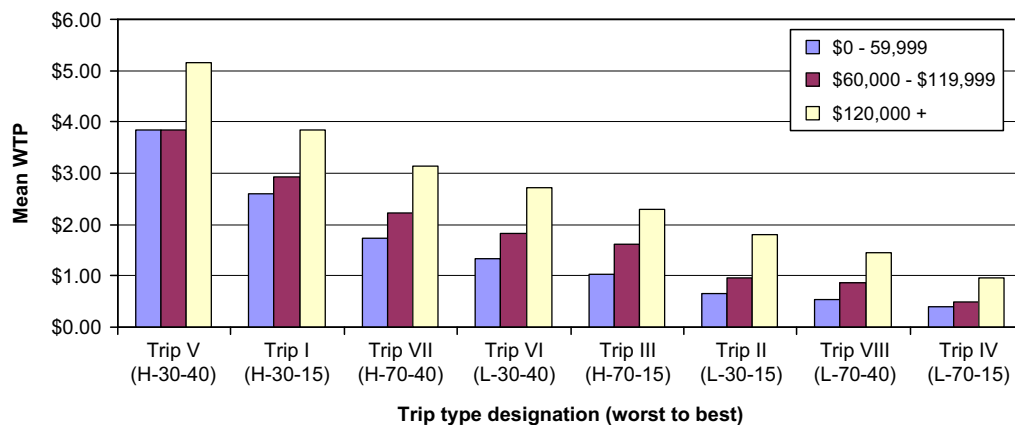


Fig. 7. WTP mean values of low-, mid-, and high-income respondents per trip type designation.

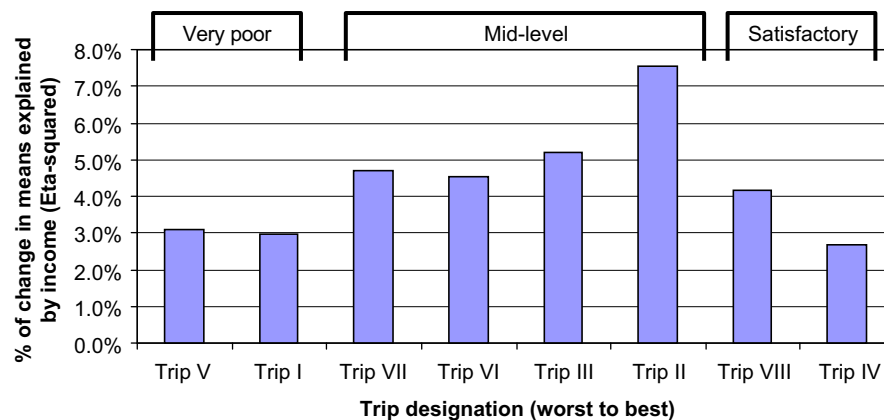


Fig. 8. Effect of income on WTP to escape congestion per trip type designation.

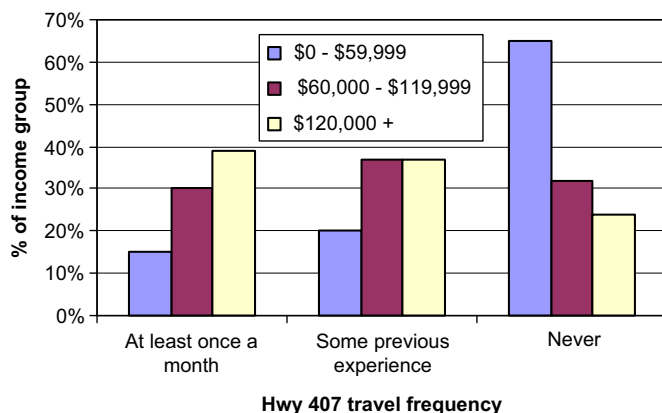


Fig. 9. Hwy 407-ETR travel frequency by income group.

From Fig. 9, we see that only 24% of high income respondents versus 65% of low income respondents have never used Hwy 407. Using one-way ANOVA, we tested whether there exist statistically different likelihoods of having traveled Highway 407 between these income levels. The results confirm that income is correlated to Highway 407 use at the 99% confidence interval.

3.3. Influence of HOT lanes on carpooling and transit use

The survey instrument asked respondents to indicate whether the presence of fast and reliable carpooling or transit in HOT-lanes would influence their likelihood to use these modes.

Table 6

Share of respondents willing to carpool and take transit per income group.

	Willingness to carpool (%)	Willingness to use transit (%)
High income	41.4	41.4
Mid-income	48.6	61.9
Low income	67.8	69.5

A majority of respondents indicated that congestion-free lanes would influence their likelihood to carpool (51.2%) and use public transit (57.6%). We suspect that these results – the increased likelihood to carpool or use transit – are not exclusive to HOT lanes but would also apply to the improved reliability and lower travel time realized through the implementation of HOV lanes.

More interestingly, we further analyzed willingness to use higher efficiency modes as a function of age and income. Our results indicate that more than 67% of young respondents (ages 18–34, $N=71$) were willing to carpool and 77% were willing to use transit. Middle-aged respondents (35–54, $N=112$) were nearly evenly divided in their willingness with 48.2% and 52.4% willing to carpool and use transit, respectively. The oldest respondent category, older than 55 ($N=70$), were much less willing to consider carpooling or transit with only approximately 40% responding positively.

The relationship between income, carpooling, and transit followed a very similar pattern. Table 6 summarizes the responses.

We performed one-way ANOVA comparing willingness to utilize higher order modes across income levels and age groups. Results

suggest that willingness to carpool and take transit is different across income levels and age groups at the 95% confidence interval.

4. Revealed preference analysis

As shown above, the Greater Toronto Area is a unique case in that the region is traversed by parallel freeways—Highway 401 which is free and Highway 407-ETR which is tolled. Rates on Highway 407 are approximately \$0.20 per km with slightly higher peak and shoulder period rates, and slightly lower off-peak period rates. By comparing demand for the two roadways at various time periods, we are able to gather some revealed evidence regarding travelers' willingness to pay for higher Levels of Service. Similarly, if we consider the sum of the roadway volumes as the total corridor demand, then we are able to compute the percentage of demand accommodated by both facilities.

Fig. 10 shows the average eastbound lane-volumes passing the screenline shown in Fig. 1 for both freeways on weekdays. On a typical weekday, Highway 401 volume begins to peak sharply between 6:00 and 7:00 AM. Highway 407 volumes also exhibit this sharp peak in the morning period, though the sharp increase in Hwy 407 volume tends to “lag behind” Hwy 401 volume by about an hour. Naturally, the peak in morning throughput is much lower on Hwy 407 than on Hwy 401.

While Highway 401 lane-volume remains approximately 1200–1400 vehicles per hour from 10:00 AM to 8:00 PM,

Highway 407 volume exhibits a much more sharply peaked afternoon profile. From 3:00 to 6:00 PM, Hwy 407 lane-volume increases from less than 600 to 1300; from 6:00 to 8:00 PM Hwy 407 lane-volume drops quickly to less than 400 vehicles per hour.

The patterns of Highways 401 and 407 volumes are different on weekends. Hwy 401 throughput grows more slowly, but eventually reaches a maximum lane-volume of approximately 1600 vehicles per hour, similar to the weekday total volume. Hwy 407, by contrast, has no peaks and reaches a maximum of only 400 vehicles per hour at 4:00 PM (Fig. 11).

We attribute the sharp peaking of Hwy 407 volumes on weekdays (relative to weekends) to the urgency associated with the trips typically undertaken during weekday peak periods. In another context, one can consider that travelers' values of time are much higher on weekdays than on weekends and, as such, the utility derived from shorter travel time is much higher. This utility prompts travelers to increase their WTP to escape congestion.

Our final observation involves the percentage of through traffic utilizing each freeway alternative. This is shown in Fig. 12. These revealed preference data suggest that in weekday peak periods – trips of high urgency – 35% (AM peak) and 45% (PM peak) of total travelers are willing to pay approximately \$0.20 per km (the Hwy 407-ETR toll rate) for their trips. In the weekday midday period, just under 25% of travelers are willing to pay to use the express tolled highway. On weekends, periods of low driver urgency, only between 8% and 17% of travelers elect to use Highway 407 to traverse the GTA.

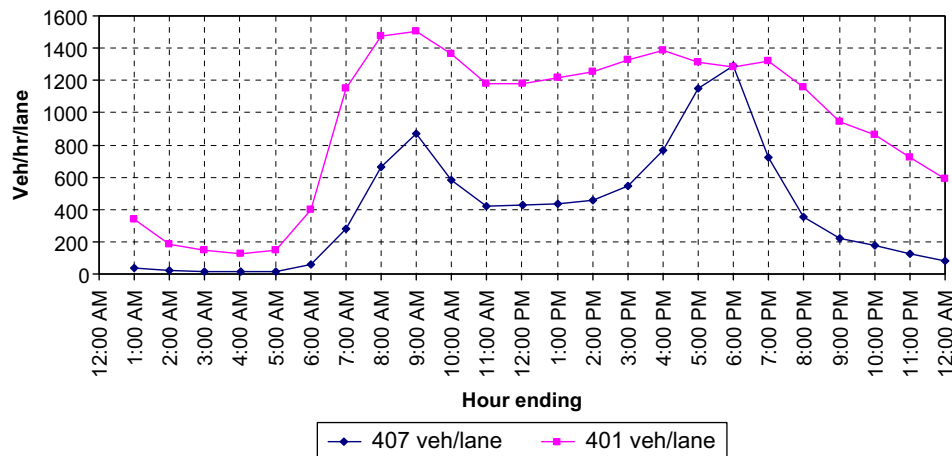


Fig. 10. Average eastbound weekday vehicles/lane along Highways 401 and 407 at the screenline.

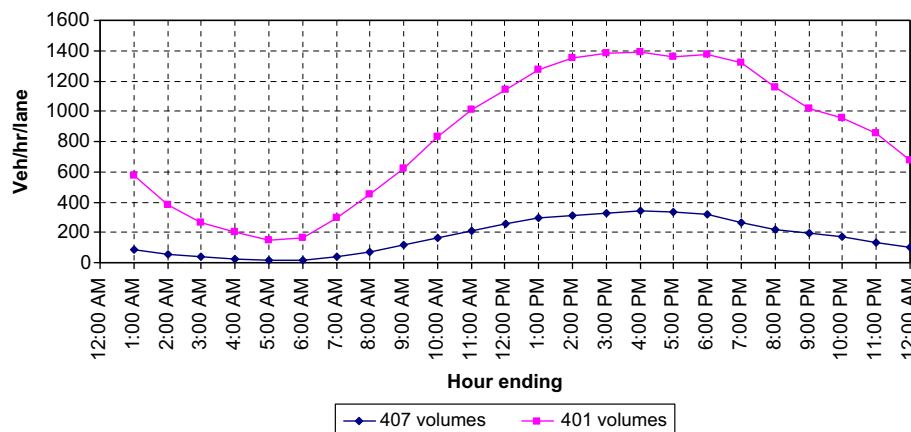


Fig. 11. Average eastbound Saturday/Sunday/holiday vehicles/lane along Highways 401 and 407 at the screenline.

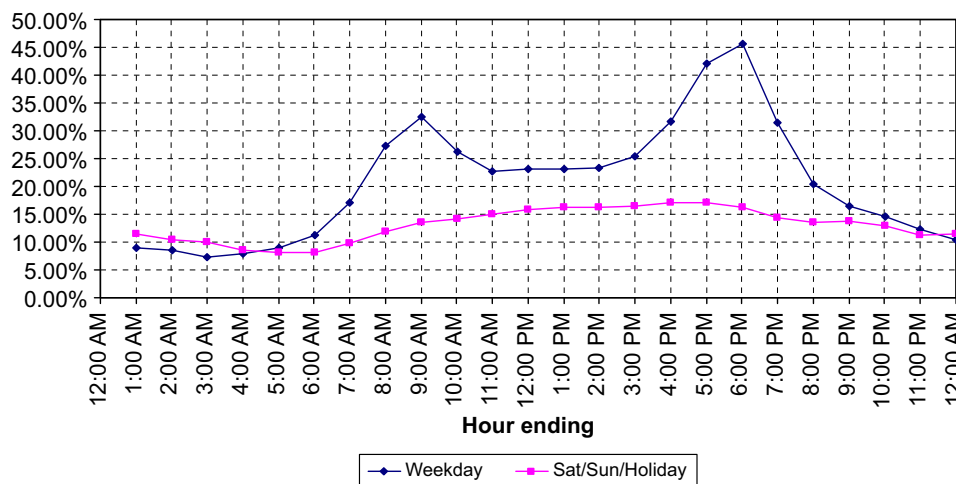


Fig. 12. Percentage of total eastbound throughput using Hwy 407 at the screenline.

5. Conclusions

The impacts of trip conditions on willingness to pay for High Occupancy Toll lanes were all found to be important. Urgency was found to have the greatest impact on WTP followed by travel speed and distance. As trip conditions worsen, the disparity in WTP becomes greater but the number of people willing to pay a “collectible amount” increases. This suggests that poor trip conditions have greater elasticity (sensitivity to toll rates) and therefore, under the worst trip circumstances, a refined ability to control LOS exists.

While our data match results found in other studies reasonably well in terms of magnitude, our curve of WTP as a function of travel time savings suggests that caution should be used when applying a single, hourly IVTTS as an indicator of WTP. For both urgent and non-urgent trip conditions, WTP/travel time saved climbs quickly and then flattens out. Logically, the slope of WTP/travel time saved is steeper to escape urgent trip conditions.

As expected, income is a statistically significant indicator of willingness to pay to escape congestion. The effects of income on WTP are most pronounced in cases where the potential travel time savings is neither substantial (worst case) or very small (best case). When roadway conditions are poorest, all income levels express a willingness to pay something to escape congestion. While not presented here, Finkleman (2010) shows that income has stronger explanatory power than age, gender, or other independent variables which may influence WTP.

Highway 407 exposure (previous exposure to road tolling) is very important in explaining respondent willingness to pay. This confirms other research findings that assert that public support for road tolling grows post-implementation. It must be noted, however, that previous exposure to Highway 407 is highly correlated to income. This suggests again that WTP (based on previous experience) varies by income.

One objective of HOT lanes is to encourage higher-efficiency travel, either through greater occupancy (persons per vehicle) of private vehicles or a shift to transit. Our results suggest that in order to have access to higher levels of service, many of our respondents would consider increasing their vehicle occupancy through carpooling or using transit. The percentage of our respondents who expressed this willingness varied by age, with the likelihood of considering higher efficiency travel decreasing with age. Income also influenced willingness to consider carpooling or transit. High income respondents were least likely while low income respondents were most likely to consider alternative travel means. Interestingly, nearly 20% more mid-income respondents expressed a willingness to consider transit than carpooling.

We interpret these results in two ways. First, we note that a stated willingness to utilize higher efficiency modes exist across all income levels in the GTA. This suggests that in the presence of competitive carpooling or transit facilities, the potential exists to improve system performance. Second, our findings indicate that with the implementation of competitive facilities, marketing and implementation should target these demographics to maximize the benefits of higher-efficiency options.

Finally, our revealed preference results indicate that a substantial share of GTA drivers already pays to escape congestion by using Hwy 407-ETR. Highway 407 throughput share is highest during weekday peak periods when Hwy 401 volume as well as overall driver trip urgency are high.

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References

- 95-Express website (Metro Miami, FL). Available online at: <http://www.95express.com/> (accessed April 22, 2010).
- Baker, R., Ungemah, D., Goodin, G., Geiselbrecht, T.C., 2008. Moving beyond Lexus lanes: equity considerations for managed lanes. DVD: Transportation Research Board 87th Annual Meeting, 20 pp.
- Barker, W.G., Polzin, S.E., 2004. Synergies of bus rapid transit and high-occupancy toll lanes: simulation of bus rapid transit in a congested corridor with roadway value pricing. Transportation Research Board (1884), 3–9.
- Burris, M.W., Appiah, J., 2004. Examination of Houston's QuickRide participants by frequency of QuickRide usage. Transportation Research Record: Journal of the Transportation Research Board (1864), 22–30.
- Chu, L., Nesmani, K.S., Benouar, H., 2007. Priority-based high-occupancy-vehicle lane operation. CD-ROM. Transportation Research Board 86th Annual Meeting, 26 pp.
- Dahlgren, J., 2002. High-occupancy/toll lanes: where should they be implemented? Transportation Research Part A 36 (3), 239–255.
- Davis III, R.W., Sinha, K., Mannering, F., 2009. Factors affecting willingness to pay for high-occupancy-toll lanes. DVD: Transportation Research Board 88th Annual Meeting, 22 pp.
- Finkleman, J., 2010. The HOT Solution: An Examination of the Desirability for High-Occupancy/Toll (HOT) Lanes in the Greater Toronto Area. Masters Thesis, University of Waterloo, ON.
- Levine, J., Garb, Y., 2002. Congestion pricing's conditional promise: promotion of accessibility or mobility? Transport Policy 9 (3), 179–188.
- Li, J., 2001. Explaining high-occupancy-toll lane use. Transportation Research Part D 6 (1), 61–74.
- Mastako, K.A., Rillett, L.R., Sullivan, E., 1998. Commuter behavior on California State Route 91 after introducing variable-toll express lanes. Transportation Research Record 1649, 47–54.
- Metrolinx/Greater Toronto Transportation Authority, 2008. The Big Move—Transportation Master Plan for GTHA. Available online at: <http://www.905express.com/>

- metrolinx.com/Docs/big_move/TheBigMove_020109.pdf>. Accessed October 4, 2009.
- Ministry of Transportation—Ontario/MTO, 2006. Ontario Provincial Highway Traffic Volumes on Demand. Available online at: <<http://www.raqsa.mto.gov.on.ca/techpubs/TrafficVolumes.nsf/tvweb>>. Accessed January 26, 2010.
- Mowday, M., 2006. Equity and high-occupancy toll lanes: literature review and Minnesotans' perceptions about I-394 High-Occupancy Toll lanes. CD-ROM: Transportation Research Board 85th Annual Meeting, 28 pp.
- OECD, 2009. OECD Territorial Reviews: Toronto, Canada. Available online at: <<http://www.oecd.org/gov/regional/toronto>>. Accessed October 21, 2009.
- Ozbay, K., Yanmaz-Tuzel, O., Holguin-Veras, J., 2006. Theoretical derivation of value of travel time and demand elasticity: evidence from New Jersey Turnpike Toll Road. *Transportation Research Record* (1985), 248–256.
- Podgorski, K., Kockelman, K., 2006. Public perception of toll roads: a survey of the Texas perspective. *Transportation Research Part A* 40 (10), 888–902.
- Rountree, R., Miller, J.M., Vu, P., Slack, T., Guensler, R., 2008. Georgia's approach to congestion with four T's: tolling, transit, telework, and technology. DVD: Transportation Research Board 87th Annual Meeting, 17 pp.
- SANDAG FasTrak Website (Metro San Diego, CA). Available online at: <<http://fastrak.511sd.com/>> (accessed April 22, 2010).
- Senbil, M., Kitamura, R., 2006. Valuing expressways under time pressures. CD-ROM: Transportation Research Board 85th Annual Meeting, 19 pp.
- Small, K.A., Winston, C., Yan, J., 2005. Uncovering the distribution of motorists' preferences for travel time and reliability. *Econometrica* 73 (4).
- Ungemah, D., Collier, T., 2007. I'll tell you what I think!: A national review of how the public perceives pricing. *Transportation Research Record* 1996, 66–73.
- Weinstein, A., Sciara, G.C., 2004. Assessing the equity implications of HOT lanes. Santa Clara Valley Transportation Authority. Available online at: <http://www.vta.org/projects/hot_lanes/hot_equity.pdf> (accessed April 22, 2010).
- Yang, H., Huang, H., 1999. Carpooling and congestion pricing in a multi-lane highway with high-occupancy-vehicle lanes. *Transportation Research Part A* 33 (2), 139–155.