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HOV to HOT Conversion Impacts on Carpooling

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NCTSPM Project Report

HOV to HOT Conversion Impacts on Carpooling

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List of Acronyms

Fampool	Family carpool
GP Lane	General-purpose (regular) lane
HH	Household
HOT	High-occupancy toll
HOV	High-occupancy vehicle
HOV2+	High-occupancy vehicle, driver plus one or more passengers
HOV3+	High-occupancy vehicle, driver plus two or more passengers
HOV-to-HOT	Conversion of an HOV lane into a HOT lane
HOVU	High-occupancy vehicle use
HOTU	High-occupancy toll use
SR	State Route
USD	US Dollar

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Executive Summary

High-occupancy toll (HOT) lanes are accepted as an effective way to manage travel demand and operate roadways suffering from capacity shortage. Thus, more HOT facilities are being planned and are under development. Given this situation, transportation agencies need to gain a comprehensive understanding of HOT operations for establishing appropriate HOT policies. To enhance their understanding, this study investigates the factors affecting drivers' choices on HOT lane use and carpooling in the Atlanta I-85 HOT corridors. In the associated survey, a self-administered mail-out/mail-back method was employed, asking respondents about their lane (HOT or regular general-purpose lanes) and carpool choices before and after the HOT lane installation, and trip patterns, as well as their personal demographic information. The retrieval rate of the survey, however, was low (about 5%) and a significant number of the retrieved surveys was not useable for developing statistical models due to missing values and multiple answers for the same question. Although this situation (low sample size) restricted this study from fully using respondents' various behavioral responses before and after the HOT installation, the developed binary choice models applying classification trees and logistic regressions produced interpretable results that explain the commuters' lane and mode choices.

The HOT lane choice models showed that the perception of the effectiveness of the HOT lanes exerts the strongest impact on the drivers' choices. In other words, commuters are more likely to choose HOT lanes when they perceive HOT lanes have improved their own commute conditions. This finding implies that HOT operators should maintain an adequate level of HOT lane performance for maximizing the utilization of the lanes. The models also suggested that HOT lane choices can be affected by commuters' socioeconomic

characteristics; commuters with an age in their 40s, higher income, and higher education are more likely to choose HOT lanes. These results suggest that commuters with a high value of time have a higher chance of using HOT lanes. Concerning trip patterns, longer commuters were more likely to choose HOT lanes. In addition, the models pointed out that former HOV lane users tend to choose HOT lanes, suggesting many former HOV lane users might opt to use HOT lanes even after the HOT conversion.

Regarding the carpool choices, the selected data set showed that most carpoolers after the HOT installation are composed of former carpoolers, suggesting a weak carpool formation even after the HOT conversion. Likewise, the developed models revealed that the former carpooler variable has the dominant effect on the carpool choices. Statistical models also showed that commuters' socioeconomic characteristics can affect the carpool choices; commuters who are in their 40s, have one or more workers in their households, and start to work between 7 a.m. and 9 a.m. are more likely to carpool. The models also indicated that commuters who have a positive perception about the HOT lanes are less likely to carpool. In particular, the constructed classification tree revealed that the perception is the most important factor when the former carpooler variable does not exist. This finding is of interest because it can be interpreted that carpools are likely to be broken up when the performance of HOT lanes becomes better. In other words, HOT installations cannot always boost carpooling, depending on HOT operational characteristics. Policymakers need to conceive adequate strategies to increase the formation of carpooling and at the same time improve HOT operations.

Introduction

Freeways are crucial elements of transportation systems as they provide travelers with a high level of mobility services. However, freeways in urban areas often experience severe traffic congestion due to growing mobility demand that exceeds facility capacity, worsening cities' economic competitiveness and quality of life (American Highway Users Alliance, 2015). Reducing freeway congestion requires implementation of strategies designed to increase facility capacity or reduce transportation demand. To this end, transportation agencies have introduced high-occupancy toll (HOT) lanes. HOT lanes typically allow three-person carpools to use the lanes for free, which limits the demand for use of the lane. Tolls are then instituted to allow non-carpools to use the lane for a fee. With proper variable pricing, which adjusts the toll to ensure demand remains lower than capacity, congestion can be prevented and travel speeds in HOT lanes can be maintained (e.g., 45+ mph for more than 90% of the time). Hence, traveling on HOT lanes can be a more reliable option compared to general-purpose (GP) lanes, in particular during peak hours. Since California's State Route (SR) 91 Express Lanes opened in December 1995 (the first HOT lane in the United States), approximately 20 HOT facilities have been installed (Guensler et al., 2013). In some cases, such as on Atlanta's I-85 corridor, HOT lanes are created from the conversion of existing high-occupancy vehicle (HOV) lanes.

Numerous HOT facilities are under development across the county. To improve operations of the current facilities and design of future facilities, transportation agencies need to understand the various impacts and travelers' behavior changes resulting from the introduction of HOT lanes. One of the potential impacts is a change in transit ridership. Previous studies demonstrated that not a small portion of new bus riders in HOT lane corridors (e.g., 23% in Minneapolis and 53% in Miami) were influenced to take transit by HOT lanes, resulting in an increase in transit ridership (Pessaro et al., 2013). However, the bus ridership increase is not always guaranteed by the introduction of HOT lanes. Castrillon et al. (2014) reported that person throughput for commuter buses remained stable, even with an 18% increase in express-bus throughput in the Atlanta I-85 HOT corridor. By comparing the numbers of carpools before and after HOT lane implementations, Burris et al. (2014) and Goel and Burris (2012) revealed that HOT lanes tended to decrease carpooling, although the impacts somewhat varied by HOT facility, and exogenous factors such as gas prices might have influenced the results.

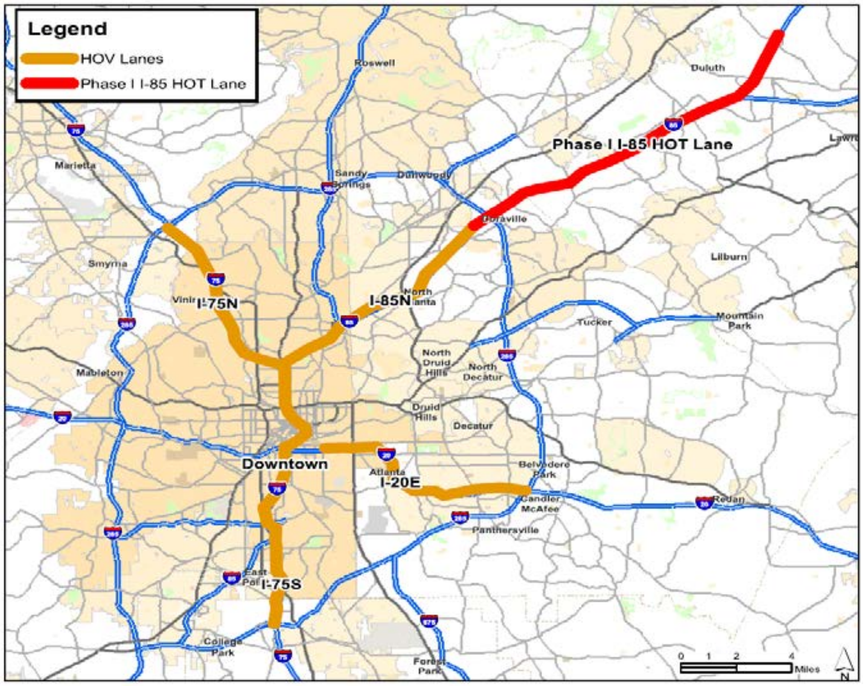
Transportation demand management activities (e.g., carpooling, vanpooling, and transit use) and toll exemption policies can also influence travelers' choices, which in turn affect traffic conditions on both managed lanes and regular GP lanes. Pessaro and Buddenbrock (2015) illustrated, by using scenario-based traffic simulation approaches, how such impacts are expected for the I-95 Express Lanes. The decision to travel in HOT lanes can be affected by drivers' socioeconomic characteristics, such as gender, age, income, household size, vehicle ownership, and education level (Khoeini and Guensler, 2014a; Sheikh et al., 2015). Khoeini and Guensler (2014b) also explored this issue using vehicle value as a proxy for income. They showed that the value of vehicles using HOT lanes is approximately 23% higher than that of vehicles using regular GP lanes in the case of the Atlanta I-85 HOT corridor. This result implies that high-income commuters are more likely to use HOT lanes, as was also found in the study of the SR 91 Express Lanes. The SR 91 study concluded that household income, vehicle occupancy, commute trip, and age are important predictors of HOT lane use (Li, 2001).

Previous studies have revealed numerous aspects of HOT impacts. However, as noted in Burris et al. (2014), the impacts and travelers' responses may vary across facility characteristics, such as toll exemption policies and HOT lane capacity. This aspect requires ongoing research efforts on HOT operations, so that transportation agencies can gain a comprehensive understanding that helps in establishing appropriate HOT design and operation policies. This study investigates the factors affecting drivers' choices on HOT lane use and carpooling in the Atlanta I-85 HOT corridor. Although this research effort is not the first attempt to assess factors that affect corridor operations, it is unique in that it utilizes data obtained from a survey administered to commuters who traveled the corridors. Indeed, previous studies utilized marketing (i.e., credit report) data for identifying the socioeconomic characteristics of drivers traveling on HOT or regular GP lanes (Khoeini and Guensler, 2014a; Khoeini and Guensler, 2014b; Sheikh et al. 2015). Although their approach was advantageous in obtaining a sizable data set at a low cost, one issue of uncertainty appears to be unavoidable: driver/household information in the marketing data will not always match those of the observed drivers. This study also recognizes that an employment of survey data is beneficial in that it allows for directly relating drivers' responses to their perception, socioeconomic characteristics, and trip patterns (e.g., commute distance and work start time), which are rarely observable from field observations and/or marketing data. Complementing the previous studies, the results of this study are expected to further enhance the understanding of drivers' behavior concerning HOT lane and carpool choices in HOT corridors.

Study Corridor: The Atlanta I-85 HOT Lanes

The spatial scope of this study is the Atlanta I-85 HOT lanes (Figure 1). The HOT lanes were installed by converting existing HOV lanes over a 15.5-mile length. The HOV-to-HOT conversion is the first to simultaneously introduce tolling while increasing the occupancy requirement (i.e., from HOV2+ to HOV3+), but the project did not add additional lanes (Guensler et al., 2013). The HOV2+ lane still exists just to the south of the HOT lane corridor, extending into downtown Atlanta. Since the HOT lane opened on October 1, 2011, dynamic tolling varies the toll price in response to congestion. Toll-exempt vehicles include vehicles carrying three or more persons (HOT3+), transit vehicles, emergency vehicles, motorcycles, and alternative-fuel vehicles with proper license plates (hybrid vehicles do not qualify). All vehicles must be registered for a Peach Pass toll tag, even if they are toll-exempt, so that corridor activity can be monitored.

The field survey data collected over the corridor showed that the number of vehicles traveling as HOV2+ in the HOT lanes decreased after the conversion, from 3966 to 613 average weekday travelers during the a.m. peak period and from 3941 to 697 travelers during the p.m. peak period. Meanwhile, the number of HOV2+ carpoolers in the regular GP lanes about doubled (Burris et al., 2014; Guensler et al., 2013). That is, carpools shifted out of the managed lane into the GP lane. Overall, morning commute carpooling on the corridor after the HOV-to-HOT conversion decreased by more than 30% (Guensler et al., 2013). Identifying those who are likely to carpool in the HOT lanes will help inform future managed-lane operational strategies.



Source: GDOT, 2011

Figure 1. I-85 HOV-to-HOT Carpool Study Corridor

Survey Data

A questionnaire-based survey (see Appendix A) was designed to explore the behavioral changes of the travelers along the I-85 HOT lane corridor. The first hurdle of the survey was to identify a sample pool, given that HOT lane users and carpoolers tend to constitute only a small portion of the overall traveling public. The research team had collected about 1.5 million license plates of the vehicles traveling the I-85 corridor one year before and one year after the HOV-to-HOT conversion. The collected data allowed the identification of households with frequent HOV/HOT users of the corridor (Khoeini and Guensler, 2014b). From the database, 10,000 survey targets were selected and questionnaires were mailed out in the form of an eight-panel folded sheet with a prepaid return envelope. The research team later discovered that an issue with the user database resulted in incorrect names printed in the survey address, which could have affected the response rate. Numerous surveys that were completed included notes indicating that the name on the form was incorrect. Given this potential problem, a second stage involved sending out 2000 additional surveys to households that were not previously targeted in the initial deployment. The research team conducted the mail-out/mail-back survey in November and December 2014 and obtained 642 responses among the target households (i.e., a retrieval rate of 5.4%). The response rates were roughly equal during both stages, indicating that the name errors in the first stage probably did not significantly influence the response rates. The geographic distribution of the survey respondents and the detailed descriptive statistics of the survey results are presented in Appendix B and Appendix C, respectively.

The questionnaire comprised four general sections, asking:

1) Primary routes and modes for morning commute before and after the HOT lane implementation
2) Perception of the HOT lane effect on the commute traffic conditions
3) Reasons why the respondent chose to use or not use the HOT lanes, or to carpool, after the HOT lane implementation
4) Individual and household socioeconomic/demographic characteristics

The socioeconomic and demographic questions included age, gender, household income, number of children, number of workers, car ownership, education, and job locations described by zip code. The questions about the commute routes included lane choices: use of HOV lanes or regular GP lanes before HOT implementation, and use of HOT lanes or regular GP lanes after HOT implementation.

1.1 Factors Considered

In this study, the researchers use the survey data to develop statistical models designed to help explain commuters' HOT-lane and carpool choices. To assess travelers' choices, the authors consider the following respondents' factors as independent variables:

- Socioeconomic characteristics (seven factors): age, gender, household income, number of children, number of commute workers, number of vehicles for commuting, and driver-education level
- Commute characteristics (two factors): typical work start time, and travel distance from home to work

- Perception about the HOT lanes (one factor): whether the respondent indicates that the HOT lanes have improved his/her own commute conditions

Because the questionnaire did not ask for a specific work address, home-to-work distance was estimated using the time-based shortest path between the zip codes of the respondent's home and work place. This estimation was implemented using the function of the Google® Maps API.

1.2 Data Selection

Self-administered mail-out/mail-back surveys are susceptible to missing values and inconsistency of answers, requiring a careful data selection procedure. As the first step of the procedure, a table illustrating changes in mode and lane choices (considering all the combinations of carpool, drive-alone, HOT, and regular GP lanes) after the HOT lane installation was developed, as shown in Table 1. The table implies that 17 (3%) respondents (i.e., 642−625=17) did not properly provide their mode and route/lane choices. In addition, the travel patterns of 73 respondents appear to be irrelevant to this study, as they did not drive on the freeway either before or after HOT implementation.

Table 1. Respondents' Mode and Route Choices Before and After HOT Installation (Before Data Screening)

Mode and Lane Choice		After					Total
		Drive Alone GP	Drive Alone HOT	Carpool GP	Carpool HOT	Other[1]	
Before	Drive Alone GP	232	99	13	10	13	367
	Carpool GP	17	5	16	9	2	49
	Carpool HOV	28	14	53	35	4	134
	Other[1]	1	1	0	0	73	75
Total		278	119	82	54	92	625

[1] This category includes walk, bicycle, transit, local roads, and work at home.

Further data screening procedures took into account whether the choices were multiple (e.g., cases in which respondents marked both HOT and regular GP lanes for their usual travel lanes) and whether respondents answered all the questions related to the explanatory variables discussed in the previous section. The screening procedure removed the cases with multiple choices and missing values, resulting in a significant loss of data (Table 2). Approximately 150 respondents did not provide any personal information. About 60% of the retrieved surveys were not usable for choice-based analysis, where all explanatory variables associated with choice need to be entered into the statistical models. An attempt to develop a multinomial logistic regression model to predict post-opening travel for former carpoolers considered four choices (i.e., drive alone in the regular GP lanes, drive alone in the HOT lane, carpool in the regular GP lanes, and carpool in the HOT lane), but the results were unsatisfactory, most likely due to the small sample size. Multinomial regression using a maximum likelihood estimation method usually requires even larger sample size than ordinal or binary logistic regression (Agresti, 1996). Given this situation, the authors developed binary choice models separately by the route (HOT or regular GP lanes) and the mode choice (carpool or drive alone) the respondents made after the HOT lane began operating. The route and mode choices before the HOT installation were also utilized as independent variables.

Table 2. Respondents' Mode and Route Choices Before and After HOT Installation (After Data Screening)

Mode and Lane Choices		After					Total
		Drive Alone GP	Drive Alone HOT	Carpool GP	Carpool HOT	Other[1]	
Before	Drive Alone GP	138	59	0	2	3	202
	Carpool GP	1	0	2	2	0	5
	Carpool HOV	12	7	28	13	1	61
	Other[1]	0	0	0	0	3	3
Total		151	66	30	17	7	271

[1] This category includes walk, bicycle, transit, local roads, and work at home.

To minimize the loss of data, the authors conducted separate data selection procedures for HOT lane and carpool choice models. This is because more samples are likely to be screened out when HOT lane and carpool choices are simultaneously considered. As previously demonstrated, the procedure screened out cases with multiple choices for both HOT and regular GP lanes (likewise for carpool and drive alone) and missing values for the explanatory variables, resulting in 313 and 332 valid cases for HOT lane and carpool choice models, respectively. Table 3 summarizes the selected sample characteristics, showing that the two data sets are very similar. This is not surprising, given that the two data sets share 285 identical respondents (91% and 86% of the data sets for the HOT lane and carpool choices, respectively). The sample is composed of slightly more males than females. More than half of the respondents are older than 50 years (about 52%). More than 60% of the respondents belong to a high-income group, above USD $100,000 per year. The income distribution seems to be reasonable since the sample contains a group of HOT lane users who are likely to have a higher value of time (Khoeini and Guensler, 2014a, 2014b). More than half of the households have children. Single-worker households comprise less than 30% of the sample, with two-worker households being dominant. About 60% of households own multiple cars for commuting. About 75% of the respondents have a bachelors' degree or higher. It appears that most respondents (about 80%) start their work between 7 a.m. and 9 a.m. and about half of the respondents commute more than 30 miles. In the HOT lane choice sample, 26.2% of the respondents replied that they usually used HOV lanes before the HOT lanes opened. In the carpool choice sample, former carpoolers occupy 24.4%. With respect to respondent opinion about whether the HOT lanes have improved their commutes, 58% were negative (definitely no and probably no), about 37% were positive (definitely yes, and probably yes), and less than 5% were not sure. Note, however, that these percentages do not control for whether the respondents are or are not regular HOT users. In fact, it turns out that users are generally positive and non-users are generally negative.

Table 3. Demographic and Opinion Responses in the Sample

Variables		HOT Lane Choice (n = 313)		Carpool Choice (n = 332)	
		Observations	**Proportion**	**Observations**	**Proportion**
Gender	Male	168	53.7%	178	53.6%
	Female	145	46.3%	154	46.4%
Age	<40	47	15.0%	48	14.5%
	40–50	103	32.9%	111	33.4%
	>50	163	52.1%	173	52.1%
Annual Household Income	<$60k	31	9.9%	38	11.4%
	$60–$100k	87	27.8%	99	29.8%
	>$100k	195	62.3%	195	58.7%
Number of Children	0	165	52.7%	173	52.1%
	1	64	20.4%	64	19.3%
	2+	84	26.8%	95	28.6%
Number of Workers	1	83	26.5%	91	27.4%
	2	180	57.5%	185	55.7%
	3+	50	16.0%	56	16.9%
Number of Vehicles for Commute	1	130	41.5%	136	41.0%
	2	144	46.0%	154	46.4%
	3+	39	12.5%	42	12.7%
Education	Less than a bachelor's degree	76	24.3%	80	24.1%
	Bachelor's	131	41.9%	141	42.5%
	Master's/Doctorate	106	33.9%	111	33.4%
Typical Work Start Time	Before 7 am	27	8.6%	28	8.4%
	7–9 am	256	81.8%	270	81.3%
	After 9 am	30	9.6%	34	10.2%
Commute Distance (miles)	<20	47	15.0%	50	15.1%
	20–30	107	34.2%	116	34.9%
	>30	159	50.8%	166	50.0%
Were you an HOV-lane user or carpooler?[1]	No	231	73.8%	251	75.6%
	Yes	82	26.2%	81	24.4%
Have the HOT lanes improved your own commute conditions?	Definitely no	151	48.2%	159	47.9%
	Probably no	32	10.2%	34	10.2%
	Not sure	14	4.5%	15	4.5%
	Probably yes	50	16.0%	58	17.5%
	Definitely yes	66	21.1%	66	19.9%

[1] The question of the HOV lane use is applied for the HOT lane choice sample, while the carpooling question is for the carpool choice sample.

The selected respondents' behavioral changes in HOT lane and carpool choices are summarized in Table 4. The table shows that 34% (107 out of 313) of the respondents typically use the HOT lanes, while the remaining 66% of respondents are regular GP lane users. In addition, it indicates that 65% (53 out of 82) of the former HOV lane users switched to the regular GP lanes. Concerning the carpool choice, 19% (63 out of 332) of the respondents usually carpool, while the remaining 81% commute alone. Changes in carpooling behavior are also observed. Responses indicate that carpool breakups outpaced carpool formation. Carpool formation was only 2.8% (7 out of 251) while 31% (25 out of 81) of former carpoolers left their carpools. The data indicate that 89% (56 out of 63) of the remaining carpoolers were former carpoolers.

Table 4. Drivers' Behavioral Changes in HOT Lane and Carpool Choices

HOT Lane Choice				**Carpool Choice**			
After / Before	**HOT Lane**	**GP Lanes**	**Total**	**After / Before**	**Carpool**	**Drive Alone**	**Total**
HOV Lane	**29**	53	82	Carpool	56	25	81
GP Lanes	78	153	231	Drive Alone	7	244	251
Total	107	206	313	Total	63	269	332

Analytical Approaches

Two approaches, classification trees and logistic regressions, were used for developing statistical models designed to explain drivers' behavioral responses in their commute travel. The approaches can be used to estimate the class membership of a categorical dependent variable (Camdeviren et al., 2007). Indeed, this study uses binary dependent variables by assigning an indicator value of one for cases where respondents choose HOT lanes (or carpool lanes), and zero otherwise.

1.3 Classification Trees

To obtain a better understanding of commuter characteristics, a multi-dimensional analysis considering interactions between factors was conducted using the tree-based regression and classification technique. This approach is attractive because the resultant trees provide a symbolic representation that lends itself to easy human interpretation (Camdeviren et al., 2007). In particular, this study applies classification trees to discrete dependent choices of HOT lane use (or carpool lane use), with the selected independent variables. The technique splits the data through a binary partition, thus generating two resultant regions. As the partitioning process continues, the tree tends to grow, resulting in over-fitted and complicated models. Meanwhile, a tree that is too small might not capture the important structure of the data. Thus, an optimal tree size should be adaptively chosen from the data.

This study utilizes the cross-validation technique in finding an optimal tree. In the approach, the cost of the tree by tree size is computed based on the 10-fold cross-validation method (Breiman et al., 1984; Hastie et al., 2001). The cost is the sum over all terminal nodes of the estimated probability of that node times the sum of the misclassification errors of the observations in that node. The best tree size, or the number of terminal nodes, is the one that produces the smallest tree that is within one standard error of the minimum-cost subtree.

1.4 Logistic Regression

Logistic regression models were also applied to identify the factors affecting drivers' choices of HOT lanes and carpooling in the I-85 corridor. In the model, the response variable has only two possible outcomes: whether the respondent generally uses HOT lanes or does not. When Y_i is an independent Bernoulli random variable for the i^{th} observation with an expected value $E\{Y_i\}$, the logistic regression model with *k* predictor variables, known constants *x*, and coefficients to be estimated β, is expressed as follows (Kutner et al., 2005):

$$E\{Y_i\} = \frac{\exp(\beta_{0+}\beta_1 x_{i1} + \cdots + \beta_k x_{ik})}{1 + \exp(\beta_{0+}\beta_1 x_{i1} + \cdots + \beta_k x_{ik})}$$

The interpretation of the estimated regression coefficients in the fitted logistic response function is not straightforward as in a linear regression model. The effect of a unit increase in predictor variables varies depending on the location of the starting point on the predictor variable scale (Kutner et al., 2005). Thus, the odds ratio, which is computed by taking the exponent value of the estimated coefficient, is used for associating the outcome with explanatory variables. Odds ratios above one indicate that the event is more likely to occur, while odds ratios smaller than one indicate lower chances of the event to occur.

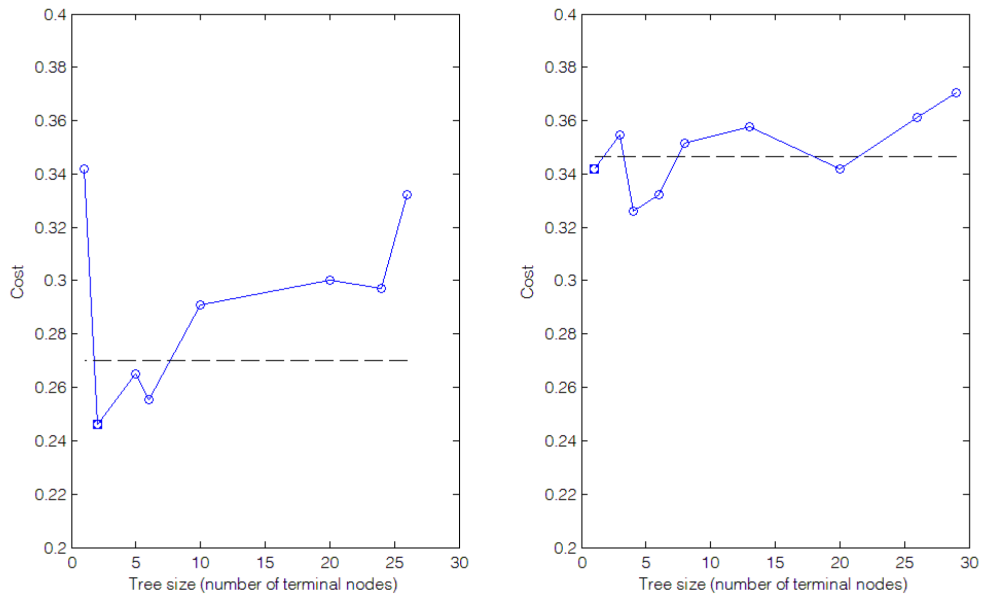
Kim (2009) showed that logistic regression models can be more efficiently developed by utilizing the results of the tree-based regression and classification technique. This is because classification trees may reveal statistically meaningful interactions between the explanatory variables, helping analysts identify which interaction effects should be entered in the regression models. In particular, the approach is substantially helpful when numerous and complex interaction effects may exist.

Results

1.5 HOT Lane Choice Classification Trees

Classification tree analyses using the 11 factors were performed to assess HOT lane choices. Firstly, the costs of the models by the tree size were estimated based on the 10-fold cross-validation approach to identify the best tree size. The graphs in Figure 2 show the estimated costs for the two models using all the 11 factors and excluding the variable of the perception of the effectiveness of the HOT lanes. The graphs imply that the perception variable has a substantially strong explanatory power, which can be explained in two ways. First, when all the 11 factors are considered, the cost is minimized at two terminal nodes, with the perception being the single variable dividing the choices. Second, the misclassification errors (i.e., costs) become much larger when the perception variable is excluded, which can be easily identified by comparing the costs in the two graphs in Figure 2.

The estimated costs in Figure 2 indicate that the best tree for the model with the perception variable has only two terminal nodes. The two-node model, however, may fail to capture the important aspects of the choices because of its simplicity. Thus, a classification tree with six terminal nodes, the second-best tree in terms of the cost, was developed as an alternative for explaining the lane choices. The developed tree with six terminal nodes is shown in Figure 3, illustrating that five variables are critical factors: perception of benefit, age, former HOV user, work start time, and number of children. The tree implies that the respondents who do not perceive that the HOT lanes have improved their own commute conditions are more likely to choose regular GP lanes instead of the HOT lanes. Of the respondents who perceive the positive effects of the HOT lanes, the ones in the 40s age group are more likely to choose the HOT lanes. In addition, the model implies that the respondents who typically used HOV lanes are more likely to use the HOT lanes. The respondents who usually start to work between 7 a.m. and 9 a.m. and have children (likely time-constrained commuters during morning peak hours) also have a stronger tendency to choose the HOT lanes.



(a) Models for All 11 Factors (b) Models without the Perception Variable

Note: The dashed line indicates one standard error of the minimum-cost subtree.

Figure 2. Classification Tree Cost (Error) by Tree Size for HOT Lane Choice

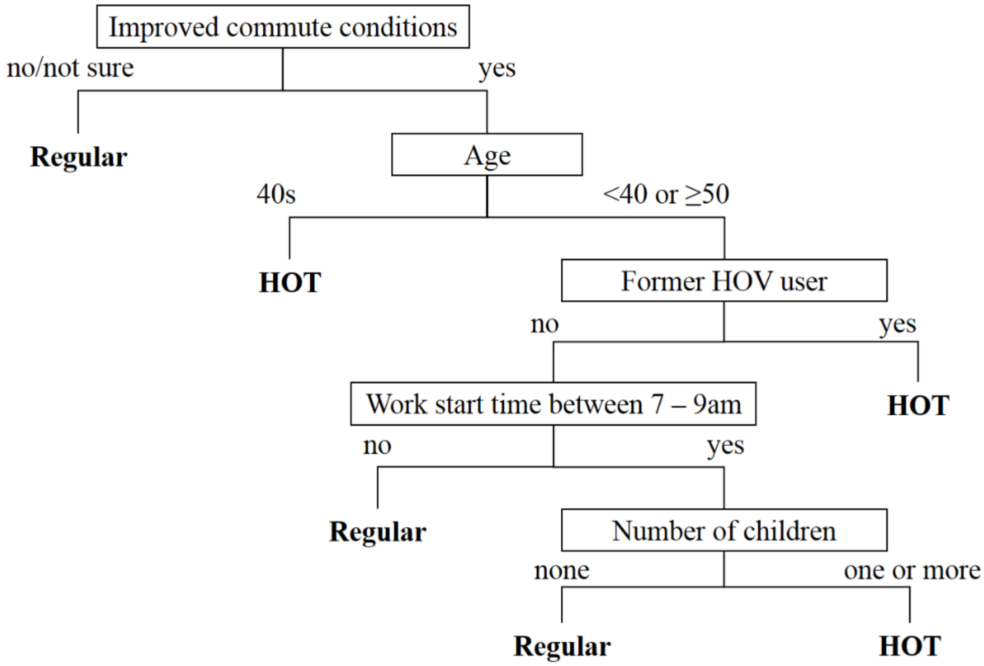


Figure 3. Classification Tree with Six Terminal Nodes for the HOT Lane Choice (Including the Perception Variable)

Because of the dominant impact of the perception variable, the influences of other variables may be concealed. Thus, an examination of a classification tree without the perception variable is also of interest. As suggested by the model costs shown in Figure 2, a tree with four terminal nodes was constructed as the best model for the perception-excluded data. Figure 4 illustrates the tree depicted by three variables: age, education, and number of children. Unlike the previous model, the education variable is found to be an important factor; the respondents with a bachelor's degree or higher are more likely to choose the HOT lanes. The research team conjectured that the education level may reflect the financial ability of the respondents to pay a toll.

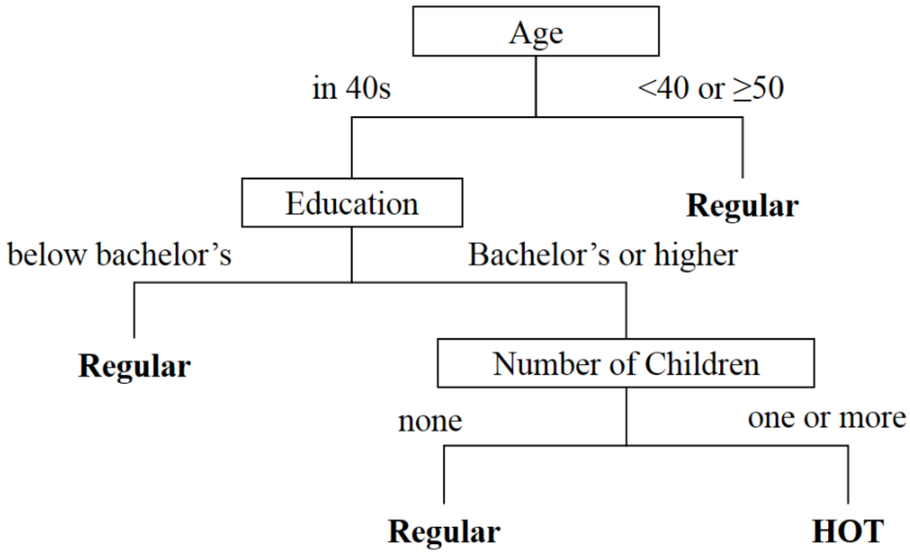


Figure 4. Classification Tree for HOT Lane Choice (Excluding the Perception Variable)

1.6 HOT Lane Choice Logistic Regression

It seems that the constructed classification trees successfully identified potential relationships between lane choices and influential factors. However, they do not appear to be sufficient to show the factors' statistical significances in a measurable way. To overcome this limitation, the researchers further investigated by developing three logistic regression models with different independent variables: models with main effects only (Model 1), with both main and interaction effects (Model 2), and without the perception variable (Model 3). The results of the classification trees were fully utilized when identifying the appropriate forms of independent variables. More specifically, the main effect variables were re-defined based on the cut points revealed by the classification trees, treating them as categorical variables. As a result, all 11 factors were simply classified into binary cases, except age and commute distance, which each use three classes. Moreover, potentially influential interaction terms were identified in an efficient and effective way based on the resultant classification trees.

Note that 261 interaction terms, all combinations of two, from nine main effects with two classes and two main effects with three classes, could be the candidate variables for specifying the model. Considering only the identified factors in the trees could limit the number of interaction terms to be entered in the model to a practically implementable level.

The resultant logistic regression models are summarized in Table 5, where only statistically significant variables at a significance level of 0.10 were captured based on a backward stepwise procedure, eliminating variables that do not add explanatory power to the model. This stepwise procedure is beneficial to systematically exclude correlated independent variables (Kutner et al., 2005). The table also shows the Hosmer–Lemeshow goodness-of-fit statistics, of which *p*-values are at least 0.181, implying that the estimated models properly follow the key property of the logistic response function at a significant level of 0.05. The Nagelkerke *R*-squared statistics suggest that the model considering main and interaction effects together (Model 2) has the strongest explanatory power among the three models, which justifies the inclusion of the interaction effects. Meanwhile, the model excluding the perception variable (Model 3) has the least explanatory power, indicating the variable's influential impact on the lane choices as already revealed in the classification tree analyses.

The model considering only main effects (Model 1) captured four statistically significant variables: the perception, former HOV user, commute distance, and age. In particular, the odds ratio for the perception variable indicates that respondents are about 11 times more likely to use the HOT lanes when they positively perceive the effectiveness of the HOT lanes. Age also appears to be influential in the lane choice decision; respondents in their 40s are 2.8 times more likely to choose the HOT lanes than respondents in other age groups. The importance of the age variable was also illustrated in the SR 91 Express Lanes study, although in that study the age group in the 50s showed a stronger tendency to use HOT lanes (Li, 2001). In addition, commute distance, which was not a significant factor in the classification tree analyses, was found to be a critical one, although its impact is rather weak compared to the other three factors. The longer-distance commuters, particularly longer than 30 miles (48 km), have a stronger tendency to use the HOT lanes. This finding may be ascribed to the aspect that those traveling longer can gain more travel-time–saving benefits by traveling on the HOT lanes during congested peak hours.

When the interaction effects are considered, five variables, including two main effects (the perception and commute distance) and three interaction terms (combinations of former HOV user, age, and perception) are found to be significant. Interestingly, the odds ratio for the perception variable decreased by about half (from 10.880 to 5.246), compared to Model 1, although perception is still significantly meaningful in explaining the choices. It seems that the explanatory power of the perception variable is dispersed over the two interaction terms combined with former HOV user and age. In fact, the interaction terms, former HOV user by perception, and age by perception, have relatively high odds ratios, 4.901 and 5.318, respectively. Model 2 also shows that two main effects of former HOV user and age in 40s are no longer significant by themselves. Instead, they appear to be significant only when they are combined with other factors, implying a simple consideration of main effects may fail to fully capture the characteristics of the data. A potential benefit of the model with interaction terms is its enhanced capability to predict the choices more specifically.

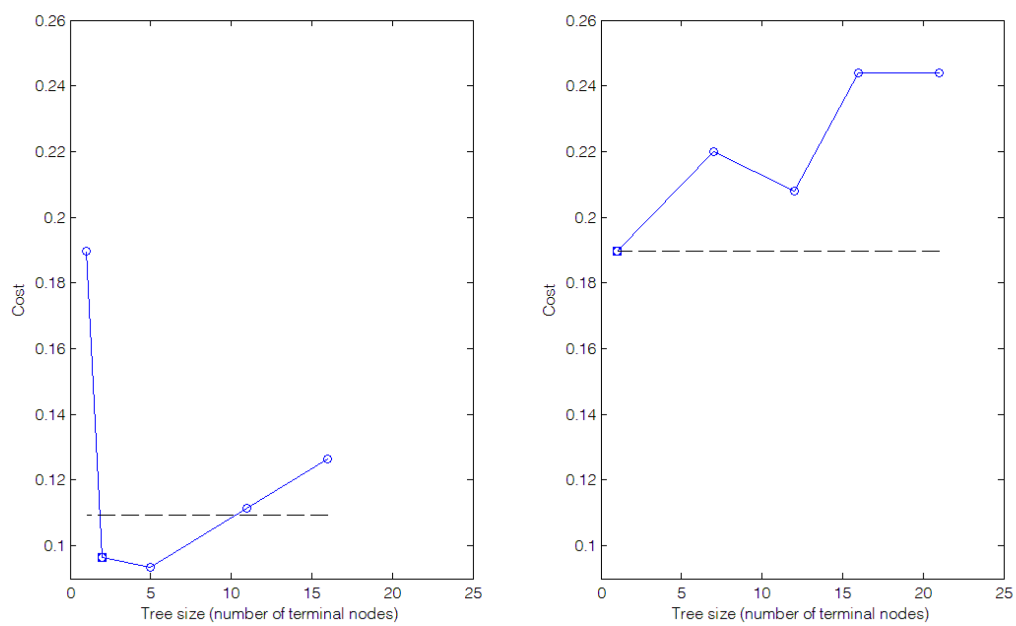
The model excluding the perception variable reveals additional significant variables not shown in the previous models: household income and age by education. HOT lane positive perception may be related to some extent to these variables, perhaps tied to employment in some way. In Section 5.5, a model is presented to show the relationship between the perception and other variables. However, the substantially lowered explanatory power of the model measured by Nagelkerke R^2 (from 0.364 to 0.145) indicates that the variables cannot fully replace the perception variable in explaining the lane choices. This aspect may justify the use of the perception variable for the model development. The estimated model shows that respondents with a high income and a higher education are more likely to choose the HOT lanes. In particular, the respondents in their 40s and with a bachelor's degree or higher are found to be 3.5 times more likely to use the HOT lanes.

Table 5. Logistic Regression Models for the HOT Lane Choices

Variable	Model 1 (Main effects only)			Model 2 (Main + interaction effects)			Model 3 (Without the perception variable)		
	B	p	Exp(B)	B	p	Exp(B)	B	p	Exp(B)
Constant	−2.592	.000	.075	−2.097	.000	.123	−1.749	.000	.174
Main Effects									
Improved commute conditions (yes = 1)	2.387	.000	10.880	1.657	.000	5.246			
Former HOV user	.851	.013	2.341						
Commute distance (>30 mile)	.610	.033	1.840	.639	.027	1.894	.787	.002	2.196
Age in 40s	1.026	.001	2.791						
Annual household income (>USD $100k)							.543	.045	1.721
Interaction Effects									
Former HOV user and Improved commute conditions				1.589	.053	4.901			
Age in 40s and Improved commute conditions				1.671	.001	5.318			
Age in 40s and Former HOV user				1.180	.013	3.254			
Age in 40s and Bachelor's degree or higher							1.263	.000	3.535
	Nagelkerke R^2 = 0.353 Hosmer–Lemeshow = 10.135 (p = 0.181)			Nagelkerke R^2 = 0.364 Hosmer–Lemeshow = 1.248 (p = 0.940)			Nagelkerke R^2 = 0.145 Hosmer–Lemeshow = 2.552 (p = 0.769)		

1.7 Carpool Choice Classification Trees

Classification trees were developed to analyze the commuters' carpool choices using the selected 332 samples. As illustrated in the HOT lane choice models, the best tree size was first identified using the cost functions of the trees. The cost changes of the trees considering all 11 factors, shown in Figure 5, indicate that a tree with two or five terminal nodes may be adequate for explaining the carpool choice behavior. When the two-terminal node tree was considered, the former carpooler variable was found to be the single factor predicting carpool choice, given that the majority of prior carpoolers are still carpooling. Indeed, the cost graph in Figure 5 illustrates that the cost becomes much larger when the former carpooler variable is excluded. Although the two-terminal node tree is meaningful, its simplicity may fail to provide sufficient information on the data structure. Thus, a five-terminal node tree was selected for analyzing the data. Meanwhile, when constructing a tree without the former carpooler variable, seven terminal nodes were considered as suggested by the tree costs in Figure 5.



(a) Models for All 11 Factors (b) Models w/o the Former Carpool User Variable

Note: The dashed line indicates one standard error of the minimum-cost subtree.

Figure 5. Classification Tree Cost (Error) by Tree Size for Carpool Choice

Figure 6 illustrates a tree with five terminal nodes depicted by four factors: former carpooler, number of workers, age, and income. The tree strongly supports that respondents are less likely to carpool unless they were already carpoolers before the HOT implementation. In fact, the importance of the former carpooler variable was expected by the sample characteristics; 89% of the carpoolers are the former carpoolers (see Table 4). The figure also shows that even among the former carpoolers, respondents in their 40s whose households have a single worker are more likely to drive alone for their commutes.

It is plausible that under a situation in which one single variable explains almost all of the variability, the effects of other important factors can be obscured. Thus, further analyses were conducted by developing an additional classification tree without the former carpooler variable. Interestingly, the developed tree with seven terminal nodes, shown in Figure 7, illustrates that the perception of the effectiveness of the HOT lanes has the strongest impact on the carpool choice decision, indicating that the respondents who have a positive perception about the HOT lanes are less likely to carpool. The positive perception about the HOT lanes is also correlated with higher chances of using the HOT lanes, as identified in the HOT lane choice models. Thus, HOT lane use and carpool choices are negatively associated, at least for the I-85 HOT corridor commuters. This finding appears to be in the same vein as the conclusion of Burris et al. (2014). The tree revealed that the number of vehicles for commuting and gender can also play a role in determining the decision. However, the influence of vehicle ownership appears to vary, and is affected by subtree factors. The tree structure indicates that females are more likely to carpool, which conforms to the findings of a study conducted in France where female survey respondents showed a stronger tendency to frequently carpool (Delhomme and Gheorghiu, 2016). This gender difference in carpooling was also reported in a study in Texas that investigated the carpooling motivation of travelers in Dallas–Fort Worth and Houston (Li et al., 2007).

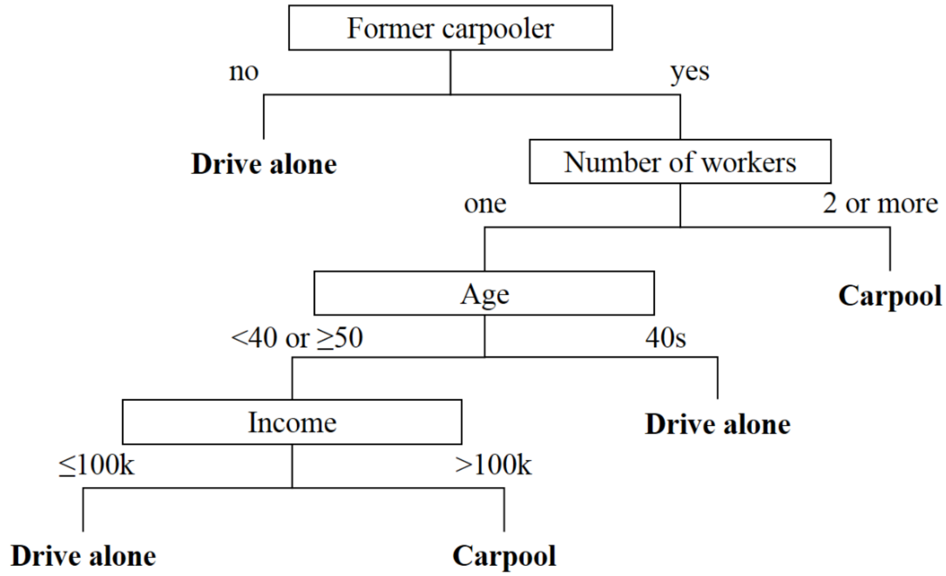


Figure 6. Classification Tree for Carpool Choice

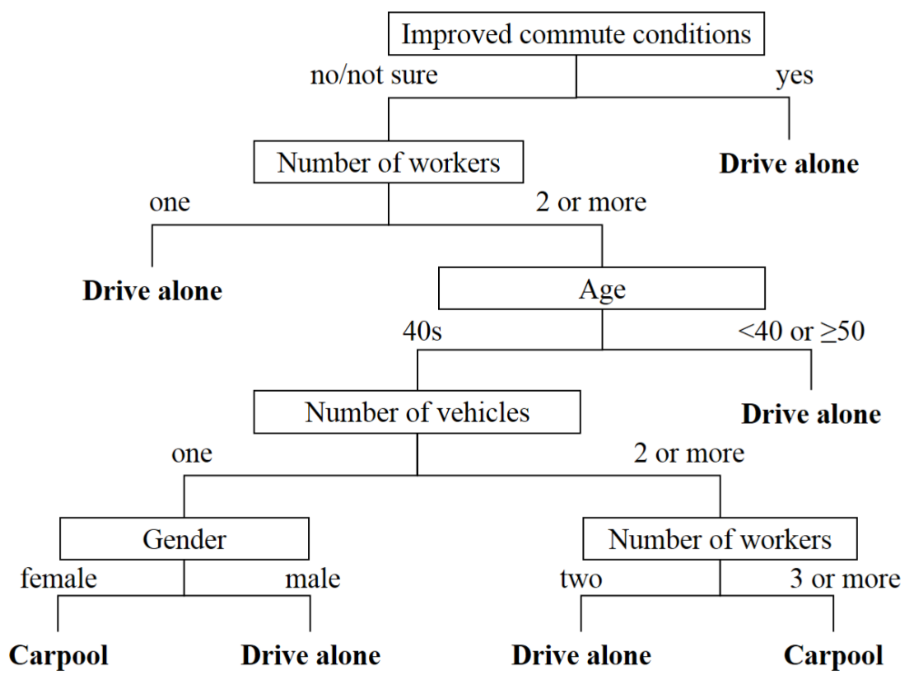


Figure 7. Classification Tree for Carpool Choice
(Excluding the Former Carpooler Variable)

1.8 Carpool Choice Logistic Regression

Further analyses were performed to examine the factors that may influence carpool choice using logistic regression models. The model specifications and procedures were identical to those of the HOT lane choice models, except that the number of workers variable was reclassified to have three groups (1, 2, and 3+), reflecting the cut points suggested in the classification trees. In addition, the number of vehicles available for commuting was not used as an explanatory variable, because the variable was found to be significantly correlated with the number of household workers (Pearson's correlation coefficient = 0.625).

The first model considering only main effects revealed that the former carpooler variable is the single dominant factor at a significance level of 0.05 with a Nagelkerke R^2 value of 0.611. This may be incurred by the data characteristics; a majority of the carpoolers are the former carpoolers (56 out of 63). This feature became more pronounced in the second model, which considers both the main and interaction effects. Indeed, the estimated parameters in that model seem to be inflated, implying the maximum likelihood estimates are not properly obtained. This situation clearly indicates that the data have a separation problem, which occasionally happens in logistic or probit regressions (Heinze and Schemper, 2002). In other words, the former carpooler variable separates the carpool choices almost completely except for seven cases. When separation occurs, two approaches are frequently employed: 1) "mechanical" measures including increasing sample size, combining the category with similar ones, and omitting the category; and 2) statistical measures, such as Firth's penalized maximum likelihood method (Gim and Ko, in press).

In this study, researchers developed a carpool choice model by omitting the former carpooler variable (one of the common "mechanical measures") to be consistent with the HOT lane choice models. Also, the authors conjectured that the use of this influential variable would obscure the impacts of other important factors, in particular for a small sample size data set. Future studies may consider other alternative approaches for this modeling. Table 6 illustrates the result of the estimated model, pointing out three main effects and two interaction effects that are statistically significant. The model suggests that the respondents who are in their 40s, start to work between 7 a.m. and 9 a.m., and have two or more workers in their households are more likely to carpool. Combined with the finding that the respondents in their 40s are prone to use the HOT lanes more, this result implies that they may also be more likely to use the HOT lanes in carpool mode.

As found in the classification tree, the interaction effects reveal that the participants who have positive perception about the HOT lanes have a weaker tendency to carpool, which may statistically support that HOT lanes may negatively influence carpooling. The perception variable is found to interact with age (40s) and the number of workers (two-worker households), and their impacts seem to be substantial as suggested by the magnitudes of the estimated parameters (i.e., −2.182 and −1.176). The resultant Nagelkerke R^2 value of 0.165 suggests that the model lacks the ability to strongly predict the carpool choices. Future studies are encouraged to incorporate more factors, including travelers’ perceptions and attitudes into the model for a better understanding of carpool behavior.

Table 6. Logistic Regression Models for Carpool Choice (Excluding the Former Carpool User Variable)

Variable	B	p	Exp(B)
Constant	−2.914	.000	.054
Main Effects			
Work start time between 7 and 9 a.m.	.822	.082	2.275
Number of household workers (reference = 1)			
2	1.102	.008	3.010
3+	.978	.040	2.659
Age in 40s	.690	.038	1.993
Interaction Effects			
Age in 40s & Improved commute conditions	−2.182	.051	.113
Number of household workers = 2, and Improved commute conditions	−1.176	.052	.308
Nagelkerke R^2 = 0.165 Hosmer–Lemeshow = 5.362 (p = 0.498)			

1.9 The Perception Model

The researchers suspected that the perception about the HOT lanes might have associations with other factors. To examine this, ordered probit models were developed, considering that the perception was measured by a five-point Likert scale, ranging from one (definitely not improved) to five (definitely improved). The model was developed based on the data set of the HOT lane choice model, and the car ownership variable was excluded due to its strong correlation with the number of household workers. Table 7 presents the resultant models, illustrating the six factors that are statistically significant at a level of 0.10: gender, number of household workers, income, former HOV user, work start time, and commute distance. Interestingly, the former HOV users appear to negatively perceive the HOT lanes, implying the HOT implementation might not be preferred by them, and thus may influence the breakup of carpools. The HOT implementation is also negatively perceived by commuters who usually start their work between 7 a.m. and 9 a.m., which may be ascribed to decreased travel speeds even in the HOT lanes during morning peak hours. Further studies are encouraged to explore these phenomena in more detail for better interpretations.

Table 7. Ordered Probit Models for the Perception of Improved Commute Conditions

Variables		Model with All Variables		Model with Significant Variables Only	
		B	p	B	p
Age (reference = ≥50)	under 40	−.277	.164		
	40–49	−.055	.733		
Gender (female)		.279	.050	.250	.073
Single worker household		.360	.020	.370	.016
No children		−.124	.391		
Annual household income (>USD 100k)		.320	.034	.412	.003
Bachelor's degree or higher		.163	.324		
Former HOV user		−.718	.000	−.731	.000
Work start time between 7 and 9 a.m.		−.344	.046	−.324	.057
Commute distance (mile)		.015	.014	.014	.026
Threshold τ_1		.381	.265	.401	.174
Threshold τ_2		.672	.050	.691	.020
Threshold τ_3		.805	.019	.824	.006
Threshold τ_4		1.336	.000	1.350	.000
Goodness of fit					
−2 log likelihood of null constant only model		836.422		819.551	
−2 log likelihood of full model		783.316		769.475	
		$p < 0.001$		$p < 0.001$	
Nagelkerke R^2		0.167		0.159	

Note: τ_j (j = 1, 2, 3, 4) is the threshold parameter (cut-off point) for ordered probit models.

Despite the appearance of the significant variables, the overall explanatory power of the perception model seems unsatisfactory, as suggested by the low value of Nagelkerke R^2 (0.159), implying the lack of capability of the model to predict HOT lane perception using the variables. This situation may justify the inclusion of the perception variable in the choice models together with other variables. More research in this area is definitely warranted.

Conclusions

The understanding of commuters' responses to high-occupancy toll installations is important in that it can help transportation agencies identify operational strategies designed to maximize the usefulness of HOT facilities, from both operators' and users' perspectives. This study explores Atlanta's HOT lane implementation and carpool choices over the I-85 HOT corridors using data collected through a questionnaire-based survey. The self-administered mail-out/mail-back survey asked respondents about their lane choices (HOT or regular general-purpose lanes) and carpool choices both before and after the HOT lane installation, as well as overall trip patterns and demographic information. This survey is meaningful in that it was designed as the first attempt to assess carpool behavior after the installation of a conversion of an HOV lane to a HOT lane. As expected, the retrieval rate of the survey was low (about 5%) and a significant number of the retrieved surveys were not usable for developing certain statistical models due to missing values and multiple answers for the same questions. Although low sample size does restrict this study from fully utilizing respondents' various behavioral responses before and after the HOT installation, the binary choice models via classification trees and logistic regressions produced interpretable results that help explain the commuters' lane and carpool choices.

The HOT lane choice models showed that the perception of the effectiveness of the HOT lanes exerts the strongest impact on the choices. More specifically, commuters are more likely to choose HOT lanes when they perceive HOT lanes have improved their own commute conditions. This finding implies that HOT operators should maintain an adequate level of HOT lane performance for maximizing the utilization of the lanes. The models also suggested that HOT lane choices can be affected by commuters' socioeconomic characteristics. Commuters in their 40s, commuters with higher income, and commuters with higher education levels are more likely to choose the HOT lanes. This suggests that commuters with a high value of time are more likely to use HOT lanes, as expected. Concerning trip patterns, commuters making longer trips were found more likely to choose HOT lanes. This situation appears to be intuitively correct, in that these travelers may have a stronger incentive to save on their travel times. The models pointed out that former HOV lane users tended to choose HOT lanes, suggesting that many former HOV lane users might opt to use HOT lanes even after an HOT conversion. However, it is not clear how those respondents use HOT lanes: paying a toll or HOV3+. Future studies are encouraged to investigate these choices in detail for a better understanding of commuters' behavior.

Regarding carpool choices, the selected data set showed that most carpools after the HOT installation were composed of former carpoolers. Weak carpool formation was noted, even after the HOT conversion. Likewise, the developed models revealed that the former carpooler variable dominated the effect on the carpool choice. Statistical models also showed that commuters' socioeconomic characteristics could affect the carpool choice. Commuters in their 40s, commuters who have two or more workers in their households, and commuters who start work between 7 a.m. and 9 a.m. are more likely to carpool. However, the models also indicate that commuters who have a positive perception of the HOT lanes are less likely to carpool. In particular, the constructed classification tree revealed that perception was the most important factor when the former carpooler variable was excluded. Based upon the survey data, this HOT project did not enhance carpooling as the project proponents originally expected—a finding also confirmed by the vehicle occupancy evaluation in the previous before–after study (Guensler, et al., 2013). It is possible that carpools could continue to break up as the performance of HOT lanes continues to improve. Policymakers may need to rethink strategies designed to increase carpool formation and retention as they implement HOT projects throughout the region.

Complementing previous studies, this investigation has enhanced the understanding of HOT lane and carpool choices on HOT corridors, in particular by revealing the strong association between perception and mode/lane choices. However, the findings obtained from the binary choice observations still leave numerous unexplained behavioral responses of the commuters, which larger samples and more complete survey responses might have overcome. A sufficient sample may be able to provide researchers with more chances to examine their complex decision-making mechanisms. In addition, the limited number of factors considered can explain only a small portion of HOT lane or carpool mode decision-making processes. Indeed, the explanatory power of the lane choice model was at most 0.36 in terms of Nagelkerke R^2. Future study efforts are encouraged to capture larger samples and explore additional variables for developing improved models.

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Appendix A: Survey Mechanism

The carpool survey was delivered to 12,000 households along the I-85 commuter shed northeast of Atlanta, Georgia. Households were identified based on their use of the corridor in previous studies. The purpose of the survey was to investigate changes in commute behavior resulting from the HOV conversion that created the I-85 Express Lanes, a value-priced HOT facility. The survey asked about commute mode choice, route choice, and carpool behavior before and after the conversion. Demographic questions asked respondents about household size, number of vehicles, household income, education, job type, etc. Respondents indicated whether they thought the tolls were burdensome to different income groups and whether the conversion was a good idea. The survey also asked carpoolers and others why they chose to use, or not to use, the lanes.

Survey Sampling

Quarterly license plate data were collected at five locations on the HOT corridor one year before, and one year after, the HOV-to-HOT conversion. Selected households were observed four or more times both before and after the implementation of the HOT lanes.

Table A-1. Six Cohorts – Frequency of Observed Managed Lanes Use

Before Conversion	**HOV Use (HOVU)**	**Cohort 1: HOVU≤0.3**	**Cohort 2: 0.3<HOVU<0.6**	**Cohort 3: 0.6≤HOVU**
	Total Obs. #HHs	213,419	9,135	18,840
	Sample #HHs	1,500	1,500	1,500
	Min Obs. Frequency	40	8	6
After Conversion	**HOT Use (HOTU)**	**Cohort 4: HOTU≤0.3**	**Cohort 5: 0.3<HOTU<0.6**	**Cohort 6: 0.6≤HOTU**
	Total Obs. #HHs	227,411	4,154	9,901
	Sample #HHs	1,500	1,500	1,500
	Min Obs. Frequency	19	6	9

Survey Questionnaire

The survey questionnaire sent to the survey participants is shown Figure A-1 to Figure A-4.

I-85 Express Lane Commute Survey

A Few Minutes of Your Time Helps Transportation Planners Manage Congestion

Georgia Institute of Technology
School of Civil & Environmental Engineering
Atlanta, GA 30332-0355

Nonprofit Organization
U.S. Postage
PAID
Atlanta, GA
Permit No. 8087

Your answers to these questions will enable us to project the results from this small sample to the population as a whole. Your responses are completely confidential and will only be reported in combination with others:

How many people, including you, live in your home? ______
How many of these people work? ______
How many of these people are children? ______

What kind of home is this?
□ Apartment □ Stand-alone house □ Condo or townhome
□ Other (please specify) ____________________________

Including all cars, trucks, vans, motorcycles, and RVs, how many motor vehicles are available to the household? ______
How many of these vehicles usually commute to work? ______

What is your gender: □ Male □ Female

What is your age: ______ (years)

Regarding your employment and volunteer status, please select all that apply:
- □ Employed full time
- □ Employed part-time in one job
- □ Employed part-time in two jobs
- □ Employed part-time in three or more jobs
- □ Not employed

In a typical 40-hour work week, about how many hours do you usually work from home rather than going to work elsewhere?
______ hours, out of every 40 hours

Even if you don't work from home, is working at home allowed by your employer? □ Yes □ No □ I don't know

What time do you typically start work at your primary job?
Hour: ______ Minute: ______ □ AM □ PM

What kind of work do you do? management, financial, services, engineering, sciences, computing, admin., sales, health care, education, arts, manufacturing, transport, military, etc.
Type of Work: ____________________________

Do you have any college degrees?
□ No □ Associate □ Bachelors □ Masters □ Doctorate

To ensure our study is representative of all income groups in the area, could you please give us your household's gross (before tax) income range?
- □ Less than $20,000
- □ Between $20,000 and $40,000
- □ Between $40,000 and $60,000
- □ Between $60,000 and $80,000
- □ Between $80,000 and $100,000
- □ Between $100,000 and $150,000
- □ Between $150,000 and $200,000

Figure A-1. Survey Questionnaire (Page 1)

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NO POSTAGE NECESSARY IF MAILED IN THE UNITED STATES

Georgia Institute of Technology
Professor Randall Guensler
School of Civil & Environmental Engineering
177 North Ave. NW
Atlanta, GA 30313-9809

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POSTAGE WILL BE PAID BY ADDRESSEE

Professor Randall Guensler
School of Civil & Environmental Engineering
177 North Ave. NW
Atlanta, GA 30313-9809

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Dear I-85 Corridor Resident:

This survey is collecting information about morning work travel, which includes the commute to work or school, work at home, and volunteer work (20+ hours per week). The survey is designed to collect data for the most work-active person in each household and should be completed by that person. The goal of the survey is to identify whether you changed your morning commute from home to work after the I-85 Express Lanes opened on October 1, 2011. The survey results will be used in future planning efforts. Please complete the survey questions on the back page and the half-page to the left, refold the survey with the Georgia Tech address on the outside, tape it closed, and drop it in a post box. No postage is required. Thank you for helping us assess the impacts of the Express Lanes!

If you did not regularly commute along I-85 or its parallel roadways, please check this box and return the survey without answering the questions. It is important for us to have a good count of households that did not commute on the corridor. Please return the survey.

☐ **I did not regularly commute to work on the I-85 corridor in 2011 or 2012**

In what zip code do you live? __________

In what zip code do you work? __________

Which best describes the race or ethnicity of your household?
☐ White ☐ African-American ☐ Asian
☐ Hispanic, Latin American, Central American ☐ Multi-racial
☐ Other (please specify) ____________________

Have the Express Lanes improved your own commute conditions on the I-85 corridor?
☐ Definitely no ☐ Probably no ☐ Not sure
☐ Definitely yes ☐ Probably yes ☐ No opinion

In general, have the Express Lanes improved overall conditions for all commuters on the I-85 corridor?
☐ Definitely no ☐ Probably no ☐ Not sure
☐ Definitely yes ☐ Probably yes ☐ No opinion

Is it fair that 2-person carpools are required to pay a toll to use the Express Lanes?
☐ Definitely no ☐ Probably no ☐ Not sure
☐ Definitely yes ☐ Probably yes ☐ No opinion

Was the I-85 carpool lane conversion a good idea?
☐ No ☐ Yes Because: ____________________
____

Are Express Lane tolls a burden on low-income commuters?
☐ No ☐ Yes

Are Express Lane tolls a burden on middle-income commuters?
☐ No ☐ Yes

Are Express Lane tolls a burden on high-income commuters?
☐ No ☐ Yes

Would you be willing to clarify any answers on this survey through a follow-up mailing? ☐ No ☐ Yes

Would you be willing to clarify any answers on this survey by e-mail or phone? We will not share your contact information.
☐ No
☐ Yes, my e-mail is: ____________________
☐ Yes, my phone is: ____________________

May we contact you again in 2015 to take a follow-up survey?
☐ No ☐ Yes

Thank you for completing this section of the survey.

Please complete the questions on the back side of the survey.

When the survey is complete, please refold with the Georgia Tech address facing out, tape closed, and drop into any mailbox. No postage is required.

Figure A-2. Survey Questionnaire (Page 2)

I-85 Pre/Post Express Lanes Morning Commute Survey

2011 Before the Express Lanes Opened

n 2011, before the Express Lanes opened, what was your primary morning commute route from home to work?
- □ Along the I-85 corridor in the regular lanes
- □ Along the I-85 corridor in the carpool lanes
- □ Buford Hwy., GA400, Lawrenceville Hwy, Stone Mountain Hwy., I-285, or other
  Please specify ______________________
- □ Along local roads only
- □ I usually worked from home
- □ I did not live along the I-85 corridor before the Express Lanes opened

n 2011, before the Express Lanes opened, how did you usually commute to work?
- □ Drove alone to work
- □ Carpooled to work
- □ Took transit to work
- □ Walked to work
- □ Biked to work
- □ Worked from home
- □ Other, please specify: ______________________

Carpool Questions for I-85 (skip to the next column if you never carpooled on I-85):

Before the Express Lanes opened, how many people, including you, were usually in your morning carpool? Please enter 2, 3, 4, 5+, or it varied: ________
How many were children? ______

Who rode in the morning carpool with you before the Express Lanes opened?
- □ Adults in my family □ Children in my family
- □ Adults not in my family □ Children not in my family

Before the Express Lanes opened, did your carpool use the carpool lanes?
- □ Yes, we usually drove the carpool in the carpool lanes
- □ No, we usually drove the carpool in the regular lanes

If your carpool did not use the carpool lanes, please select all reasons that apply
- □ The regular lanes were less congested
- □ The regular lanes were more reliable
- □ It was too difficult to get into the carpool lanes from our freeway entrance
- □ Too difficult/expensive to register for a toll tag
- □ It was too difficult to leave the carpool lanes and get to our freeway exit
- □ Other, please specify: ______________________

2012 After the Express Lanes Opened

In 2012, after the Express Lanes opened, what was your primary morning commute route from home to work?
- □ Along the I-85 corridor in the regular lanes
- □ Along the I-85 corridor in the Express Lanes
- □ Buford Hwy., GA400, Lawrenceville Hwy, Stone Mountain Hwy., I-285, or other
  Please specify ______________________
- □ Along local roads only
- □ I usually worked from home
- □ I did not live along the I-85 corridor after the Express Lanes opened

In 2012, after the Express Lanes opened, how did you usually commute to work?
- □ Drove alone to work
- □ Carpooled to work
- □ Took transit to work
- □ Walked to work
- □ Biked to work
- □ Worked from home
- □ Other, please specify: ______________________

Carpool Questions for I-85 (skip to the section below if you never carpooled on I-85):

After the Express Lanes opened, did any carpool members begin driving alone?
- □ Yes, one or more of our participants left the carpool and began driving alone
- □ Nobody left the carpool to start driving alone (may have left for other reasons)

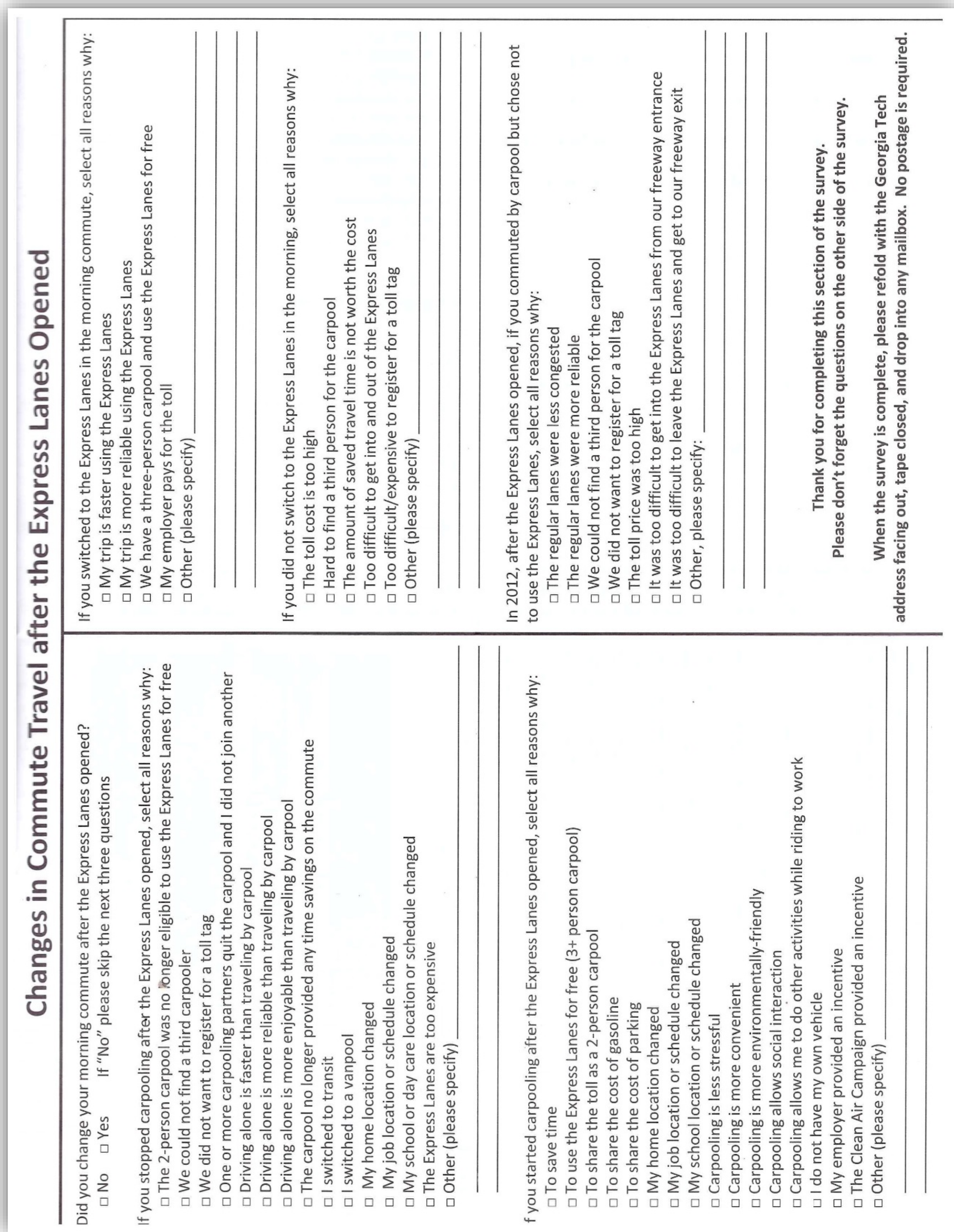
After the Express Lanes opened, how many people, including you, were usually in your morning carpool? Please enter 2, 3, 4, 5+, or it varied: ________
How many were children? ______

Who rode in the morning carpool with you after the Express Lanes opened?
- □ Adults in my family □ Children in my family
- □ Adults not in my family □ Children not in my family

After the Express Lanes opened, did the commute vehicle have a Peach Pass toll tag?
- □ Yes □ No □ I don't know

After the Express Lanes opened, did the morning carpool use the Express Lanes?
- □ Yes, we usually drove the carpool in the Express Lanes
- □ No, we usually drove the carpool in the regular lanes

Figure A-3. Survey Questionnaire (Page 3)



Changes in Commute Travel after the Express Lanes Opened

Did you change your morning commute after the Express Lanes opened?
□ No □ Yes If "No" please skip the next three questions

If you stopped carpooling after the Express Lanes opened, select all reasons why:
- □ The 2-person carpool was no longer eligible to use the Express Lanes for free
- □ We could not find a third carpooler
- □ We did not want to register for a toll tag
- □ One or more carpooling partners quit the carpool and I did not join another
- □ Driving alone is faster than traveling by carpool
- □ Driving alone is more reliable than traveling by carpool
- □ Driving alone is more enjoyable than traveling by carpool
- □ The carpool no longer provided any time savings on the commute
- □ I switched to transit
- □ I switched to a vanpool
- □ My home location changed
- □ My job location or schedule changed
- □ My school or day care location or schedule changed
- □ The Express Lanes are too expensive
- □ Other (please specify) ______

f you started carpooling after the Express Lanes opened, select all reasons why:
- □ To save time
- □ To use the Express Lanes for free (3+ person carpool)
- □ To share the toll as a 2-person carpool
- □ To share the cost of gasoline
- □ To share the cost of parking
- □ My home location changed
- □ My job location or schedule changed
- □ My school location or schedule changed
- □ Carpooling is less stressful
- □ Carpooling is more convenient
- □ Carpooling is more environmentally-friendly
- □ Carpooling allows social interaction
- □ Carpooling allows me to do other activities while riding to work
- □ I do not have my own vehicle
- □ My employer provided an incentive
- □ The Clean Air Campaign provided an incentive
- □ Other (please specify) ______

If you switched to the Express Lanes in the morning commute, select all reasons why:
- □ My trip is faster using the Express Lanes
- □ My trip is more reliable using the Express Lanes
- □ We have a three-person carpool and use the Express Lanes for free
- □ My employer pays for the toll
- □ Other (please specify) ______

If you did not switch to the Express Lanes in the morning, select all reasons why:
- □ The toll cost is too high
- □ Hard to find a third person for the carpool
- □ The amount of saved travel time is not worth the cost
- □ Too difficult to get into and out of the Express Lanes
- □ Too difficult/expensive to register for a toll tag
- □ Other (please specify) ______

In 2012, after the Express Lanes opened, if you commuted by carpool but chose not to use the Express Lanes, select all reasons why:
- □ The regular lanes were less congested
- □ The regular lanes were more reliable
- □ We could not find a third person for the carpool
- □ We did not want to register for a toll tag
- □ The toll price was too high
- □ It was too difficult to get into the Express Lanes from our freeway entrance
- □ It was too difficult to leave the Express Lanes and get to our freeway exit
- □ Other, please specify: ______

Thank you for completing this section of the survey.
Please don't forget the questions on the other side of the survey.

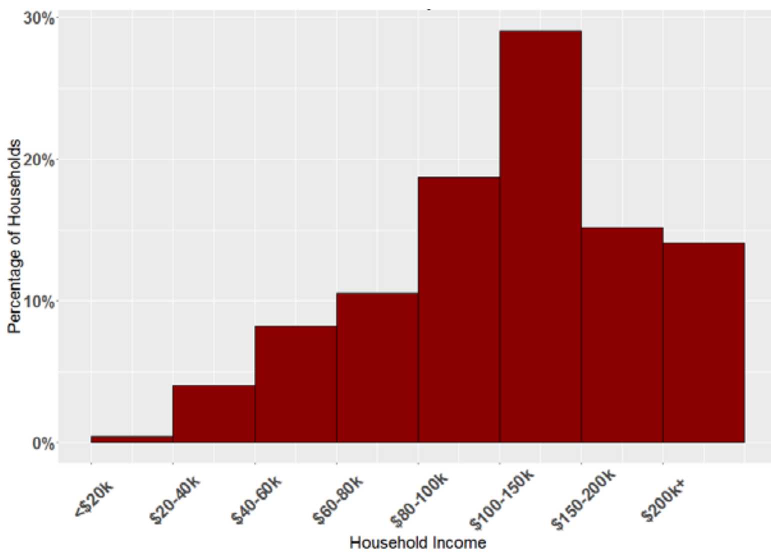
When the survey is complete, please refold with the Georgia Tech address facing out, tape closed, and drop into any mailbox. No postage is required.

Figure A-4. Survey Questionnaire (Page 4)

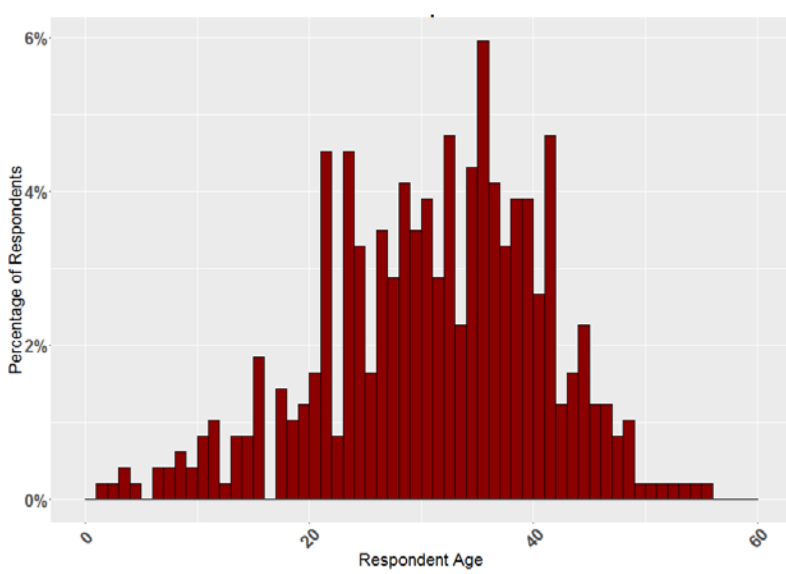
Appendix B: Characteristics of Survey Respondents

Respondent Demographics

The distributions of household incomes and ages of the survey respondents are presented in Figure B-1.



(a) Distribution of Household Income (n=642 Respondents)



(b) Distribution of Respondent Age (n=612 Respondents)

Figure B-1. Distributions of Respondent Demographics

Geographic Distribution of Respondents

The geographic distribution of the survey respondents is presented in Figure B-2 and Figure B-3. The figures show that a large portion of respondents lives in the northeastern regions of the Atlanta metropolitan area. In contrast, the workplaces of the respondents are widely distributed across the city. The figures suggest that many respondents potentially use the I-85 corridor for their commuting.

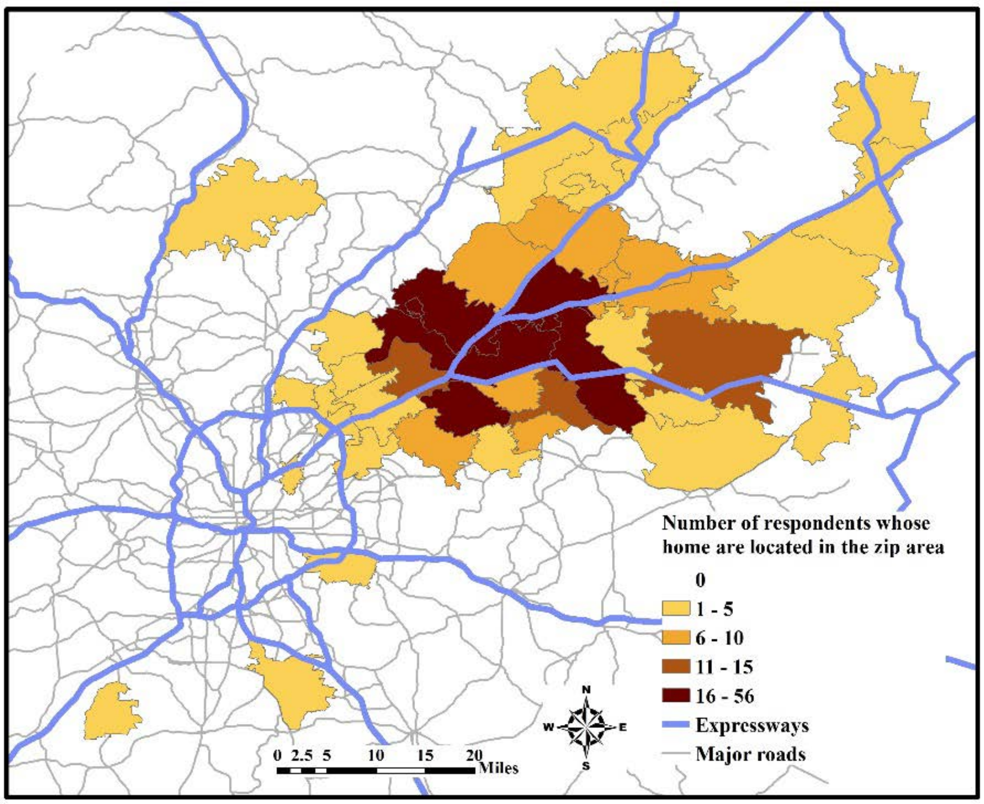


Figure B-2. Geographic Distribution of Respondents' Homes

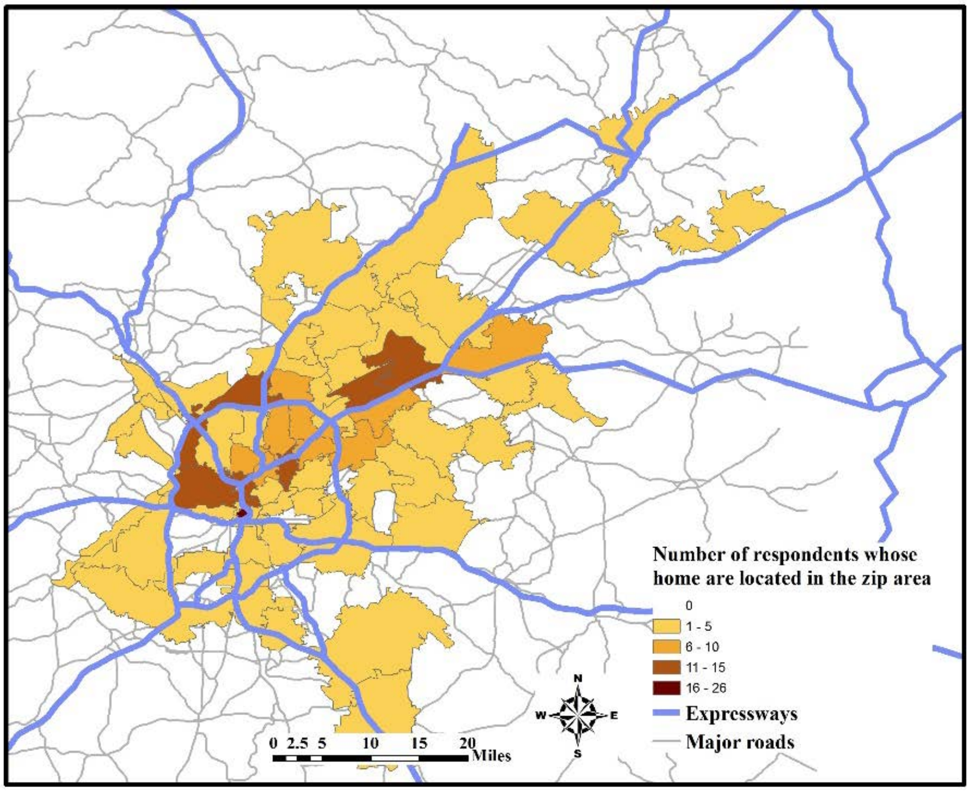


Figure B-3. Geographic Distribution of Respondents' Workplaces

Appendix C: Descriptive Statistics of Survey Result

Carpool Composition Changes

Table C-1 represents the carpool composition changes after the HOT lanes installation. The result shows that the share of family carpool (fampool) increased from 62% to 70% after the installation of the HOT lanes.

Table C-1. Carpool Composition Changes

Who rode in the morning carpool with you before the HOT Lanes opened? (n unique = 201)		
Adults in my family	88	43.8%
Adults not in my family	94	46.8%
Children in my family	36	17.9%
Children not in my family	6	3.0%

Who rode in the morning carpool with you after the HOT Lanes opened? (n unique = 155)		
Adults in my family	76	49.0%
Adults not in my family	60	38.7%
Children in my family	32	20.6%
Children not in my family	6	3.9%

Mode and Route Changes

Table C-2 represents the mode and route changes of the survey participants after the installation of the HOT lanes. The results indicate that the use of the managed lanes (HOV or HOT lanes) among the survey participants increased from 28% to 34% after the installation of the Express Lanes. On the other hand, the number of carpools reported in the survey responses decreased from 146 to 128.

Table C-2. Mode and Route Changes

n = 534		In 2012, after the Express Lanes opened, what was your primary morning commute route from home to work?		
		GP Lanes	**HOT Lane**	**Total**
In 2011, before the Express Lanes opened, what was your primary morning commute route from home to work?	**GP Lanes**	265 (50%)	120 (22%)	385 (72%)
	HOV Lane	87 (16%)	62 (12%)	149 (28%)
	Total	352 (66%)	182 (34%)	534 (100%)

n = 540		In 2012, after the Express Lanes opened, how did you usually commute to work?		
		Drove Alone	**Carpool**	**Total**
In 2011, before the Express Lanes opened, how did you usually commute to work?	**Drove Alone**	367 (68%)	27 (5%)	394 (73%)
	Carpool	45 (8%)	101 (19%)	146 (27%)
	Total	412 (76%)	128 (24%)	540 (100%)

Reasons for (or Not) Switching to HOT Lanes

Figure C-1 and Figure C-2 show the survey participants' reasons for switching to HOT lanes, or not switching to HOT lanes. A large portion of respondents who switched to the HOT lanes responded that faster and more reliable trips induced them to use the HOT lanes. However, a majority of survey participants decided not to switch to the HOT lanes due to the cost.

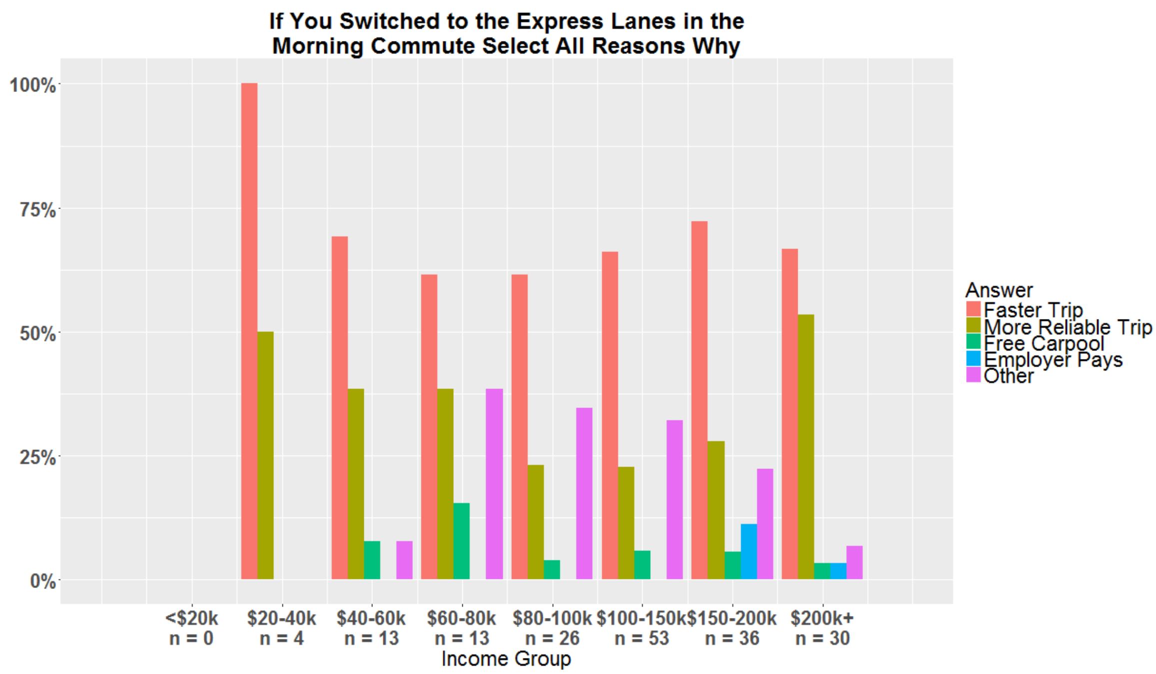


Figure C-1. Reasons for Switching to HOT Lanes

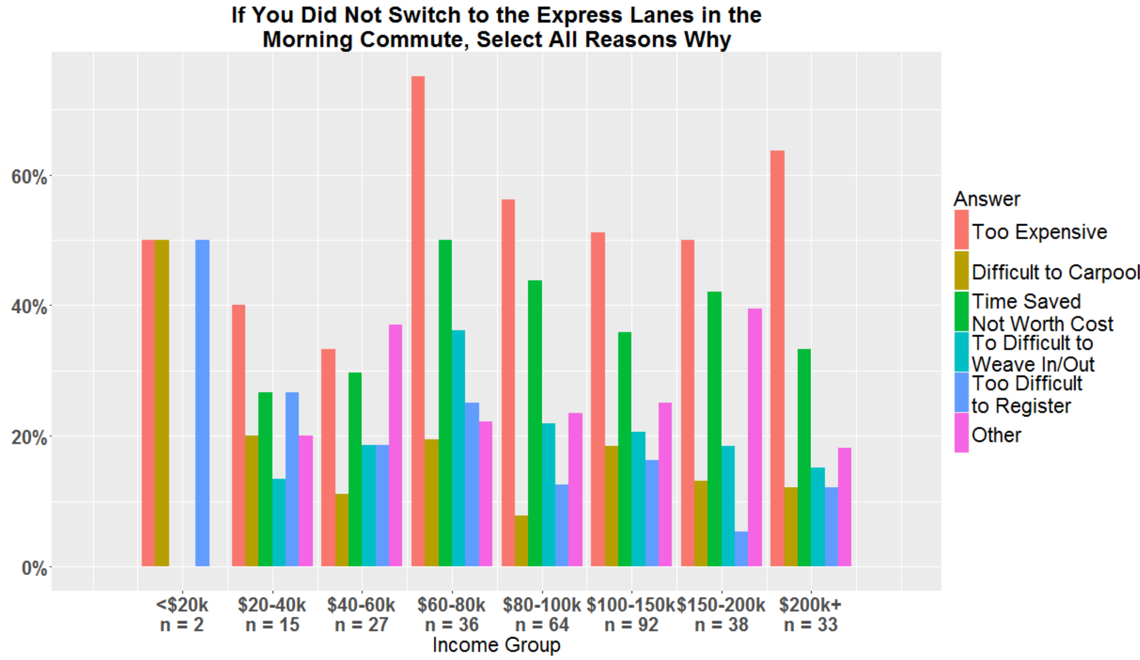


Figure C-2. Reasons for Not Switching to HOT Lanes

Carpools in the General-Purpose Lanes

Figure C-3 presents the participants' reasons for carpooling in the GP lanes. The amount of toll is the most-cited factor for carpools not using the HOT lanes.

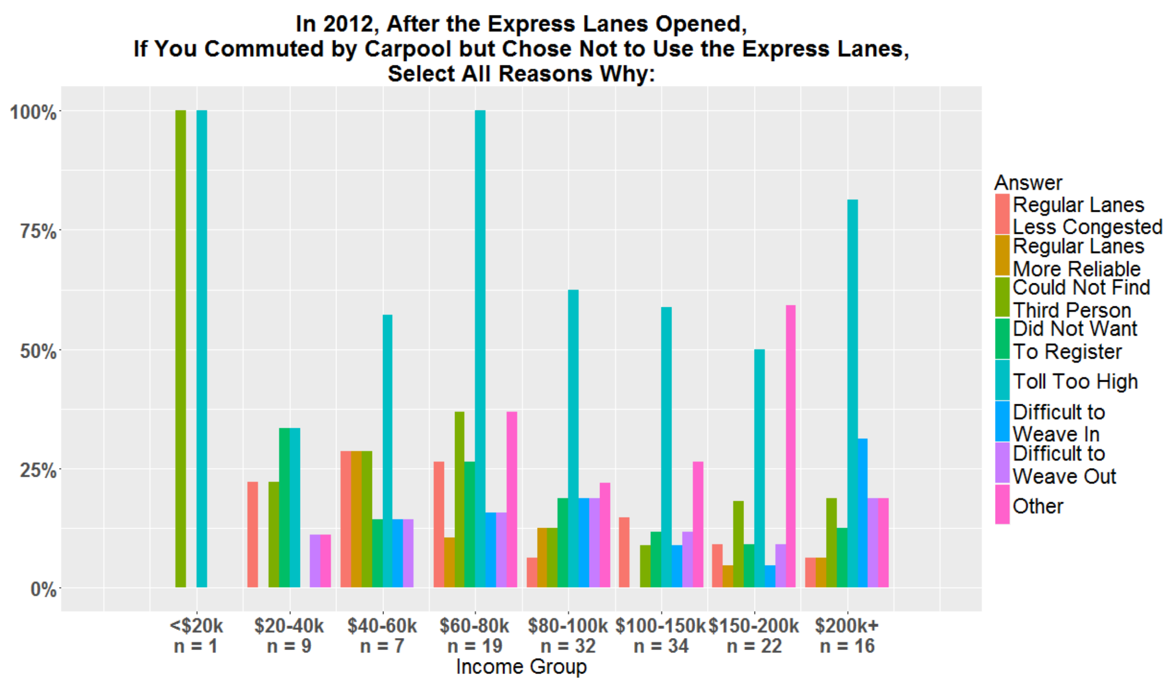


Figure C-3. Carpools in the General-Purpose Lanes

Are Tolls a Burden on Commuters?

Figure C-4 to Figure C-7 represent the survey participants' opinions on the HOT lane tolls by the different household income groups. The survey participants report that they believe HOT lane tolls are a burden on low-income and middle-income groups. Yet, the respondents state that tolls are not a burden on the high-income group. A large portion of survey respondents reported that they believe it is unfair for two-person carpools to pay for HOT lane use. However, it should be noted that there are enough carpools using the GP lanes to form an additional carpool lane; if tolls were eliminated for two-person carpools, the HOT lanes would become as congested as the GP lanes (Guensler, et al., 2013).

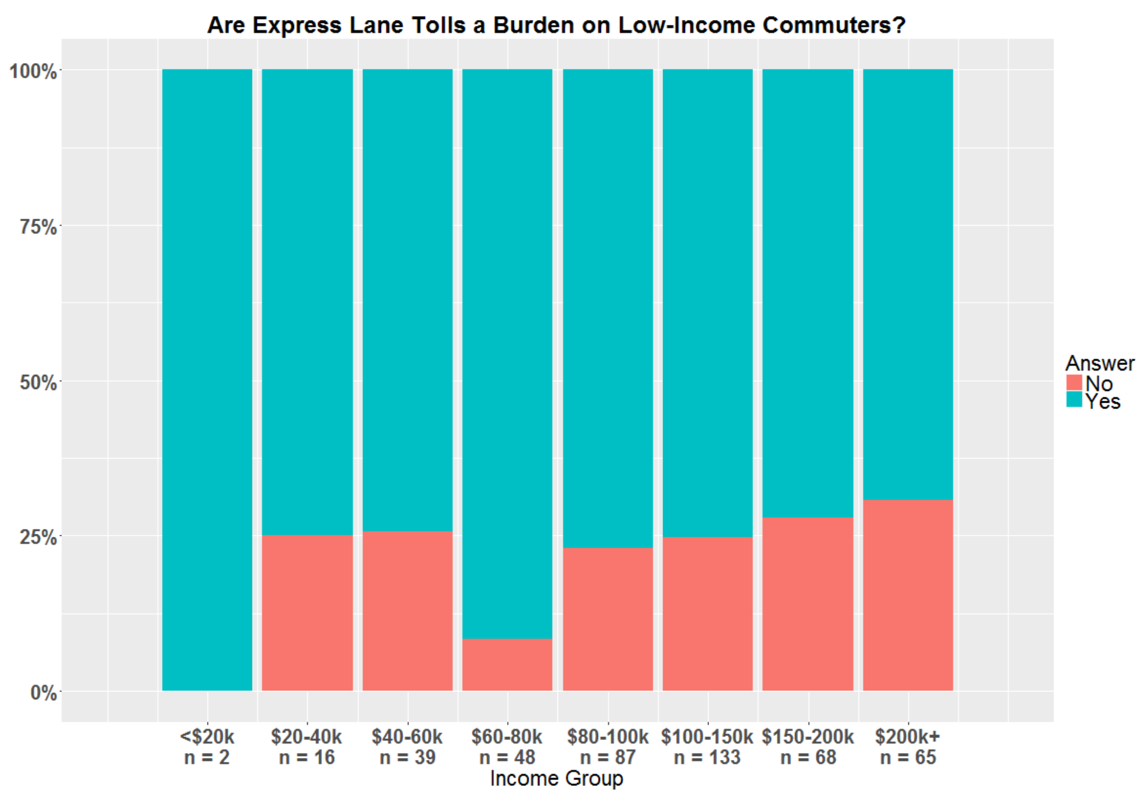


Figure C-4. Burden on Low-Income Commuters, by Income Group

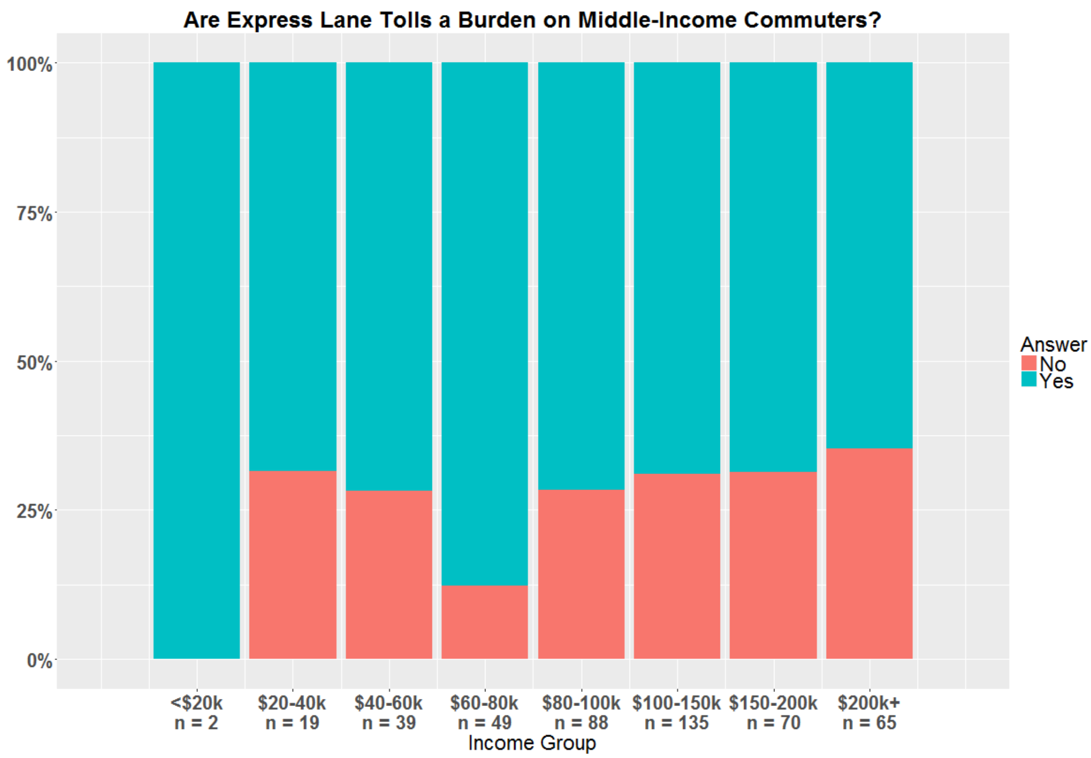


Figure C-5. Burden on Middle-Income Commuters, by Income Group

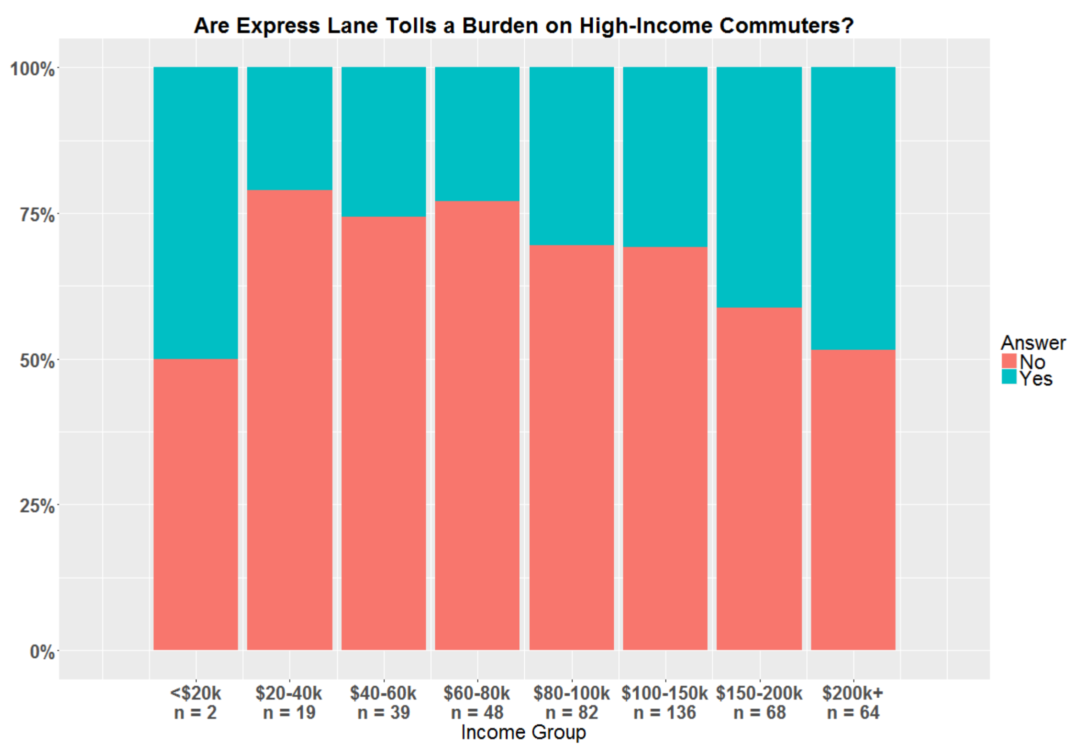


Figure C-6. Burden on High-Income Commuters, by Income Group

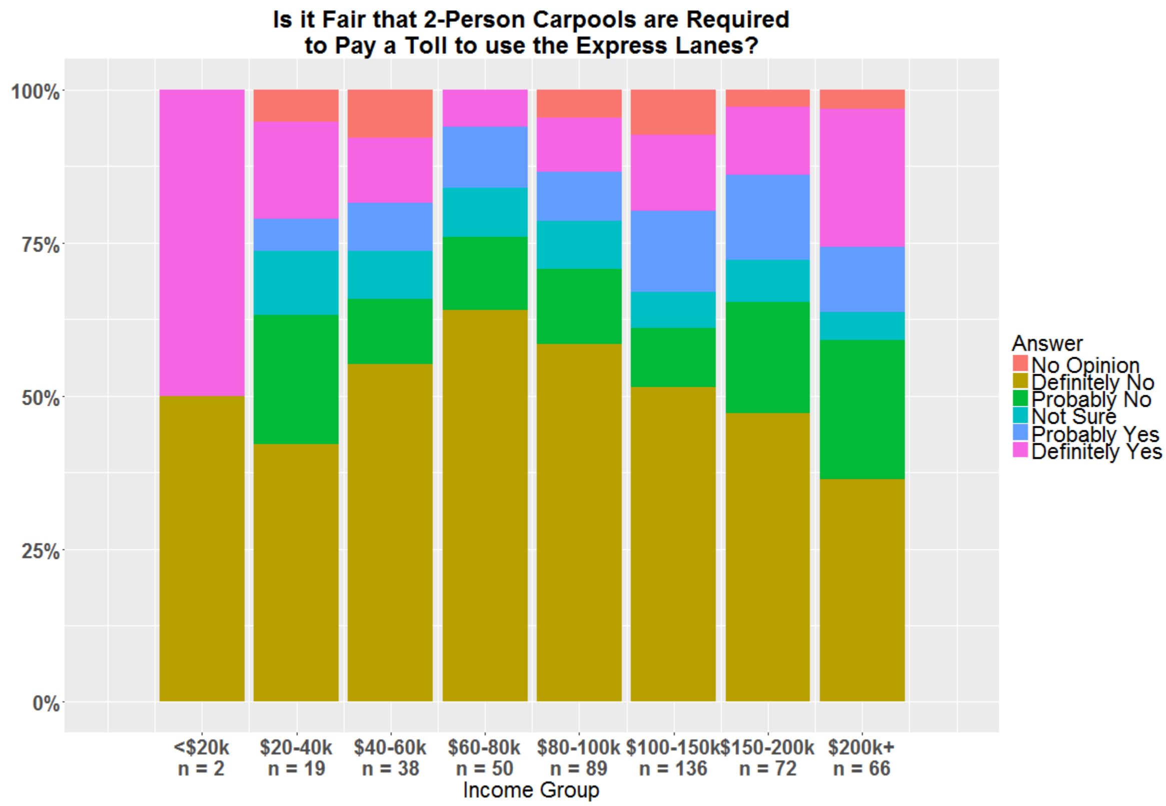


Figure C-7. Fairness of Carpoolers Paying to Use Express Lanes, by Income Group

User vs. Non-User Performance Opinions

Figure C-8 and Figure C-9 show the opinions by different commuter groups on the performance of the HOT lanes. The HOT lane users report that the HOT lanes improved their own commute conditions; however, non-users report that the HOT lanes did not improve their commute conditions.

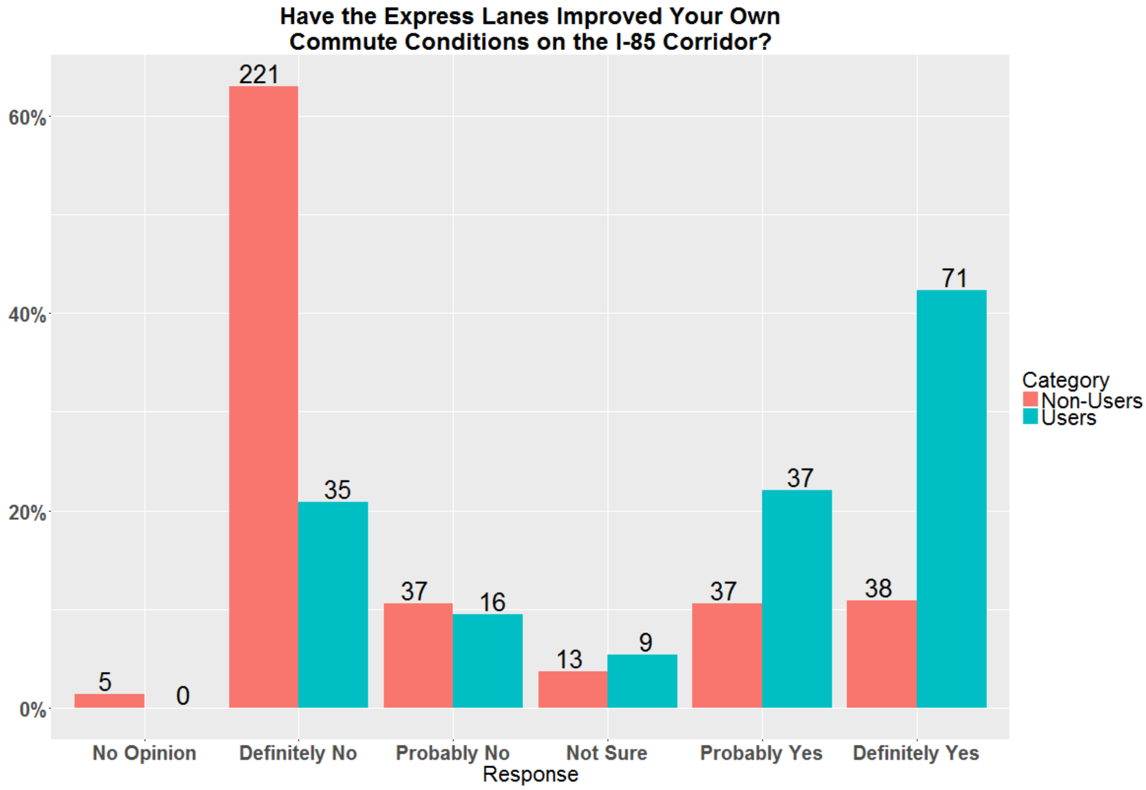


Figure C-8. Have HOT Lanes Improved Your Commute, by User Status

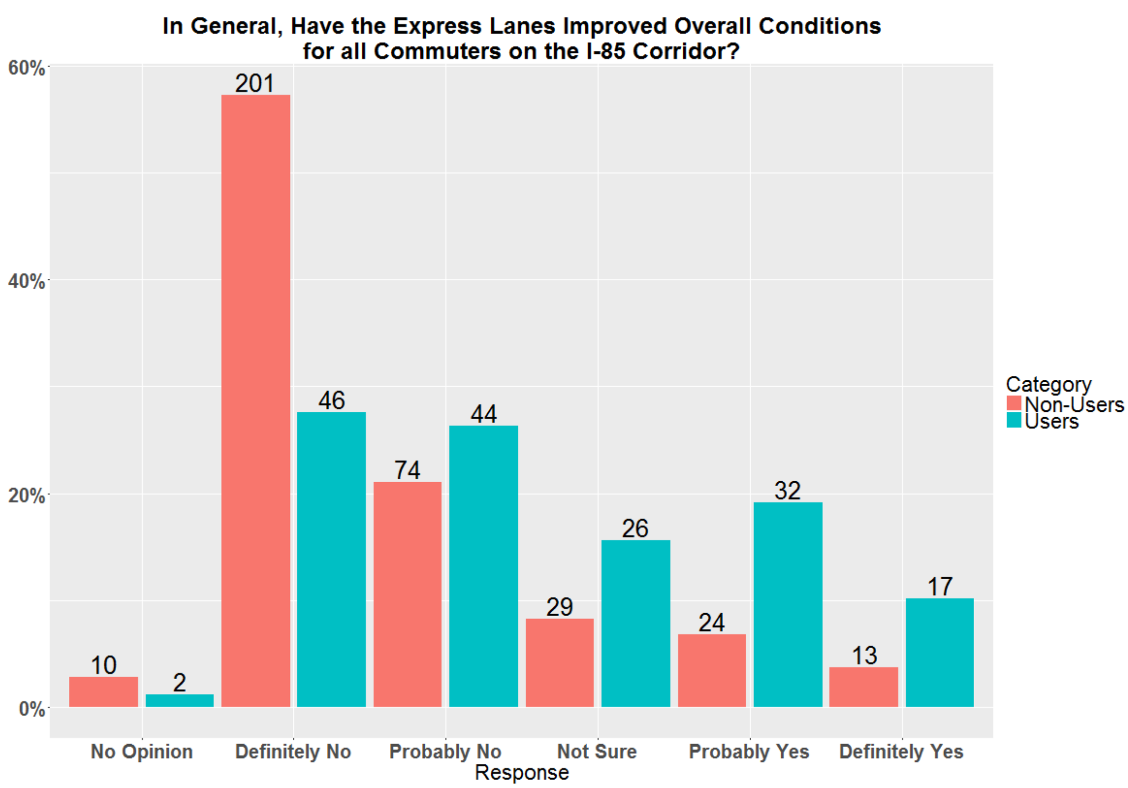


Figure C-9. Have HOT Lanes Improved Overall Commute Conditions, by User Status

Reasons for Starting/Stopping Carpooling

Figure C-10 and Figure C-11 show the various reasons respondents provided for starting (n = 42) or stopping (n = 45) carpooling after the installation of the HOT lanes, by income group.

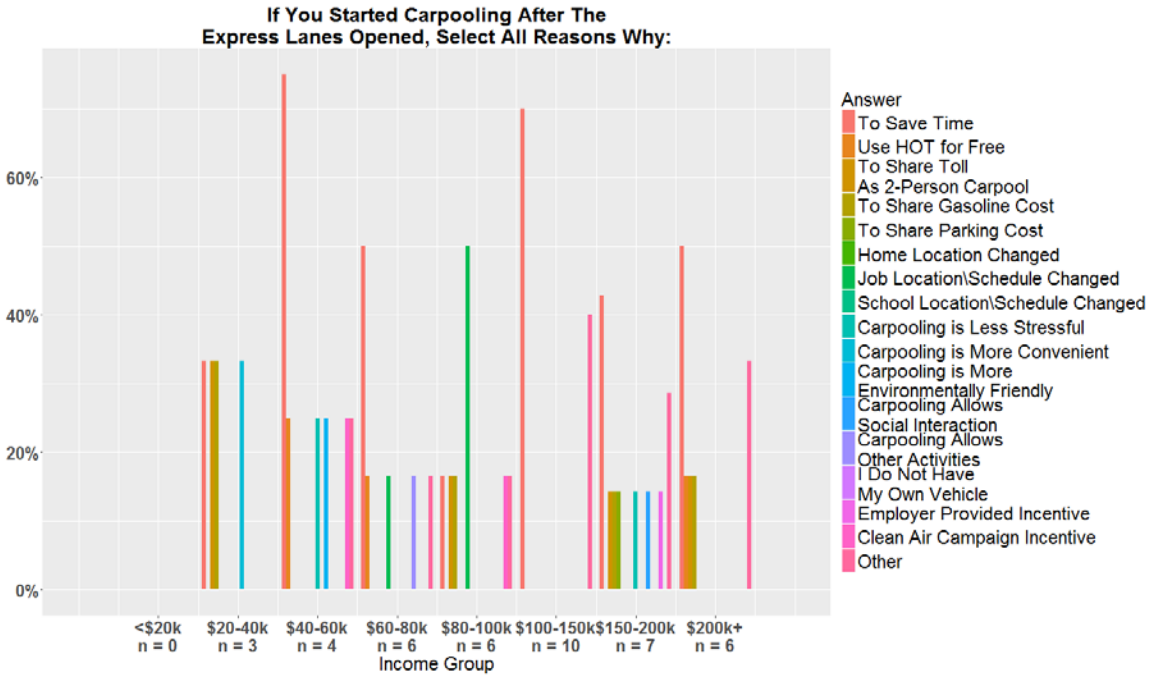


Figure C-10. Why Respondents Started Carpooling, by Income Group

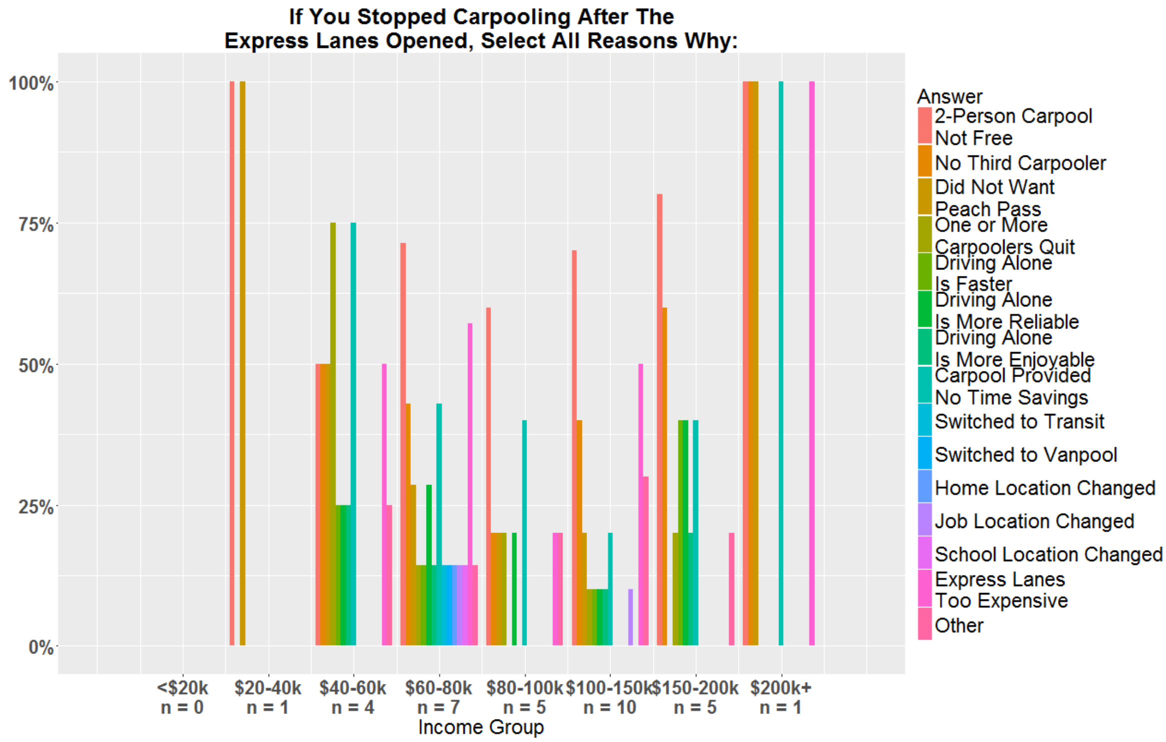


Figure C-11. Why Respondents Stopped Carpooling, by Income Group