Washington State University

I-405 Tollway Project

Team 4

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CPTS 424

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Abstract

The objective of this project was to analyze drivers' value of time while traveling on the Interstate-405 highway during 2019. Data was obtained from the Washington State Department of Transportation (WSDOT) that contained volume counts, travel times, and toll rates for segments of the highway between Bellevue and Interstate-5. The data was analyzed to explore relationships between time of day, speed, volume, and toll rate. The value of time estimates how much a driver is willing to pay to save time. Travel time variability has been shown to play a significant role in determining a commuter's value of time. The results demonstrated higher variability during times of peak congestion. Travel in the southbound direction experienced the slowest average speeds and the highest travel time variability. Southbound toll lane commuters were correspondingly found to have the highest value of time.

Introduction

This project was undertaken to investigate the value of time for commuters on the Interstate-405 tollway between Bellevue and Interstate-5 in the year 2019. The primary objective was to determine any relationships concerning the tolls that commuters were willing to pay in order to reduce their travel time during periods of peak congestion. The team was interested in finding the value of time that commuters placed on taking the express tolled lane over the general purpose lane in order to save on travel time. As part of this analysis, relationships between vehicle speed, volume, and toll rate were also evaluated. Travel time variability was calculated to determine if unreliable travel times may be a factor in the value of time for certain sections of the freeway.

Background

The I-405 tollway spans a 15-mile stretch extending north from Bellevue to the I-5 freeway. Toll rates are adjusted based on real-time traffic volumes and speed collected by WSDOT (WSTC, 2020). The objective of the adjustable rate is to keep traffic flowing at speeds of at least 45mph (WSDOT, 2019). Signs tell drivers the current rate before each entry point, and the rate stays fixed for the duration of the driver's trip. WSDOT states that peak traffic hours are 3-7pm for the northbound direction and 6-10am for the southbound direction.

Calculating the value of time was one of the primary objectives of the study. The value of time quantifies the value a driver places on travel time savings, and is expressed as a dollar amount. The ability to calculate travelers' value of time allows for insights into a commuter's attitude towards time spent on travel, and how much they are willing to sacrifice monetarily to reduce the time spent traveling. Estimates of value of time are important to a wide range of industries, ranging from air travel to public transportation services.

Along with the value of time, another quantity that was investigated was travel time variability. This statistic is a measure of how the commute time of a road link varies within a certain period of time. It is an important determinant in how commuters perceive the reliability and practicality of travelling upon a particular road link, which impacts their willingness to pay a toll, and thus the value of time associated with that road link (Peer et al, 2012). By extension, companies and corporations that make use of the freeway examine travel time variability to better manage the opportunity costs of affairs such as transportation, delivery, or cargo operation. In the vast majority of real-world cases, travel time variability should be minimized whenever possible such that the travel time of a freeway may be made more predictable and commuting made more convenient.

Methods

For this project, several Excel data files were obtained from the WSDOT website, and additional files were provided by an employee of the WSDOT Toll Division upon written request. The data sets contained information on the volume of cars traveling in the toll and general lanes, the travel time for certain segments, and the toll rate being charged for dates in 2019.

The volume, speed, and rate data were analyzed to investigate and model relationships between variables. For the volume measurements, the file provided contained counts of the number of cars traveling in the general and toll lanes at five minute intervals, for both north and southbound directions. There were four locations along the highway where these counts were recorded. The speed at each of these locations were calculated from data containing the travel times for a given highway segment of known length. The toll rate in effect at a given time was identified for segments corresponding to the locations of the volume counts and calculated speeds (Table 1).

Table 1 Available data sets were matched by location along the tollway.

Travel Time Segment	Toll Rate Segment	Volume Count Location
Bellevue to Rosehill Rosehill to Bellevue	NE 6th to NE 124th (NB) NE 85th to NE 6th (SB)	NE 53rd
Bellevue to SR 522 SR522 to Bellevue	NE 70th to NE 124th (NB) NE 128th to NE 6th (SB)	NE 100th
NE 148th to SR 522 SR 522 to NE 148th	NE 115th to SR 522 (NB) NE 195th to NE 128th (SB)	SR 522
Bellevue to SR 527 SR 527 to Bellevue	SR 527 to I5 (NB) SR 527 to NE 128th (SB)	SR 527

Multiple comparison tests were used to check for statistically significant differences between groups. This method was applied in regard to travel time saved between toll rate groups, and volume differences between sections of highway. An analysis of variance model was fit to the north and southbound volume data to show if variations between mean differences were due to true differences or to sampling variability.

Several visualizations were created to highlight locations that have significant changes in toll lane usage and speed. For these analyses, weekends and holidays were omitted. Where necessary, dates corresponding to the two major snow events in January and February were also omitted. Days containing missing values were also removed.

The distribution of observed speeds in the toll lane for each toll being charged was also evaluated. Average speeds in the toll lane were calculated for the October through December period for each toll rate between seventy-five cents and ten dollars. A Shapiro Wilke normality test was used to test the assumption that average speeds during peak travel times were approximately normally distributed. A linear model was fit to the data with toll lane rate as the predictor and average speed as the response.

To calculate the value of time, the volume and rate datasets were used. Additionally, the value of time model incorporated operational costs. Gas price data for the year of 2019 was obtained from the US Department of Energy website. The value of time was calculated using the following model (Equation 1).

$$c_{ir}(N_r) = \beta L + \alpha_i T_f L[1 + \gamma(N_r / K_r)^k] \quad i=1, 2 \; ; r= G, T$$

Equation 1 Value of time equation (Small & Yan, 2001).

The model incorporated a number of different variables in order to accurately represent a driver's value of time. Two types of users were represented in this model by the variable 'i', and were assigned as a driver either in the toll lane, or the general lane. The roadway was denoted as 'r', and is assumed to have the same distance for both types of user. The left hand side of the equation included the total travel time cost represented by 'c_{ir}' multiplied by the number of drivers currently in the lane, written as 'N_r'. The variable 'β' was the operating cost, which consisted of the average gas price for the given week as well as the average wear and tear cost for a standard midsize car. The distance of the trip was represented by the variable 'L' and the variable for the value of time was introduced by 'α_i'. Free flow travel time was represented by '$T_f L$', which was the travel time for the distance of the trip without any traffic. The team utilized the average travel time in the middle of the night to represent the free flow travel time in the model implementation. The model accounted for traffic by incorporating the delay cost, represented by 'N_r / K_r', the ratio of the current volume of the lane and the lane capacity. Lastly, the variables 'γ' and 'k' were constant parameters. The Bureau of Public Roads formula indicated that 'γ' be assigned the value of 0.15, and 'k' be assigned the constant value of 4.0

(Small & Yan, 2001). These parameter assignments were implemented in accordance with published industry and practice standards.

The volume data reported observations at each entry point in five minute intervals. In order to eliminate double counting cars and overestimating the value of time, calculation intervals were created based upon the travel times at particular locations and times of day. Beginning at the first segment of highway, groups of cars were tracked to the next entrance based upon their travel time and when they should be arriving at the next entry point. Once this time had elapsed, it was assumed that the volume reported at that time at the first segment of highway consisted of a new group of cars and the value of time was then calculated accordingly. To account for the entrance of new cars into the lane beyond the first entrance point, groups of cars continued to be tracked down the stretch of the highway. The volume count at the initial segment was compared to the volume count at the second entrance at the time the cars should arrive based upon their travel time. If the volume was greater at the second entrance, the assumption was made that the difference in volume represented new cars entering the lane. The value of time was then calculated for cars that were determined to have entered the lane. Volumes at each sequential exit were compared for every group of cars for the distance of the toll lane, and value of time calculations were conducted accordingly.

The model used was heavily dependent upon distance traveled. Unfortunately, with the data given, it was not explicitly known where a driver exits or the distance of their trip. In order to overcome this challenge, averages were used. When an entrance into the lane was observed, the value of time was calculated for each combination of highway stretch that the driver could pursue. For example, at the first entrance, the value of time was calculated for drivers going to the next exit, the next two exits, the next three exits, and the full duration of the tollway. The average of the value of time calculations was then used to represent the final value of time calculation for the particular group.

To calculate the travel time variability of the I-405 commute, the travel time datasets were used. These datasets consisted of data from the last three months of 2019 (Oct-Dec). Some days were removed from consideration due to a significant number of erroneous values caused by glitches in the WSDOT traffic detection system. The model defined travel time variability as the standard deviation of travel time per quarter-hour (Equation 2).

$$SD_{q,l} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(tt_{i,q,l} - \mu_{q,l})^2}$$

Equation 2 Travel time variability equation (Peer et al, 2012).

where q represents a specific quarter-hour, l a specific road link, i a particular day of the year, n the number of days (on a per road link basis), tt the observed travel time, and μ the expected travel time (Peer et al, 2012).

Note that the data was intervaled every five minutes rather than fifteen minutes. Therefore, to get quarter-hours, the averages of every three five-minute intervals were computed. The occasional remaining glitch-induced values were replaced with NA values for the averaging calculations. At each milepost, the average daily volume in toll lanes during peak periods was calculated. The difference between each possible milepost moving northbound and southbound were calculated. Volume changes were plotted against the potential trips combinations commuters may take along I-405.

Results

The average southbound speed was found to drop below 45 mph during the morning commute. Average northbound speeds were within the acceptable range (Figure 1).

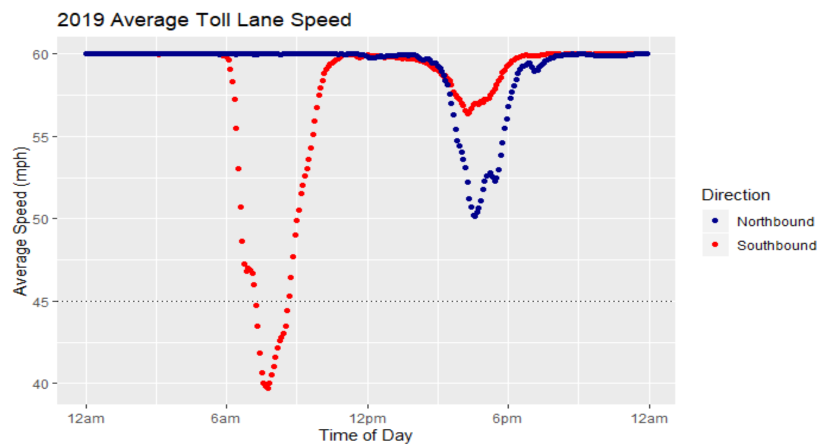

Figure 1The average toll lane speeds show the southbound lanes dropping below the 45 mph threshold between 6 and 9 am.

Travel in the toll lane was found to save commuters up to nineteen minutes during peak travel times, with southbound travelers experiencing the greatest time savings (Figure 2).

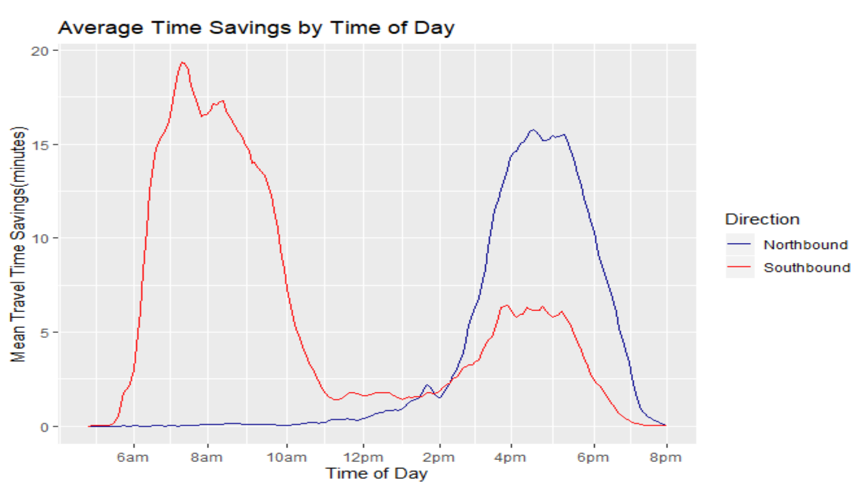

Figure 2 Commuters in the toll lane saved up to nineteen minutes on average when compared to travelers in the general lane.

Northbound speeds were found to be negatively skewed during peak travel times between 3 pm and 7 pm. Southbound observed speeds during the morning commute from 6 am to 10 am were more normally distributed (Figure 3).

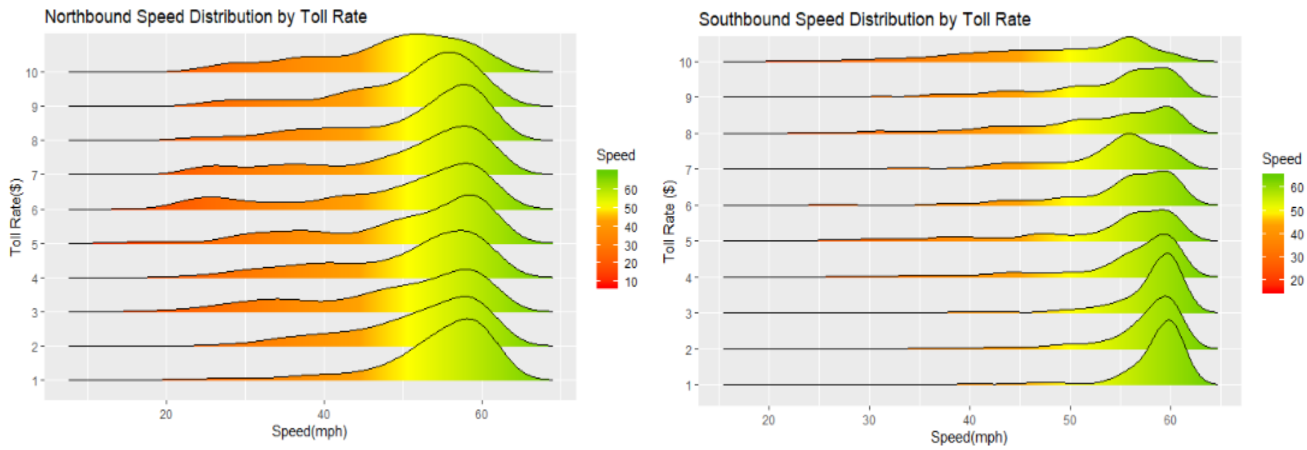

Figure 3 Speed distributions during peak travel times show a wide range of speeds were observed at each toll rate.

The test for normality validated the assumption that average southbound speeds between 6 am and 10 am were approximately normally distributed. A linear model was fit to the data and the results were plotted. The northbound data was not normally distributed, and no linear relationship was evaluated (Figure 4).

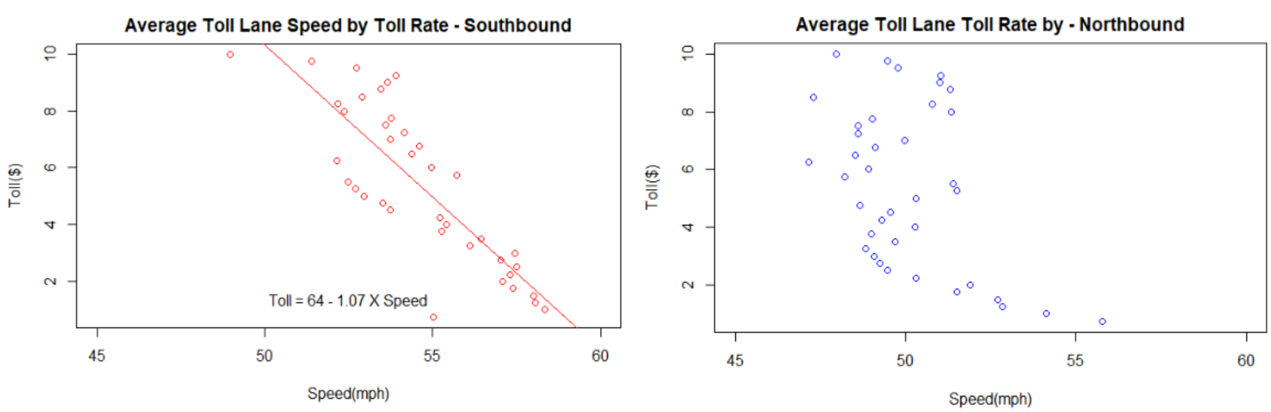

Figure 4 A linear relationship was modeled to predict toll rate based on speed for the southbound lane. The northbound data was not linearly distributed.

Average volume changes were plotted against the potential trips commuters may take along I-405. The largest change in traffic volume was observed between NE 100th and SR 527, with a positive change in volume exceeding 150 cars (Figure 5). This implies traffic in the toll lane is significantly heavier between SR 527 and NE 100th than between NE 100th and NE 53rd.

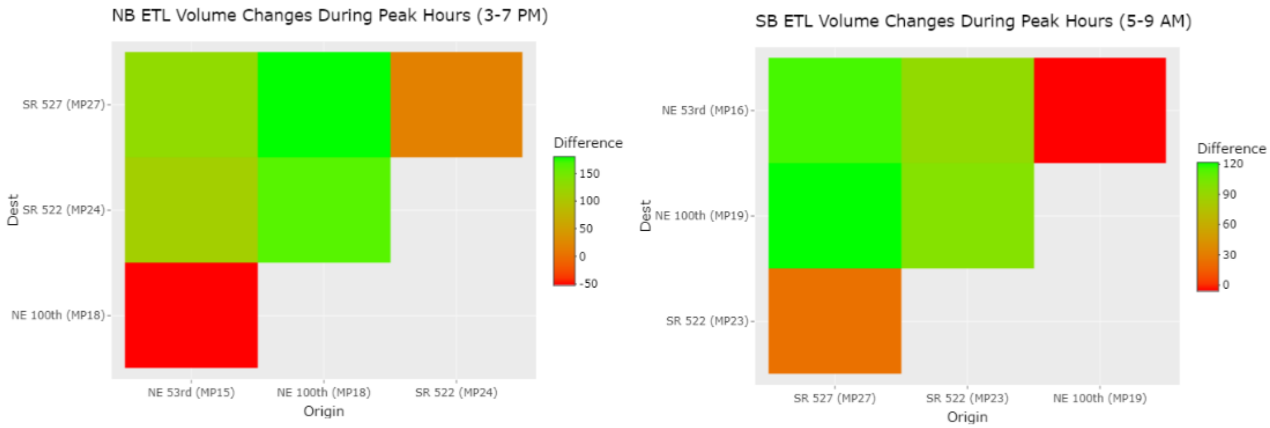

Figure 5 The biggest volume changes were observed on the section of tollway between NE 100th and SR 527 in both directions.

For the southbound direction between SR 527 to NE 53rd, there was no decrease in traffic volume. Volume differences at each milepost continuously increases moving southbound, except between NE 100th and NE 53rd.

The speed of cars traveling in the toll lanes was found to be consistently slower near SR 522 in both directions. Travel speed slowed across the entire tollway during the morning and evening commutes in the southbound lanes. The slowest speeds occurred from approximately 8 am to 9 am near SR 527. Travel in the northbound direction was primarily impacted during the evening commute, with the slowest speeds observed between 4 pm and 6 pm near SR 522 (Figure 6).

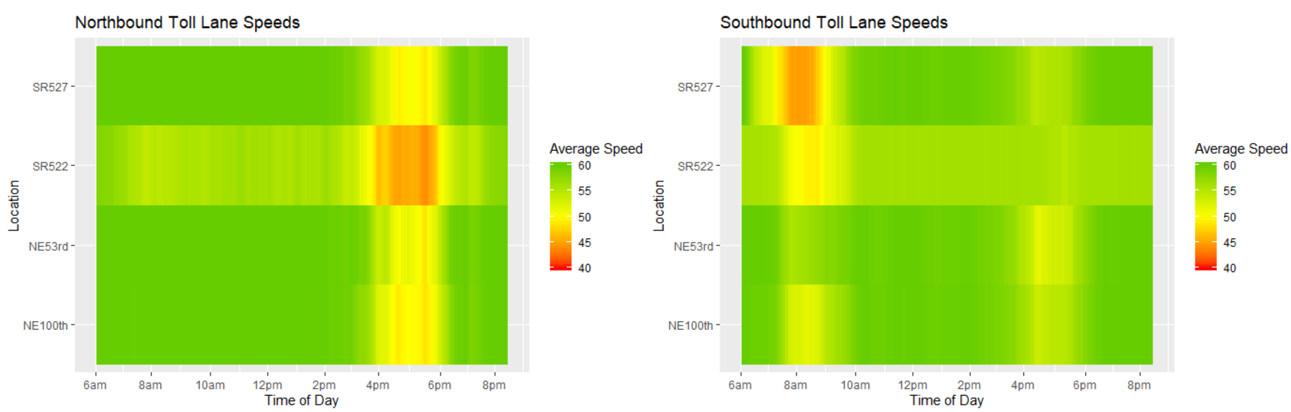

Figure 6 Speed in the toll lane slowed the most near SR 522 headed northbound during the evening commute, and near SR 527 headed southbound during the morning commute.

Multiple group wise comparison tests results demonstrate there is a significant relationship in volume differences between each pair of mileposts in both directions (Figure 7).

```
        Simultaneous Tests for General Linear Hypotheses

Multiple Comparisons of Means: Tukey Contrasts


Fit: aov(formula = Diff ~ trip, data = NB15)

Linear Hypotheses:
                                        Estimate Std. Error  t value Pr(>|t|)
( MP15 - MP24 ) - ( MP15 - MP18 ) == 0 -164.062      1.707  -96.105   <2e-16 ***
( MP15 - MP27 ) - ( MP15 - MP18 ) == 0 -180.847      1.707 -105.937   <2e-16 ***
( MP18 - MP24 ) - ( MP15 - MP18 ) == 0 -216.303      1.707 -126.706   <2e-16 ***
( MP18 - MP27 ) - ( MP15 - MP18 ) == 0 -233.087      1.707 -136.538   <2e-16 ***
( MP24 - MP27 ) - ( MP15 - MP18 ) == 0  -69.025      1.707  -40.434   <2e-16 ***
( MP15 - MP27 ) - ( MP15 - MP24 ) == 0  -16.785      1.707   -9.832   <2e-16 ***
( MP18 - MP24 ) - ( MP15 - MP24 ) == 0  -52.240      1.707  -30.602   <2e-16 ***
( MP18 - MP27 ) - ( MP15 - MP24 ) == 0  -69.025      1.707  -40.434   <2e-16 ***
( MP24 - MP27 ) - ( MP15 - MP24 ) == 0   95.037      1.707   55.671   <2e-16 ***
( MP18 - MP24 ) - ( MP15 - MP27 ) == 0  -35.456      1.707  -20.769   <2e-16 ***
( MP18 - MP27 ) - ( MP15 - MP27 ) == 0  -52.240      1.707  -30.602   <2e-16 ***
( MP24 - MP27 ) - ( MP15 - MP27 ) == 0  111.822      1.707   65.503   <2e-16 ***
( MP18 - MP27 ) - ( MP18 - MP24 ) == 0  -16.785      1.707   -9.832   <2e-16 ***
( MP24 - MP27 ) - ( MP18 - MP24 ) == 0  147.278      1.707   86.273   <2e-16 ***
( MP24 - MP27 ) - ( MP18 - MP27 ) == 0  164.062      1.707   96.105   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
(Adjusted p values reported -- single-step method)
```

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        Simultaneous Tests for General Linear Hypotheses

Multiple Comparisons of Means: Tukey Contrasts


Fit: aov(formula = Diff ~ trip, data = SB15)

Linear Hypotheses:
                                       Estimate Std. Error t value Pr(>|t|)
( MP23 - MP16 ) - ( MP19 - MP16 ) == 0   98.630      1.665   59.25  < 0.001 ***
( MP23 - MP19 ) - ( MP19 - MP16 ) == 0  104.539      1.665   62.80  < 0.001 ***
( MP27 - MP16 ) - ( MP19 - MP16 ) == 0  122.041      1.665   73.32  < 0.001 ***
( MP27 - MP19 ) - ( MP19 - MP16 ) == 0  127.950      1.665   76.87  < 0.001 ***
( MP27 - MP23 ) - ( MP19 - MP16 ) == 0   29.320      1.665   17.61  < 0.001 ***
( MP23 - MP19 ) - ( MP23 - MP16 ) == 0    5.909      1.665    3.55  0.00532 **
( MP27 - MP16 ) - ( MP23 - MP16 ) == 0   23.411      1.665   14.06  < 0.001 ***
( MP27 - MP19 ) - ( MP23 - MP16 ) == 0   29.320      1.665   17.61  < 0.001 ***
( MP27 - MP23 ) - ( MP23 - MP16 ) == 0  -69.311      1.665  -41.64  < 0.001 ***
( MP27 - MP16 ) - ( MP23 - MP19 ) == 0   17.502      1.665   10.52  < 0.001 ***
( MP27 - MP19 ) - ( MP23 - MP19 ) == 0   23.411      1.665   14.06  < 0.001 ***
( MP27 - MP23 ) - ( MP23 - MP19 ) == 0  -75.219      1.665  -45.19  < 0.001 ***
( MP27 - MP19 ) - ( MP27 - MP16 ) == 0    5.909      1.665    3.55  0.00534 **
( MP27 - MP23 ) - ( MP27 - MP16 ) == 0  -92.722      1.665  -55.70  < 0.001 ***
( MP27 - MP23 ) - ( MP27 - MP19 ) == 0  -98.630      1.665  -59.25  < 0.001 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
(Adjusted p values reported -- single-step method)
```

Figure 7 Multiple comparison tests show significant differences in the volumes between groups

The multiple comparisons test showed that when toll rates are grouped in $2 increments, there are significant differences in time savings between rate groups (Figure 8).

```
         Simultaneous Tests for General Linear Hypotheses

Multiple Comparisons of Means: Tukey Contrasts


Fit: lm(formula = Time_Saved ~ Groups, data = joined_March)

Linear Hypotheses:
                      Estimate Std. Error t value Pr(>|t|)
(2,4] - (0,2] == 0     231.537     10.843   21.35   <2e-16 ***
(4,6] - (0,2] == 0     488.511      9.900   49.35   <2e-16 ***
(6,8] - (0,2] == 0     762.886     10.929   69.80   <2e-16 ***
(8,10] - (0,2] == 0    948.813      8.845  107.28   <2e-16 ***
(4,6] - (2,4] == 0     256.974     14.009   18.34   <2e-16 ***
(6,8] - (2,4] == 0     531.349     14.754   36.01   <2e-16 ***
(8,10] - (2,4] == 0    717.276     13.284   53.99   <2e-16 ***
(6,8] - (4,6] == 0     274.376     14.075   19.49   <2e-16 ***
(8,10] - (4,6] == 0    460.302     12.526   36.75   <2e-16 ***
(8,10] - (6,8] == 0    185.927     13.355   13.92   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
(Adjusted p values reported -- single-step method)
```

Figure 8 A multiple comparison test showed significant differences in time saved by travelers paying different toll rates.

The value of time calculations averaged across both directions was found to be $27.19 for the toll lane, and $24.08 for the general lane. Commuters traveling southbound in the toll lanes were shown to have the highest comparative value of time at $34.31 per hour (Table 2).

Table 2 The value of time calculation results.

	Northbound	Southbound	Both
Toll	$20.08/hr.	$34.31/hr.	$27.19/hr.
General	$23.71/hr.	$24.44/hr.	$24.08/hr.

Results for the travel time variability of I-405 indicate that during peak rush hours, commute time varies significantly, though this is dependent on the specific road link. Northbound road links were fairly consistent in variability, with the primary peaks occurring simultaneously near the 5 pm mark. Interestingly, the southbound links tended to be less predictable in variability. While all southbound links have two major spikes at 8 am and 5 pm, the height of these peaks fluctuates significantly. The general and toll lanes tend to rise and fall in harmony in both directions, with general lanes having higher variability (Figure 9).

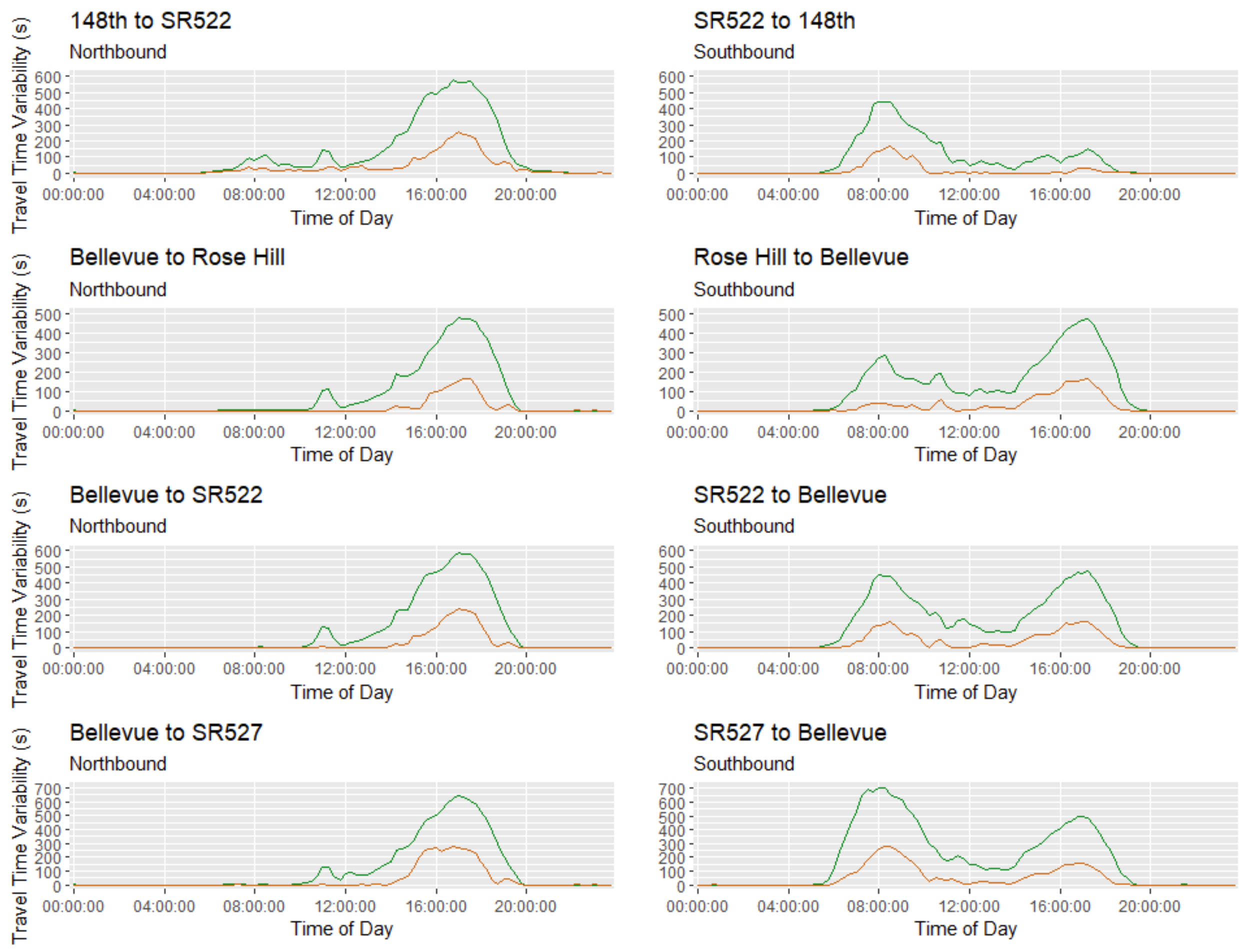

Figure 9 Each plot represents a section of 1-405 for which the travel time variability was plotted. General lanes are shown in green, and toll lanes are shown in brown.

Discussion

The speed analysis showed that on average, cars in the northbound lane stay above the 45 mph target set by WSDOT, while morning commuters in the southbound direction drop below that threshold. Travel time variability was shown to increase during the morning and evening commute, respectively, with southbound lanes having the greatest overall variability. On average, southbound commuters saved more time by taking the toll lane than their northbound counterparts, and were shown to value their time almost $15 an hour more. These results seem to indicate the heavier traffic and greater variability in the southbound lanes leads travelers to place a higher value on their time.

Volume analysis reveals the differences between each locations traffic volume. This helped the team to understand locations on I-405 that may have influenced the value of time. A greater increase of cars in toll lanes at a certain location may have contributed to a commuter's decision to merge into the toll lane. Further investigation would be needed to create a range of values along I-405 that reflect how value of time may change as a commuter travels north or south along the road.

The results of the calculations demonstrated a decrease in the value of time for I-405 drivers in comparison to the most previous study conducted on the same highway. This result could have arisen for a variety of reasons, ranging from the way operational costs were accounted for to the progression of in-car technology. Though the most likely explanation for this discrepancy is due to the differences in available data and the methods used. Value of time has been shown to vary across roadways and methodologies (Table 3).

Table 3 Recent published value of time figures for nearby roadways.

Location	Year	VOT	2019 inflation adjusted VOT	Source
Downtown Seattle	2009	$18.75	$22.34	Danna et al., 2012
SR 167	2012	$38.00	$42.31	Brent & Gross, 2017
I-5 Chehalis	2014	$12.00	$12.96	Hallenbeck, et al., 2014
I-405 Tollway	2018	$53.00	$53.96	Leung et al., 2019
I-405 Tollway	2019	$27.19	-	This study

One of the largest challenges the team faced was conducting analysis with real world data that did not exactly subscribe to the project's specific needs. The travel time data, for example, was found to have been calculated from a single speed camera measurement and extrapolated to the entire segment. Based on volume count and inference, it was determined that this was not an accurate representation of travel time, but rather a general estimate. This introduced a measure of uncertainty into the calculations. Future studies could attempt to resolve this issue by contacting WSDOT for clarification on their methods, and requesting additional data if needed.

In terms of value of time calculations, one of the largest challenges was not having the data necessary to accurately compute the value of time with the model chosen. One limitation to the model surrounded the value of total travel cost. The project lacked the data to truly represent this value, due to the fact that it is very difficult to understand the endured travel time cost for each person. For example, travel time could be more costly to someone due to frustration they experience while driving, or physical pain it may cause them, while another driver may view driving indifferently, or even leisurely. Another limitation of the model is the ability to truly understand operational costs. It did not take into account the increasing amount of electric cars that are now present on the road, and how this affects the ability to accurately represent operational costs. The team also did not consider how many commuters have gas or mileage compensation plans through their work. This may also have a dramatic impact on how drivers view travel time as well the fact that it eliminates the operational cost to the driver completely. Team members could have been more selective when deciding on models to ensure that all of the variables incorporated in the model could be accurately represented by the available data.

Additionally, the rough estimate of driver entry and exit locations was another limiting factor. Though understandably there may be privacy restrictions that protect this information, it is a factor that may vastly impact the results. Lastly, single volume counts for the toll lane was a limiting factor to the accuracy of the model. The data provided a single volume measure of drivers in the toll lane, though drivers who have a high occupancy vehicle (HOV) pass are allowed to use this lane for free. The data did not distinguish in the volume count how many drivers were HOV drivers, and how many were not. Incorporating the number of HOV drivers in the toll lane would have an impact on the value of time calculation results. The team made the necessary assumptions in order to complete the computations with the data available.

A few additional components exist that could have been incorporated, were it not for limitations of time, the first being a willingness to pay model. Paired with the other findings, this aspect of the project could have provided further insight on the monetary value drivers would be willing to place on travel time saved. Another aspect that could be explored further is the relationship between the project findings and demographic census data. It would have been interesting to identify patterns that exist between the value of time for drivers based on their corresponding income or age. Another interesting aspect to investigate could have been the relationship that exists between the volume of toll lane entrances and the physical layout of that particular entrance point. For example, is there a decrease in the volume of lane entrances for entry points that require drivers to merge over two or more lanes of traffic? Do direct toll lane access ramps increase toll lane entrance volumes drastically? These are a few components recommended for future studies.

Conclusion

This study quantified the value of time, travel time variability, time savings, toll lane speeds, and volume changes from the available 2019 I-405 data. Results showed drivers on routes with the greatest variability were willing to pay more to save time on their commute. These findings were in agreement with other published works. The analyses performed in this project have revealed intriguing statistics and relationships that helped quantify the behavior of commuters. The students hope that the discussions into the challenges faced and the results obtained will be beneficial for future research concerning the value of time. Further research is recommended to evaluate I-405 data for previous and subsequent years, and to investigate factors that may contribute to changes and trends over time.

Executive Summary

The primary objective of this project was to analyze drivers' value of time while traveling on the I-405 highway during 2019. The value of time estimates how much a driver is willing to pay to save time. This analysis can be applied to a wide range of industries, from airlines to public transportation services. Through the duration of this project, data was used containing volume counts, travel times, and toll rates for particular segments of the I-405 highway. The data was analyzed to explore relationships between time of day, speed, volume, and toll rate. The study also calculated the travel time variability. The team hypothesized that the findings would be comparable to existing published studies on this and similar tollways. The results produced an average value of travel time in the toll lane of $27.08 for both directions. This value is lower than the most recent study on the same tollway. The discrepancy is likely due to different equations used, and a wider range of factors considered based on data that was not available for use in this project. Future research could evaluate data from prior years using a consistent methodology, and then analyze patterns in the results to find possible trends. Demographic data, information on public transit ridership, and usage trends in the prevalence of various technologies, could all be investigated as potential influencing factors.

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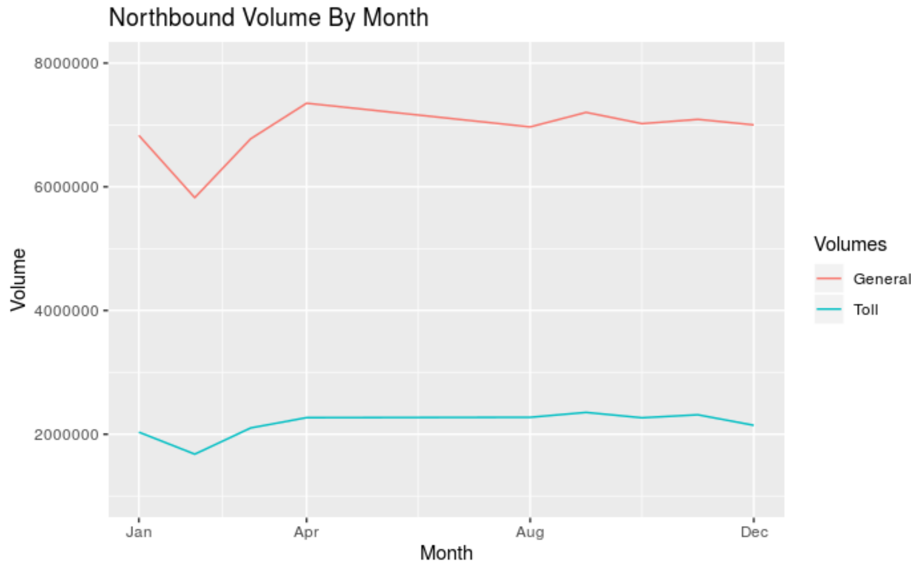
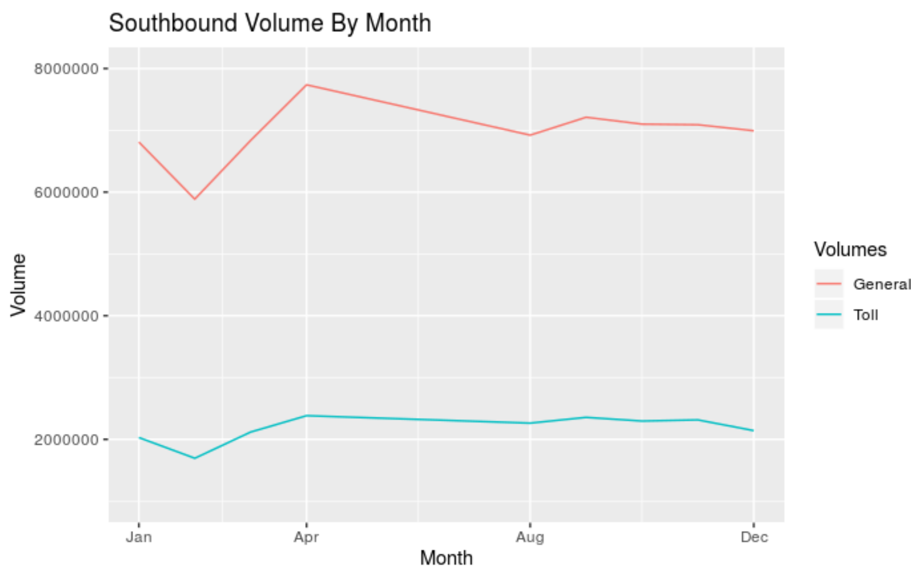
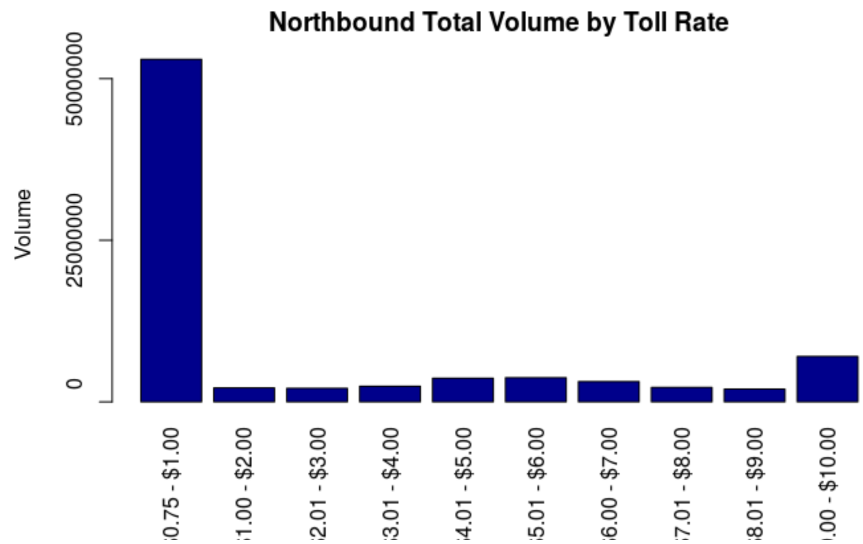
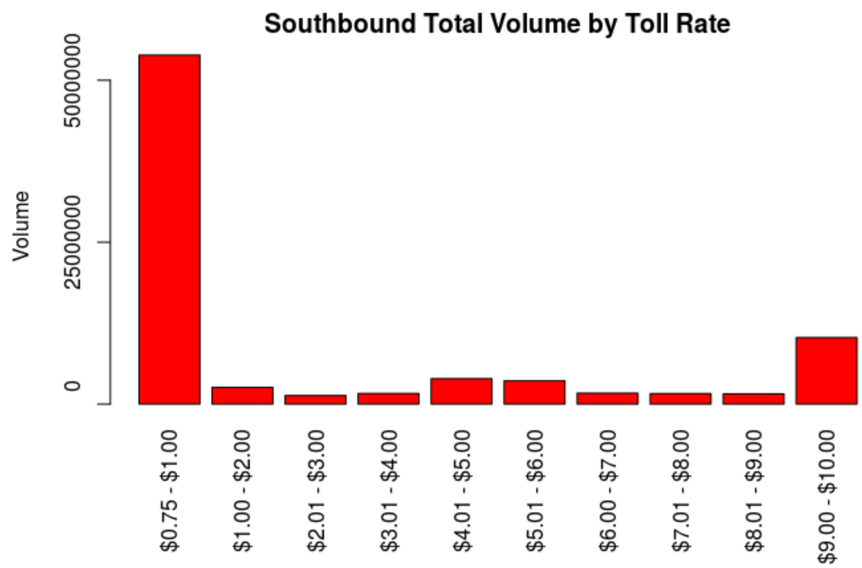
Appendix



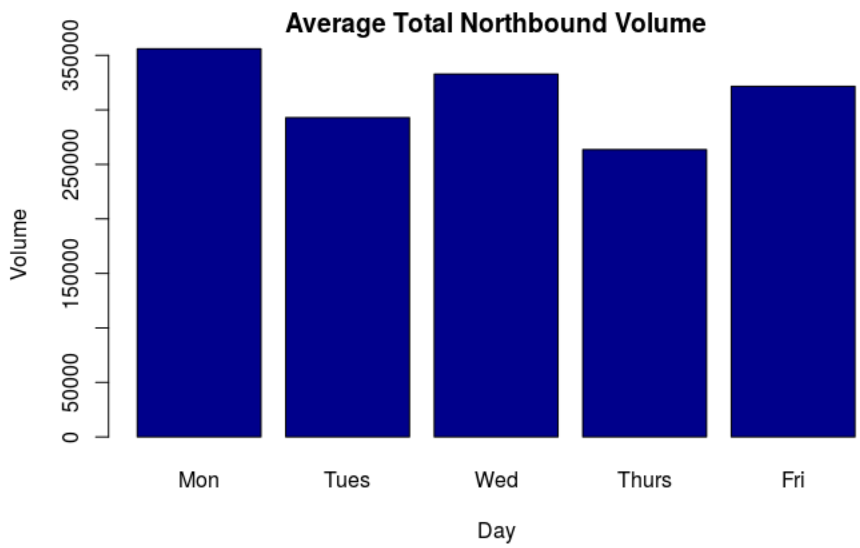


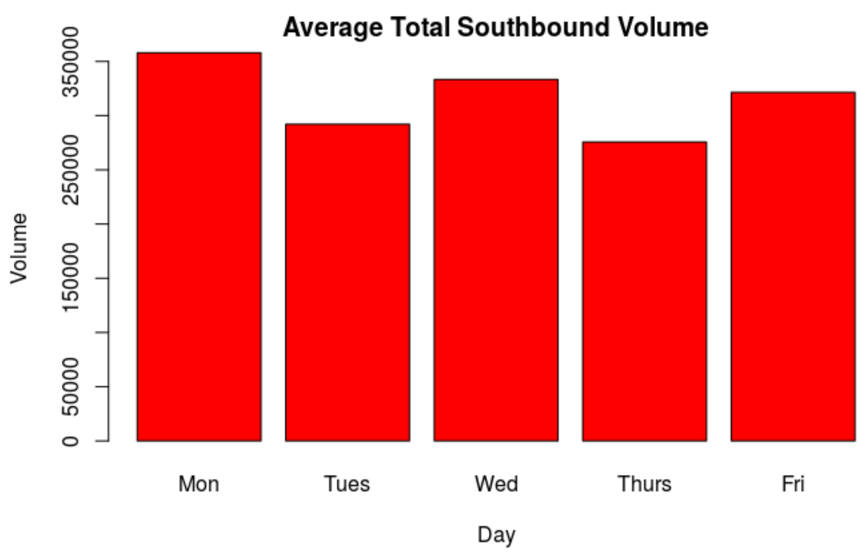
These plots illustrate trends over time. The lane volumes by month were plotted for both general and toll lanes. Only data was considered from times when a toll was being charged. The plots reveal a dip in late January/ early February. This has been attributed to a regional snowstorm event. Other than the storm anomaly, volumes seem relatively consistent throughout the year.





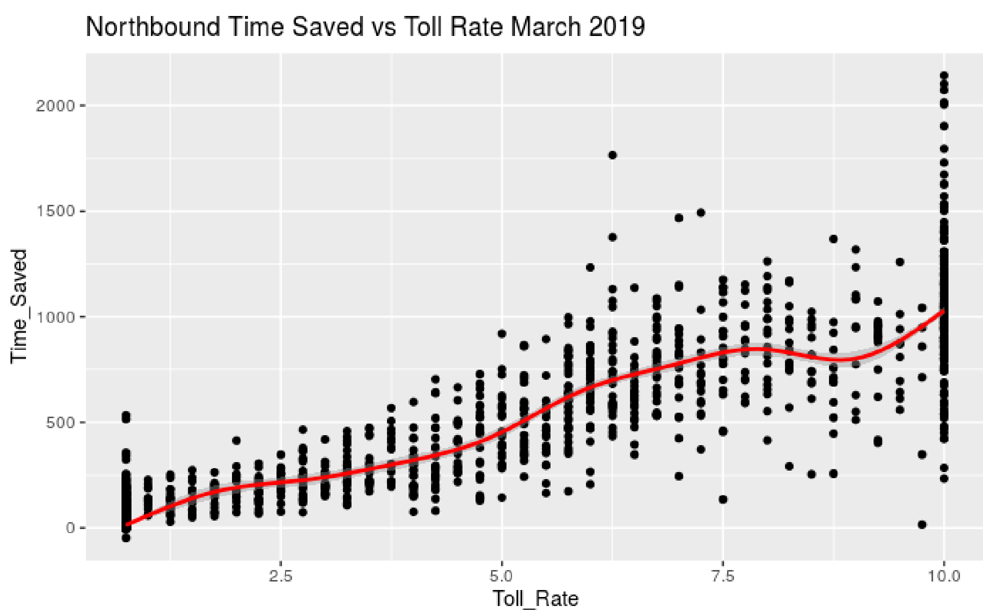
The bar chart shows that the highest volume of vehicles occurs when a toll between $0.75 and $1.00 is being charged. The second highest volume occurs at the $10 rate.





Tuesday and Thursday are the lowest volume days for both directions.

The average travel time savings were plotted for both directions against the average rate for each time interval. The plot shows what appears to be a general positive linear relationship between time savings and toll rate.



The northbound data for the month of March was plotted using the precise time savings for a day and time, and the actual rate at that time, rather than using averages as in the previous plot. Since this is a large data set, the month of March was arbitrarily selected to simplify the plot. Only times where a toll was being charged were considered. Visual inspection shows the relationship may be better described by an exponentially fit model. Further exploration of the data found the distribution of time saved does not appear normal, and the data has some outliers.

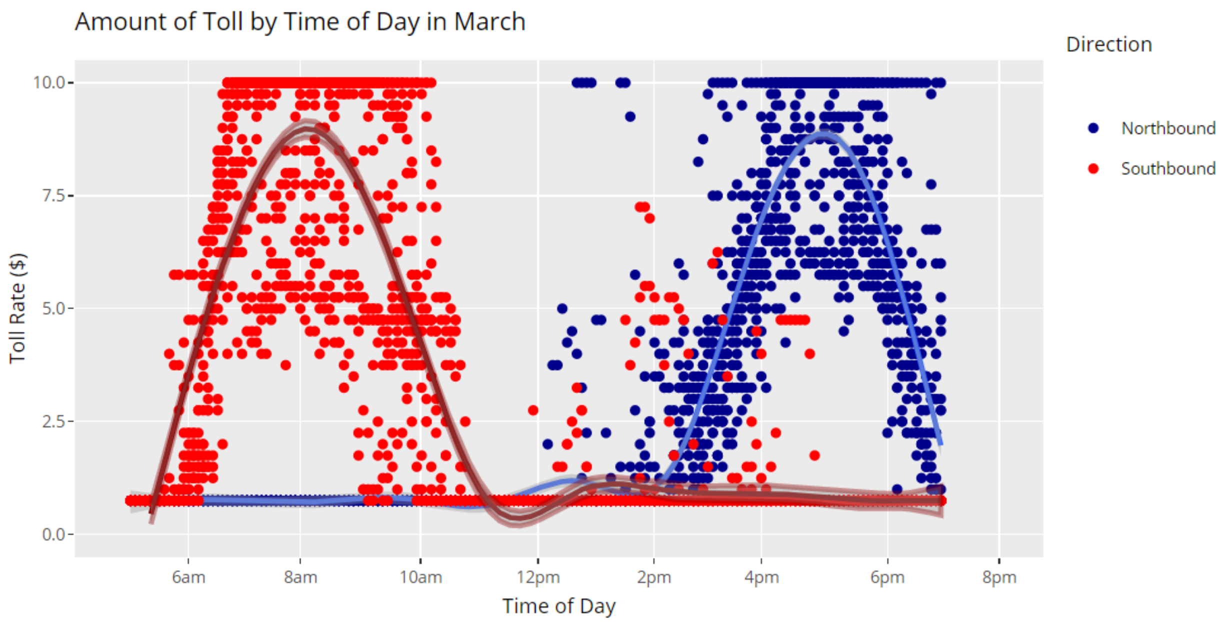
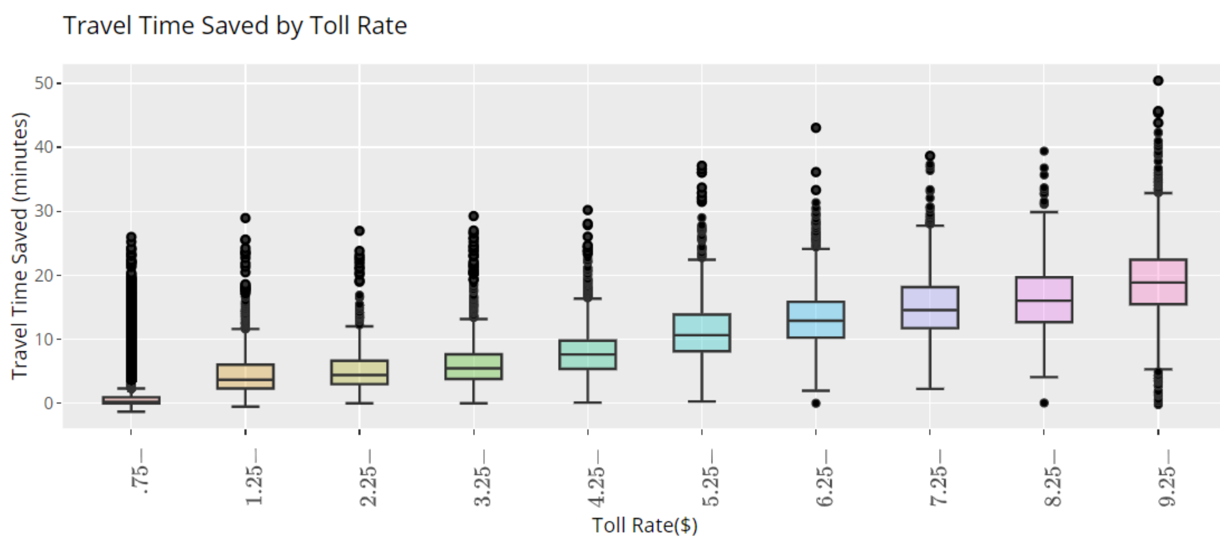


Figure 10 This plot shows the toll rate charged at each time of day during March 2019. Weekends and holidays were removed from this data set.



This plot is for all 2019 data with weekends, holidays, and snowstorm dates included, for both north and southbound travel directions. Travel time saved is calculated as the difference in travel time between Toll and General Lanes