

AN ANALYSIS ON THE I-405 HIGH OCCUPANCY TOLLS IN WASHINGTON STATE

Submitted by
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TABLE OF CONTENTS

ACKNOWLEDGMENTS	3
ABSTRACT.....	4
PURPOSE OF STUDY.....	5
RESEARCH QUESTIONS	5
LITERATURE REVIEW.....	8
METHODOLOGY.....	12
RESULTS AND DISCUSSION.....	14
CONCLUSION.....	19
APPENDIX.....	22
BIBLIOGRAPHY.....	34

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ABSTRACT

In September of 2015, the Washington State Department of Transportation (WSDOT) by approval of state legislature, opened the express toll lanes on the auxiliary highway known as Interstate 405 (I-405). Part of a master plan¹ to improve one of Washington's most congested highways². WSDOT's objective was to add a dynamic tolling system to improve commutes in both South and North directions of the highway³. In this paper, I will examine the efficiency⁴ of the I-405 High Occupancy Toll (HOT) lanes using commuter data provided by WSDOT for the year 2017-2018⁵ through regression models I created. It is important to further investigate into the efficiency of tolling systems as it becomes more commonly utilized by several state departments of transportation across the United States as a method to moderate congestion. Through this analysis, I hope to add additional information to help further develop an understanding and to provide feedback on its efficiency. The current HOT pricing model is guided by a mathematical algorithm that manages toll rates from real time traffic and updates every ten minutes with a maximum charge of \$10. Although this analysis requires additional future research, I concluded that the I-405 HOT lanes have not been operating above forty-five miles per hour ninety percent of the time during the peak hours that it was required to be according to the Revised Code of Washington 47.56.880. As a result, there appears to be little differentiation from the HOT lanes to the general-purpose lanes in terms of congestion moderation.

¹ <https://www.wsdot.wa.gov/Projects/I405/I405MasterPlan.htm>

² [https://en.wikipedia.org/wiki/Interstate_405_\(Washington\)](https://en.wikipedia.org/wiki/Interstate_405_(Washington))

³ See Appendix A for a visual on the portion of the highway that is being observed.

⁴ "Efficiency" in this context refers to RCW 47.56. 880 as the "average vehicle speeds in the HOT lanes remain above forty-five miles per hour at least ninety percent of the time during peak hours." <https://app.leg.wa.gov/rcw/default.aspx?cite=47.56.880>

⁵ Data was compiled by Sara Myers, Urban Mobility & Access – Tolling Toll Systems Operations Data & Reporting Specialist for WSDOT.

PURPOSE OF STUDY

Congestion is one of the biggest concerns for major urban cities around the world⁶. According to an analysis by the U.S. Census Bureau (2004), the share of people carpooling was 12.2% in 2000, which accounts for the second largest share: 77% of people drive alone; and 4.7% use public transit⁷. As High Occupancy Toll (HOT) lanes increase in popularity⁸ throughout the United States, dynamic pricing becomes an increasingly common topic for researchers. The concept is firmly based in microeconomic theory Pigou⁹ (1920) who was first to recognize that traffic congestion entails an external cost, and that efficiency requires a toll equal to the marginal external congestion cost. According to Lou et al. on optimal pricing in “Optimal Dynamic Pricing Strategies for High-Occupancy/Toll Lanes,” explains time operation policies of HOT lanes are to provide a superior free-flow traffic service on the toll lanes while maximizing the throughput rate of the freeway.

Currently, it is highly debated whether or not HOT lanes actually reduce congestion or if they even have any impact on general purpose (GP) lanes as a result. Although this issue has many sides to it, this paper focuses on efficiency of the I-405 lanes. The purpose of this analysis is whether the current HOT lanes on I-405 going Southbound and Northbound are relieving congestion as defined by the Washington State Law, Revised Code of Washington (RCW) 47.56.880. The RCW's states that vehicles must

⁶ https://transportgeography.org/?page_id=4621

⁷ US Census Bureau **Journey to work: 2000—census 2000 brief** (2004)
<http://www.census.gov/prod/2004pubs/c2kbr-33.pdf>

⁸ <https://www.pewtrusts.org/en/research-and-analysis/blogs/stateline/2016/09/12/express-lanes-have-a-popularity-problem>

⁹ A.C. Pigou *The Economics of Welfare* Macmillan, London (1920)

continuously flow at a minimum of forty-five miles per hour ninety percent of the time during peak hours of traffic in the HOT lanes otherwise the HOT lanes must be immediately dismantled. In addition, I examine if these results impact the GP lanes in terms of congestion reduction. In other words, by looking at the HOT lane data from the Washington State Department of Traffic (WSDOT), I hope to determine whether the HOT lanes are operating according to plan and then consequently assess if the current toll lanes are influencing the non-toll traffic. Through an additive statistical model, I examine the following two research questions: Are the I-405 High Occupancy Toll lanes in Washington State operating efficiently according to state law (RCW 47.56.880)? As well as, finding out whether the current pricing algorithm used on the I-405 lanes influence the efficiency of the High Occupancy Tolling lanes thus effect the General-Purpose lanes by not reducing congestion as intended to by WSDOT.

According to a study done by Hideo Konishi et. al., "Carpooling and Congestion Pricing: HOV and HOT lanes" (2010), policy improves the social welfare in some cases, but aggravates the situation in other cases. Konishi et. al. states that, HOV policy encourages carpooling, thereby reduces the total traffic, however, concludes that this policy also causes distortion from the difference in congestion levels between the two types of lanes. They proceed to discuss the two basic types of pricing and the effect of two alternative policies: uniform congestion pricing and differential pricing with lane division. He explains that uniform pricing is equivalent to the conventional Pigouvian toll, but also articulates that this policy is "not the first-best option". Their study particularly looks at how the optimal allocation is attained through differential pricing in which where two groups of lanes with differentiated tolls and no charge for carpoolers. Finally,

Koshini et. al. concludes that the results really depend on the particular situation but believes tolling in the regular (GP) lanes encourages carpooling more so than just on HOT lanes. Similarly, Joy Dahlgren, author of, *High occupancy vehicle lanes: Not always more effective than general purpose lanes*, states that it is not clear that constructing a high occupancy vehicle lane will necessarily reduce delay more than construction of a general-purpose lane through her research. Additionally, Small, claims that the specific problems addressed are failing infrastructure, financially weak public transit, environmental impacts of motor vehicles, motor vehicle accidents, and traffic congestion. He argues that quantitative economics is not the only vantage point from which to examine transportation policy, but it can at least focus attention on a range of sensible options.

HOT lanes have been adopted by the Los Angeles, San Diego, Houston, Salt Lake City, Denver, and Minneapolis-St. Paul metropolitan areas, and many other cities are still considering introducing HOT lanes (Koshini et. al.). Although this is a fact, many researchers suggest that tolling practices is not for everyone the reason being each HOT system is unique in its own way and the demands are different. For instance, the HOT lanes in Washington D.C. do not have a price cap of \$10 such as the ones on I-405 in Washington State. The first ever HOT lane in Orange County, California, focuses on a main twofold goal to reduce congestion and improve air quality¹⁰.

Examining Washington States' current HOT lanes, my first research question examines both sides of the I-405 HOT lanes, above 522 to Lynnwood (Southbound and

¹⁰ https://lao.ca.gov/2000/010700_hov/010700_hov_lanes.html

Northbound) and toll lanes below 522 to Bellevue (Southbound and Northbound). Through a logistic regression and multiple regression to determine its efficiency according to the definition in RCW 47.56.880. I hypothesize that due to the pricing dynamics of the tolls on the I-405 with the ten-dollar maximum charge, the HOT lanes cannot operate at their intended efficiency due to the price restraint and causing lane-changing issues between the HOT and GP lanes. To investigate this hypothesis, I conduct a regression analysis using a stepwise approach from the 224,000 total data points. Regression analysis is used to measure two HOT lanes of traffic first below Lynnwood Southbound and Northbound and the second model focusing on to Bellevue (Southbound and Northbound). The second research question asks if the HOT lanes are not operating as they were intended to do consequently causing the general purpose (GP) lanes to be affected by the HOT lanes pricing.

LITERATURE REVIEW

The purpose of this study is to determine if the I-405 HOT lanes are operating efficiently and for its purpose in accordance to RCW 47.56.880. As a result, I hope to determine whether HOT lane efficiency influences the general purpose (GP) lanes.

The Washington State Department of Transportation is a Washington governmental agency that constructs, maintains and regulates Washington's transportation infrastructure. It was established back in 1905 when then-governor Albert Mead signed a bill that gave \$110,000 to fund new roads that linked the state¹¹. WSDOT is responsible for more than 20,000 miles of roadway, including the I-405 toll

¹¹ <https://historylink.org/File/7272>

lanes that are implemented today. According to WSDOT, the purpose of implementing the I-405 toll lanes is to collect tax for the tolling system to pay off the borrowed structure from Texas and ultimately reduce congestion in the I-405 corridor. As mentioned earlier, by law, the HOT lanes are required to operate at a continuous minimum forty-five miles per hour ninety percent of the time the tolling system is in operation to be considered “efficient.” If the criteria were not met, the state law instructs that the I-405 tolling lanes be immediately dismantled. (The lack of enforcement is additionally an issue within this type of policy itself.)

Additionally, HOT lanes bring on several other troubles such as wasted fuel, added pollution, health problems and other socioeconomic issues. Jonathan D. Hall, a professor at the University of Toronto, highlights this side to the topic of HOT lanes in his recent publication, “Can Tolling Help Everyone? Estimating the aggregate and distributional Consequences of Congestion Pricing*” (2018). In this article, Hall acknowledges that road-pricing “creates losers as well as winners” which is why he says it is usually hesitantly implemented. However, as HOT lanes continue to become a common practice in many major cities across the states the consideration to equity [becomes] less of a priority as the focus is mainly on optimal pricing (Hall, 2019, p.1). “Impacts of congestion pricing and reward strategies on automobile travelers’ morning commute mode shift decisions” Li et. al. depicts why congestion pricing strategies were not implemented in major cities such as Beijing or Shanghai after an evaluation of equity and public acceptance. Their study illustrates the importance of developing complementary modules that target numerous factors in different stages of the mode shift decision-making process to promote mode shifts from automobile to sustainable

travel modes without overlooking certain populations (Li et. al., 2019, p.1). In “Sustainable cities: Innovative solutions for mobility and logistics” by Chiara et. al. (2019), uses Rome, Italy as an example of how they consider equity matters. Road users affected by the pricing policy are limited to those travelling in city zones where the mass public transport network is available and the toll amount is related to the level of accessibility to public transport whether only in origin/destination of the trip or in both (Chiara et. al., 2019, p.95). California’s State Route 91 (SR91) in Orange County was studied by Small et. al. in which they concluded that “HOV and HOT policies do not appear to have answered the long-standing call for efficient yet politically viable road pricing policies” (Small et. al. 2006). Additionally, The United Nations Development Programme¹² acknowledges and constitutes a goal which “provides access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport.” Some argue that HOT lanes increase economic disparity. A local grassroots group of all parties in Washington, *Stop405tolls.org*, demand to get the legislature to remove the tolls and not expand them when they widen I-405 south to SR167. The group has over 32,000 signatures petitioning for the removal of the I-405 tolls for various reasons. In an interview with Founder of *Stop405Tolls*, David Hablewitz, states that the biggest concern is that Snohomish county residents are footing the higher end of the bill compared to those on the Bellevue side of the HOT lanes. Due to the construction and placement of the HOT lanes, Bellevue’s side of the toll lanes has an extra tolling lane and are not necessarily in-use during peak traffic

¹² A program from the United Nations' global development network. It advocates for change and connects countries to knowledge, experience and resources to help people build a better life for themselves.

hours whereas Snohomish county residents have the disadvantage and in addition come from a lower income bracket.

Although several studies examine numerous sides to current HOT practices, most researchers agree that current HOT lanes implementations are not operating at its best efficiency rate. Furthermore, Konishi et. al., suggests that under differential pricing, a positive toll needs to be charged on regular lanes even in the presence of HOV/HOT lanes. An optimal toll structure in the latter case is similar to HOT policy in that a higher toll is charged on carpooling lanes. However, a (lower) toll on regular lanes is necessary to accompany a toll on carpooling lanes, since otherwise the carpooling incentive is thwarted. This policy reduces the total number of vehicles by promoting carpooling while controlling the distortion from any difference in congestion levels between lanes (Konishi et. al., p. 174). In “Flat Versus Spatially Variable Tolling: A case study in Fresno, California” (2014) by Rouhani et. al. examines three different road segments. This case study ended up revealing that optimal toll patterns are not dependent on vehicle miles traveled (VMTs) or volumes but, rather, are related to targeted volumes per capacity (V/Cs). Therefore, flow-dependent charges along a corridor should be based on V/Cs rather than on volumes or VMTs was their recommendation.

This goes to say that depending on the area or dynamics of HOT lanes in place, further studies should be done according to location for best outcomes. In an article by Aman Batheja, “Logistical Issues And Elitism in Toll Lanes,” focuses on the issues of the toll lanes in Houston, Texas coping with the financial deficit with major highway projects. The Houston HOT lanes have two entrance ramps. Single-occupant vehicles

take a ramp where an electronic reader charges the account linked to each car's toll tag. Vehicles with multiple passengers are directed to the HOV ramp, where a toll worker counts the passengers in a car as it passes and notifies a police officer if any vehicles are trying to skirt the system. They are developing a system similar to one used in Atlanta, where drivers, either online or by phone, update their toll tag accounts in advance when they expect to have enough passengers in the vehicle to qualify for discounted tolls. However, author Batheja, articulates that greater public subsidies are needed in HOT projects "to make it work." Currently the I-405 operates through a dynamic tolling system at a discounted price with the *Good to Go!* pass, however, does not have HOT lanes as detailed as those in Houston or Atlanta.

METHODOLOGY

Data for this study was the hourly HOT lanes transactions for the 2017-2018 year. To access this data, I contacted the WSDOT Urban Mobility and Access specialist for the years 2017-2018 which contains over 224,000 data points regarding the operating hours of the HOT lanes on an hourly basis for every day between January 2017 up until the end of the operating time of December 2017. Note, these tolls do not operate on weekends, during major US holidays, and recently due to community request, overnight between 7:00PM to 5:00AM. Nonetheless, to achieve the most possible accurate average with the provided data, I created regression models in Microsoft Excel to examine the relationships between hours in the day and the dependent variable as the number of cars using the toll lanes. The purpose of this analysis is to determine if the

dynamic pricing has an impact on efficiency and consequently causing the general purpose (GP) lanes to be affected by the HOT lanes pricing.

Analysis Strategy

To analyze the first research question, I examine both sides of the I-405 HOT lanes, above SR-522 to Lynnwood and toll lanes below SR-522 toward Bellevue. Through a logistic regression, I assess its efficiency using RCW 47.56.880 as the rubric. The first model is a simple regression with the hours as the independent variable and the dependent variable as the number of cars passing through the toll lanes. Here the dependent variable is whether the vehicle used the HOT lane or not.

The second model, is a multiple regression model that has hour as the independent variable as well as price. Its dependent variables are the number of cars using toll lanes (transactions). For the hours, I had thirteen dummy variables that represented each hour of the operating tolls (0/1).

Ethical Considerations

The primary purpose of the Institutional Review Board (IRB) is to protect the rights and welfare of human subjects involved in research activities being conducted under its authority¹³ however, since the data I received from WSDOT is not directly traceable to individual human subjects, this project did not require going through the IRB process. Owing it to the data points on each side of the HOT lanes being

¹³ <https://www.irb.pitt.edu/content/chapter-2-purpose-human-research-protection-office-and-institutional-review-board>

safeguarded by WSDOT, the anonymity of drivers passing through the HOT lanes were protected and never undisclosed for this analysis.

RESULTS AND DISCUSSION

Demographics

Again, due to privacy laws, I am not able to precisely pinpoint the origin of each vehicle that passes through the HOT lanes so I assume these lanes are primarily used by residents of Snohomish and King county where the I-405 HOT lanes operate. Using a five-year average of statistics from the *U.S. Census Bureau (2013-2017)*, the median income of Lynnwood residents of Snohomish county is \$58,852. Whereas residents in Bellevue City of King county, make an average of \$105,402. Also, according to the American Community Survey (ACS) 5-year summary report (2013-2017), of the 38,511 Lynnwood resident households, 87.9% (+/-0.7 MOE) persons of over 25 years had an educational attainment of high school graduate (or higher but not finishing the degree) and 28.8% with a bachelor's degree bachelor's degree or higher. The dominant race in this city was White at 62.2%, then 17.1% Asian, 13.3% Hispanic or Latino, and 7.1% Black or African American. Workers over the age of sixteen reportedly had an average time of 31.3 minutes' travel time to work. On the other hand, the 147,599 Bellevue City households surrounding the I-405 tolls had a 95% educational attainment of high school graduate (or higher but not finishing the degree) and 65.5% with a bachelor's degree bachelor's degree or higher. The dominant race in this city was White at 55.9%, 33.8% Asian, 7.2% Hispanic or Latino, and 2.8% Black or African American. Workers over the age of sixteen reportedly had an average time of 23.4 minutes' travel time to work.

Main Study Results

Results of the logistic regression analysis stratified by the pricing algorithm that is supposed to moderate congestion on the I-405 lanes at least ninety percent of the time revealed that according to the p-value (>0.05), I do not reject the null hypothesis for both models one and two. However, taking into consideration the privacy laws protecting individuals as they go through the HOT lanes was a limitation to being able to attain precise concrete data points thus thwarted accurate results. Nonetheless, this regression best estimates and describes the size and direction of the relationship between the predictor and the response variable. Coefficients are the numbers by which the values of the term are multiplied in the regression equation.

Table 1 (see appendix) is the Southbound regression data and estimated transactions for the first regression model stated above. Due to the nature of the pricing algorithm, privacy laws, and restrictions from WSDOT, I had to use this model to estimate price and as a result number of transactions per hour. Earlier in the paper I distinguished that a maximum of 1,920 vehicles is considered the optimal number of automobiles permitted within the HOT lanes. So, by looking at *Table 1*, Southbound, at the intercept for the first regression model, the number of transactions is still operating efficiently at 5AM with a coefficient of 1516.43 transactions for the first hour ($B=1516.43$, $P>0.05$). However, from 6AM until 10AM, the system fails at running efficiently and has over 1,920 vehicles per hour in the HOT lanes. At 6AM (D1) the number of transactions is 3396.45 ($B=1880.01$, $P>0.05$) then the number of transactions increase to 4377.01 at 7AM ($B=2860.57$, $P>0.05$). It is not until 8AM ($B=2752.79$, $P>0.05$) that the number of transactions start to decrease to 4269.23 at 9AM ($B=2113.57$, $P>0.05$). 10AM

($B=831.96$, $P>0.05$) has 2348.39 transactions. At 11AM ($B=262.05$, $P=0.01$) the HOT lanes become optimal again with 1178.48. Transactions continue to decrease until 12PM ($B=232.58$, $P=0.01$) with 1749.01 transactions. 1PM the transactions being to increase but remain optimal at 1853.49 ($B=337.06$, $P>0.05$). It is until 2PM that the optimal capacity of the HOT lanes is broken with 2067.27 transactions ($B=550.84$, $P>0.05$). At 3PM and 4PM transactions remain over the 1920 optimal capacity count at 2256.30 ($B=739.87$, $P>0.05$) and 2190.68 ($B=674.25$, $P>0.05$). At 5PM transactions barely reach the cutoff at 1914.68 transactions ($B=398.25$, $P>0.05$). For the last hour of the operating system, transactions decrease to 1178.19 ($B=-338.24$, $P>0.05$).

For model one Northbound, from 5AM until 1PM, the HOT lanes remain at optimal capacity however from 2PM up until the HOT lanes cease to operate for the day, they fail to serve its purpose. Intuitively, during those hours is when rush hour occurs so one can infer that the tolls have reached the price maximum thus lane capacity.

Model two Southbound (*Table 4*), the HOT lanes are only optimal for its first hour of operation with 1137.4 transactions at seventy-five cents during 5AM ($B=-98.70$, $P=0.01$). Then by 6AM ($B=185.78$, $P>0.05$) the number spikes to 2607.93 transactions at three dollars. 7AM ($B=351.84$, $P>0.05$) its 3255.17 transactions at the maximum charge until 8AM ($B=417.27$, $P>0.05$) with 3126.90 transactions. Then by 9AM ($B=416.47$, $P>0.05$) 2515.43 transactions are at three dollars. By 10AM ($B=424.34$, $P>0.05$) the HOT lanes become capable of being optimally used with only 1623.31 transactions being recorded at a dollar toll. This decreasing number of transactions

trend continues until the tolls cease operating at 6PM ending with 773.73 transactions (B=1260.67, P>0.05).

Model two Northbound (*Table 3*) demonstrates an optimal capacity until 2PM comes around at 2037.96 transactions (B=1145.30, P>0.05). At 5AM there is the minimum seventy-five cent charge at 149.84 transactions (P>0.05), 6AM has 334.64 (B=185.78, P>0.05) transactions, 7AM total 499.78 (B=351.84, P>0.05), 8AM is 564.68 (B=417, P>0.05) transactions, 9AM is 565.05 (B=416.47, P>0.05), 10AM 574.25 (B=424.34, P>0.05) transactions, 11AM 648.98 (B=497.57, P>0.05) transactions, 12PM 788.55 (B=636.67, P>0.05) transactions, 1PM 1139.53 (B=989.33, P>0.05) transactions. At 3PM is when the shift occurs at 3056.82 (B=510.19, P>0.05) transactions. Then at 4PM 3210.41 (B=433.88, P>0.05) transactions at a maximum ten-dollar toll charge, 5PM 2955.75 (B=411.66, P>0.05) transactions at eight-dollars a toll and then, 6PM 2142.15 (B=1260.68, P>0.05) transactions at three-dollars.

Research Question 1: Does the pricing algorithm influence the efficiency of the HOT lanes?

According to the regressions inputted on excel the tolls are not operating at its efficiency rate (see appendix). The first regression (*Figures 1, 4, 5, and Tables 1,2 in appendix are visual representations regarding the first regression*) tells us that the toll lanes are not always at optimal efficiency levels. This means that at times, there are too many vehicles utilizing the lanes, or that there are too few vehicles using the tolled lanes. I calculated the maximum efficiency levels for the HOT lanes, which came out to be 1,920 cars for both I-405 northbound and southbound. Looking at the first regression

model on northbound, five of the fourteen hours from 2:00 PM to 6:00 PM are running on levels above maximum efficiency meaning that the lanes too crowded for the current system to operate as desired by WSDOT. The rest of the nine hours are running at levels below the maximum efficiency, making a lot of room for improvement. The Southbound had eight of the fourteen hours running above the maximum efficiency in two segments from 6:00 AM to 11:00 AM and from 2:00 PM to 5:00 PM. The rest of the six hours ran at times below maximum efficiency.

The second regression (*Figure 2 in appendix*) included theoretical calculated hourly pricing. Through this regression, the willingness to pay from consumers is based on an hourly segmentation. After running this regression, the number of individuals that would pay to use the tolls during each hour is revealed. However, due to the constraint of a different market each hour and having a \$10 maximum charging fee, I was unable to create an effective pricing demand model for *every* hour due to the random fluctuation. However, this regression uncovers the trend that individuals are more willingly to pay during busier hours when the market has more customers (*Figure 3*).

Research Question 2: Are the HOT lanes having any impact on the GP lanes?

As a result of the findings in research question one, it is identified that the HOT lanes are not operating at the appropriate efficient speeds. What this means for my second research question in this additive model analysis, is that due to the failure of the tolls, congestion occurs despite the pricing algorithm that is meant to function.

CONCLUSION

Although the research has reached its aims, there were some unavoidable limitations. First and foremost, the lack of available data. Data used in this analysis was only looking at a single year and a data set that only contained hourly segments. To improve its accuracy and precision, it would be beneficial for future researchers to have access to individual information as well as the complete data set to the rest of the years of the operating system. Since the I-405 HOT lanes are relatively new opening in 2015, it is difficult to get an accurate average from the current data available. It is important to continue research on this topic as these systems gain popularity and impact several populations in various ways from equity issues to environmental impacts. Despite limitations to this research, I suggest a follow-up study at the end of the 2020 year to have five years' worth of data and create an average through the same regression models presented earlier.

One of the largest managerial implications I encountered was the idea of "carpoolers and solo drivers". If more drivers carpooled, then it would eliminate the number of cars on the road, intuitively speaking. However, if there are more solo drivers, it would increase capacity on any lane of the highway. During peak traffic hours, solo drivers may feel that they can pay a premium to avoid traffic in the GP lane. However, the WA-522 split at Bothell separates a two-lane expressway as opposed to one lane above WA-522 near the Snohomish county line. When we derive the per capita income in neighboring cities like Bellevue, Redmond, or Kirkland, it is much higher than it is in Bothell, Lynnwood, or Woodinville. When there is a traffic bottleneck at the WA-522 'chokepoint' and more cars pile into the single lane express lane, the

dynamic tolling algorithm will skyrocket which means that Snohomish county residents are footing the higher bill which brings us to another side of the issue on equality which this paper does not get into but acknowledges. Although this is counterintuitive in the sense that those of a lower median income range, pay more than those who have a higher income range, and are still subjected to one less lane. This is briefly explained by the regression data which shows the 'above capacity' points going northbound at the WA-522 chokepoint which means that people are heading away from the metropolitan areas and heading home.

Anyway, the aims of this research were to highlight how tolls affect our transportation initiatives and how our knowledge of these things can help us make more informed decisions. Future endeavors include looking at pricing models and how optimal High Occupancy Toll lanes can run without the use of the current I-405 tolling system. Perhaps take on a model to the one in D.C. with no price maximum? Or charge a toll on all lanes as other researchers recommended?

Nevertheless, pricing models WSDOT was unwilling to provide data regarding revenue per transaction, limited this study from accurately analyzing the regressions through optimal pricing. However, by estimating the pricing per hour, I was able to analyze the pricing demand model for each individual hour. Although, there are restraints to this method, such as the \$10 cap and the possibility of inaccurate calculated data, to avoid these limitations I decided to focus on hours *not* including the \$10 cap and look for other methods to verify and produce a more accurate pricing per hour model.

In conclusion, the I-405 HOT lanes have not been operating above forty-five miles per hour ninety percent of the time during the peak hours that it was required to be according to the Revised Code of Washington 47.56.880. As a result, there appears to be little differentiation from the HOT lanes to the general-purpose lanes in terms of congestion moderation. The High Occupancy Toll lanes are not running at the optimal effective rate on I-405, however, data shows that there is much room for improvement when looking at the optimal efficiency of the HOT lanes. When the lanes are below and near optimal capacity levels we should find a way to increase the levels and likewise when the lanes are above optimal levels. However, to do so we cannot rely on optimal pricing being the only solution as some other researchers also mentioned. Some may claim the solution to increasing the efficiency on the I-405 HOT lanes would be optimal pricing, while this could work theoretically, when capacity within the HOT lanes are above optimal levels by increasing price to reduce the amount of driver would ultimately benefit those on the higher end of the income bracket. I believe this is not the solution, traffic should be elevated and effective for all individual not just those who are able to afford the luxury of paying for the HOT lane. Short-term solutions could involve reducing the price when the HOT lanes are running below optimal capacity to increase the amount of users in the lane. I am unable to say that this solves the problems and create more optimal lanes, but the current data indicates that the current tolling pricing dynamic is creating bottleneck problems rather than relieving congestion preventing the HOT lanes from reaching its optimal capacity and operate accordingly.

APPENDICES

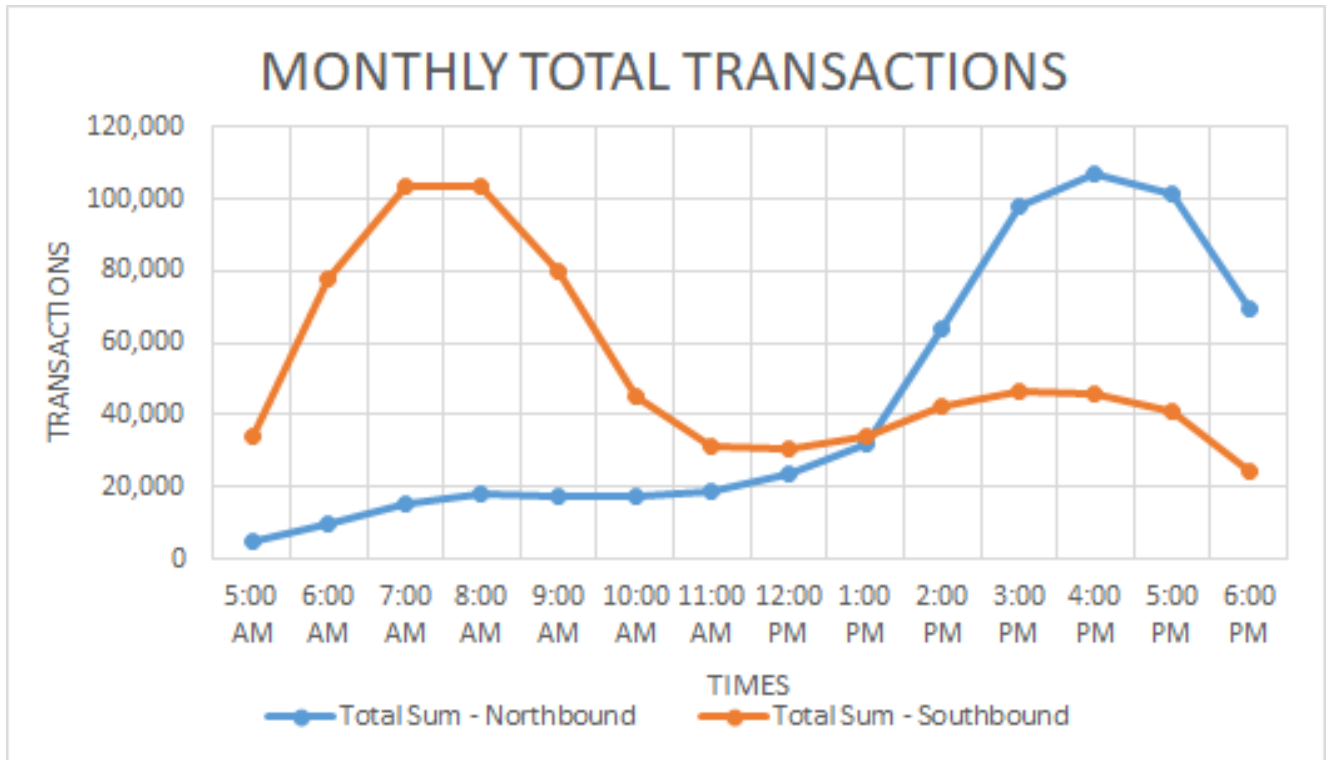
A.

Toll Location Map

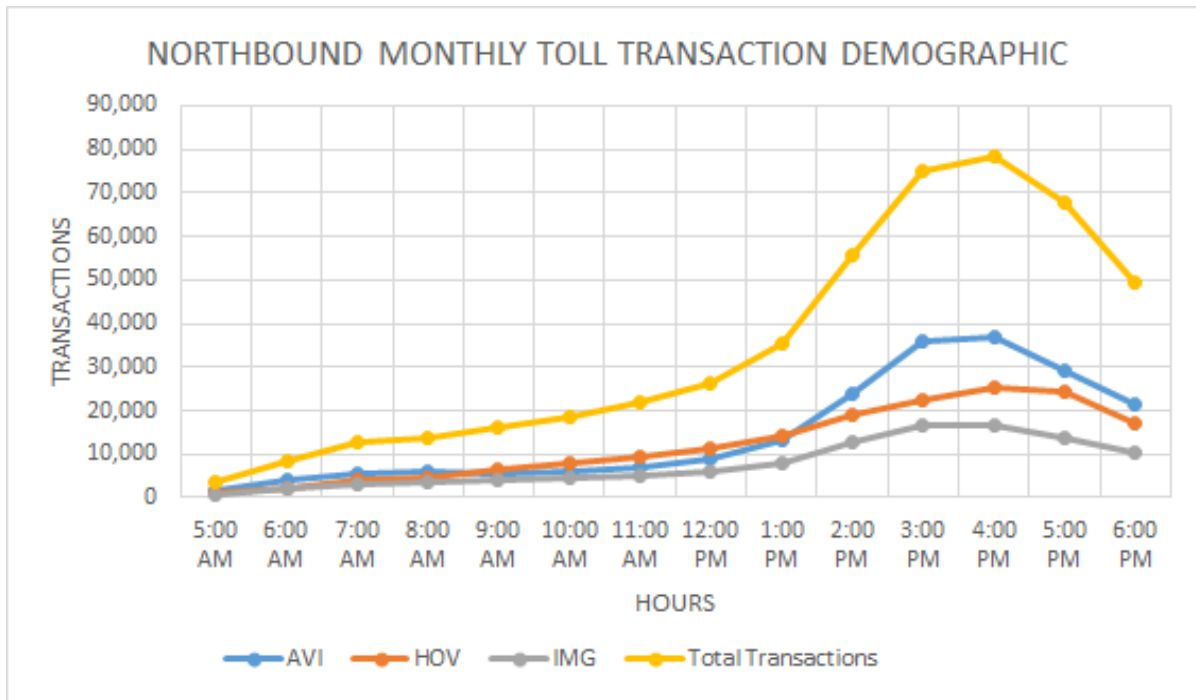


B. Figure 1 - Monthly Total - Transactions on 405 – NB/SB

(First regression)



C. Figure 2 - Monthly Toll Transaction Demographic for 405 Northbound
(First regression) ¹⁴

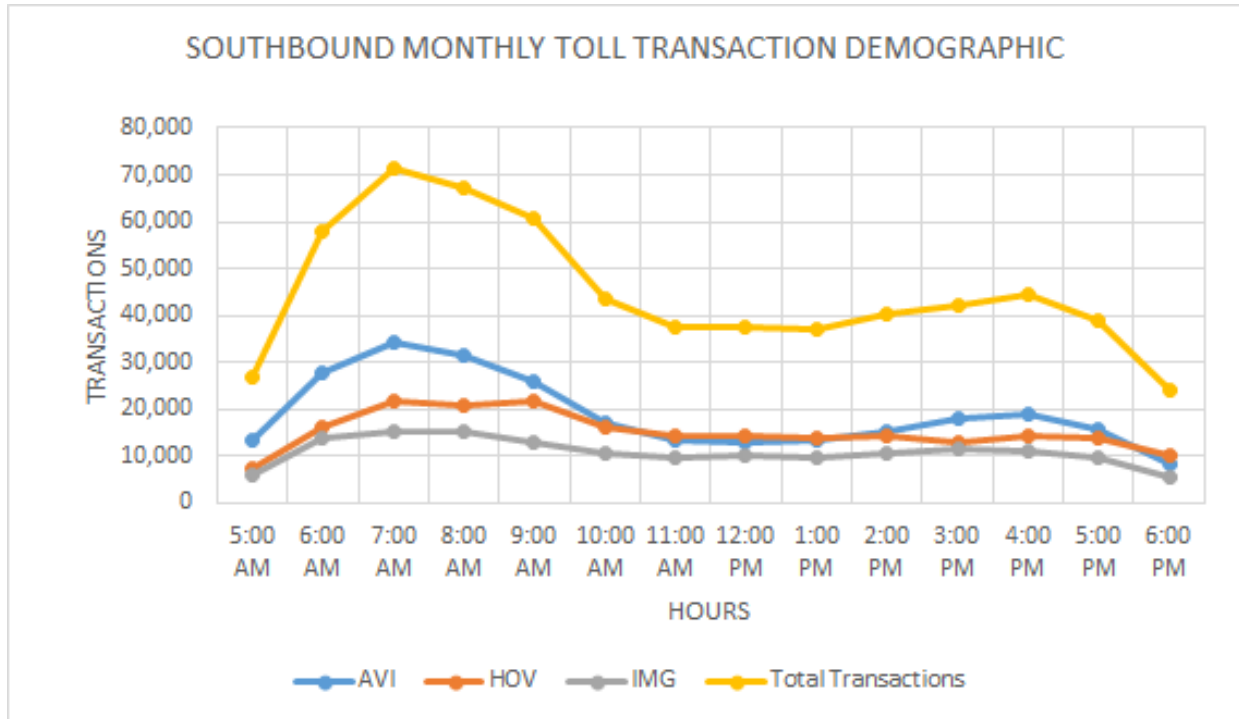


NorthBound - Monthly Toll Transaction Demographic				
Time	AVI	HOV	IMG	Total Transactions
5:00 AM	1,560	1,315	771	3,646
6:00 AM	3,994	2,241	1,948	8,183
7:00 AM	5,371	4,009	3,153	12,533
8:00 AM	5,866	4,609	3,413	13,888
9:00 AM	5,533	6,474	4,143	16,150
10:00 AM	6,054	7,862	4,645	18,561
11:00 AM	7,113	9,574	5,271	21,958
12:00 PM	9,011	11,479	5,915	26,405
1:00 PM	13,165	14,043	8,164	35,372
2:00 PM	23,917	19,156	12,718	55,791
3:00 PM	36,098	22,405	16,671	75,174
4:00 PM	36,650	25,291	16,541	78,482
5:00 PM	29,387	24,502	13,898	67,787
6:00 PM	21,515	17,328	10,408	49,251

14

AVI: People who have the *Good To Go!* pass.
 HOV: 2-3 Person Carpool, Flex Pass is 3+
 IMG: People who pay by mail.

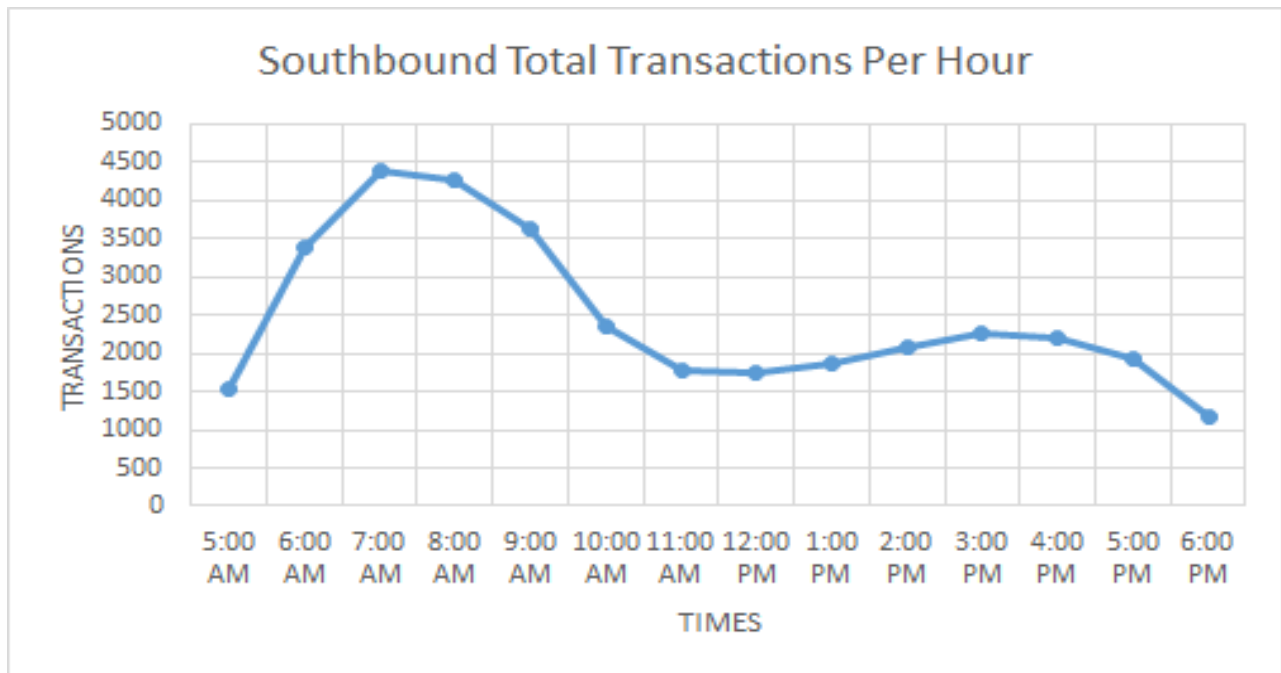
D. Figure 3 - Monthly Toll Transaction Demographic for 405 Southbound



SouthBound - Monthly Transaction Demographic				
Time	AVI	HOV	IMG	Total Transactions
5:00 AM	13,308	7,449	5,885	26,642
6:00 AM	27,930	16,262	13,786	57,978
7:00 AM	34,232	21,791	15,217	71,240
8:00 AM	31,394	20,684	15,060	67,138
9:00 AM	25,854	21,747	13,003	60,604
10:00 AM	16,918	15,963	10,752	43,633
11:00 AM	13,438	14,348	9,716	37,502
12:00 PM	13,065	14,076	10,230	37,371
1:00 PM	13,276	13,970	9,840	37,086
2:00 PM	15,314	14,432	10,737	40,483
3:00 PM	17,908	13,102	11,338	42,348
4:00 PM	19,002	14,243	11,245	44,490
5:00 PM	15,829	13,675	9,475	38,979
6:00 PM	8,337	10,121	5,592	24,050

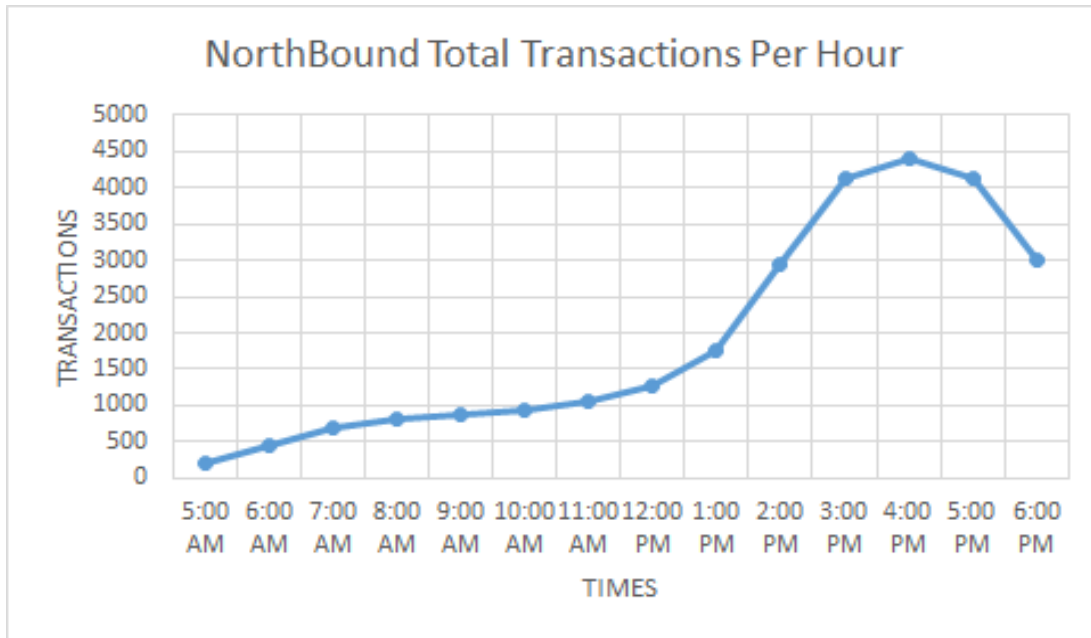
E. Figure 4 - Total Transactions/Hour for 405 SB

(First Regression Model)



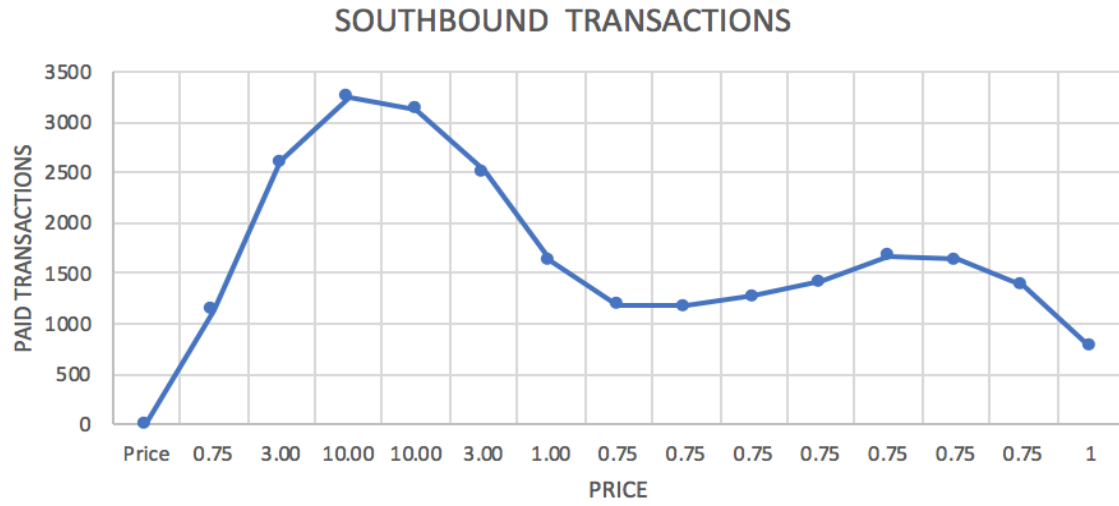
F. Figure 5 - Total Transactions/Hour 405 NB

(First Regression Model)



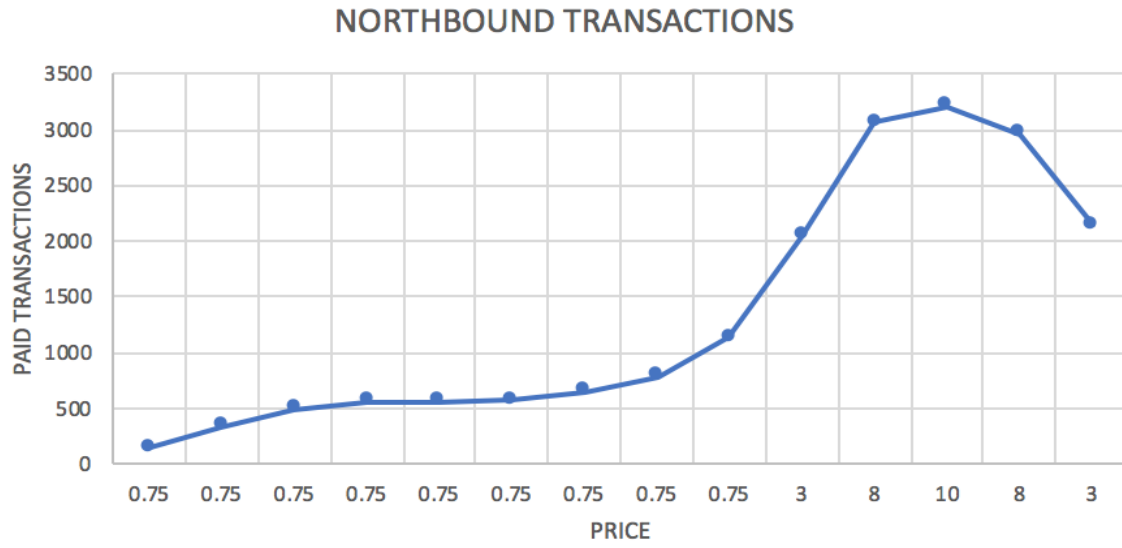
G. Figure 6 - Total Transactions/Hourly Price SB

(Second Regression Model)



H. **Figure 7** - Total Transactions/Hourly Price NB

(Second Regression Model)



I.

Table 1**Southbound Regression Data and Estimated Transactions for First Regression**

	Coefficients	p-value	Time	Transactions
Intercept	1516.432653	0	5:00AM	1516.432653
D1	1880.008163	0	6:00AM	3396.440816
D2	2860.575477	0	7:00AM	4377.00813
D3	2752.799054	0	8:00AM	4269.231707
D4	2113.579542	0	9:00AM	3630.012195
D5	831.9616559	0	10:00AM	2348.394309
D6	262.0510868	0.0000002517613193	12:00PM	1778.48374
D7	232.5795421	0.000004686475323	1:00PM	1749.012195
D8	337.0592169	0	2:00PM	1853.49187
D9	550.8356396	0	3:00PM	2067.268293
D10	739.8681599	0	4:00PM	2256.300813
D11	674.2502738	0	5:00PM	2190.682927
D12	398.2502738	0	6:00PM	1914.682927
D13	-338.2415962	0	7:00PM	1178.191057

Note: >1920 transactions is considered a failing system and <1920 is optimal. n=3,443

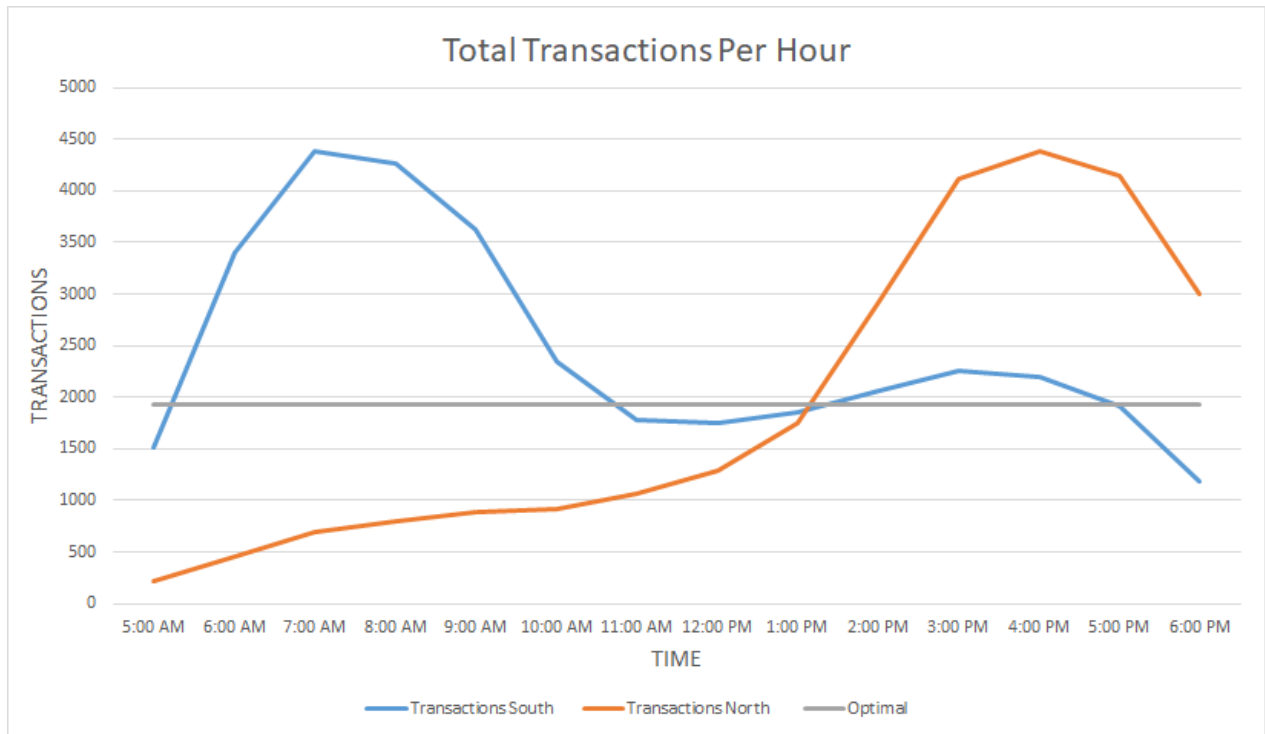
J.

Table 2**Northbound Regression Data and Estimated Transactions First Regression Model**

	Coefficients	p-value	Time	Transactions
Intercept	221.1693548	0	5:00AM	221.1693548
D1	232.266129	0.00000001343092198	6:00AM	453.4534839
D2	474.1157857	0	7:00AM	695.2851406
D3	581.9872717	0	8:00AM	803.1566265
D4	669.6499223	0	9:00AM	890.8192771
D5	701.0595608	0	10:00AM	922.2289157
D6	846.1760267	0	12:00PM	1067.345382
D7	1064.991288	0	1:00PM	1286.160643
D8	1523.26438	0	2:00PM	1744.433735
D9	2706.099721	0	3:00PM	2927.269076
D10	3891.927031	0	4:00PM	4113.096386
D11	4168.248316	0	5:00PM	4389.417671
D12	3917.637874	0	6:00PM	4138.807229
D13	2783.818597	0	7:00PM	3004.987952

Note: >1920 transactions is considered a failing system and <1920 is optimal. n=3,485

K. Figure 8 - Total Transactions/Hour with Optimal Transactions



Total Transactions Per Hour			
Time	Transactions South	Transactions North	Optimal
5:00 AM	1516.432653	221.1693548	1922
6:00 AM	3396.440816	453.4354839	1922
7:00 AM	4377.00813	695.2851406	1922
8:00 AM	4269.231707	803.1566265	1922
9:00 AM	3630.012195	890.8192771	1922
10:00 AM	2348.394309	922.2289157	1922
11:00 AM	1778.48374	1067.345382	1922
12:00 PM	1749.012195	1286.160643	1922
1:00 PM	1853.49187	1744.433735	1922
2:00 PM	2067.268293	2927.269076	1922
3:00 PM	2256.300813	4113.096386	1922
4:00 PM	2190.682927	4389.417671	1922
5:00 PM	1914.682927	4138.807229	1922
6:00 PM	1178.191057	3004.987952	1922

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