Evaluation of Congestion Pricing for Management Highway in Seattle

Aman J. Aman, Diana C. Nuñez, Mohammed Hamideddin, Pankaj Laungani, Wail Abbo

Abstract—Congestion is one of the most important and complex transportation problems facing the American population. The Texas Transportation Institute reported that delays due to congestion cost up to an average of $63.1 billion per year and 5.7 billion gallons of wasted fuel every year. An important area of interest is Seattle Washington, where, according to the Washington State Department of Transportation, residents averaged over 46 hours of annual delay per traveler in 2003. The rapid increase in population and travel demand along with the unmatched growth of infrastructure in Seattle has resulted in the desire for evaluating a Congestion Pricing strategy that will help reduce traffic delays and improve the throughput of the I-5 network, in the Puget Sound Region.

Analysis of a similar existing system (State Route 167) showed success, and similar key parameters are being used in the evaluation of the new system, such as population, traffic trends, income levels, etc. The performance of the new system is evaluated based on three decision variables or metrics: throughput of system, average speed and trip reliability. We are using Noblis' traffic model known as INTEGRATION 1.5x7 which simulates traffic data but does not incorporate prices (toll prices). We will be looking at existing systems such as SR 167 and California Freeway and Expressway System to incorporate prices in our model. An Arena Simulation model was created and calibrated to the INTEGRATION model. Preliminary analysis and results show that variably priced lanes (HOT lanes) seem to be the best fit for our region of interest. All three models work together to simulate existing traffic data and the results are evaluated to analyze the performance of the different congestion pricing systems in the I-5 network, along the Seattle Central Puget Sound Region.

I. INTRODUCTION

Traffic congestion is one of the major issues affecting cities in the United States throughout the past 70 years. The Texas Transportation Institute reported that delay cost sums up to an average of $40 million per year and 5.7 billion gallons of fuel were wasted every year, because of congestion **[1]**. As populations grow, the demand for travel grows and more vehicles are purchased every year. This increase is not evenly matched with the supply of roads and highways. According to the U.S. Government work Accountability Office, from 1980 to 2000, VMT (Vehicles Miles Traveled) increased by 80% while urban lane miles increased by only 37% **[2]**.

Travel demand is increasing at a fast rate that is unmatched by highway capacity. As a result, traditional methods of reducing traffic congestion such as construction and building of highways and roads are proving to be less cost-beneficial in the mean time.

Congestion Pricing was first introduced as an economic tool to match supply and demand. Due to increasing rates of travel demand, this approach was more effective and the focus shifted to managing demand. Managing demand aims to improve traffic flow by reducing travel demand or redistributing it in space or in time. This is believed to be more cost-effective than building new roads and than of expansion of lanes.

II. SYSTEM DESCRIPTION

A. System Overview

The specific region being studied includes the northern portion of the corridor stretching from Everett to Downtown Seattle. This sub region totals 193 square kilometers, of which Interstate 5 Stretches roughly 38 kilometers from Everett to Seattle City. As of 2003, the Federal Highway Administration sites that on average the length of the average rush hour's trip has increased an additional 37% since1982 **[3]**. The increase in population and travel demand in Seattle has resulted in the desire for evaluating a Congestion pricing (CP) system that will help reduce traffic delays and improve the throughput of the I-5 network in the Puget Sound Region. Two pricing strategies are evaluated: High Occupancy Toll (HOT) Lanes with Prescheduled Tolling (PCP), and HOT Lanes with Dynamic Tolling. Our proposed CP system will convert all High Occupancy Vehicle (HOV) lanes to HOT lanes in the I-5 network. As a result, drivers will be encouraged to carpool in order to save time. HOT Lanes with Dynamic Tolling (DCP) will vary in prices according to peak hours of congestion. The performance of the new system should increase the throughput of the I-5 transportation network, increase travel reliability, and increase average speed.

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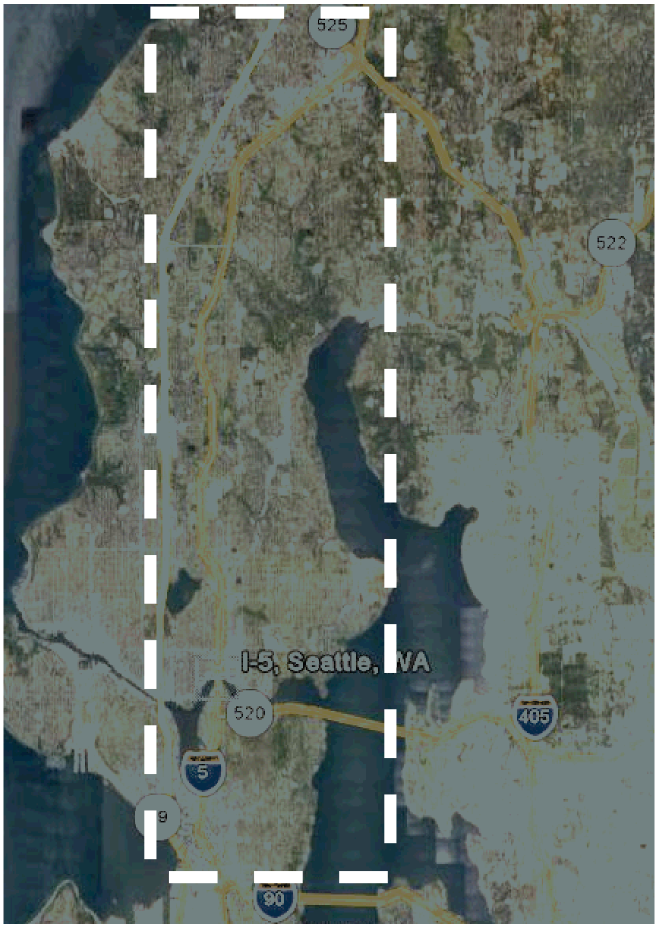

Figure1: Map of our Study Area.

III. SYSTEM DESIGN

Extensive research was done on existing systems and their effects on their networks. A plethora of data and information was collected about existing congestion pricing, from the Department of Transportation, WSDOT and interviews with tolling companies such as Tran urban. After analyzing all the information acquired, we decided to focus all of our efforts on HOT specifically. The other CP strategies were disregarded based on the following:

- **Cordon Pricing**- charges the drivers per entering a inner city area. Usually implemented in inner cities and urban areas. Our network is composed of major highways and implementing a cordon pricing scheme will not be effective because the corridor being evaluated does not fit the criteria, considering its size and location. Also most of the trips made by the drivers in the network being evaluated are not to sub-urban or inner city areas.

- **Area-Wide Pricing**-Based Charges- implementing this pricing scheme will not be beneficial because of the short length of the I-5 being evaluated for the purposes of this project. This pricing scheme follows the motto: "the more you drive the more you pay and the less you drive the more you save". Since our network only stretches for 38.14 Km due to the limitations of our simulation software, Integration 15x7, the cost of implementing it will overweigh the benefits of using it.

The travel trends of the Seattle Puget Sound Region helped in determining which congestion pricing schemes would best fit their network. Trends of the entire Puget Sound Region suggest that an overwhelming amount of users travel as Single Occupancy Vehicle (SOV) **[6]**. The overall throughput of the HOV lanes didn't match the capacity of each lane, which led our team to believe conversion of the current HOV lanes to HOT lanes was the most appropriate strategy.

A. Design Alternatives:

1) ***Base Line***

The first alternative is not to do anything and leave the existing system as is. This means considering leaving the area of interest of the I-5 unchanged, with no implementation of HOT lanes or transformation of existing HOV lanes into HOT lanes.

2) ***HOT Lanes with Prescheduled Tolling (PCP)***

The second alternative is to evaluate HOT lanes with a predetermined toll schedule. Predetermined schedules use existing travel data as an input to determine the toll price. The most well known system that utilizes this scheme is California's State Route 91 Express Lanes. Predetermined schedules relieve congestion delays with the variable tolls but also in providing more predictability to the individual users.

3) ***HOT Lanes with Dynamic Tolling (DCP)***

The third alternative is to evaluate HOT lanes with a dynamic tolling scheme. These systems are more complex, and use sensors in the roadways to collect live traffic data. This live data is the basis of the toll price. A similar system was recently implemented on State Route 167 in Seattle, which is parallel the Interstate 5.

B. Value Hierarchy

A value hierarchy was developed to provide the basis of the design alternatives and the utility function. The variables' weights were based on a weight elicitation method, in which experts on the subject matter, who represent stakeholders, were surveyed. Our CP System's top-level values are Network Performance and Cost. Network performance includes: throughput of the transportation network, average travel speed, and trip reliability which we will measure based on trip predictability. Cost consists of only 1 parameter which is user cost. The sub values for both top-level values were derived from existing reports and data of the WSDOT Project State Route 167 HOT Lanes Pilot Project.
Figure 2 below is a diagram of CP System's value hierarchy.

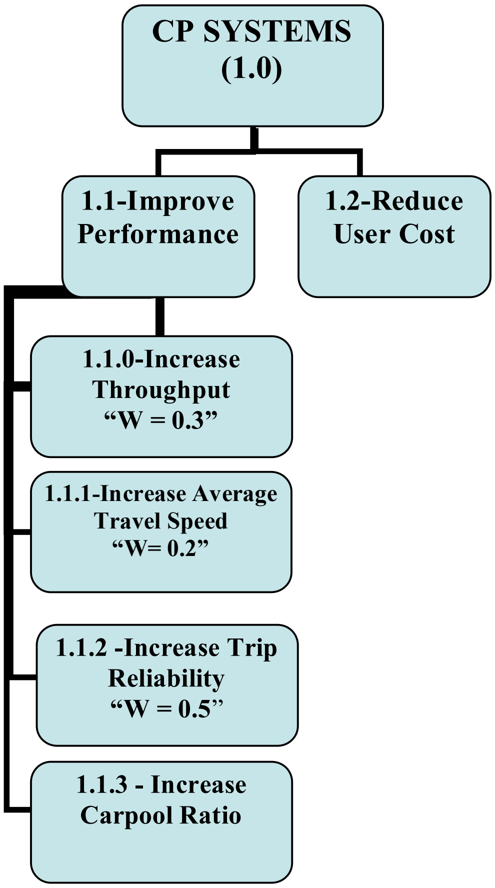

Figure 2: Value Hierarchy

Our Network performance measures will be analyzed based on estimated volume, speed and reliability conditions. For example, if we take a specific location, I-5 184th St. and we plot an estimated frequency of congestion, volumes and speeds graph, we can demonstrate how congestion affects vehicle speed and throughput. Figure 3 below, shows congestion, measured in vehicle volumes per lane by time of the day in HOV and GP lanes. It also demonstrates how congestion can entice the use of HOV lanes. However, the increase of usage of HOV lanes can overwhelm the capacity of its lanes, which results in a decrease of travel speed; which is denoted by the color coded segments of the line. By converting HOV lanes into HOT lanes we can manage the volume of cars on the lanes, and thus maintain a good flow travel speed in both: the HOT lanes and the GP lanes. As far as reliability is concerned, due to the daily fluctuation of conditions, we can examine reliability by reporting on the frequency with which congestion occurs.

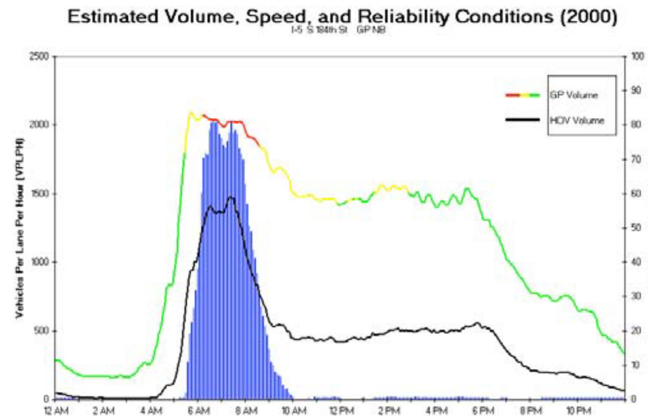

Figure 3: Estimated frequency of congestion for GP lanes with GP and HOV lanes volumes **[4]**. The shaded region represents the traffic congestion, which is the high volume or over capacity of cars/lanes, between 6 am and 10 am.

C. Utility Functions

The utility function will be a sum of the variables as presented in the value hierarchy. These values include Performance (P) and User Costs (UC). We have derived the following utility functions from the value hierarchy:

$$U(P,C) = 0.8*P + 0.2*UC$$

Both top-level variables are then broken down into sub functions, which are also determined from the value hierarchy.

$$P = 0.3T + 0.2S + 0.5R$$
$$C = 1.0\ UC$$

T = Throughput (Vehicle per lane)
S= Average Speed (kilometers per hour)
R = Reliability (hours per trip)
UC= User cost ($/year)

The parameter units will be scaled and converted into percentages. These percentages will be calculated from the differences between existing and baseline data and the results obtained from our simulation runs and model outputs.

IV. System Model and Analysis

For this project, we will use the Noblis Integration model and an economic model that we created, to implement dynamic tolling (DCP) and sensitivity analysis. For prescheduled tolling (PCP), we created an ARENA discrete dynamic model, which simulates specific segments of the I-5, and incorporates user costs, and uses sensitivity analysis on arrival rates, to determine prices.

Noblis Integration Model

Noblis Integration model was provided to the team to use to evaluate congestion pricing. Noblis Integration model analyzes traffic flows at the individual vehicle level. This approach allows a dynamic queuing-based traffic assignment, which is essential to modeling diversion and re-routing of traffic during congested conditions. The model's consideration of individual vehicles improves the resolution of the analysis that is carried out during the model's internal calculations, but it does not require the user to collect data at the individual vehicle level. Instead traffic flow characteristics and traffic demand can be specified by the user at a more aggregate level.

Computed measures include delay reduction, which is calculated based on the difference between the travel time and free flow, and throughput, that measures the number of cars that can successfully travel though the network during peak time. The most effective solution could be selected in terms of absolute minutes of delay saved per traveler. The model includes five heavy demand scenarios, and two weather/accident combination scenarios. The model classifies vehicles into seven classes, such as experienced drivers, HOV drivers, etc and provides individual data for each class.

Integration 1.5x7 does not support "prices" and the only input that could be manipulated is travel demand. Due to this limited flexibility, we developed an economic model that established a relationship between travel demand and toll prices. The model was used to study how changes in the toll price would affect travel demand in Integration, and vice versa. We ran the models several times, with different prices and travel demands and the results were consistent with our expectations, which are: an increase in toll price would lead to a decrease in travel demand. For the purposes of this project, we made two major assumptions/decisions:

(1) We will run Integration under only one "normal" scenario, assuming no accidents or weather conditions or external circumstances

(2) Of the seven driver classes, we will only analyze the HOV class, since the only HOV lanes are along our I-5 area of study

(3) We are only analyzing morning peak hours and travel periods i.e. 6am – 9 am

Economic Model

As mentioned earlier, this model was developed to establish a relationship between travel demand and toll price. The model uses price elasticity, which is an economic parameter that measures price sensitivity and how a small change in price will affect demand. According to the Victoria Transport Policy Institute, "price elasticity is defined as the percentage change in demand caused by a one-percent change in its price or other characteristics (such as traffic speed or road capacity)

The relationship that we established between toll price and travel demand (quantity of cars) was based on existing data of a similar congestion pricing system, primarily SR 167 in Seattle; we came up with the following equation:

$$Q=\alpha P^{\beta}$$

where "**Q**" is travel demand, measured in number of cars, "**α**" is a constant, "**P**" is the toll price, measured in dollars, and "**β**" is the price elasticity. We plugged in existing data for Q and P, from the SR167 and used the above equation to calculate α and P.E. We will also compare our β value to existing β values, which we obtained from transportation journals, publications and sources **[5]**. These sources were found through research and provided by sponsors and studies have shown that transportation price elasticity values usually fall between -0.20 and -0.30, with a range of -0.03 to -0.50 [Lawley Publications (2000)].

We used the equation and existing data to construct the graph on Figure 4. Using the model and graph, we obtained the following values for price elasticity and the constant:

$$\beta = -0.305$$
$$\alpha = 1195$$

To help verify our results and determine the accuracy of the data, we transferred our function to a linear equation using logarithms, and we came up with the graph in Figure 5. As shown in the graphs, the values for price elasticity and the constant were very close and consistent with our initial findings.

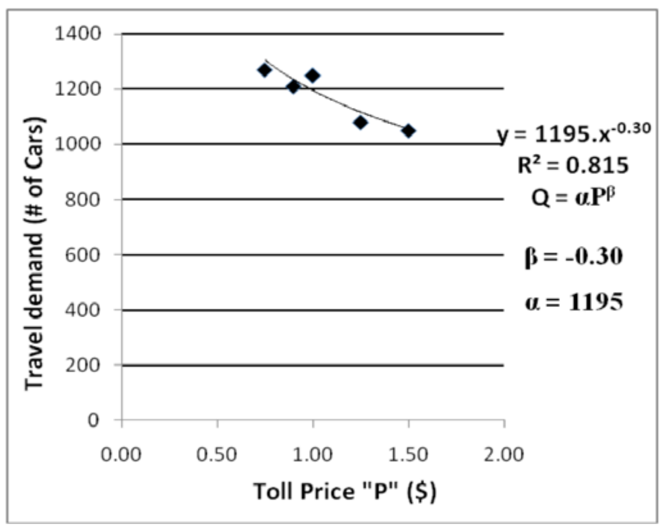

Figure 4: Price Elasticity Economic Model (1)

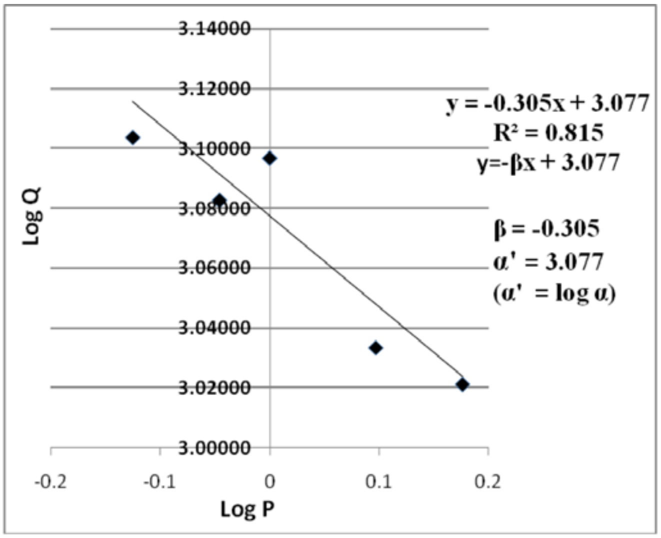

Figure 5– Price Elasticity Economic Model (2)

GMU Arena Model

A discrete dynamical model was developed to represent our region of study. This model includes congestion pricing, specifically pre-determined toll schedule. The decision to utilize the Arena simulation environment stems from the limited functionality of the Noblis Integration model to incorporate prescheduled pricing. The Noblis model serves as an accurate and microscopic depiction of the traffic patterns in the Northern region of Seattle and will be used to implement the dynamic pricing alternative.

Within Arena, the I-5 corridor is broken to several segments. Each represents a portion of the highway between entry or exit points. Vehicles enter the system and are designated basic characteristics including number of passengers, value of time, and destination. The vehicles proceed to their destination, and if it best serves the vehicles to take the HOV lanes it will do so. This is strictly based on assessing the cost of taking the HOV versus staying on the general purpose lanes.

The cost is a product of that specific vehicles estimated value of time multiplied by the total travel time across the path. The cost along the HOV links is the sum of that cost plus the monetary amount of the toll. To determine the price, sensitivity analysis was conducted for each arrival rate (within the rush hour period) and the results were evaluated against the values of our stakeholders.

Surveys developed by the Puget Sound Regional Council to determine the most popular origin and destination of work trips of the Seattle residents. The studies allowed the surveyors to characterize their trips by to 5 main Central Business Districts. The Interstate 5 is a major link to access two of the 5, the CBD of Seattle and Tacoma, which will we will focus on.

Arrival Rate: Exponential (0-1) (cars/second)
Value of Time: Normal ($14.60,σ) **[7]**
Process Rate: The capacity of each segment was evaluated by the number of cars it can hold at a specific point in time. This capacity is a constant value which represents vehicles traveling at free flow speeds.

V. Conclusion

Our study consists of determining the best congestion pricing strategy to reduce traffic delays in the Seattle Puget Sound Region. The Noblis Integration model is utilized as an accurate depiction of the study area, and is used, along with an economic model to implement dynamic congestion pricing. An Arena discrete model was developed and calibrated to the Integration model, to incorporate prescheduled toll pricing and decision modules,. The models and simulations are run numerous times and the output and results are analyzed and a sensitivity analysis is performed, to help in the tradeoff analysis of our design alternatives based on the values of our stakeholders.

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