Traffic Choices Study

– Summary Report

Puget Sound Regional Council
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The Puget Sound Regional Council (PSRC) is a regional planning agency that develops policies and makes decisions about transportation, economic development and growth management in the central Puget Sound region of Washington state. PSRC's primary activities are long-range planning, prioritizing and distributing federal funding for transportation in the region, and providing regional data and analysis.

The region's natural setting includes snowcapped peaks, abundant waterways and shorelines and lush forests and greenery. The region rises from seawater tidelands to the crest of the Cascade mountain range and extends through the glacially sculpted lowland of the Olympic Peninsula. The region is made up of four large counties: King, Kitsap, Pierce and Snohomish, which encompass 6,290 square miles and contain 82 cities and towns. The five major cities are Seattle and Bellevue in King County, Tacoma in Pierce County, Everett in Snohomish County and Bremerton in Kitsap County.

Traffic Choices Study – *Summary Report*

A Global Positioning System Based Pricing Pilot Project: Evaluating Traveler Response to Variable Road Tolling Through a Sample of Volunteer Participants

prepared by.........**Puget Sound Regional Council**

for the.........**Value Pricing Pilot Program**
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1. Overview

Technical studies and popular opinion agree: congestion in urban areas is getting worse. The standard approaches, such as building more roads, urban mass transit systems, even better land use planning, are not doing enough to solve the problem. Citizens in the greater Seattle metropolitan area face significant traffic congestion problems[1]; they spend 40 percent more time traveling by automobile during peak periods than they would spend if congestion were not present. Estimates of the cost of congestion, to residents and businesses in the central Puget Sound region, range from between $1.5 billion to $2 billion annually. These costs are primarily in the form of lost time that cannot ever be recovered. Many look to state, regional and local agencies for improvements.

But the region's topography and existing development patterns make the construction of new transportation capacity expensive. Planners are concluding that adding to transportation supply (whether highways, transit lines and vehicles, bike lanes, or sidewalks) is only part of the solution, and that public policy must pay more attention to improving the effectiveness of existing systems and managing the demand for travel.

Congestion-based road tolling attempts to make more efficient use of roads by charging the people who use them. Flat rate tolls are one form of charging for the use of roads. But the major transportation problem in urban areas is congestion, which occurs when too many people want to use the same route at the same time. Thus, roadway pricing is based on charging a variable toll: one that is higher on congested routes at congested times, offering a lower cost option when demand is less.

The few existing variable road-tolling projects have demonstrated that pricing can increase the efficiency of a transportation system. Instead of rationing space on the highway by wasting time in a queue, it gets rationed through payments. Those payments mean that the public sector gains revenues that it can use to further improve the transportation system, address issues of fairness (e.g., by finding ways to compensate travelers made worse off by the toll) or offset other existing taxes and fees.

In 2002, the Puget Sound Regional Council (PSRC) received a grant from the Federal Highway Administration to conduct a pilot project to see how travelers change their travel behavior (number, mode, route, and time of vehicle trips) in response to variable charges for road use (variable or congestion-based tolling). The project, called the Traffic Choices Study, placed Global Positioning System (GPS) tolling meters in the vehicles of about 275 volunteer households. The project observed driving patterns before and after hypothetical tolls were charged for the use of all the major freeways and arterials in the Seattle metropolitan area.

The primary aims of the Traffic Choices Study were to (1) accurately describe the behavioral response to the congestion-tolling of roadways, (2) better understand issues of policy related to the

[1] The Texas Transportation Institute's Urban Mobility Report (2007).

implementation of road network tolling, and (3) test an integrated system of technical solutions to the problem of tolling a large network of roads without deploying substantial physical hardware on the roadside. The study has met these goals and is the most comprehensive study of demand response to network tolls in existence. Primary conclusions from the study include:

1. Observed response of drivers to tolls suggests there is a dramatic opportunity to significantly reduce traffic congestion and raise revenues for investment.

   1.1 Motorists made small-scale adjustments in travel that, in aggregate, would have a major effect on transportation system performance.

   1.2 When approached systematically, variable road tolling, with investments of toll revenues, could make excessive reoccurring congestion a thing of the past.

   1.3 The scale of the revenues confirms the theoretical expectation that "optimal" tolls would support expanding transportation supply when and where it is needed most.

   1.4 While most revenues are generated on a small portion of the toll roads, the secondary road network (arterials) should not be ignored, as diversion causes real problems with revenue loss and displaced traffic.

   1.5 Users demonstrating a willingness to pay for high value roadways could expect that improvements would be forthcoming.

   1.6 Done right, network tolling could provide broad benefit, including lower vehicle emissions, fewer accidents, travel time savings, improved roadway performance reliability, and lower operating costs.

   1.7 A conservative analysis of the benefits of network tolling in the Puget Sound region indicates that the present value of net benefits could exceed $28 billion over a 30-year period.

2. Not all aspects of a road network tolling system have been fully demonstrated yet. But the core technology for satellite-based (and whole road network) toll systems is mature and reliable.

   2.1 The tolling system performed as expected, and met basic system operating requirements. Further work on system refinement and design of enforcement and billing systems would be required prior to any full system deployment.

   2.2 Tolling of dense road networks with facilities that have only minimal access controls requires special attention to issues of GPS accuracy, and the overall approach to facility use determination.

   2.3 The approach to processing road use information (within the on-board device or in the toll system back office) has implications for user privacy, system stability, and data communications costs.

   2.4 Enforcement would require other facility use verification approaches (DSRC, video capture, mobile enforcement) in addition to the GPS-tolling technology.

   2.5 Installing in-vehicle tolling devices is a costly logistical challenge, but relying on equipment to come standard with new automobiles won't be practical if it doesn't represent a trusted platform for road tolling.

   2.6 The costs for GPS-based tolling systems are dominated by the initial investment in in-vehicle tolling equipment, and the communication of data during operations. Over the last few years, costs have declined dramatically and are expected to continue to come down.

3. A large-scale U.S. deployment of a GPS-based road tolling program will depend on proven systems, a viable business model, and public acceptance of underlying concepts.
   3.1 The public sector business case is based on the sizable social benefits of road tolling. There are ways to generate revenues that are less administratively burdensome, but these displace economic activity, and fail to address traffic congestion.
   3.2 A transition to road network tolling would be costly and complex. It must be seen to be worth the sizable upfront effort.
   3.3 Road tolling will be seen as unfair unless people understand that directly charging users addresses existing inequalities across users of the transportation system, and improves overall economic efficiency, leaving society with greater resources available to address remaining issues of fairness.
   3.4 Concerns over user privacy depend on what data leaves the vehicle, and what safeguards are in place to limit its availability and use. A road tolling system can be developed such that user privacy is maintained. But like so many things, this would come at a price.
   3.5 Some experience and familiarity with road tolling makes people more open to the concept, but all programs are unique and will succeed or fail on their own merits. Road users are particularly interested in the question of how revenues will be used.

This report summarizes the approach and results of the Traffic Choices Study. It has three sections in addition to this **Overview**:

- Section 2, **Background**, describes (1) the reasons to expect that variable road tolling might help reduce peak-period congestion in urban areas, and (2) how variable tolling was implemented in this study;
- Section 3, **Behavioral Analysis**, summarizes the study's analytical approach and behavioral results;
- Section 4, **Analysis of Implementation**, goes beyond the results to suggest what they mean for the future of road tolling.

This report is a **summary** of the study. It is intended for a broad audience of decision makers, policy analysts, and interested citizens. Those wanting more detail can find it in a longer technical report (*A GPS-Based Pricing Pilot Project: Evaluating Traveler Response to Variable Road Tolling Through a Sample of Volunteer Participants; Volume 1: Project Report*; April 2008) and in yet more detailed technical appendices to that report.

2. Background

PROBLEMS COMMON TO URBAN AREAS: CONGESTION AND ROAD FINANCE

Metropolitan regions throughout the nation face increasing problems with urban congestion. Their citizens want better (or, at least, not deteriorating) mobility. Yet, in most cases new road and transit capacity is only a small increment of total capacity, is increasingly expensive, and is often quickly congested with new trips.

Not only is new capacity less effective and more expensive than it used to be, but funding to build that capacity has grown slower than the growth in traffic.

These dual and related problems (the large increases in travel demand and congestion, and small increases in the funding to address them) have encouraged transportation professionals and regional policy makers to consider more seriously the role that road tolling can play in bringing more balance to transportation supply and demand.

The current transportation system is financed through a combination of use-related taxes and fees, and broad taxing instruments that have little relationship to transportation system use. Most fees are scaled to recover some costs by applying an average charge to all similar users. Conventional road finance exacerbates rather than remedies the fundamental problems. The low charges on all mileage allow excessive congestion during peak periods. While the congestion prompts road authorities to build new capacity, the low charges cannot generate sufficient revenues to cover these new investments.

Correct pricing can help solve this problem. There are many ways to improve efficiency and to address the underlying demand for travel. Some are regulatory, such as restricted lanes and ramp metering. Others derive from the observable fact that the use of something

Variable Pricing: How and Why it Works

Variable pricing, based on peak periods of use, is a common form of pricing in other industries. It is used when capacity is fixed in the short-run, and demand fluctuates significantly between the peak and off-peak periods. Before cell phones, phone companies used peak-period pricing to encourage consumers to shift their use of the fixed capacity of the phone system to off-peak hours (e.g., by charging lower rates evenings and weekends). Some energy utilities use peak pricing. So do theaters. Economists recommend congestion pricing of roads for the same reason private firms use peak-period pricing: to use available resources more efficiently.

How would such pricing work for roads? Imagine that the vehicle you drive could tell a computer what road it is on, and at what time. Location and time correlate to the amount of congestion and delay you are experiencing. Higher (variable) prices during peak periods would encourage you, or travelers with less pressing needs, to shift to other routes, modes, or times.

That system has many advantages. By charging selectively at certain locations and times, one can influence the amount of congestion during peak periods. Variable pricing could reduce the immediate need for building new highway capacity. By knowing where people are willing to pay tolls, planners would have a direct measure of where to build more capacity: namely, where drivers are willing to pay high tolls because the travel is so important to them. When those signals suggested that new capacity would be beneficial, the accumulated toll revenues would provide money to pay for those improvements. Fairness could also be improved, as revenue is collected from those who burden capacity directly.

declines as its price increases. Variable or congestion-based tolls attempt to make more efficient use of roads by charging the people using them for a greater part of the costs their use imposes (in particular, the costs of reduced travel times for all other users of the transportation system).

Congestion occurs when too many people want to use the same route at the same time. Thus, road tolling, based on charging a variable toll, sends a signal to let people know that they are imposing uncompensated burdens on others, and that they are contributing to the scarcity of road capacity. It is appropriate that these users contribute the greater portion of the funding required to improve the supply. By failing to price road use under congested conditions, current policy inadvertently distorts the signals society uses to justify new capacity and, simultaneously, limits the fiscal capability to respond. In this sense, the absence of congestion tolls leads to too much of society's time resources dedicated to travel on the existing roadway system, an overstatement of needs, and fiscal disarray. Congestion-based tolling can not only turn stop-and-go congestion into flowing traffic; it can also generate revenue and give signals to the public sector about where travelers think trips are important enough that they are willing to pay for improvements.

DOING SOMETHING ABOUT THE PROBLEMS

The PSRC created a Transportation Pricing Task Force in 1995 to set some direction for road pricing policies. The Task Force consisted of local elected officials, transportation professionals, area business representatives, and environmental and public interest group representatives. The Task Force's mission was to provide public and elected officials with a framework for discussion and problem solving. The Task Force's work examined the underlying structural problems with the current transportation financing systems, paving the way for the general consideration of market-oriented approaches to finance. The Task Force also recommended the implementation of pricing demonstration projects to advance local understanding of the opportunities and consequences of variable road tolling.

In 2002 the PSRC received a grant from the Federal Highway Administration to conduct a pilot project to see how travelers change travel behavior (number, mode, route, and time of trips) in response to variable charges for road use (congestion pricing). The project placed Global Positioning System (GPS) tolling meters in the vehicles of about 275 volunteer households.

The project observed driving patterns before and after hypothetical tolls were charged for the use of all the major freeways and arterials in the greater Seattle metropolitan area. The study was designed to monitor and explain the travel choices of drivers as they faced road tolls (which varied by time and location). The primary aims of the study were to:

- accurately describe the behavioral response to the congestion-based tolling of roadways
- better understand issues of policy related to the implementation of road tolling
- test an integrated system of technical solutions to the problem of tolling a large network of roads without deploying substantial physical hardware on the roadside
- familiarize the public and policy makers with road network tolling
- generate price response data for use in other modeling and analysis
- develop an understanding of technological applications and standards, and
- better define a set of policy issues to be addressed in actual program design

Because no comparable real-world examples of such a congestion tolling system exist, this study (a wholesale departure from current road finance policy) required careful experimental design and implementation. The most important part of the Traffic Choices Study was observing travel. What choices did drivers make when required to pay tolls reflecting the amount of congestion a road was experiencing? The Traffic Choices Study is the most comprehensive study of demand response to network tolling in existence. The Traffic Choices Study recruited a statistically significant sample of volunterrs and, after establishing their baseline "before-tolling" driving routine, began charging them for access to selected roadway facilities at particular time periods in the day. In other words, they had to pay road tolls. The study monitored driving behavior of participants for an average of approximately 18 months per household.

Participants did not lose money. They were given an account (their travel budget, or endowment account) from which tolls were deducted. If their driving patterns remained unchanged over the experiment, they would "spend" their account balance by the time the experiment concluded. If they changed their driving patterns to reduce the amount of driving on toll roads, they would keep the difference. This method held participants financially harmless, yet offered them the incentive of keeping their leftover budget if they changed their driving patterns. In this way, the study introduced real price incentives of a toll system, and measured whether and how much participants responded to those incentives.

Conventional road tolling technologies would not support this experiment at any reasonable cost. Fortunately, recent interest in less infrastructure-intensive toll systems, and rapid advances in mobile computing and satellite-based positioning technologies, created an emerging industry for charging systems based on vehicle positioning capabilities. The experiment integrated functions that are already commonly found in automobiles into a single on-board device, or meter. The meter used Global Positioning System (GPS) technology to provide a highly detailed (second by second) record of travel behavior for each vehicle.

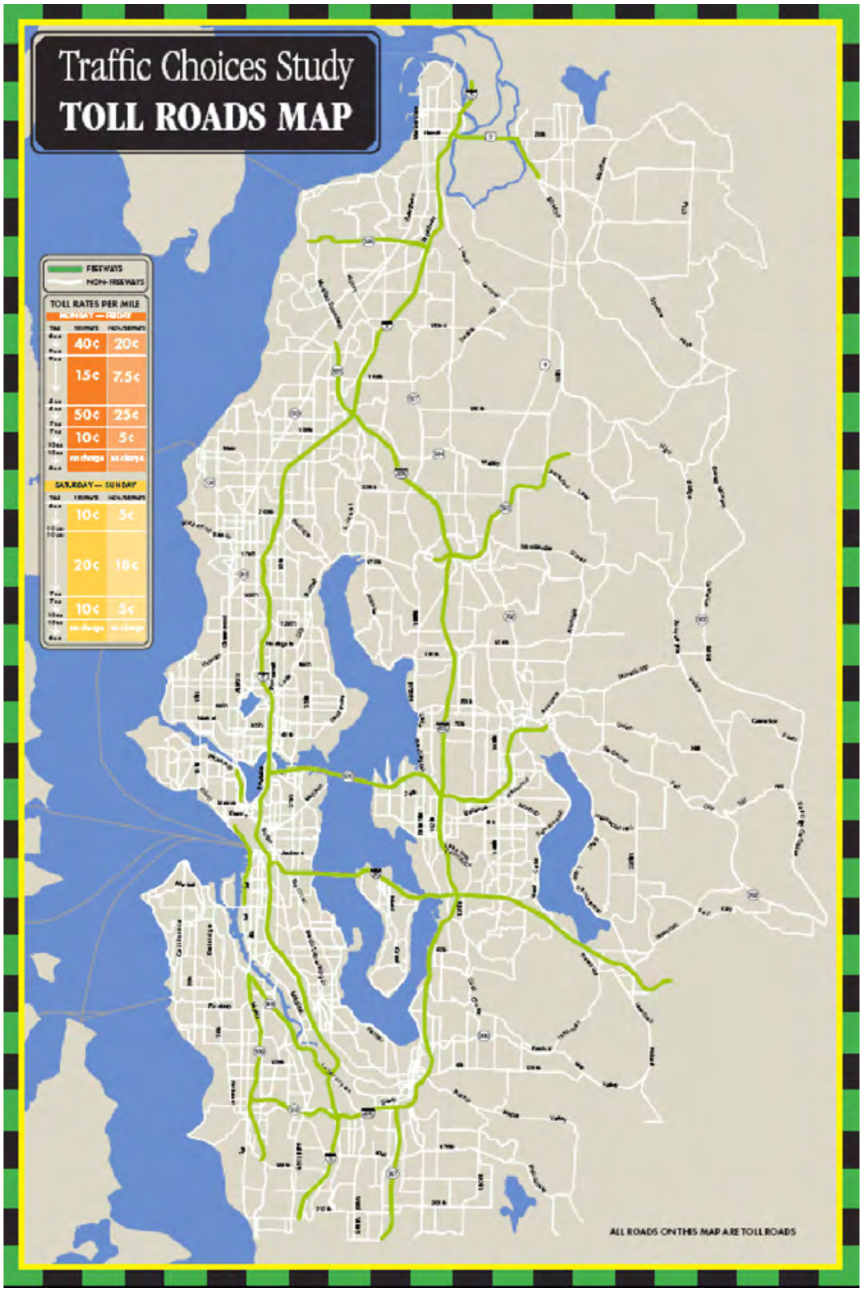
The GPS receiver in a vehicle's meter used radio signals sent from satellites to determine the vehicle's position, and matched that position to a map of the toll-road network embedded in the meter. The meter's display showed toll rates and a road description. The meter stored location (spatial coordinates, in latitude and longitude) and toll information, and periodically communicated them to a central computer using cellular wireless communications. Through this approach, the Traffic Choices Study covered an entire road network (including arterial roads) with a toll system without incurring extensive roadside infrastructure costs.

Congestion varies across time and space within the road network, and the ways that drivers respond to congestion-based charges will include using different roads in the network, as well as shifting time and mode of travel. So, an experiment attempting to understand the behavioral implications of efficient road pricing needed to be able to levy tolls on most major components of a region's road network: major surface roads *and* highways. Also, tolls had to vary depending on the facility and time of day. The Traffic Choices Study Toll Road Map (**Figure 1**) displays all the tolled facilities and the toll rate structure, which charged higher rates for travel during peak travel times on high demand roads.

Practical constraints restricted the road network that would be tolled to an area loosely bounded by Puget Sound to the west, Everett to the north, the east boundary of the Sammamish Plateau to the east, and Renton/SeaTac to the south. Project participants lived within this geography, ensuring that they drove on roads in the tolled network.

On July 1, 2005 the Traffic Choices Study tolling system became operational. As study participants drove their vehicles on tolled roads the appropriate charges were deducted from their account balance. The on-board tolling meters, or OBUs, which had previously been displaying only the name of roads driven, were now displaying the name of the road and the toll rate per mile. The OBUs also displayed the cumulative toll incurred during the current trip, thus allowing the participants to gain a better understanding of the cost of their travel decisions.

Figure 1. Traffic Choices Toll Roads Map



Participants also used their on-line accounts to monitor their travel, reflect on trip choices, and gauge the overall consequences of those choices on their account balances. **Figure 2** displays basic guidance provided to the participants.

An important aspect of the customer accounts, unique to the Traffic Choices Study, was the availability of a fine level of detailed information about the customers' vehicle trip activity and their use of tolled facilities. Each vehicle trip (determined by changes in vehicle ignition state) was stored in the system, along with details about the links (segments of tolled roadway, traversed during the trip). With this level of trip detail, participants were able to engage in a careful examination of the financial consequences of various types of travel behavior. Alternately, participants could simply wait until they received their invoice of all trip records issued each month.

Administrator functions (included the initial handling of the raw data transferred from each OBU, and monitoring OBU communication status) were managed behind the scenes. All information was stored in a relational database. Standard reports of project data were available for review and analysis to support the monitoring of system operations and to provide quick and easy summaries to researchers.

Toll operations for the Traffic Choices Study continued through February of 2006. System operations represented a small-scale version of a full revenue operation, including customer service functions and direct user invoicing. By the end of the study the toll system had:

- Fielded hundreds of customer service calls
- Issued over 4,000 customer billing invoices
- Supported over 100,000 vehicle to central system wireless data communication transactions

- Recorded over 750,000 individual vehicle trip records
- Logged over 4.5 million vehicle miles traveled in trip records database

Figure 2. **Participant Guidance**

1. Log In to Your Project Account at the Project Website

You will receive an e-mail from the Traffic Choices Study that includes your login name and password.

Go to the project Webpage:
- http://www.psrc.org/projects/trafficchoices/index.htm
- Navigate to My Account and follow the instructions.

The default login is your last name and the first letter of your fist name. If this doesn't work, please call the hotline at 1-800-815-4073 and press #2 for customer service.

2. Review Your Household Travel Budget Online

Your household has been assigned a travel budget. The budget account balance can be reviewed at any time during the study. As you drive on the region's roads when tolls are in effect, the toll values will be deducted from your household travel budget account.

3. Learn About the Road Tolls

The Traffic Choices Study is about understanding how individuals might alter their travel if they had to pay tolls to use the region's roads.

Tolls for this study are based on:
- Time of Day................Peak Commute Travel or Off Peak Travel
- Day of Week..............Monday–Friday or Saturday–Sunday
- Type of Road.............Freeway and Non-Freeway

4. Make Travel Choices and Review Trip Information Online

Once you are familiar with your travel budget and the tolls that will be deducted from your account while you drive, all you have to do is make travel choices on a day-to-day basis.

If you choose to avoid tolled roads when tolls are in effect, you will preserve the funds in your travel budget. Since the tolls are higher in peak commute periods and on high demand roads, there are lots of different ways you can economize:
- Modifying the time of day you start your trips.
- Rerouting your trip to avoid high demand roads.
- Combining trips.
- Choosing to take the bus or share a ride.
- Foregoing a trip altogether.

At the end of the study, the balance left in your account is yours to keep.

5. Collect Your Account Balance

At the end of the study, we will send information about removal of the Travel Choices Meter. This is a simple procedure performed at a local CarToys Store at our expense.

They you're done! Once your Travel Choices Meter is removed we will send you the remaining travel account balance. It is yours to keep!

Thank you for participating in the Traffic Choices Study.

WHAT WE HOPED TO FIND OUT

The imposition of tolls raises the perceived cost of travel for road users. Since the demand for travel is a demand derived from the desire to perform other activities (working, shopping, sightseeing, etc.), the higher generalized costs impair the utility of the primary travel purpose. Theory suggests that travelers will seek ways to minimize this impact, so as to preserve as much as possible of the value ("utility") of the primary purpose of the travel. There are numerous ways that travelers can respond to the increase in the generalized cost of travel. In the short-run, they can 1) travel by alternative paths, 2) change the number of times that the affected tours occur, 3) select another mode of travel, or 4) travel at a different time.

In the longer run, travelers can make other choices that can further reduce the costs of travel. The experiment was not expected (by participants) to be long-term, so the incentive to make such adjustments was not strong. With a permanent tolling program, one might expect travelers to 1) change the location of employment, residence, or both, 2) make changes in the time or path of travel, as a consequence of re-negotiated workplace and residence choices, 3) change the vehicles used for travel to economize on operating costs or to provide higher amenities to offset the costlier travel.

Thus, for this experiment we expect the effect of the tolling to be some combination of the following:

- Reduce the number of auto tours[2], either through tour suppression or through changes in mode.
- Increase the number of trip segments per tour to economize on the total cost of travel across all travel purposes.
- Reduce the amount of tolls paid per tour relative to the tolls that would have been paid for base-line travel.
- Alter the time of travel in favor of lower-toll times of travel.
- Alter the path taken, with attendant changes in distance traveled and time spent traveling. Depending upon the opportunities available to change paths, modes and the time of travel, the duration of travel and distance traveled per tour may either increase or decrease.

For any given travel purpose, the response may be different from that postulated above since the household likely considers its costs and opportunities of travel in an integrated fashion. That is, households may be able to offset the toll impact of one travel purpose by modifying other travel. Similarly, impacts on one household member may be able to be offset by changes in behavior of other household members. The less integrated the household's thinking (or greater the constraints on integrated planning), the less likely are such responses. Across households of various demographic characteristics, we generally expect:

- The response to tolls to be less responsive (less "elastic") for higher income households.
- An ambiguous relationship between travel response and the number of drivers in the household.
- Households with better transit options to display more toll-elastic behavior regarding auto tours, drive time, and distance traveled, at least in the home-to-work and work-to-home periods.

[2] The unit of observation of travel behavior was defined to be tours; that is, aggregations of trips that were closely linked, serially, in time. Individual trips (measured by vehicle ignition state changes) thus became tour segments.

3. Behavioral Analysis

THE ANALYTICAL APPROACH

Put simply, the analytical task was to determine how travel behavior (distance, timing, and number of vehicle trips) is affected by (depends on) a range of other factors that the experiment measured (e.g., household income, size, location; number of vehicles; availability of transit; day or time of travel; congestion price charged). Put more technically, the study estimated statistical models to explain how measures of travel demand, across households, vehicles, and workers (the dependent variables) are affected by changes in the generalized costs of travel (tolls, out-of-pocket costs and time costs), while controlling for household demographics (income and number of drivers), seasonal factors, and a measure of transit viability (the independent, explanatory variables). The study estimated the *elasticities* of travel demand with respect to changes in the price of travel (tolls).[3]

The study was not intended to comprehensively inventory all factors that contribute to differential travel behavior. Rather, impact studies, such as this, introduce big shocks in the variable of primary interest (toll costs) and minimize the influence of unaddressed variables by focusing on *changes* (the delta structure of the impact model) rather than *totals*.

In addition to explaining behavioral responses to tolling the road network, the Traffic Choices study offered the opportunity to observe travel behavior across a sample of households for an extended period of time. Travel surveys are often performed to support travel models or other aspects of transportation planning. Large-scale surveys, however, are expensive to administer, and are often limited to collecting travel diary information about a few days of consecutive travel. The Traffic Choices Study observed the travel of participant households over an 18-month period. As an example of the kind of extensive information gathered about household travel, **Figures 3-6** display measures of travel activity for home-to-work and work-to-home tours distributed across participating study households.

FINANCIAL INCENTIVES INFLUENCE TRAVEL CHOICES

There is no single answer to the question of how participants changed their travel in order to save money by paying fewer tolls. Each household is unique, with specific flexibilities and constraints. Findings from the Traffic Choices Study illustrate the magnitude of the short-run response to tolls, across a broad range of behavioral dimensions. **Figure 7** depicts short-run elasticities of demand for all household vehicle tours. These elasticities with regard to toll costs may be interpreted as direct estimates of the actual magnitude of changes in behavior for the sample of households included in

[3] A compact way of measuring behavioral responses to changes in the generalized cost of travel is to examine something economists call the "elasticity" of behavioral responses to travel costs. Simply put, elasticity measures the percentage change in behavior (say, tour-making) with respect to a 100 percent change in the cost of travel.

Figure 3. Average Home-to-Work Departure Time

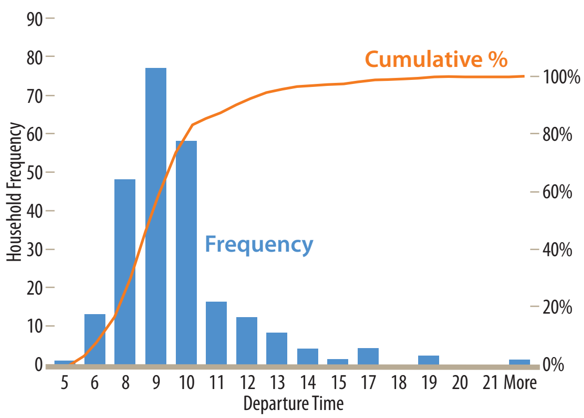


Figure 4. Average Work-to-Home Tour Departure Time

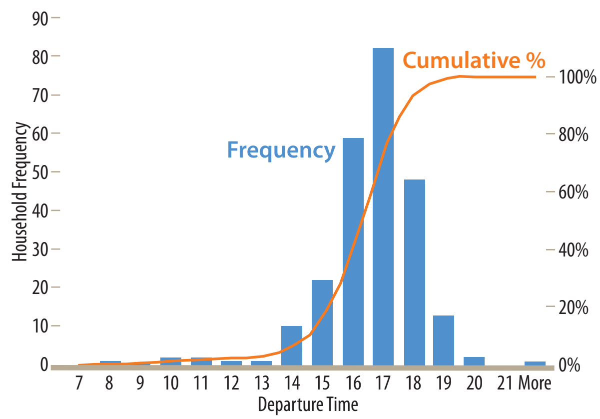


Figure 5. Average Home-to-Work Drivetime (Minutes)

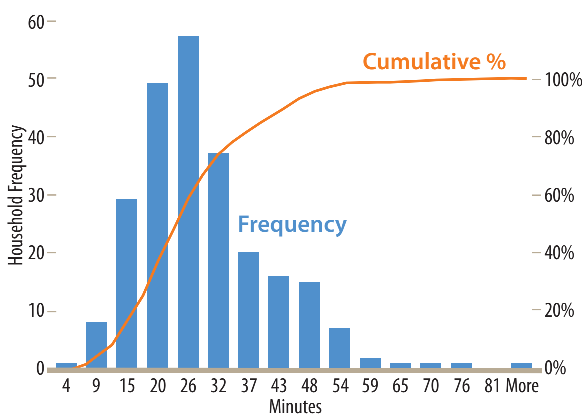
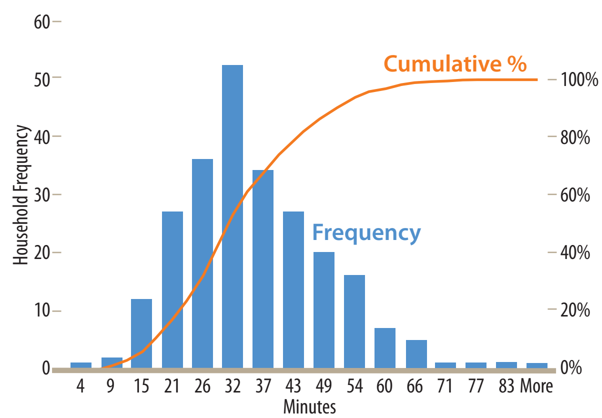


Figure 6. Average Work-to-Home Drivetime (Minutes)



the study. In other words, the elasticity of tour distance is reported as -.12, this can be thought of as estimating a 12 percent reduction in weekly vehicle travel distances across the sample of households.

When measured across all types of travel purposes, and all study participant households (or vehicles), the toll policy used in the study resulted in a number of important changes in aggregate travel demand. These included:

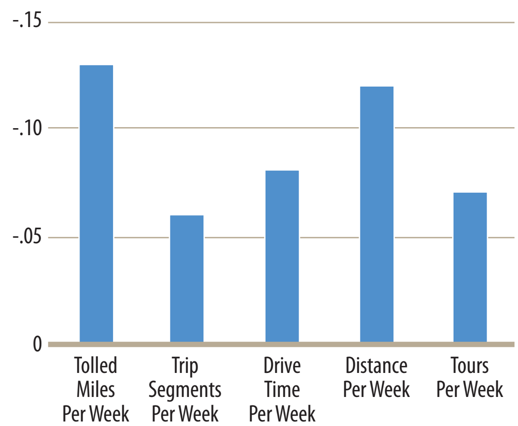
- 7 percent reduction in all vehicle tours (tours per week)
- 12 percent reduction in vehicle miles traveled (miles per week)
- 8 percent reduction in tour drive time (minutes of driving per week)
- 6 percent reduction in tour segments (segments of tours per week)
- 13 percent reduction in miles driven on tolled roads (tolled miles per week)

The participating households altered the nature and amount of vehicle use in response to experimental tolls that increased the costs of travel but did not result in improved travel times. To demonstrate the full consequences of the variable toll policy the study needed to estimate a new demand and supply equilibrium. These results are presented on pages 22-23 of this report.

Motorists made small-scale adjustments in travel that, in aggregate, could have a major effect on transportation system performance.

Analysis of the data revealed important changes in household driving patterns that could significantly reduce congestion if variable tolling were implemented within a regional road network. Many households made notable changes in their travel practices. Households that modified their travel did so in many different ways: taking fewer and shorter vehicle trips, choosing alternate routes and times of travel, or linking trips together to reduce vehicle use altogether. Some households altered their routine travel practices (such as how they moved between home and work); other households made changes when they could, in more irregular ways over the course of daily events. Some participants report that these changes have persisted beyond the end of the study. Other households appear to have had very limited opportunities, in the short-run, to avoid using high demand roads during peak travel times.

Figure 7. Household Sensitivity to Toll Costs (percent change in measures of demand)



When approached systematically, variable road tolling could make excessive reoccurring congestion a thing of the past.

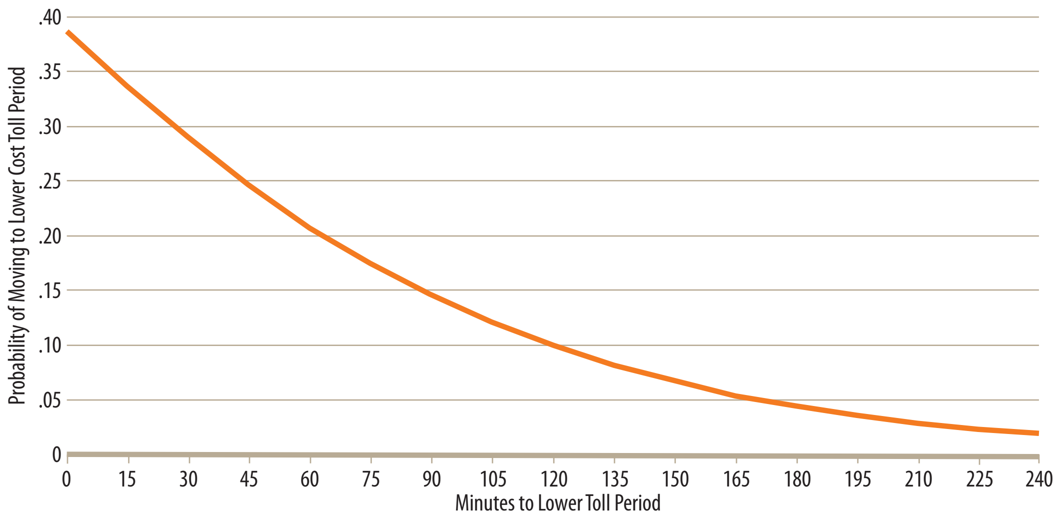
Demand response is less pronounced as income increases, and moderately more pronounced as higher quality transit services are available as options to the auto trip. The toll elasticity of tours for the Home-to-Work tour measured across all workplace locations was approximately -0.04. For the workers with the best transit service options (above the 90th percentile) the tour response (effect on the number of vehicle tours per week) increased to as much as -0.16. Current transit service options appear to provide only a very modest opportunity to avoid paying tolls in all but the most transit "friendly" of circumstances.

All these results are consistent with the study team's expectations. Having to pay tolls that reflect the costs of congestion caused many travelers to change aspects of travel behavior, some more than others, depending on the usefulness and convenience of the opportunity for change.

THE TIMING OF TRAVEL

In addition to the behavioral responses discussed above, study participants could also respond to tolling by moving the start time of their tour into a lower cost time of travel. The probability of moving to a lower toll-cost time period, for home-to-work tours, as a function of the proximity to the toll change threshold is displayed in **Figure 8**. If a study participant typically made a work trip (during the baseline/no-tolling part of the project) at a point in the day that is within 15 minutes of a lower toll-cost time period, then there is a 40 percent probability that during the tolling part of the project, the trip was made during the lower toll-cost time of day. This probability dropped to 20 percent when the trip typically occurred within 60 minutes of the lower toll-cost time period, and was below 5 percent when the trip would have occurred within 180 minutes of a lower toll-cost time period. This is strong evidence of time shifting response to tolls when the departure delays necessary to avoid some increment of toll costs are small. A more finely tiered tolling structure (with shoulder tolls different from the peak and off-peak period) than the one used in the study would afford opportunities to finely tune the performance of major road facilities.

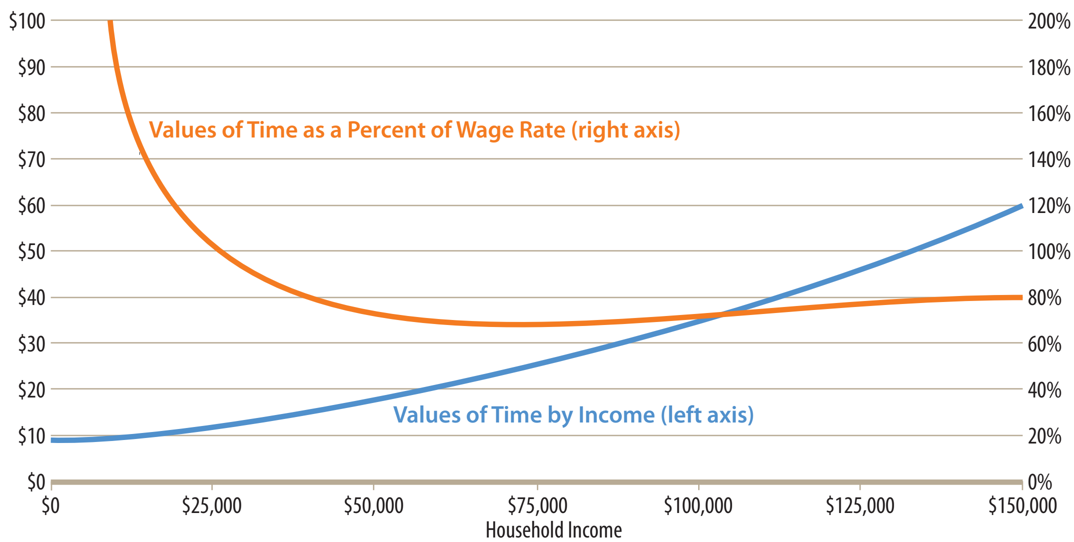
Figure 8. **Home-to-Work Tour Probability of Moving to Lower Toll**



THE VALUE OF TIME SPENT DRIVING

The Traffic Choices Study also provided an opportunity to observe values of time directly as a function of actual route choices. Participants faced a financial incentive to avoid routes with high toll values. In many cases participants chose longer, more time consuming routes that resulted in lower toll costs. The primary finding is that the value of commute (home-to-work tours) travel time appears to be close to 75 percent of the wage rate (higher than is often assumed in the absence of better data) for the greater Seattle metropolitan area. **Figure 9** plots home-to work values of time against household income and also displays the fraction of wage rates that these values represent.

Figure 9. **Observed Home-to-Work Tour Values of Time (As a Function of Route Choice)**



One of the most striking aspects of the Traffic Choices Study is the high degree of internal consistency in the analytical results. The statistical techniques employed to explain user behavior are complex and often difficult for non-technicians to interpret, so it is reassuring to discover that the basic findings of the impact models are consistent with theoretical expectations, and with each other. Observed changes in behavior are in the right direction (demand goes down as price goes up) and of appropriate magnitudes, relative to each other and the general empirical body of evidence from other studies.

The idea that the variable tolling of roads can result in substantial improvements in traffic conditions is unfamiliar to most motorists. There is a natural skepticism about how this might work, and how individuals might be affected by such an approach to road financing. If motorists do not believe that the traffic reduction benefits of road tolling will materialize, they will see the policy as a veiled attempt to simply raise revenues for government. The Traffic Choices Study has demonstrated that households and motorists faced with variable tolls do make the small adjustments in their travel that will translate into large-scale reductions in roadway congestion. Many study participants even characterized their travel changes as minor, but the sum total of all their individual decisions can be shown to result in important shifts in the time, amount, and mode of travel so as to minimize the amount of time the region's residents would be stuck in traffic. The implications of these findings are explored in more detail in the rest of this report.

4. Analysis of Implementation

If most economists think that variable or congestion-based road tolling is such a good idea, why isn't it being implemented anywhere at any large scale? Some of the main arguments for and against variable tolling are highlighted below. The statements below are simplistic, and abstract from the complexity of specific applications of road tolling, but as a result offer a clear and largely uncontroversial set of statements about the advantages and disadvantages of just the kind of tolling systems that the Traffic Choices Study has attempted to better understand.

Variable road tolling addresses many interrelated problems. Full network tolling:

- can reduce reoccurring delay on the roads and improve travel reliability
- can help to finance transportation projects even when traditional financing approaches have proven insufficient
- provides a powerful signal for investment that is hard to ignore
- lessens, or even eliminates, the current disconnect between who pays and who benefits
- can overcome the problem that the flow of funds for improvements often doesn't make its way to the facilities that experience the greatest demand
- addresses a long-term need to replace fuel taxes as a mainstay of highway financing
- could mean that non-SOV services become increasingly viable
- avoids the problem of diverted traffic congesting previously uncongested facilities that is associated with more limited applications of tolling

There are plenty of arguments for not implementing variable road tolling. Road network tolling:

- is a significant departure from current practice
- would create new winners and losers
- could be hard on those with few alternatives to driving alone on busy roads
- could increase the fiscal burden on consumers of transportation services unless toll revenues in part offset existing taxes and fees
- would make everyone worse off if the toll revenues are not used wisely; which highlights current feelings of distrust about government priorities
- may compromise user privacy, depending on the technical approach
- would be complex, intrusive and costly to implement

A further exploration of a few of the critical issues in the implementation of network-wide road tolling follows. First, it is important to address broad questions about the technical and administrative feasibility of road tolling. Since, if such a system is impossible to implement, there is little point in further contemplation of its policy implications. This report concludes that a system for charging for the use of an entire network of roads is indeed feasible, and even cost-effective, given the sizable opportunities to realize broad benefits to society. Second, these benefits depend upon sensible policy about how road tolling revenues would be used, a topic addressed in some detail in what follows. Third, the application of road tolls and the use of those revenues will have consequences for how costs and benefits get distributed throughout society. Policy-makers and the public will want to understand these consequences in order to make some determination about how such a system could be designed to ensure fairness. Fourth, the technology that makes network road tolling possible creates circumstances where road users personal and road use information are collected and stored by the toll operations. This situation could lead to compromised user privacy if careful consideration of how data is managed and protected is not explicitly taken into account.

IMPLEMENTING NETWORK ROAD TOLLING IS FEASIBLE

Standard practice in electronic tolling involves the use of relatively simple in-vehicle radio tags, or transponders. The toll tags contain a unique electronic signature that is communicated to roadside equipment as the equipped vehicle drives on a toll facility. Current systems use various short-range communication technologies and protocols, and are typically procured from vendors that supply proprietary hardware and software elements. Roadside equipment includes the toll tag readers and any equipment necessary for vehicle classification and enforcement, and equipment to transfer all necessary transaction information to a central toll operations center. This electronic toll collection approach has proven a successful model since first introduced in the late 1980s, with rapid growth in market penetration in recent years.

Similar technology has been used in the Singapore area pricing program since 1998. The London Congestion Charging Zone also relies upon roadside equipment for vehicle identification and account processing, although of a different nature. Automatic number plate reader video cameras capture the license plates of each vehicle entering or driving within the charging zone, where cameras are positioned at all points of access to the zone and also at key intermediary locations within the zone.

All of these approaches require dedicated roadside tolling equipment be deployed in a manner that covers the full extent of the tolling network and, as a consequence, also require new civil infrastructure any time that a tolling network is expanded or altered. The approach to network tolling that was investigated as part of the Traffic Choices Study does not rely on roadside equipment for vehicle charging, although enforcement does depend upon strategically located video license plate reader equipment. The in-vehicle tolling devices locate the vehicle on the road network and communicate directly with the central tolling operations system, resulting in significantly less civil infrastructure, and enabling flexible extensions or alterations of the road tolling network, in the case of including likely traffic diversion routes.

The tolling system performed as expected, and met basic system operating requirements. Further work on system refinement and design of enforcement and billing systems would be required prior to any full system deployment.

Still, there are few true network tolling programs in operation. Heavy vehicles are tolled on major roads in a few European countries, and the Netherlands is making real progress toward a national kilometer charging program to be implemented for heavy vehicles in 2011 and all other vehicles by 2016. With few operational systems, and none that rely exclusively on GPS tolling technology, there have been lingering questions about the complexity and cost of such an approach.

Tolling of dense road networks with facilities that have only minimal access controls requires special attention to the quality of the toll system base map, issues of GPS accuracy, and the overall approach to facility use determination.

Yet, an extremely important emerging realization (to which the Traffic Choices Study has contributed) is that the implementation of full network tolling is no longer fundamentally constrained by technological limitations. The toll system elements implemented for the Traffic Choices Study met the base requirements for toll system operations. Indeed, it is technically possible to implement the same pricing policy principles within the highway realm that have, for so long, been in common use in virtually all other markets in the economy. This is not to say that there are no issues that need to be addressed in an actual implementation. But the Traffic Choices Study is a strong "proof of principle" from a technological standpoint.

There were important aspects of toll systems operations that were never implemented during the behavioral research; enforcement, for example. As a consequence, the study team had Siemens (the study's technology consultant) assist in outlining the basic structure for full road network implementation. Implementing such a system would involve managing a range of technical, institutional, enforcement, legal and cost issues. While not a proposal, the architecture provides some insight into questions about the level of effort and cost that would be required. The architecture envisioned for a network tolling scenario consists of two basic programs:

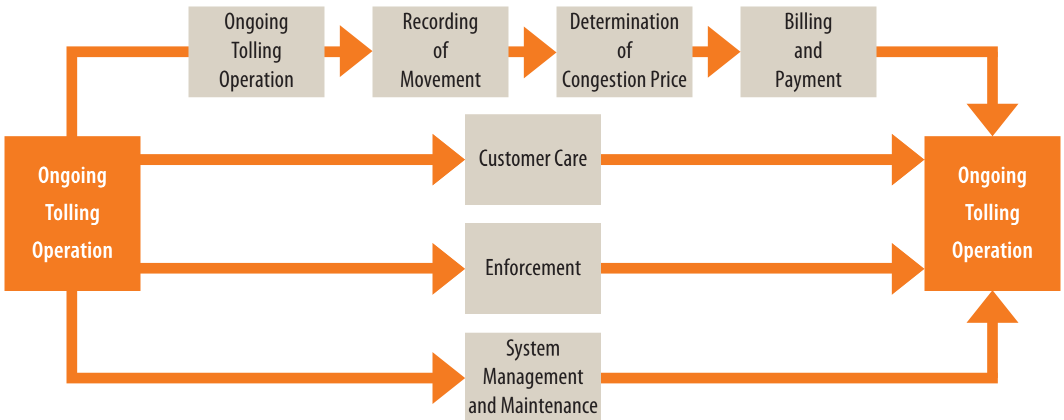
- The *Main Program* is intended for most of the vehicles belonging to residents and companies resident within a tolling region. This main program consists of an on-board unit (OBU) that is permanently mounted to a vehicle during its entire lifetime. Residents and companies resident outside the tolling area (but that frequently enter and travel within the tolling zone) are also included in this main program.
- The *Occasional Program* is intended for residents with "non-regular" vehicles (e.g., motorcycles, classic cars), or who choose not to have an OBU installed in their vehicle due to limited usage of the vehicle (e.g., campers). The *Occasional Program* is also used for non-residents who drive into and travel within the priced network on an infrequent basis. The *Occasional Program* offers a flat rate charge for the usage of the road network for a specified time period. The exact road usage is not measured or recorded. The flat rate is calculated in a way such that it is more expensive than the road charges based on the OBU-based *Main Program*.

The business processes of the network tolling system are shown in **Figure 10** and summarized below, and a block diagram of the tolling system is shown in **Figure 11**.

Registration of Users

Under the *Main Program*, the installation of an OBU to a vehicle must be done by an authorized technician. Owners of registered vehicles might have this performed as part of emissions tests; or they could arrange for OBU installation with a technician authorized by the tolling authority. After OBU installation, the vehicle owner/user registers for participation in the *Main Program*. The toll system operator would have access to all available data on registered vehicles and their owners via a vehicle licensing database. The user would also specify the desired payment method and provide the associated payment data (e.g., bank account number), the channel for invoices and the associated billing data (post address, e-mail address, etc.) and contact details. For the *Occasional Program*, the user would register over a variety of possible channels (Internet, phone), and specify the license plate number, address, and the usage period (daily, weekly, monthly, annual).

Figure 10. **Road Network Tolling Business Processes**



Measurement and Recording of Road Usage and Movement

Under the *Main Program*, road usage (distance, road types, time of day) would be recorded by the OBU. These OBU data are transferred to the Electronic Tolling Back Office (ETBO) using a mobile communication network for further processing. Road usage would not be measured or recorded under the *Occasional Program*, other than a determination of whether or not a vehicle traveled within the road tolling network on a particular day (using Automated License Plate Readers) as part of the enforcement process.

Determination of Charge

Costs would be determined based on the measured and recorded data about road usage (i.e., miles driven by type of road and time of day), coupled with vehicle classification information. The *Occasional Program* offers only a flat rate for the usage of the road network for a period of time. The flat rate would be based on the vehicle category and the registration period.

Billing and Payment

Invoices for road usage under the *Main Program* would be generated (monthly) and distributed over several channels (e-mail, Internet, postal service) depending on the choice of the user. Payment would be possible by several methods (e.g., direct debit, credit cards, debit cards, and checks). The *Occasional Program* requires prepayment via any of the same payment methods used for the *Main Program*.

Customer Care

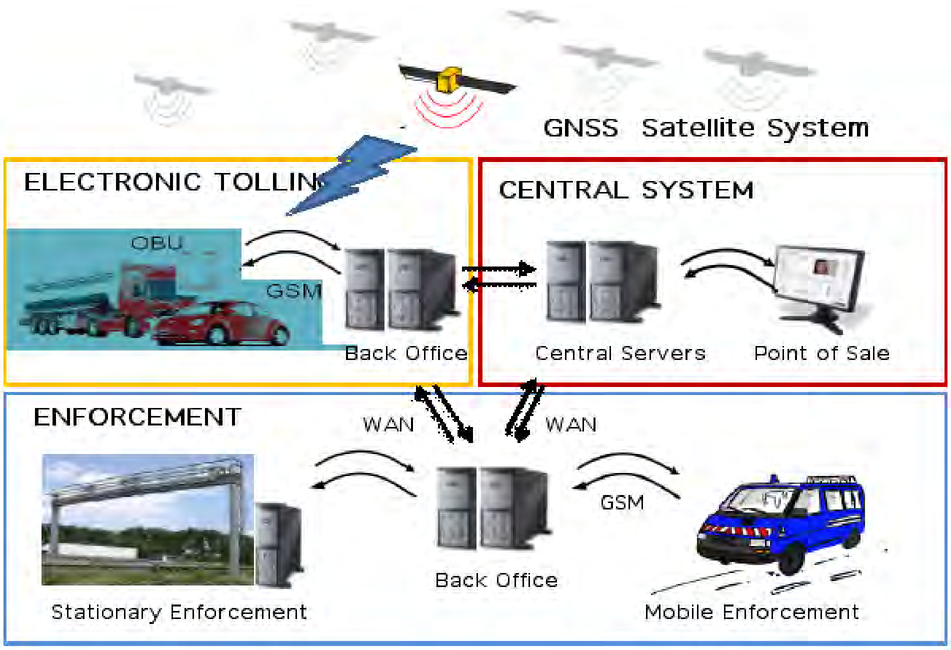
To minimize costs, customer self-services, such as Internet services, should be made widely available and strongly encouraged for all processes requiring client interaction. Nevertheless, a system agent should be available whenever the client requires help. Customer care addresses all functions related to road user services and support, including:

- Responding to user questions, including common information and questions about the tolling system and programs, and also questions about an individual participant account
- Administration of user attributes (e.g., contact details, billing details)
- Handling various types of user complaints
- Exchange of defective OBUs

Enforcement

Automatic enforcement equipment would be used to check the compliance of road users when they enter and are driving within the road tolling network. Stationary and transportable/mobile enforcement setups would be utilized. Photographs are taken of each checked vehicle, and automatic license plate recognition equipment determines the vehicle identification. The license plate number would be sent to the enforcement back office along with location and timestamp, which checks for consistency and compliance. In the event of a possible violation, the enforcement back office sends a notification to the tolling back office for subsequent action.

Figure 11. Block Diagram for a Network Road Tolling System



THE COSTS OF IMPLEMENTATION

In 2006, the Dutch government initiated a process of industry consultation in order to better reflect the range of costs likely to be encountered if the government selected to implement a national program for kilometer charging. Kilometer charging is being considered as a replacement for existing vehicle taxes and fees. The Dutch Cost Monitor[4] invited 12 separate parties from industry to provide written guidance on an approach to kilometer charging and help to refine estimates of implementation costs. The Dutch Parliament has since indicated its intention to proceed with plans to implement a national road pricing program (similar in approach to the one used in this study) for all vehicles by 2015. Siemens was one of a few parties invited to produce a report on the total system costs.

The costs for GPS-based tolling systems are dominated by the initial investment in in-vehicle tolling equipment, and the communication of data during operations. Over the last few years, costs have declined dramatically and are expected to continue to come down.

[4] http://www.verkeerenwaterstaat.nl/english/topics/mobility_and_accessibility/roadpricing/index.aspx

The estimate of implementation costs that follows is based, in part, on findings from the Dutch Cost Monitor applied to the above system architecture and local conditions in the central Puget Sound region. The Traffic Choices Study cost model assumes that 90 percent of the vehicles located within the tolling network region would opt for the Main Program and have tolling equipment installed in the vehicle. The remainder would opt for the Occasional User Program. Moreover, it is assumed that 10 percent of the vehicles in select counties adjoining the tolling area would also have OBUs installed. **Table 1** displays the summary results of the cost model. The largest category of initialization costs for network tolling are the in-vehicle equipment and installation ($665 million). Largest costs associated with annual operations involve the data communication functions ($201 million).

A transition to road network tolling would be costly and complex. It must be seen to be worth the sizable up-front effort.

Table 1. Network Road Tolling Cost Estimate for Puget Sound Region

System Elements	Capital (2008 Dollars)	Annual (2008 Dollars)
OBU and installation	$665,000,000	–
OBU / Installation – New Vehicles	–	$31,500,000
OBU – Repair / Replacement	–	$25,200,000
Training / Certification – Installers	$500,000	$50,000
Spare OBUs	$1,750,000	$20,000
OBU Subtotal	**$667,250,000**	**$56,770,000**
Stationary Stations	$20,000,000	$1,060,000
Transportable Stations	$1,875,000	$187,500
Mobile Stations / Vehicles	$1,200,000	$1,400,000
Enforcement Back Office	$5,000,000	$2,750,000
Enforcement Subtotal	**$28,075,000**	**$5,397,500**
Central System	$25,000,000	$20,000,000
Staff / Operations Training	$500,000	$100,000
Space for Central System / Back Office / Call Center	–	$200,000
Central System Subtotal	**$25,500,000**	**$20,300,000**
Data Communications Subtotal	**–**	**$201,758,800**
Other Subtotal	**$27,715,000**	**$3,500,000**
Grand Total	**$748,540,000**	**$287,726,300**

VARIABLE TOLLING AFFECTS THE PERFORMANCE OF ROADS

The study extended its experimental findings to emulate system tolling within a full network travel demand model maintained by the PSRC. The behavioral results described earlier in this report are not equilibrium results. Participants did not enjoy the improved conditions on the region's roads that would result from peak-period variable tolling. Assigning tolls to the entire modeled road network resulted in a number of key changes in the way the transportation network (a network of existing and funding improvements through the year 2010) performed, as compared to a base no-toll scenario.

First, there were 4.8 percent fewer vehicle trips under network tolls (mainly trips not made, and a modest mode choice response). In addition to changes in mode of travel (**Table 2**) there were notable changes in the timing of vehicle trip-making. Most notably, vehicle trips were reduced during the a.m. and p.m. peak travel periods (**Table 3**), and vehicle trips increased during the nighttime (including the early morning). And, of course, vehicle trips rerouted to avoid tolls and to take advantage of improved speeds on some facilities. Total vehicle miles traveled in the tolling scenario were lower by 7 percent than for the base no-toll case. The total hours of vehicle travel within the region were also lower by 5 percent in the tolling scenario.

Table 2. Baseline and Toll Scenario Travel Mode

Home Based Work	Base	Toll
SOV	79.3%	78.1%
Carpool	7.2%	7.9%
Transit	9.2%	9.5%
Transit–walk	7.2%	7.9%
Transit–auto	2.0%	1.6%
Bike	1.4%	1.7%
Walk	2.8%	2.9%
Non Work Trips	**Base**	**Toll**
SOV	46.0%	45.0%
Carpool	45.5%	46.4%
Transit	2.2%	2.3%
Bike	0.9%	0.9%
Walk	5.5%	5.5%

Table 3. Baseline and Toll Scenario Travel Time of Day

Percent of Person Trips	Base	Toll
AM	15.7%	13.3%
Midday	37.8%	36.3%
PM	21.1%	18.4%
Evening	17.4%	18.5%
Night	8.0%	13.5%
Total	100.0%	100.0%
Percent of Vehicle Trips	**Base**	**Toll**
AM	13.1%	12.1%
Midday	42.1%	40.5%
PM	20.6%	18.9%
Evening	18.5%	19.0%
Night	5.7%	9.6%
Total	100.0%	100.0%

THE BENEFITS TO THE COMMUNITY COULD BE LARGE

Changes in transportation system performance associated with a road tolling strategy can be used to estimate the benefits to transportation system users. Changes in mode choices, route choices and time of day choices do not necessarily result in positive user benefits, even if the result is less traffic during peak travel periods. Changing mode, route or time of travel implies that users are opting for a previously less attractive alternative for meeting their travel needs. There will also be increases in utility to those users who can take advantage of improvements in travel speeds that follow from lower traffic volumes on previously congested roadways. The PSRC employs a modeling tool that correctly accounts for consumer surpluses, or user benefits in a number of areas including: time benefits, reliability benefits, operating cost savings, accident cost savings and vehicle emission cost savings.

The societal benefits of road network tolling were estimated for a single year of operation. These benefits were based on a test of full network implementation within the regional travel demand model. These annual benefits (starting with a 2010 modeled year) were extended to a 30-year implementation scenario (2015-2044) making some basic assumptions about the effects of forecasts of traffic growth on the annual estimate of benefits.

Done right, network tolling could provide broad social benefit, including lower vehicle emissions, fewer accidents, travel time savings, improved roadway performance reliability, and lower operating costs.

Table 4 displays the benefit cost findings. The present value of the travel time savings benefits alone is well over $36 billion. Total implementation and operating costs are approximately $5.5 billion (present value). The net present value (benefits less costs) of the benefits to society from implementation of this network wide scenario of road tolling is estimated in the range of $28 billion[5]. Over the implementation period for this scenario the present value of toll revenues is estimated at $87 billion.

Table 4. Benefits and Costs of Network Road Tolling

Present Value Benefits/Costs	Millions of 2008 Dollars
Benefits	
Time Savings	$36,600
Reliability Benefits	$4,500
Operating Cost Savings	$2,500
Toll Effects on Consumer Surplus	-$97,100
System Operator Benefits (Tolls)	$87,000
Present Value of Benefits	$33,600
Costs	
OBU Costs	$1,500
Enforcement	$100
Central System	$500
Data Communication	$3,300
Other	$100
Present Value of Costs	$5,500
Present Value of Benefits less Costs	**$28,200**
Benefit-to-Cost Ratio	**6.1**

The direct benefits to transportation system users are sizable, and dominated by the value of travel time benefits. These are an estimate of the welfare, or “efficiency”, benefits associated with the correct pricing of congested roads. While the experiment was an approximation of optimal pricing policy, a number of important observations can still be made. Those who benefit most from network tolling are users with high values of time (higher income motorists and trucks). Transit users and occupants of high occupancy vehicles all realize benefits from tolling as well. The user benefits are large, but the toll revenues that result are considerably larger. This is to be expected, but emphasizes the importance of using those revenues to provide further benefits to the road system users through reinvestment, or rebating other taxes and fees.

The costs of implementing a variable road tolling system on a full regional network of road facilities is not small, as demonstrated in **Table 1**. The annual costs of operating such a system are significantly larger than current approaches to financing transportation. For example, administrative costs for a tax on the volume of fuel sold are in the range of 1 percent of the fuel tax proceeds.

A conservative analysis of the benefits of network tolling in the Puget Sound region indicates that the present value of net benefits could exceed $28 billion over a 30-year period.

Congestion-based tolling generates revenues for investment but also limits the wasted time resources associated with overconsumption of scarce peak period roadway capacity. So, a full accounting of the costs and benefits of road tolling compares the implementation and operating costs of the program with the full benefits of more efficiently allocating road space resources. The tolling revenues themselves are treated as an economic transfer since the revenues represent a cost to road users and a benefit to the toll system operator. In the case of public sector management of a tolling system, the revenues could be expected to be reinvested in the transportation system or used to offset other taxes and fees that support public investments.

Under the implementation scenario outlined above, the tolls paid by users and collected by the operator exceed the value of the user benefits. This is expected under all but the most congested pre-tolling road network conditions. If toll revenues are somehow squandered, the effects on society from road tolling will be negative. This finding reinforces the general conclusion that it is not productive to discuss road tolling without simultaneously addressing the issue of how toll revenues will be used.

[5] Toll revenues are an economic transfer (a cost to road users but a gain to toll system operators). The strength of road pricing is that it generates revenues that can be reinvested in ways that generate benefits to users, and society in general.

USE OF REVENUES

A major portion of the benefits from any application of road tolling is locked up in the revenues that are generated. How these revenues are utilized is clearly a significant determinant of the broader social value of the tolling program, and is an important part of gaining public approval.

A couple of important points can be made about tolling revenues as a result of the study. First, revenues are generated where travel demand is high. This tells the operator that there is a high willingness to pay for the use of this portion of the network at specific times of day and days of the week and, as such, a high demand for improved conditions. There is a constituency for supply improvements and, under tolling, this constituency is actually providing revenues needed for the improvements. Second, the magnitude of the revenue opportunity appears sufficient to make these investments in new supply. Without question there are situations where the costs (capital, environmental, or social) of making road improvements will be prohibitive. However, reconfiguration of existing lanes, access and egress could possibly prove operationally superior if funding was available for those improvements. Similarly, where road improvements cannot be made there is a much stronger case for transit subsidization within, or parallel to, a specific corridor.

Altering transportation finance to more closely reflect the marginal costs that users impose will result in both higher and lower user fees for access to some facilities and services during various times of day. Price increases are never popular among consumers, even when these higher prices reflect the higher value of goods and services. Since variable roadway tolling would result in time of day prices that respond to roadway congestion, failure to make capacity investments of some sort in the face of growing travel demand would eventually result in pricing conditions harmful to the consumers.

Non-grade-separated transit services operating within a corridor that is managed through variable tolls should expect to see operational benefits from better traffic management — less time that buses are stuck in traffic. To some degree, these managerial efficiencies should be capitalized in service improvements for customers. But there are also conditions under which it would be desirable to invest some portion of road tolling revenues to supporting transit services in the tolled corridor.

Current Financing or Variable Charges?

The roadway system today, throughout the United States, does not employ peak-period tolling. Rather, users pay for most of their highway services through a charge per gallon that is collected at the fuel pump. In rough terms, the charge is the same, per mile, regardless of which segments of the roadway are being used, and regardless of whether the travel occurs in the peak or the off-peak period for that particular roadway.

This system of flat fees necessarily has the effect of underpricing peak use, and overpricing off-peak use, at least in relative terms. The result is that:

- roads are overused and experience queuing (congestion) during the peak periods
- users lose valuable time sitting in congestion
- use of the roads by High Occupancy Vehicles (HOVs) such as carpools and buses is less than it would otherwise be

These problems, in turn, affect the investment incentives and fiscal balance of the road system:

- Congestion provides a misleading signal to road authorities as to which facilities or routes need more capacity, which, in turn, may cause road authorities to build some roadway capacity or routes that the users themselves would not be willing to pay for.
- Revenue generated by non-peak users, users on other routes and users from other regions must be used to pay for capacity that is not self-financing.

Such a system of finance can remain solvent only if aggregate gasoline tax revenues are sufficient to permit cross-financing of road segments. Otherwise, the cost of revenue-deficit segments of roadway may grow to overwhelm the revenue surplus implicitly generated on other segments. When such a system is applied across a state or the entire nation, cross-financing raises large-scale fairness questions that are not easily handled through political processes.

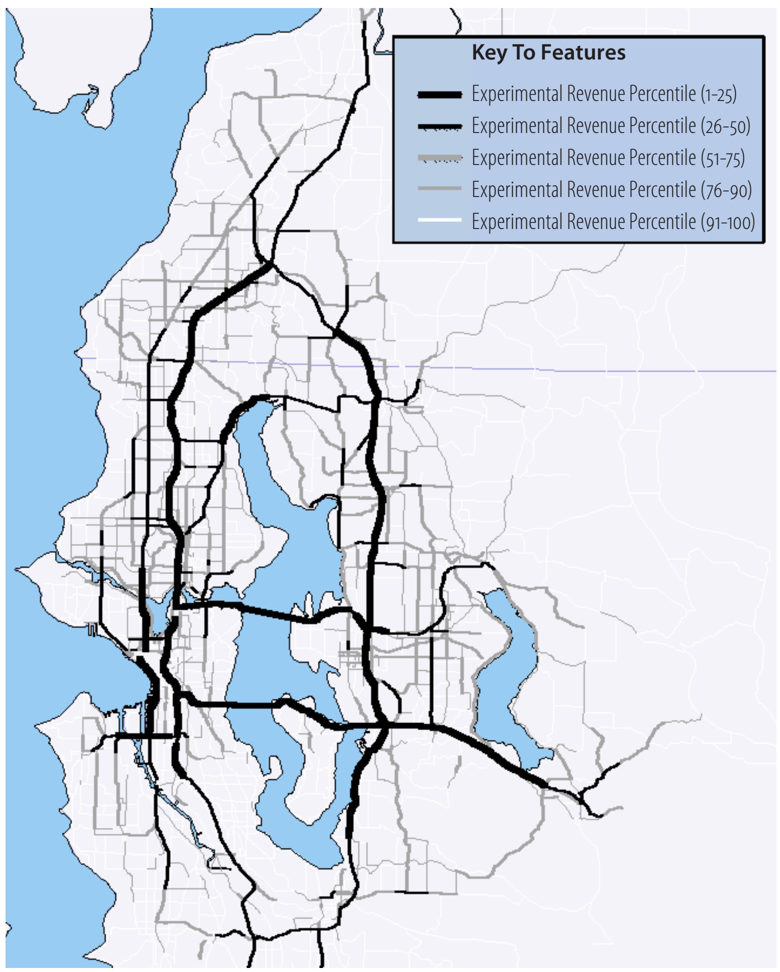
The scale of the revenues confirms the theoretical expectation that "optimal" tolls would support expanding transportation supply when and where it is needed most.

In addition to direct investment in transportation infrastructure and services, another possible use of revenues is in offsetting less efficient taxes and fees. When fuel tax revenue from travel on a facility more than covers all associated facility and external costs, a volume based fuel tax will overcharge users for access to that infrastructure. This is a strong argument for reducing flat rate charges for transportation, including fuel taxes and registration fees.

With 275 Traffic Choices Study households paying road tolls every time they used individual roads in the central Puget Sound region, it was possible to gain some insight into which roads drivers are willing to pay to use. Since the study offered the participants the opportunity to retain funds for avoiding the highest demand facilities (that were their preferred choices), those facilities that generated the most revenues represent a truly high value service. The households paid over $275,000 in road tolls during the 10 months of toll operations. And just over 5 percent of the tolled road network (centerline miles) generated 50 percent of the toll system revenues (**Figure 12**).

During peak driving times it is no surprise that key multi-lane limited access highways carry the largest volumes of traffic, and as a result generate sizable revenues when operated as toll roads. These same facilities, designed for high speeds under less than capacity loadings, are notably congestible when demand is high. While a few roads generated half of the toll revenues during the course of the study, the other half of the revenues were generated on a larger network of secondary roads distributed throughout the core urban area. This finding has at least two implications for any system of toll roads that focus on the limited-access facilities: 1) failing to include secondary roads in the tolling network represents a sizable loss of revenue opportunity, and 2) failing to appropriately toll the secondary roads will result in traffic diversion onto those roads and result in a significant degradation of service quality. Traffic diversion may be a particularly onerous problem in environments (such as the

Figure 12. **Traffic Choices Study Revenues by Facility**



greater Seattle region) where bus transit systems move large numbers of people during peak travel hours using the secondary road network.

While most revenues are generated on a small portion of the toll roads, the secondary road network (arterials) should not be ignored, as diversion causes real problems with revenue loss and displaced traffic.

The modeling of network tolling using the region's travel demand model produced results very similar to those described above. A small number of major facilities generated a majority of tolling revenues. Most of the facilities generating sizable revenues are corridors where major investments have been contemplated and, in many cases, are not yet funded.

The pay-for-use type system should only be used to pay for the road network for which we are charged.

– Participant Comment

I will continue to use the new routes I discovered while part of the survey, but at no time did I ever consider using public transit. I believe that a pay-per-use system will only encourage use of public transit if the public transit system is improved as well. I, for one, am not prepared to spend twice as long (or more) getting from point A to B.

– Participant Comment

Under such a tolling policy, revenues would be generated from the urban road network, across facilities that are owned and operated by many individual jurisdictions. The magnitude of the revenue opportunity is such that most existing revenue sources for transportation investment purposes could be eliminated. In particular, revenue sources that have no clear relationship with system use impose a deadweight welfare loss on society by distorting other economic decisions that are related to the taxes that are imposed. These tax sources could, without question, be put to rest. Toll revenues would still be sufficient to cover major investments in transportation supply throughout the road system.

FAIRNESS

Whenever a policy change occurs, it creates potential winners and losers, and this is no less true of variable road tolling. Transportation services are central features of a regional economy. Consequently, a change in the pricing of highway services will have a mixture of good and bad impacts on certain types of travelers, and on businesses and residents in subareas of the region.

Implementing variable road tolling means travelers using congested facilities during the peak period will face greater out-of-pocket costs than they currently pay through the gasoline tax alone. Off-peak and night charges, on the other hand, could be less than they currently are if tolling were implemented broadly enough to permit average gasoline taxes to be reduced. This change in costs would cause some diversion of trips to different routes, at different times, by different modes, and may induce some travelers not to travel at all. Because these adjustments in travel behavior relieve traffic levels on the priced roadway, the roadway offers faster and more reliable travel times to all vehicle types, which may benefit even those who are induced to change their travel behavior.

There are several important things to note about any accounting of winners and losers. First, some travelers will benefit from congestion tolling only if the HOV/transit response is good. Those who are "tolled out" of their single-occupant vehicles, for example, can benefit only if this is the case. This underscores the importance of removing any institutional impediments to increased bus, vanpool and carpool services. It may also argue for use of some of the congestion tolling revenue to assist transit.

Second, the pattern of winners and losers does not decompose directly into rich vs. poor[6], as is sometimes assumed. Although drivers of single-occupant vehicles (SOVs) with low time values are the ones most likely to be "tolled off" the road, many may be better off despite this if the performance of the highway-based HOV alternatives improves significantly.

Some experience and familiarity with road tolling makes people more open to the concept, but all programs are unique and will succeed or fail on their own merits. Road users are particularly interested in the question of how revenues will be used.

Winners and Losers Under Congestion-Based Tolling

Gomez-Ibanez identifies three groups that are likely to be winners:

1. Motorists who would drive with or without the toll but who place a high value on travel time savings (for these motorists, the gains from improved traffic speeds outweigh the toll cost).
2. Travelers who would use HOV services on the tolled road whether or not tolls are charged (they benefit from improved speeds while paying little or no toll).
3. Recipients of toll revenues (i.e., taxpayers if tolls reduce the pressure for tax increases or, alternatively, the clients of government programs if tolls are used to finance an expansion of government services).

Four other groups are likely losers:

1. Motorists who would continue to drive on the road despite the toll but who place a relatively low value on travel time. (Even though the time savings does not compensate these motorists for the toll charge, they may have to tolerate this loss because alternate routes or HOV services are too inconvenient for trips they are making.)
2. Motorists who shift from the tolled road to a competing untolled facility. (The untolled facility is less convenient; otherwise, these motorists would have used it even in the absence of tolls.)
3. Other users of the competing untolled roadway (since congestion will increase on that road).
4. Motorists who choose not to make the trip at all because of the toll (or who, with congestion tolling, now drive at a less convenient time of day when the tolls are lower).

One final group may benefit or lose depending on specific circumstances — travelers who switch from driving to vanpool or bus services on the tolled road. Some of those who switch may benefit if the bus speeds are improved greatly by the tolls, but others may lose if the bus or high-occupant vehicle speed improvements are modest or these modes were fairly inconvenient to begin with.

A distinctive feature of congestion-based tolling is it generates revenue that can be used to offset any such negative effects, by financing transit alternatives where appropriate, or other compensatory actions. Indeed, the reason economists recommend road tolling over regulatory and land use approaches to congestion problems is because it is a policy that has the potential to make everyone better off through prudent use of the revenues generated by the policy. In contrast, regulatory and land use policies produce no revenue, and generally require additional taxation to implement.

All else being equal, higher income Traffic Choices Study participants were associated with less pronounced travel response to the experimental tolls. More modest price sensitivity for higher income households and individuals was expected, and is most clearly demonstrated in the values of time measurements developed through examination of travel time and toll trade-offs. Interestingly, values of time rise with income, but not in a purely linear fashion. As a percent of wage rates (or income), values of time initially drop as income rises and then rise gradually with income. This gives some support for the notion that it is middle income households that may be most opposed to variable road tolling.

While an important and consistent set of findings, none of this leads to strong conclusions about the fairness of road pricing. The challenge is that variable road tolling is a policy that both asks users to pay for the use of a high value asset, and generates revenues for investment. A full assessment of fairness must consider the incidence of toll payments,

[6] Gomez-Ibanez, J. "The Political Economy of Highway Tolls and Congestion Pricing." Transportation Quarterly 46 (3 1992): 343-360.

the incidence of taxes that would have been levied in the absence of tolls, the user benefits (speed and other improvements), the losses associated with some less desirable form of travel for users who avoid tolls, and the final results from the investments made with toll revenues. Only the effects of the toll rates on behavior were directly captured in the Traffic Choices Study. Both the effects of tolls and the resulting travel time improvements are captured in the travel demand modeling of the experiment (only work-related trips are segmented by income class) and the estimation of user benefits. And the computer modeling is consistent with expectations that lower income users may do the most to avoid paying road tolls.

An important finding of the experiment is that households make adjustments in behavior where they have flexibility to do so, and in a manner that compensates for paying higher tolls at times when they have fewer opportunities to make adjustments. For example, the descriptive models containing a measure of transit viability demonstrate that high quality transit service increases the rate of substitution away from vehicle use. Transit services could be important in offering effective means for avoiding tolls. As such, the most distinctive feature of road pricing is that pricing generates revenues that can be used to directly address any issues of fairness.

ADDRESSING PRIVACY

Why Privacy Is an Issue

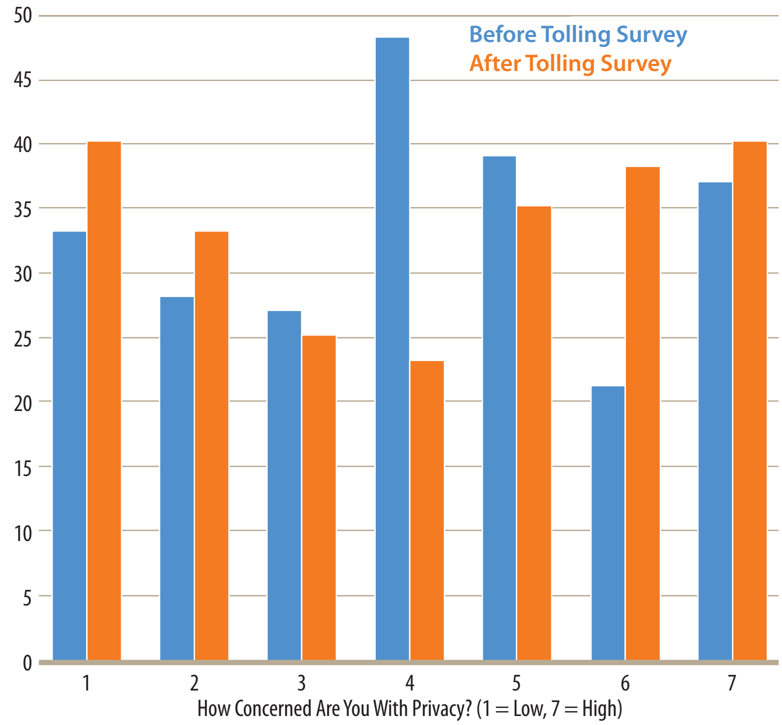
Information systems are becoming increasingly complex. As information is collected, stored and used in more and more beneficial ways, there are also increasing concerns over how information that might be considered "private" is managed and protected against malicious use. Road tolling systems with automated tolling transactions that associate the use of roads with an account holder are just one aspect of life that raise issues of privacy protection in the minds of consumers. A road tolling system that collects and stores detailed information about a large extent of the roads visited by all road users is by extension a larger source of the same kinds of concerns. The fact is that a road tolling system, like the one used in the operation of this experiment, collects extensive and detailed information about individual users and their travel behavior. It is impossible to imagine such a system being put into operation without significant safeguards in place to protect personal information. A question regarding privacy was asked of the Traffic Choices Study participants during a "startup" and an "exit" survey. Experience with the road tolling experiment appears to have helped individuals clarify their own views (**Figure 13**) on the topic of privacy. Before the experiment a fair number of participants were ambivalent about the issue of privacy. After the project was complete, participants had become less ambivalent and were (as a group) both more and less concerned about privacy.

Privacy Concerns That Might Be Raised By a Network Tolling System

Illegal or unauthorized use of personal data: Even as more commerce and personal transactions take place through digital means, the illegal possession and use of personal data is rare. But when a breach in corporate or institutional security does occur it can have sizable consequences for innocent parties. However, data security and encryption technology has become so advanced that an actual breach of computer systems is extremely rare. Still, all technical systems have vulnerabilities, and a road tolling system with a large database of account holder information could never be 100 percent immune to breaches in security.

One suggested way to address data security for road tolling applications is to limit the detail of information a road tolling system would retain in its central office. This is the so-called "thick-client" model discussed on page 31. Since information about specific road use is never sent to the central office, two important points of data vulnerability become less critical: data transmission and central data storage. However, it is important to realize that detailed data will still be stored (at least temporarily) within the vehicle itself. The user end of the data chain is possibly the point of greatest security risk, as examples of breaches in the security of financial accounts suggests.

Figure 13. **Participant Concerns for Privacy Before and After the Study**



Official use of data for other than intended purposes: Another concern regarding the storage of detailed information about people's physical movements using their vehicles involves the availability of information to "official" entities, but that supports purposes other than those originally intended by the road tolling program. Law enforcement, for example, might be keen to make use of information about the movements of "parties of interest." Lawyers involved in litigation might find use for similar information in particular cases. Road tolling would not be the first situation where such complex questions about privacy protections are raised. Legal and institutional structures can be put into place to minimize the opportunities for unintended use of personal data. The Directive of the European Parliament discussed on the next page is an example of such a legal framework. Still, the process of sorting this out can be a messy business involving courts and legislative refinements taking place over a number of years. An approach that focuses on legal and institutional protections is one that must, by necessity in the short-run, say: trust us; we will be responsible and keep your personal information secure. Trust is essential, and institutional protections often involve what has become referred to as a "trusted third party" (an institution that has controls over the processes but has no direct interest in the control of the data itself).

The biggest concern is the close tracking and movement monitoring. This device tracked a little too close. I think a check point system on freeway entrance and exits and on main roads would be more palatable. I had friends who seemed very concerned about being monitored in this way. Personally, however, I did not have a real problem with this.

– Participant Comment

Information That Is Collected and Stored By a Network Tolling System

Tolling a network of road facilities involves collecting detailed road use information and associating that information with account holders that are responsible for payment. GPS tolling devices can calculate and store a high level of detail about a vehicle's location for an extended period of time. In the case of the Traffic Choices Study, the tolling meters could store weeks of positioning data before running out of memory. When this level of detailed vehicle use data is associated with user account information (in a tolling back office) it is possible to determine the precise movements of vehicles and individuals.

Concerns over user privacy depend on what data leaves the vehicle, and what safeguards are in place to limit its availability and use. A road tolling system can be developed such that user privacy is maintained. But like so many things, this would come at a price.

Thus, protection of privacy has little to do with the data that is stored within the vehicle on the tolling meter but rather concerns what data actually leaves the vehicle to be stored as part of the back office operations (facility use determination, violation processing, and billing) of the toll system. Two different operating approaches have come to be known as a "thin" or "thick" client. The thin client uses an OBU (in-vehicle toll meter) where all raw data is transferred to the back office. In the back office, the data is processed and the road segments are recognized and matched with toll rates. This means that all information relevant for tolling is calculated in the back office and retained at appropriate detail to meet evidentiary standards and for a period sufficient to cover dispute opportunities. In the thick client approach, the tolling process takes place in the OBU. After the road section is recognized, the toll rate is processed in the OBU according to the type of the road, time period, and vehicle class. The road use information can be sent to the back office in aggregate form together with the fee. Specific road details are never stored in the toll system back office. If the fee is calculated in the OBU, it is also possible to integrate a card slot (for usage of cash cards) into the OBU in order to achieve maximum privacy for the participants.

However a toll system is operated, it is important to remember that there is no absolute technical safeguard for personal information when road usage must be verified and processed for payment. Even if detailed data is stored only in the participant's vehicle, it is vulnerable to discovery and misuse. But reasonable safeguards are an essential part of any business or government process that makes use of, or has access to, private information.

Establishing a Right to Privacy

In 1995 the European Parliament passed Directive 95/46/EC, on the protection of individuals with regard to the processing of personal data and on the free movement of such data. This Directive is an example of specific direction on how information collected by governments about private individuals could be managed. The main provisions of the Directive states that Member States shall provide that personal data must be:

(a) processed fairly and lawfully

(b) collected for specified, explicit and legitimate purposes and not further processed in a way incompatible with those purposes

(c) adequate, relevant and not excessive in relation to the purposes for which they are collected and/or further processed

(d) accurate and, where necessary, kept up to date

(e) kept in a form which permits identification of data subjects for no longer than is necessary for the purposes for which the data were collected or for which they are further processed

The Directive also covers the subject's rights of access to the data, rights of notification about data processing and rights to formally object to data processing, how data can get transferred to other parties, judicial remedies, liabilities and sanctions. Such an approach renders less ambiguous questions about whether any given governmental program complies with basic privacy protections. In the case of a road tolling system, it is feasible to design systems, practices and safeguards that will meet international standards, thus moving any debate about privacy from the abstract to the particular.

Conclusions

Many states, such as Oregon, Colorado, California, Georgia, Florida, New Jersey, New York, Washington, and Texas, are currently testing the real world application of a number of variable road tolling approaches. Distance-based road use charging is being considered as a long-term replacement for fuel-based taxes for both individual states and the U.S. The National Surface Transportation Policy and Revenue Study Commission, the National Surface Transportation Infrastructure Financing Commission, and the U.S. Chamber of Commerce have all emphasized the importance of developing road financing approaches based on time of use, as well as distance and location traveled. Many European countries are actively considering comprehensive road use charging systems as a way to support a single integrated market for transportation, pay for infrastructure, manage congestion and address environmental concerns about growing traffic. The Traffic Choices Study has significantly contributed to this mounting interest and body of knowledge.

The primary aims of the Traffic Choices Study were to (1) accurately describe the behavioral response to the congestion-based tolling of roadways, (2) better understand issues of policy related to the implementation of road tolling, and (3) test an integrated system of technical solutions to the problem of tolling a large network of roads without deploying substantial physical hardware on the roadside. The study has met these goals and, with the release of this report, has begun an effort to widely distribute the findings from the research. In particular, the study has:

- **Familiarized the public and policy makers with road tolling.** The project provided a limited number of households with a direct experience with road tolling. The motorists involved in the project gained a better understanding of how price relates to the benefits of their travel choices. Travel decisions were made explicitly in relation to price. The technology involved in road tolling was unfamiliar to most people; but the experience with the technology has made it seem less strange. The project received a fair amount of local and national news coverage and has been cited by numerous other efforts to develop road tolling public policy.
- **Generated price response data for use in other analytical efforts.** A properly developed sample stratified by income produced data and behavioral models necessary for broader analysis of transportation tolling. These results were incorporated into regional travel demand models, as well as revenue and benefit cost models. Appropriately derived elasticity measures can, in the future, aid in corridor transportation studies where tolling may be considered as a financing or management tool. The PSRC travel demand model has already undergone modifications based on findings from the study, and the extensive analytical database will be available to researchers for a broad range of further analysis. And most importantly, the direct observation of motorist behavior has demonstrated the sizable opportunities to realize broad social benefits (converting wasted time resources into revenues for reinvestment) through price management.

- **Developed an understanding of technological applications and standards.** Specific vehicle positioning, communications, and billing applications were developed for the administration of the project. Other systems, as would be needed for the broader actual implementation of a system wide tolling program, were discussed as part of full system architecture. The GPS-based tolling system deployed for the study is mature. There are countless details that would need fuller resolution prior to being used as part of any specific road tolling program. But these technical issues are all resolvable within a normal process of engineering a specific solution. Most of the remaining technical design questions depend upon a better articulation of tolling policy rather than stem from an underlying deficiency in technical capabilities.
- **More finely defined a set of policy issues to be addressed in actual program design.** The demonstration project allowed the study team to better understand dimensions of key issues in policy. Generally, these policy issues encompass user privacy, payment security, enforcement, use of revenues, and other elements of program design and marketing. None of these are new issues, and insights that have been gained do not lead to obvious or simple answers. But, ordinary people faced with a new way to pay for transportation have provided an important perspective. Opinions are not immovable, but are shaped by experiences and evolve with new information. Public discussions of variable road tolling are in their infancy and it is hoped the Traffic Choices Study will contribute by helping to better measure road users' responses and preferences.

The Puget Sound region, like many growing regions, is struggling to accommodate and manage increased travel activity. Responding to this growth requires understanding the nature of travel behavior and how it might respond to policies to manage existing transportation system capacity, and evaluating the potential of infrastructure improvements. The Traffic Choices Study sought to fill voids in our understanding of the underlying traveler behavior.

The project started with an assumption about the behavior of individuals in society; that they are essentially rational beings who respond to incentives in ways that, on balance, are logical and reflect their own individual preferences. And that as public planners, those of us in the business of designing public programs would do well to try to understand these preferences and resulting behaviors. This, of course, is easier said than done. Social experimentation is challenging, often expensive (but significantly cheaper than getting things wrong), and even potentially controversial. Nonetheless, the authors of this report have attempted to conduct such an experiment. Debate about road tolling has been going on for centuries, and discussions of congestion pricing for decades. But all signs are that the policy debate is heating up and that the use of road pricing and tolling (in its many forms) will have an increasing role in the management and evolution of our urban transportation systems.

The Traffic Choices Study was not designed to make the case for variable road tolling. The study was based on an expectation that road users would respond to price, and that the specific choices road users make determine whether variable road tolling is a useful approach to road finance and management. However, the case for road tolling is compelling. The study endeavored to also document the problems associated with tolling an entire network of road facilities; it would be complex and costly, the technology raises concerns about privacy, and some fear the charges would be particularly burdensome to particular users. Yet the opportunities to limit roadway congestion (and its wasted resources) and address the inefficiency and instability of current finance methods are significant and merit serious consideration in the development of future transportation financing policy.

Acknowledgments

This report is our attempt to contribute to the policy discussion of road tolling, by tapping into the preferences, behaviors, and insights of the traveling public. The project observed driving patterns of about 275 volunteer households before and after hypothetical tolls were charged for the use of all the major freeways and arterials in the Seattle metropolitan area. These households willingly participated in a study that imposed on their patience and their personal lives. They did so with grace, dignity and a sincere interest in helping to explore new ideas for addressing old problems. Those of us involved in the study were encouraged by the open-mindedness, and cheerfulness (but this is Seattle) of these participants. We hope we have done their generosity some small measure of justice through our analysis.

Over the years, a single individual has provided consistent leadership in pressing for a more complete evaluation of road tolling within the central Puget Sound region. Mr. Aubrey Davis has had many careers in his lifetime, but also found time to serve on the Washington State Transportation Commission. Mr. Davis has also been a longstanding member of the PSRC Transportation Policy Board and serves as Chair of that body's Pricing Task Force.

The Puget Sound Regional Council thanks several organizations and their staff for contributions to this study and report:

- The **U.S. Department of Transportation's Federal Highway Administration's Value Pricing Pilot Program** contributed major funding to this project, and provided guidance and oversight throughout the effort.
- The **Washington State Department of Transportation** was the fund administrator and state partner in the project.
- The **Puget Sound Regional Council** provided local funding, project management, oversight, research and analysis.
- **ECONorthwest** was the lead on project management, research design, technology selection, and data preparation and analysis. Their team included **PB** (technology selection and travel-demand modeling) and **PRR** (recruitment, participant management, survey administration).
- **Siemens** provided the tolling system technology, systems integration and toll system operations. Their team included **CarToys** (installation of in-vehicle equipment) and **Cingular** (wireless communications).

Countless individuals contributed to the success of this project; but any errors or omissions are the sole responsibility of the Puget Sound Regional Council.

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