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Traffic Choices Study: Measuring Response to a Network of Time of Day Tolls in the Central Puget Sound Region of Washington State

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Call for papers on Approaches to Modeling Traveler Response to Road Pricing

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Introduction

In 2002, the Puget Sound Regional Council (PSRC) received a grant from the Federal Highway Administration to study how travelers change travel behavior (number, mode, route, and time of trips) in response to variable charges for road use (congestion pricing). 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. This paper outlines the major elements of the study and examines the implications for the formal modeling of transportation networks under tolled circumstances. This paper describes:

- The basic mechanics of the experiment.
- The data that was collected and the preparation of it for behavioral analysis.
- Primary behavioral findings.
- Preliminary efforts to augment existing PSRC travel demand models.
- The results from modeling full network tolling (including benefits cost analysis results).
- Further opportunities to translate the study's findings into improvements to transportation modeling.

The Traffic Choices Study

The Traffic Choices Study emphasized the complex choices drivers make when the road network is managed and financed through tolls that vary by time of day, day of the week, and facility type. Because no comparable real-world examples of such a congestion pricing system exist, or are even being contemplated, this study—a wholesale departure from current road pricing policy—required careful experimental design and implementation. The Traffic Choices Study recruited a statistically significant sample of motorists and, after establishing their baseline "before-pricing" driving routine, began charging them for access to selected roadway facilities at particular time periods in the day. In other words, it was as if motorists had to pay road tolls. The tolling system equipped and monitored the movements of over 275 households (450 vehicles) for an average of approximately 16 months per vehicle. The economic principle underlying the study's tolling policy recognizes that the social marginal cost of travel exceeds the private marginal cost recognized by the vehicle user; that is, our travel costs others more than it costs us. The project team based the toll structure in our study on this principle. The toll rates are displayed in Figure 1.

Figure 1: Tariff Structure

Time Period		Description of Time Period	Toll Rates	
			Freeways (Class 2)	Non-Freeways (Class 1)
A	PM Peak Period	4-7 PM (Mon-Fri)	$0.50 / mi	$0.25 / mi
B	AM Peak Period	6-9 AM (Mon-Fri)	$0.40 / mi	$0.20 / mi
C	Midday	9 AM-4 PM (Mon-Fri)	$0.15 / mi	$0.075 / mi
D	Weekend Peak	10 AM-7 PM (Sat-Sun)	$0.20 / mi	$0.10 / mi
E	Off Peak & Weekend Off Peak	7-10 PM (Mon-Sun) 7-10 AM (Sat-Sun)	$0.10 / mi	$0.05 / mi
F	Late Night	10 PM-6 AM (Mon-Sun)	N/C	N/C

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 were consistent, 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 simulated real price incentives for participants, allowing measurement of their behavioral response to value pricing.

Data Preparation

The tolling system (on-board devices and back office functions) provided by Siemens produced vehicle use data records appropriate for all aspects of toll system operation and user account management. These data records, organized around vehicle trip details, were the basis for the creation of an analytical dataset that would support the project's core behavioral analysis. The underlying data elements of the trip records were second by second location and time stamp details. The requirements of behavioral analysis, however, necessitated some additional data preparation. Since the analysis of demand response to tolls was expected to be influenced by trip purpose, it was necessary to devise a method through which trip purpose could be inferred from the underlying toll system data records. A number of heuristics were employed in automating the identification of household employment locations where each household could be associated with multiple employment locations if necessary. The workplace location identification methods made use of information about trip timing, frequencies or patterns, dwell times, and employment and land uses at trip ends. With all appropriate trips associated with home and work locations, all trips were then linked together into tours. Tours were the organizing framework for all analysis of travel behavior. The definition of a tour was determined by available and unambiguous information about each participant's home and work locations. The end result of the tour formation process was that all 700,000+ trip records in the trip database were organized into 200,000+ individual tours categorized into one of four tour categories.

Analysis Approach

The Traffic Choices Study produced a large volume of highly accurate household-level vehicle trip data records collected over an 18-month period. This resulted in numerous repeat observations (records of the same kind of trip activities), but over a modest sample of participating households. The basic analytical approach to understanding behavioral response to tolls involved estimating linear impact regressions with observed dimensions of travel demand (across households, vehicles, and workers) as dependent variables, and with measures of the generalized costs of travel (tolls, out-of-pocket costs and time costs), household demographics (income and number of drivers), seasonal factors, and a measure of transit viability as explanatory, or independent variables.

Traffic Choices was primarily a study of driver behavior in response to paying tolls for road network use. The primary explanatory factor in the modeling of travel demand behavior was the tolls costs to which the households/vehicles/workers were exposed. Other important explanatory elements that were included in the modeling were household income, the number of drivers in the household, dummy variable for summer weeks, measures of transit accessibility for each household (described in more detail above), and a dummy variable for households that exhibited highly anomalous behavior in response to the toll "treatment."

Results

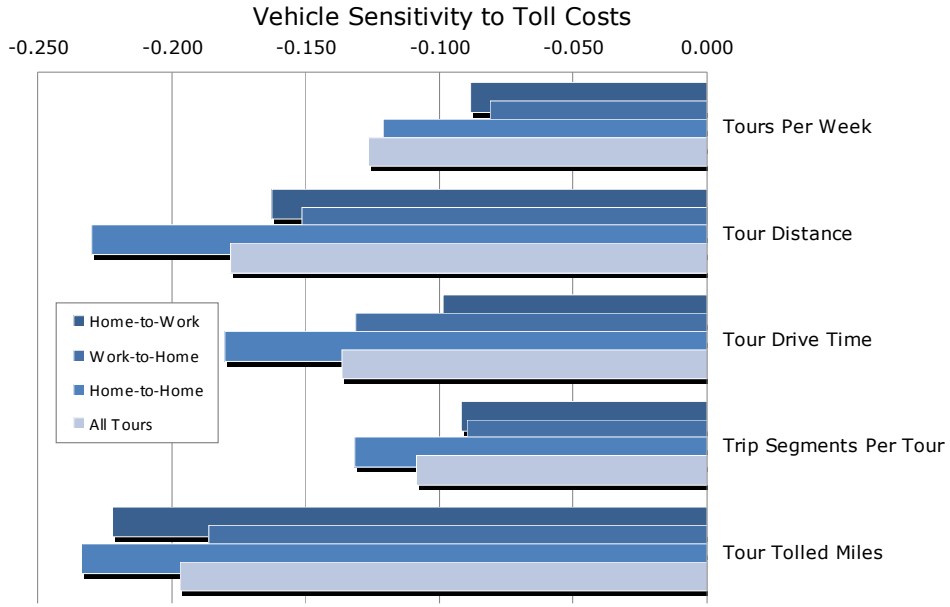
Travel surveys are often performed to support the development of travel models or other aspects of transportation planning. Large-scale surveys, however, are expensive to administer, and are often limited to collecting travel diary information about a few days of consecutive travel. While only being able to observe vehicle travel directly, the Traffic Choices study measured dimensions of vehicular travel unambiguously (without reporting error) and over an extended duration. This offers a unique opportunity to better understand the complexity and variability of vehicle travel both across and within households in our region. The study team has only scratched the surface of the possible use for the extensive trip data. Some selected descriptive statistics regarding household-level travel characteristics are displayed in Figure 2.

Figure 2: Select Descriptive Statistics

Characteristic	Tour	Average	Std. Dev.	Rel. Var.
Tour Freeway Miles	Home-to-Work Tour	5.46	3.56	2.22
	Work-to-Home Tour	5.79	4.95	2.17
	Home-to-Home Tour	4.65	9.49	2.52
Tour Distance (miles)	Home-to-Work Tour	12.26	7.70	0.67
	Work-to-Home Tour	14.18	12.68	0.94
	Home-to-Home Tour	15.97	35.58	2.23
Tour Drive Time (min)	Home-to-Work Tour	25.35	13.95	0.57
	Work-to-Home Tour	32.00	22.97	0.74
	Home-to-Home Tour	35.06	51.60	1.48
Tour Speed (mph)	Home-to-Work Tour	28.63	7.19	0.24
	Work-to-Home Tour	26.38	8.48	0.31
	Home-to-Home Tour	20.11	20.78	0.78
Tour Total Time (min)	Home-to-Work Tour	68.40	230.87	2.92
	Work-to-Home Tour	93.23	257.07	2.42
	Home-to-Home Tour	227.82	751.19	3.14
Tour Departure Time	Home-to-Work Tour	8.75	2.18	0.24
	Work-to-Home Tour	16.33	2.35	0.15
	Home-to-Home Tour	13.83	4.17	0.30
Tour Arrival Time	Home-to-Work Tour	9.23	2.09	0.22
	Work-to-Home Tour	17.30	2.58	0.16
	Home-to-Home Tour	15.77	4.30	0.27

Primary findings from the study document the magnitude of the short-run travel behavior response to tolls across a broad range of behavioral dimensions. All trip records were associated with one vehicle and each household participant was associated with one or more vehicles. All trips linked to a work location were associated with a working household member. Short-run elasticities of demand were estimated for models explaining household, vehicle, and worker behavior independently. Trip data for households, vehicles, or workers was assembled into weekly measures of trip making behavior, such as the number of tours (per tour type) made each week of the study. These measures of travel demand were the dependent variables in the linear modeling. Models were estimated explaining behavior in regard to changes in generalized costs of travel and are reported in regard to the changes in toll costs. (Figure 3)

Figure 3: Vehicle-level Elasticities of Toll Costs



Network Modeling Approach

Participants in the experiment made explicit choices about the value of various dimensions of trip-making behavior, but did not enjoy the network efficiencies (speed improvements on roads) that would result from an actual implementation of road pricing to all users. The results are not equilibrium results, where decisions reflect all the costs and benefits resulting from road pricing. An important extension of the analytical findings is to emulate the experiment within a full network travel demand model. Such a model is maintained by the PSRC as part of our regional transportation planning responsibilities. A preliminary approach to modeling a network application of tolls is described in some detail below. The travel demand model results were used to estimate user benefits, toll revenues, and general performance of the road network. The basic approach to the modeling exercise was to introduce results from the Traffic Choices Study into appropriate steps in the travel demand model, and to organize modeling in a manner consistent with the short-run nature of the experiment. The PSRC model is an advanced "4-step" model with *time-of-day* and *vehicle availability* as added elements in the operation. Modeling the Traffic Choices Study results involved three specific departures from standard model practice. It 1) introduced a trip

generation response to tolling, 2) employed values of time consistent with the findings from the experiment, and 3) limited the trip distribution response to tolls. Each issue is discussed in more detail below.

Trip Generation

If tolling were to be implemented on the entire road network the total amount of travel demand would likely be lower than for non-tolled conditions. The Traffic Choices Study directly measured this demand response for trip-making with a set of impact models (described earlier in this report) for the number of total tours. The tours examined in these impact models were auto tours, but where transit viability (between origin and destination zones) was a significant explanatory variable. By estimating the tour elasticity with respect to generalized costs of travel with the transit measure reduced to zero (implying no available transit alternative), the impact models allowed the team to establish expectations about the magnitude of total trip generation response to network tolling. A base case of the travel demand model without tolls and a traffic assignment with the toll structure in place were used to produce weighted average deltas in the generalized costs (time and model costs) of travel from each traffic analysis zone to all other zones. These zonal measures of change in generalized costs were used with the tour elasticities from the study's impact regressions, to modify the number of trips generated from each traffic analysis zone prior to completing the rest of the travel demand model steps.

Values of Time

Common assumptions about values of time often focus upon the 50% of gross wage rate estimate. This assumption is often a result of the lack of available local data about people's revealed behavior in the face of time-money trade-off opportunities. As an example, the PSRC regional travel demand model has historically employed value of time assumptions that are approximately 50% of average regional wage rates for each of four household income quartiles. With no tolling projects or demonstrations in operation, the region has had to adopt more global estimates, and has only recently conducted stated preference experiments in an attempt to refine such estimates. As stated above, the study measured time and money trade-offs as a function of route choices made by the study participants. These value of time findings were incorporated into the travel demand modeling as part of traffic assignment and mode choice, and represent about a 50% increase in values of time over the previously employed parameters.

Trip Distribution

By making use of the estimated elasticity of demand for tours with regard to changes in generalized costs, the travel demand modeling of network tolling started with a modified set of trip tables for use in the downstream steps of the modeling process. The Traffic Choices Study was a short-run experiment, where short-run responses were limited by previous household level choices such as home locations. In the long-term, if road pricing were implemented, these constraints would be relaxed and the magnitude of the measures of demand response to tolling should be larger. One dimension of long-run response that clearly did not occur during the experiment was a change in residence and workplace locations in response to the tolls. The travel demand modeling of the experiment also needed to limit this response. To this end, the trip distribution process of the modeling was implemented without tolls as an influencing factor. Once trips were distributed, origins associated with destinations, the mode choice and assignment elements of the model were implemented with the study's toll structure embedded in the traffic assignment and feedback through mode choice.

The modeling provides a useful guide to understanding the likely type and magnitude of general equilibrium results. A formal benefit cost analysis of the modeling results is currently underway. The modeling currently suggests, however, the following type of system implications from full network time of day variable tolling (all results are preliminary at this time and will be revised prior to the conference):

- An 11% reduction in average weekday auto travel time.
- Travel time savings valued at over $5 million per average weekday.
- Gross toll revenues in excess of $9.5 million per average weekday.
- A 5.8 percent reduction in single occupancy trips.
- Sizable shifts in time of travel (60% increase in nighttime trips).

Further Implications for Transportation Modeling

The Traffic Choices Study is unique in its implementation. The study combined a technical trial of road pricing with a carefully administered social experiment. The resulting data, its behavioral significance, and its modeling implications will continue to be explored over the coming months and years. The study offers opportunities for model development in a number of broad areas, including:

- The development of trip and/or activity generation models.
- Insights into the characterization of journey or tour composition, and the variability of travel characteristics over many observations, e.g., over different days of week.
- Further investigation of the distributions of speeds on various facility types and the relationships between speeds and volumes (where volume information can be matched to speed observations from the study)
- Analysis of repeat observations of travel times between numerous origin and destination combinations
- Analysis that supports the development of better route choice models