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Current Practices of Modeling the Impact of Roadway Tolls on Mode Choice

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Abstract
This study aims to present current practices in mode choice analysis addressing the contemporary toll study. A literature review is conducted based on several case studies to assess the impacts of road pricing. Previous experience in developing effective mode choice models are discussed, including the model structure, input data, critical factors influencing mode choice, elasticity of demand, and mode shift. Based on this review, a general procedure for implications of new toll roadways are suggested for transportation planners and policy makers.

Structure – the Mode Choice Model

A traveler's chosen mode of travel is a rational trade-off decision weighing the various costs imposed on and benefits available for that particular mode choice. Due to this, the impact of roadway tolls on mode choice is complex because the cost of travel is but one of many factors that influence a traveler's choice of transportation. It is therefore necessary to assess other factors that weigh in a traveler's decision in order to estimate the impact of tolling on mode choice.

Naturally, the efficacy of discrete choice modeling is dependent foremost on the diligent inclusion of explanatory variables. This review catalogues four interrelated dimensions of analysis shown to exert significant influence on mode choice (see Table I):

Table I: Mode Choice Explanatory Variables by Dimensions and Planes of Analysis

Planes of Analysis	Dimensions of Analysis			
	Socio-economic	**Travel Cost**	**Temporal**	**Categorical**
	Household Income	Parking	On-Vehicle Time	Transit Strike
Time of Day	Autos per Drivers	Gasoline	Walk Time	Seasonal Variation
Trip Purpose	Vehicle Occupancy	Maintenance	Transfer Wait Time	Alternative-specific Intangibles
Mode	Number of Workers	Tolls	Number of Transfers	
Household Income		Fares	Headway Wait Time	
			Transit to Work Time	

Source: Train 1980, Dehghani, et. al. 2003, Washbrook, et. al. 2006, Kazimi et. al. 2003, Hirchman et. al. 1995

Two additional "planes" of analysis: time of day and trip purpose, are included in several comprehensive model structures. Typically, these additional planes of analysis are included to more realistically capture real-world conditions in each unique study region, as well as to extend a logit model's capability to effectively micro-analyze the impact of different policy scenarios. For example, by splitting the travel cost dimension by peak and off-peak time periods, as well as by work and non-work trips, variations in a traveler's sensitivity to increased travel costs (e.g., choosing a toll roadway) may be detected and quantified. Results from the Florida DOT Turnpike Enterprise's (FLDOTTE) recent comprehensive mode choice model found that an increase in travel costs was tolerated more during off-peak than peak hours for work than non-work trips (Dehghani, et. al. 2003). Integrating the time of day and trip purpose planes of analysis enables the logit model to effectively identify and fine-tune potential operational or policy changes (e.g., variable toll pricing scheme) aimed at maximizing efficiency.

Data Source – Populating and Calibrating the Mode Choice Logit Model

The mode choice model must be properly calibrated by real-world data for forecasting future conditions. Each explanatory variable is accompanied by a coefficient value that represents its magnitude of influence. Two types of data sources are typically used, including surveys and observations, to populate and calibrate a mode choice model.

- *Revealed and Stated-Preference Surveys* – Survey questions can directly address explanatory variables chosen for the mode choice model. Essentially this provides quantifiable data along various dimensions and planes of analysis. Revealed-preference surveys focus on trip characteristics that actually took place, yielding such information as origin and destination, mode choice considerations and travel time. However, surveys of this type are limited by the inability to predict behavior under conditions that do not yet exist (COMSIS 1996). Stated-preference surveys fill this void by presenting the respondent with scenarios based on hypothetical conditions. Despite concerns as to the accuracy of stated-preference data (e.g., unrealistic optimism, unforeseen influences), it provides crucial statistical data for projects in which new travel modes or improvements are proposed, such as a new toll facility.

- *Observations* – Observed data, such as land use patterns, traffic counts, and other network characteristics, are useful as a reference against revealed-preference data and, in some cases, a substitute for missing data. For example, origin and destination data may be extrapolated from a longitudinal analysis of traffic volumes, employment location and density, and motor vehicle registration data (Hirchman et. al. 1995). Other cases in which observed data are required include transportation facilities with endogenous attributes that influence a traveler's decision. For example, modeling traveler behavior for the San Diego I-15 congestion pricing project required the inclusion of an explanatory variable to account for potential time savings from an existing HOT lane facility. As a function of the difference in travel time between the I-15 HOT lanes and its parallel free lanes, the required data on potential time savings was estimated using two months of time-of-day speed data collected by loop detectors embedded in the roadway (Kazimi et. al. 2003). For choice modeling projects with a future planned road pricing scheme (e.g., congestion management), data for the time savings explanatory variable may be calculated through travel demand analysis and adjusting relevant data observed at other roadways with a comparable facility.

The use of feedback and observed data for calibrating mode choice models deserves special note, given its potential impact on the statistical accuracy of explanatory variables. Since some of the outputs of the linear four step travel forecast procedure are not consistent with inputs to preceding steps, substantial distortion of explanatory variables that influence traveler behavior may occur (FHWA report 1999). As a solution, the process of "feedback" has been implemented by reintroducing output of one step as input to a previous step until the revised output "converge" on a defined set of criteria. Employing feedback as a calibration mechanism for mode choice modeling requires the integration of outputs from route assignment through an iterative feedback process. Heavily emphasized by the comprehensive FLDOTTE modeling system, iterations of the feedback loop should continue until a reasonable convergence between modeled outputs (e.g., average trip length, speed, link volumes) and observed or revealed data (e.g., screenline volumes, patronage at key toll plazas, average trip length) is achieved (Dehghani, et. al. 2003). This best practice approach arguably ensures that the model is properly calibrated to produce realistic highway loadings and travel times based on crucial explanatory variables that affect the mode choice.

Tolls and Mode Choice – Factors of Influence, Elasticity of Demand, and Mode Shift

Table II presents averages and ranges of the magnitude for 140 coefficient values along the four dimensions of analysis, summarizing the findings from three mode choice models surveyed in this study.

Table II: Typical Influence of Explanatory Variables by Dimensions of Analysis

Dimensions of Analysis	Magnitude/Coefficient of Influence			
	Negative		Positive	
	Range	Average	Range	Average
Socio-economic	-0.0000474 to -0.008	-0.0041	1.21 to 2.08	1.77
Travel Cost	-0.00091 to -0.206	-0.019		
Temporal	-0.004 to -4.595	-0.077		
Categorical	-0.524 to -5.17	-2.66		

Source: Train 1980, Dehghani, et. al. 2003, Washbrook, et. al. 2006

Factors of Influence

Overall, temporal factors had the largest influence on mode choice decisions, followed by travel cost and socioeconomic dimensions. Due to complex interactions between variables in the logit function, the influence of many explanatory factors may exhibit threshold dynamics in traveler mode choice decisions despite its representation as a constant coefficient. For example, Washbrook (et. al. 2006) found that the likelihood of a traveler choosing a transit mode dramatically decreases as transit in-vehicle time variable approaches revealed SOV in-vehicle time, and as headway or transfer wait time approaches 10 minutes. This threshold effect emphasizes that the systemic impact of any one explanatory variable on traveler mode choice may be non-linear.

The large range of coefficient values for each dimension in Table II reflect not only the different magnitudes of influence, but also the variation in traveler preferences from different regions captured by each mode choice model. For example, the coefficients of in-vehicle time for both auto and transit are -0.037 in Vancouver, -0.015 in Florida, and respectively -0.0473 for auto and -0.0192 for transit in San Francisco. This indicates that while the disutility of auto and transit in-vehicle times are comparable in Vancouver and Florida, travelers in San Francisco may better appreciate the benefits of riding transit, such as being able to read and avoiding the stress of commuter traffic (Train 1980). Due to the fact that there are numerous instances of such divergences even for basic attributes of travel, many conclusions drawn from a mode choice model (especially highly aggregated conclusions such as elasticity) in one region may not be fully applicable to others.

It is therefore difficult to assess the impact of roadway tolls based on the experiences of comparable facilities elsewhere. Despite the limited generality of modeling results, there are several inter-variable relationships with regard to travelers' perceived utility for roadway tolls that are typical of the three mode choice analyses surveyed herein. Trip length, as captured by the temporal dimension, is highly correlated with travelers choosing tolled roadways due in part to the longer spacing between interchanges (Dehghani et. al. 2003, Kazimi et. al. 2003). In the socioeconomic dimension of analysis, household income is a significant explanatory factor of a traveler's sensitivity to toll prices, an aspect that may be more fully explored by concurrently considering the temporal and travel cost dimensions.

The mode choice model based on revealed-preference data for nested automobile modes (i.e., FasTrak HOT lanes, SOV parallel free lanes, and carpool users) in the San Diego I-15 HOT facility discovered that during peak demand periods with high variability in time savings, more travelers are willing to pay to use the FasTrak HOT lane when toll price exceeds the threshold of $1.90. Conversely, peak periods with high variability results in lower FasTrak patronage if toll prices are below $1.90, suggesting that the disutility of roadway tolls diminishes as toll price increases (Kazimi et. al. 2003). This counterintuitive finding is also echoed by the mode choice model in Vancouver based on stated-preference data, in which it was also found that this threshold relationship between temporal and cost dimensions is statistically significant only for travelers above a certain income bracket ($40,000 CND) (Washbrook, et. al. 2006). Similarly, the sample of travelers using FasTrak HOT lanes is relatively wealthy, with 33% of all respondents in the $100,000 USD income bracket. These relationships suggest that middle to higher income travelers tend to view toll price as a measure of congestion, and therefore are more willing to pay higher tolls for potentially greater time savings.

Elasticity

The complex relationships between explanatory variables as captured by mode choice models ultimately culminate in elasticity values, or aggregate estimates of the influence of any one variable on the disutility of a traveler mode choice. In other words, elasticity measures the ratio of decrease in the likelihood of a certain mode being chosen due to the absolute increase in an explanatory variable. Table III below summarizes typical elasticity estimates gathered from a wide range of mode choice studies for a number of explanatory variables.

Table III: Typical Elasticities of Travel Demand

Explanatory Variable	Elasticity	
	Range	Average
Fuel	-0.05 to -0.55	-0.24
Parking	-0.11 to -0.16	-0.14
Tolls	-0.02 to -1	-0.32
Travel Time	-0.27 to -1.33	-0.59
Auto Wear and Ownership	-0.12 to -0.31	-0.22
Overall Operating Costs	-0.06 to -0.52	-0.24

Source: Burris 2003

As expected, time elasticities of travel demand were highest among the list of influences followed by elasticity related to cost. Due to variations in magnitude of influence for the myriad explanatory variables in the temporal dimension, the large range of travel time elasticities (-0.27 to -1.33) is not surprising. However, an equally large range of toll elasticities (-0.02 to -1) require explanation.

Toll elasticity factors in Table III include both fixed- and variable-rate tolls. The cause of the large range in elasticities is revealed in Table IV, which presents elasticities by type of toll. The much higher average price elasticity for variable tolls reflects the general understanding that the more flexible travel choices are to the traveler, the higher elasticities are prone to be (Washbrook et. al. 2006, Burris 2003, Hirchman et. al. 1995). In this regard, variable tolls offer travelers additional flexibility in travel decisions unavailable in most fixed-rate facilities, notably time shifting of trips or changing routes to avoid tolls, as well as toll-free incentives for carpooling. However, the large range of elasticities in Table IV (-0.02 to -1) suggests that not all variable-rate tolled facilities exhibit high elasticities. For example, a bridge crossing in Lee County, Florida, employs toll pricing that is variable by time of day, and yet achieved a price elasticity of only 13%. This relatively inelastic effect on traffic demand is due to a small savings in cost (average of 25 cents), tolerable existing congestion, poor transit options, inconvenient free alternate crossings, as well as the lack of a toll-free carpool crossing option. Due to these factors, travelers found the high toll price to be rational despite the additional flexibility offered by variable-rate tolling.

Table IV: Typical Toll Elasticity of Travel Demand by Type of Toll

Type of Toll	Elasticity	
	Range	Average
Fixed	-0.03 to -0.35	-0.18
Variable	-0.02 to -1	-0.45

Source: Burris 2003

Elasticity studies from other regions also corroborate the effectiveness of offering flexible travel choices. Based on stated-preference data, the Vancouver mode choice model offered respondents a full range of hypothetical mode choice alternatives to SOV travel. The resulting high elasticities of 31% to 46% across household income segments for a 10% increase in toll reflect significant mode shift due to hypothetically improved bus transit times as well as new carpool services. Likewise, the comprehensive FLDOTTE mode choice model accounts for a broad range of mode choices, data sources, as well as planes of analysis, including time of day, trip purpose, and route choice (via model feedback). As a result, reported elasticities based on a doubling of existing tolls are relatively high: 30-33% for peak periods and 36%-43% for non-peak. This finding also suggests that peak toll users are less sensitive to changes in toll rates due to a higher value of time during periods of high traffic demand (Dehghani, et. al. 2003).

On the other hand, a study of price elasticity of traffic demand yielded elasticities of only 7% to 20% for six out of eight fixed-toll bridges and tunnels in New York City. This scenario reflects a lack of convenient free alternative crossings (Hirchman et. al. 1995). However, elasticities for the two remaining bridges in the NYC region—the Henry Hudson Bridge and Brooklyn Battery Tunnel—were found to be relatively high, 50% and 26% respectively. Hirchman (et. al. 1995) attributes this to well-developed mass transit options for Manhattan-bound Brooklyn and Bronx residents, as well as the availability of free alternate crossings—the Brooklyn, Manhattan and Williamsburg bridges, as well as other free city-owned crossings of the Harlem River—that travelers may conveniently choose to avoid tolls.

Mode Shift

When changes in the transportation environment affect factors of influence in a traveler's decision-making process, elasticities of mode choice are formed in the logit model. The affected modes' share of travelers will decrease, resulting in a rebalancing of the percentages of travelers that choose each mode. This effectively estimates contingent mode shift dynamics that may occur as a result of planned or anticipated changes in the transportation environment. In the Vancouver stated-preference mode choice model, potential mode shift dynamics due to an increase in road charges were estimated by first establishing a baseline mode split scenario, then comparing it to a hypothetical scenario in which increased tolls and parking costs were implemented alongside much improved transit modes and toll-free carpool incentives (Washbrook et. al. 2006). With a moderate $2 total increase in driving costs, it was estimated that the share of SOV travelers would decrease from 83% to 75%, while an extreme $18 increase would result in a mode split of 17% SOV, 74% carpool and 9% transit.

Naturally, results of this kind are of utmost interest to transportation planners and policy makers who seek to apply conclusions from mode choice studies elsewhere to their constituent regions. However, conclusions drawn from mode choice modeling with regard to highly aggregate dynamics, such as mode shift, are potentially the most inapplicable between different regions. Washbrook (et. al. 2006) concedes that their findings from mode choice modeling are dependent on a specific range of choices potentially available to travelers in the Vancouver region. By definition, mode choice models factor in all the disaggregate characteristics of the population and transportation environment captured for a region of study, yielding highly aggregate findings such as toll elasticities and mode shift dynamics. It is therefore arguable that these aggregate conclusions may be unique, given that travelers' perception of even basic attributes of travel may differ between regions (e.g., values of time). Thus, the generality of modeling results involving aggregated estimates may be severely limited (Train 1980, Washbrook et. al. 2006, Burris 2003, Hirchman et. al. 1995).

<u>Summary – Implications for a New Toll Roadway</u>

Predicting the response of traveler behavior to a new toll roadway falls within the standard methodology of logit modeling assessed in this study. Predicting the overall impact of a new toll roadway requires the development of a discrete mode choice model encompassing existing factors identified in the study region which influence travelers' decision-making processes. This approach involves capturing explanatory variables in the logit form along four basic dimensions of analysis—socioeconomic, travel cost, temporal, and categorical—that adequately represent potential travelers' orientation within and relationships with the existing transportation environment. Integrating additional planes of analysis—such as time of day and trip purpose—into the logit structure would also improve a model's ability to accurately capture existing conditions as well as analyze the impact of proposed changes to the transportation environment.

While the actual selection of explanatory variables relevant to a project may be constrained by the focus and scope of the proposed changes under study, the collection of data with which to populate and calibrate a mode choice model must be structured to fit the type and purpose of the project. A new toll roadway does not offer travelers a new mode of travel, but rather offers an alternative that serves to improve mobility of travel and accessibility between origin and destination. To the traveler, this represents a trade-off decision that weighs potential travel time savings against a higher cost of travel for automobile modes, as well as concurrent comparison against the utility of other modes such as transit. In this scenario, the ideal mode choice model must capture both the existing travel conditions in the area (e.g., congestion, transit options) as well as the utility that travelers are likely to place on the new route choice. The former requires the collection of revealed data on actual trips made by travelers in the region of study, thereby producing crucial statistical and categorical information for journeys of particular interest to the project. Ideally, assessing the potential utility of an additional alternative choice suggests the use of stated-preference surveys, through which the mode choice model may systematically reflect a traveler's trade-off decision process that weighs various factors based on a hypothetical scenario implied by the proposed travel improvements (e.g., reduced auto in-vehicle time, higher cost of travel due to tolls). Observed data may also play a crucial role by corroborating and tempering both revealed and stated-preference data by independent observations of related travel conditions (e.g., level of service/congestion, travel speeds, traffic volumes). Furthermore, since the mode choice model must take into account the impact of a new route choice on travel times, observed data may be used to estimate potential time savings for travelers choosing to take the new toll roadway.

Once a mode choice model is calibrated to reflect real-world conditions, it may be used to analyze the impact of proposed changes to the transportation environment. In addition to estimating the efficacy of a new toll roadway in the regional network, the feasibility and effectiveness of operational decisions such as the implementation of variable toll pricing or traffic demand management schemes (e.g., HOT lanes) can be directly measured and simulated. Crucial statistics such as elasticities and mode split also emerge from mode choice modeling, giving planners and policy makers a powerful tool with which to effectively manage the present and future transportation environment.

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