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Incorporating Traveler Response to Pricing Policies in Comprehensive Activity-Based Models of Transport Demand: Literature Review and Conceptualisation

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Abstract

The growing number of studies and continued policy interest in road pricing strategies and technologies represent new challenges to transportation researchers in their attempt to better understand and predict the impact of various pricing strategies on travel behavior. We contend that these policies and associated modeling approaches should ideally be embedded in the next generation of comprehensive models of transport demand: dynamic activity-based models. This statement is based on the fact that these pricing strategies are implemented to induce behavioral change. To the extent that these policies are successful, such behavioral change potentially involves both primary and secondary changes in the strongly linked set of choice facets that make up comprehensive activity-travel patterns. For several decades, the basic form of the travel demand model was known as the “four stage travel demand model’’. Generally, it relies on data and model development supporting a local jurisdiction’s long-range plan. But to adequately forecast traffic and revenues or to analyze the effect of pricing policies, the model system must be sensitive to the effects of these policies on both travel behavior and land use. This is where the new generation of activity-based transport demand models provides most information for road pricing analyses. Activity-based models and micro-simulation modeling techniques distinguish the new generation models from the conventional four-step model. To assess the state-of-the art, a literature review was conducted to examine to what extent the current state-of-the art meets this ambition. This paper reports the findings of this state-of-the-art review of road pricing analysis and travel demand modeling. Based on this, limitations are identified and several needs for future research are suggested.

Keywords: Disaggregate travel demand modeling; Road pricing analysis; Dynamic activity-based modeling

1. Introduction

The growing number of studies and continued policy interest in road pricing strategies and technologies represent new challenges to transportation researchers to perceive and predict the impact of different pricing strategies on

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travel behavior. Broadly speaking, road pricing modeling techniques can be classified as four major types of tools which exist in the literature (Vovsha et al., 2005): static user equilibrium assignment; dynamic traffic assignment (meso-scale or micro-simulation of individual vehicles); conventional 4-step trip-based models, and advanced activity-based/tour-based models. The first two tools serve the purpose of modeling route choice with predetermined trip tables. The last two tools are related to a more general modeling stage referred as trip generation, trip distribution, mode choice, and time-of-day choice. The literature on road pricing has demonstrated that the most frequently applied combination, and the most advanced design so far is a 4-step model with the static assignment following by an activity-based model combined with dynamic traffic assignment.

For several decades, the basic form of the travel demand model was the "four step travel demand model". Generally, it relies on data and model development supporting a local jurisdiction's long-range plan, despite the different intended purposes. However, 4-step models have several principal limitations that reduce their value as a modeling tool for road pricing. First, 4-step models can incorporate only a limited number of segments in terms of time-of-day periods, vehicle types, value-of-time, payment type and etc., which makes it difficult to realistically model all road pricing markets. Second, by ignoring the linkage across different trips included into the same tour made by the same person, and by ignoring daily schedule constraints on individual travel, 4-step models fail to properly model time-of-day and mode choice sensitivity, which is of crucial importance for road pricing. Also a trip-based 4-step model is not sensitive to any effects of pricing policies on both travel behaviour and land use.

We contend that pricing policies and associated modeling approaches should ideally be embedded in the next generation of comprehensive models of transport demand: *dynamic activity-based* models. Activity-based models show promising results to address road pricing in a much more integrated way, although they are characterized by a significantly higher degree of complexity compared to 4-step models. In addition to the standard technique of using trip travel time and toll skims as variables throughout the modeling procedure, activity-based models offer a wide range of additional options relevant to road pricing. First, the tour-based structure of mode and time-of-day choice ensures much more realistic sensitivities of those choices to road pricing. Second, activity-based models implemented in a micro-simulation fashion are characterized by unlimited segmentation by travel segments and person types which better suits road pricing markets. Third, activity-based models can incorporate such additional choice dimensions as possession of a pass or transponder by each individual traveler, as well as address non-trip pricing forms through their impact on daily activity patterns. In the current paper, we primarily focus on application of discrete choice and activity-based models in road pricing studies. The paper is organized as follows. The next section provides the literature review of existing research, differentiating between single facet and more comprehensive approaches. Based on this literature review, we will then summarize major conclusions and provide a brief discussion of issues and future research directions.

2. Literature

Modeling travel patterns has been a central area of concern in transportation research for a long time. Traditionally, spatial interaction and entropy-maximizing models have dominated the field. These models are based on origin-destination tables and were typically embedded in a four-step modeling approach. However, in the 1970s these aggregate zonal models were criticized for their lack of theoretical appeal. This criticism let to the development of Discrete Choice Analysis (DCA) and then tour-based and activity-based approaches to Transport Demand Modeling (TDM). Figure 1 shows the schematic organization of existing approaches to TDM. The following summarises the weaknesses and limitations of four-step models which have been discussed by many authors (e.g., McNally and Recker (1986), USDOT (1997), and Li et al. (2010), and also demonstrates the most important differences between four-step and activity-based modeling approaches: ignorance of travel as a demand derived from activity participation decisions; a focus on individual trips, ignoring the spatial and temporal interrelationship between all trips and activities comprising an individual's activity pattern; inadequate specification of the interrelationships between travel and activity participation and scheduling; misspecification of individual choice sets, resulting from the inability to establish distinct choice alternatives available to the decision maker in a constrained environment; the construction of models based strictly on the concept of utility maximization, neglecting substantial evidence relative to alternate decision strategies involving household dynamics, information levels, choice complexity, and habit formation.

In fact, trip-based methods do not reflect (a) the linkages between trips and activities, (b) the temporal constraints and dependencies of activity scheduling, nor (c) the underlying activity behavior that generates the trips. Therefore, there is little policy-sensitivity.

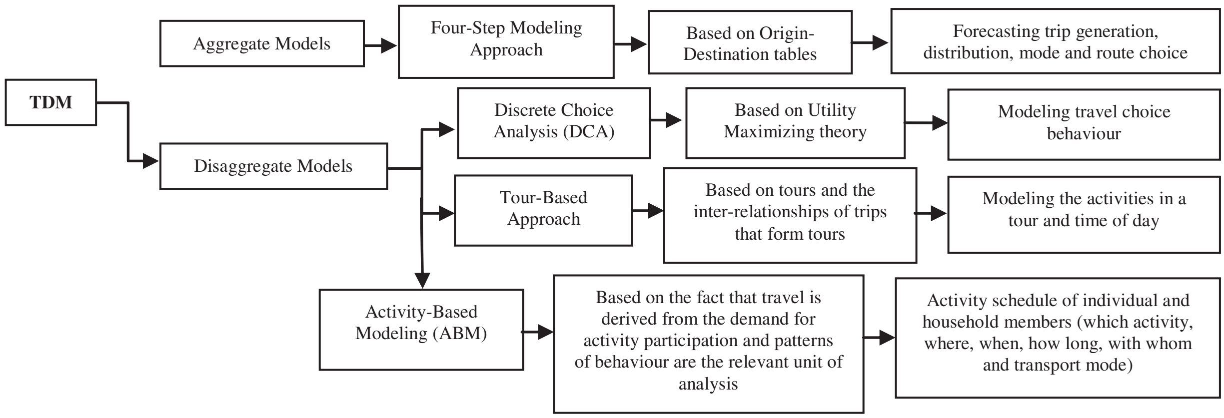

Figure 1. Schematic organization of existing approaches to TDM

To achieve our goals, the evolution of modeling techniques for road pricing from Discrete Choice Analysis (DCA) to advanced Activity-Based Modeling (ABM) is reviewed in the following sections.

2.1. Discrete Choice Analysis (DCA) for Road Pricing

Understanding the attitude of car users to road pricing and public acceptance of new schemes is considered as the highest priority for generating a successful pricing policy. In recent years, the behavioral response and attitude of the general public towards road pricing has received increased attention and consequently, many studies have focused on this topic (Replogle and Reinke (1998) and O'Grady et al. (2006)). In order to model travel behavior, disaggregate demand modeling is an appropriate tool, which can be successfully adopted for micro-level characteristics over individual perspectives by describing travel behavior with discrete variables. Discrete choice analysis (DCA), which is based on the principle of utility maximization, lies within this disaggregate analytical framework. It provides a number of promising techniques to analyze travel behavior (Ben-Akiva and Lerman, 1985). Especially the binary, multinomial and nested logit models, probit model, and the recent mixed logit model have been used in several studies, depending on the nature of the research. Some of these studies have been based on Revealed Preference (RP), but the vast majority has used Stated Preference (SP) methods in anticipation of the road pricing scheme.

Road pricing may affect many dimensions of travel behavior. Generally, road pricing studies focus on three dimensions of travel: time of day choice; route choice, and mode choice. Figure 2 shows the overall framework of these studies. The primary impacts of road pricing are mostly related to route choice and time-of-day choice (peak spreading). These aspects are among primary important issues for inter-city toll roads, as well as bridges and tunnels in metropolitan areas where transit does not play a significant role. However, this represents a very limited view of the general case. For example, in over congested urban areas where transit plays a significant role and represents a viable alternative, mode choice should certainly be included as a central modeling aspect. In other words, most of these studies have considered only short term response to single pricing policy in terms of changing time of day, switching route, and switching mode of transport, often also in isolation. Vehicle occupancy, willingness to pay (toll/non-toll), payment method, and toll facility/lane are other dimensions which have been considered in some studies, but these relate less to travel behavior and more to the general acceptance of new technology related to road pricing. Socio-economic variables and trip related characteristics are, usually, used in estimating models and evaluation the results. The key questions of these studies are: whether such policies will lead individuals to change their current behaviour and if so, how?; and what are the most important factors in this regard?

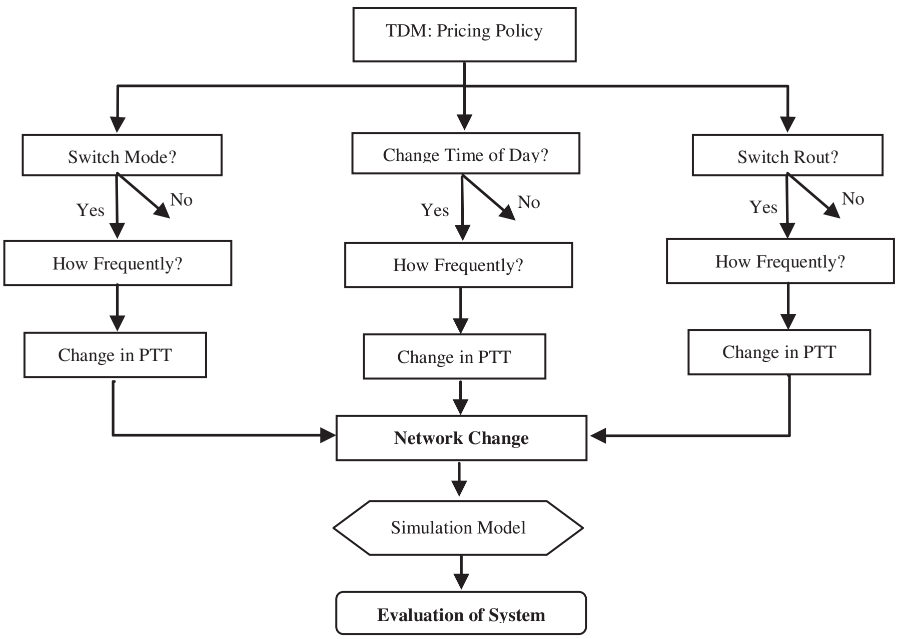

Figure 2. Framework for analyzing impacts of pricing policies. Notes: PPT= Peak Period Traffic volumes

2.1.1. Single- Faceted Choice Studies

Most studies thus consider only one choice facet of travel in their analysis and most frequently time of day, route or mode choice. In the following section we review some examples of these studies. There are various studies that have focused on changing time of day choice under pricing policies. Bianchi et al. (1998), Mahmassani (2000), Xie and Olszewski (2005), Burris and Pendyala (2002), and Ettema et al. (2004) are some examples of such studies. Bianchi et al. (1998) focused on re-timing responses to price differentiation by period for the Santiago metro. The aim of their study was to model traveler's behavior in order to predict their re-timing responses to fare changes and improvements in comfort. For this purpose, they used SP data collected during peak period in September 1993. Based on the concept that in some cases the time displacement required has the meaning of less leisure time availability, they only considered the information regarding time displacements no longer than 45 minutes for their analysis. They tested four modeling approaches for SP rating data and found that ordinal probit provide the best modeling results. The authors concluded that individuals are indeed reluctant to change trip time and traveling after the current time is perceived as more unpleasant than doing it earlier. Burris and Pendyala (2002), similarly, studied the impact of variable tolls on traveler's time of day and frequency choices using disaggregate models. They reported the results from two bridges with differential time of day tolls in the Lee County area of Florida in the United States. Using travel survey data collected at these two bridges, binomial and multinomial logit models were estimated. First, they developed a binomial model of variable pricing participation. In this model, explanatory variables including trip purpose, flexibility in time of travel, retirement status, flextime availability, and household income were found to contribute significantly to the model. A multinomial logit model of frequency of variable pricing participation was developed in the next step. Overall, these models showed that specific characteristics, such as flextime availability at the traveler's place of employment and being retired both increase the likelihood of the driver altering his/her time of travel to obtain the toll discount. Conversely, having a high household income or being on a commute trip decrease the likelihood. The study described by Ettema et al. (2004), again, focused on departure time shifts in response to time based road-pricing schemes. An operational model was developed and calibrated on a SP data set collected in London. In fact, they developed a model structure that can be used to describe responses to road pricing schemes. The basis of the approach is that individuals seek to maximize the overall utility derived from activities and trips when deciding on the timing and duration of trips and activities. In order to estimate a discrete choice model on SP data, they assumed that a commuter chooses between a limited numbers of feasible activity patterns characterized by total utilities. The choice between activity patterns (and thereby departure time choices) is described by a multinomial logit model. The results indicated that the marginal utility of work activity consists of a time-of-day dependent and a duration dependent component, whereas the pre-work and after-work activity, are largely duration dependent. Another important finding is the disutility of travel time, consists of various components, including travel itself and an activity related disutility component associated with shorter activities.

Similar to the changing time of day studies, there are different reports that consider other travel dimensions such as changing route, mode, and vehicle occupancy, while others examined willingness to pay. Below are some examples of such studies and associated choice structures. Nielsen (2004) examined behavioral response to different pricing schemes (kilometer-based pricing and cordon-based) in the AKTA road pricing experiment in Copenhagen using multinomial and mixed logit models. The author specifically focused on route choice models. Five hundred cars equipped with a GPS-based device were followed in the experiment and participants' normal travel patterns were observed. Next, pricing schemes were implemented. In addition, the participants completed questionnaires before and after the experiment, and completed a SP experiment before the field experiment. Results showed that the kilometer-based schemes are, in general, fairer than cordon-based schemes. Also, the main behavioral changes are using new routes, occasional trips to a new destination, time of day to non-peak, and to some extent, fewer trips. In terms of modeling, error term component models (mixed logit) improved the fit to SP data significantly comparing to multinomial logit models, however without altering the value of time. Dissanayake, and Kouli (2007) also investigated driver response to a proposed toll motorway project connecting the cities of Corinth and Patras in Greece. The overall objective of this research is to develop discrete choice models to investigate driver behavior on inter-city route choices and to explore driver attitudes to road pricing. Socio-economic and journey related characteristics of current road users along with their SP for the proposed toll motorway were explicitly incorporated in the model estimations. The binary logit model that comes under discrete choice methods was found to be an analytically convenient modeling method. The overall set of transportation routes consisted of the new toll motorway (NTM), and the existing alternative roads (EXR), which included the existing toll road, and scenic coastal road. Results showed that drivers prefer the NTM over the existing alternative routes. In the model, both the travel time and travel cost coefficients were negative and highly significant, indicating that travel utility decreases with increasing travel time and cost.

For the case of mode choice, Bhat and Castelar (2002) formulated a mixed logit model for joint RP-SP analysis, to study the behavioral response under congestion pricing in San Francisco Bay Area. Also, Bhat (1997) applied an endogenous segmentation model to estimate inter-city travel mode choice in the Toronto-Montreal corridor. Using the Bayesian Information Criterion, the author found that the preferred specification had a three-segment solution. The probability of belonging to any segment is a function of income, sex, travel group size, day of travel, and trip distance. In comparison with other commonly used methods, the author found the endogenous segmentation model to be the most appropriate based on fit to the data and reasonability of the results. The results of model showed that the intrinsic preferences for modes and level-of-service sensitivity are quite different among the three segment groups. Generally, the endogenous segmentation model represents a valuable methodology for evaluating the effects of inter-city traffic congestion-alleviation strategies in urban and inter-city travel contexts. The study reported by Peters et al. (2011) in the New York City area is other example in this regard. The San Diego I-15 Congestion Pricing Project is a demonstration of the policy of selling excessive capacity of HOV lanes to solo drivers by means of HOT lanes described by Ghosh (2001). In this research, the morning and afternoon commutes are modeled as a joint decision process. The multinomial logit choice model is developed for occupancy choice combination for both commuting legs joined with the pass (transponder) binary choice. This leads to seven choice alternatives. The trip price is then adjusted depending on the traffic conditions on the HOT lanes in order to maintain a satisfactory level of services for HOV. HOVs use the lanes at no cost. A time-variability variable has been introduced, and it is found that morning commuters dislike variability, while commuters are more tolerant to variability in the afternoon. The attempt of modeling both parts of the commuter trip is of high importance as the majority of studies have only examined departure time choice, ignoring the return trip.

2.1.2. Multi-faceted choice studies

Most of studies that we have reviewed above focused on one dimension of travel behavior. In this section we go one step further and review studies which considered two or more dimensions of choice behavior. Yamamoto et al. (2000), using a SP survey in the Osaka-Kobe metropolitan area administered in 1993 through 1996, focused on time allocation, departure time choice and route choice when a congestion pricing scheme is implemented on toll roads. A unique feature of their model system is that departure time choice and route choice are analyzed in conjunction with the activities before and after the trip. First, they developed a regression model of time allocation to discretionary activities based on utilitarian resource allocation theory. Hence, departure time is depicted on a continuous time dimension in the model. Then, a multinomial logit model of route and departure time choice behavior was developed considering the utilities of the activities before and after the trip. The results of parameter estimation of a regression model indicated that an in-home activity, except for the first or the last one of the day, tend to have shorter durations if the individual lives in a multiple family housing unit, but not if the individual lives in a single family home. The results imply that the durations for in-home discretionary activities are strongly affected by dwelling type and duration of a social activity is dependent on income level, mobility, and dwelling type. Wen et al. (2006), in the similar way, attempted to investigate how the Taipei Metro passengers respond to in terms of possible changes in their time of travel and/or shift to other modes when peak surcharge or off-peak discounts would be implemented. Interactive computer-aided interviews were conducted to collect SP data from metro peak users. This study evaluated two temporally differential pricing schemes – peak surcharge and off-peak discounts. Both pricing schemes may mitigate peak congestion by shifting partial peak demands to off-peaks or to other modes. Multinomial logit and nested logit models were employed to analyze the potential behavioral changes in arrival times to take metro and in mode choices. The findings of this study supported the idea that temporally differential pricing could be effective in mitigating peak-hour congestion. In addition, elasticity analyses indicated that metro passengers are very sensitive to fare changes in peak periods. Vrtic et al. (2007) considered route, mode and departure time choice as choice facets of travel. In this research, an extensive, self-administered, SP survey was conducted in Switzerland with the purpose of providing the Swiss government with detailed information for the evaluation of mobility pricing schemes. Similar to the previous studies, the authors use the multinomial logit model. The estimated models were in line with the results of previous studies. Results indicated that traveler behavior strongly depends on socio-demographic, trip and transport supply characteristics. Choice models reported by Yan et al. (2002) are based on surveys administered in 1999 on California State Route 91. Several dimensions of traveler responses to value pricing were modeled. First is the decision of which route to take. This decision is represented as whether to travel in the SR 91 Express (91X) Lanes, the SR 91 free lanes (91F), or the Eastern Toll Road (ETR). Other traveler responses included changing time of day and changing car occupancy. Five time periods were distinguished based on the toll schedule, while three car occupancy categories were identified. In addition, as part of the route decision but still distinct from it, the traveler decides whether or not to acquire a transponder in order to pay tolls electronically. Two bi-level nested logit models were estimated. The models gave good estimates of the effects of travel times and tolls. Several other factors appeared to affect toll road use more indirectly, by favoring a willingness to acquire an electronic transponder. Finally, they found that shifts to different vehicle occupancies or times of day in response to toll changes were very small. Mastako et al. (2002) used data on telephone survey in the SR-91 to estimate individual choice sets for commuters in this value-priced corridor. In the short term, travelers' response to value pricing in the SR-91 corridor occurs along several choice dimensions including route, vehicle occupancy, and time-of-day. A binary representation was selected for each choice decision in order to keep the number of alternative combinations to a minimum. For route choice, the decision is whether to pay a toll (Paid) or not pay a toll (Free). The two alternatives for vehicle occupancy mode are travel solo (SOV) or share a ride with at least one other person (HOV). Mode choice was equated with vehicle occupancy because the share of bus and rail in this corridor is very small. Also, two alternatives for time of day choice were travel in the middle of the peak (Peak) or travel outside the peak (Off-Peak). The three responses were represented simultaneously as fully joint decisions giving eight commute alternatives. The results indicated that there is a substantial amount of choice set diversity in the commuting population and that women are more likely than men to consider a greater number of alternatives.

2.1.3. Long Term Response to Road pricing

In contrast to the extensive literature on short term responses to road pricing, the influence of pricing policies on (re)location choices, i.e. dwellings and job locations, has received only limited attention to date. In this section we review some studies related to long term response to road pricing. In one of the earliest attempts in this regard, MuConsult (2000) estimated the percentage of people who would relocate due to a pricing measure. The reported percentages are in the range of one to seven percent. With respect to the kilometer charge, MuConsult expects that the percentage will be higher with regard to job change than with regard to residential change. For a toll-based charge a higher residential change is anticipated. No explanation is given for this difference. This in itself is not strange because the relocation percentages vary only slightly. Arentze and Timmermans (2005), also, study the relocation intention of Dutch households on the basis of a stated adaptation experiment. The road pricing scenario used consists of a time differentiated Kilometer charge with a higher price level in the peak period. Different price levels were used. This makes the charge quite comparable to the average price level in the time differentiated kilometer charges applied in this thesis. They found that 88.2 percent of the respondents would not consider a change, 2.0 percent would change their work location and 11.1 percent would change their residential location. Another example is the study reported by Tillema et al. (2006) that aims at providing additional insight into the effect of road pricing on relocation decisions of households, using a SP survey. Central to their approach is the observation that relocation decisions consist of several stages. The first stage is the decision whether or not to relocate and the choice of the new residential and/or job location. Secondly, even if a household chooses to relocate for another reason, road pricing might still influence the choice of a new residential or work location. With respect to the probability of moving, on average 5 percent of the respondents indicate a quite high, high or extremely high probability of moving to another residential location. The probability of searching for another job on the other hand is found to be significantly higher for all price measures.

2.2. Tour-based/Activity-based Modeling for Road Pricing

Tour-based models focus on the formation of tours that are the closed chains of trips starting and ending at the base location (home or workplace) and the inter-relationships of trips that form tours. These models incorporate activity-type choice models to model the activities that will be undertaken in a tour, and provide time of day modeling capabilities to reflect impacts of time varying supply attributes on behavior. For example, Bowman, et al. (1998) document one of the early demonstrations of a tour-based model for Portland and its application to the analysis of a congestion pricing policy. Preliminary application results demonstrate the model's ability to capture activity substitution, time of day shifts, and increased leisure travel demand in response to a congestion pricing policy. Note that this spectrum of interrelated responses is much broader than the facets considered in the studies, discussed in the previous sections. Activity-based models advance the notion of tour-based models further by adding further critical dimensions of behavior that are not fully reflected in tour-based models. The potential applicability of activity-based micro-simulation model systems for modeling the impacts of peak period congestion pricing has been demonstrated (e.g., Pendyala, et al., 1997; Pendyala, et al., 1998). These applications show how an activity-based micro-simulation model system simulated the adaptation behavior of an individual in response to a pricing policy. Despite the extensive literature on road pricing, there are very few comprehensive studies of road pricing analysis using activity-based /tour-based models. Similarly, Hamed and Mannering (1993) reported applications of hazard-based duration models, which included the length of time that travelers delay their departure from work in order to avoid congestion.

An early example of an activity-based model is the AMOS model, designed specifically to deal with short-term responses to transportation control measures (RDC, 1995). In an application of the AMOS model in Washington D.C., six policies were considered including congestion pricing. Input to the model is a customized stated response survey in which respondents are asked how they would respond to a control measure in the context of their activity and travel behavior on the previous day. Possible response categories are do nothing, change departure time to work, change mode to carpool, change mode to transit, change mode to walk, change mode to bicycle, work at home, and other (e.g., long term changes). These responses were used to train a neural network to predict commuters' basic responses to a control measure, using socio-demographics, land use, the transportation network and control characteristics. Lam and Huang (2002) presented a combined activity/travel choice model and proposed a flow swapping method for obtaining the model's dynamic user equilibrium solution on congested road networks with queues. Their proposed approach can be used to assess the impacts of various traffic control/management policies and urban development schemes in general networks with queues. They, also, presented a stochastic model for solving the combined activity/destination/route choice problem (Lam and Huang (2005).

Arentze et al. (2004) reported the estimation of several discrete choice models describing reactions of individuals to congestion pricing scenarios as an extension of their Albatross model. An activity-based approach was used, meaning that all choice facets of activity patterns were taken into account. The study differentiated between a primary and secondary response to policies and this study focused on a model of the primary response. A primary response refers to the choice of a strategy aimed at reducing a negative impact or increasing a positive impact of the policy. Examples of a primary response are changing transport mode, reducing frequency of trips or changing departure time. A secondary response then involves adaptations required to make the broader activity pattern consistent with the change. For example, switching from car to public transport for trips to work may limit the possibilities for trip chaining and hence induce extra separate trips as a secondary response. A stated adaptation experiment, administered on the Internet was used to collect the data. Respondents indicated if and how they would adjust the departure time, route, destination, transport mode, and/or trip frequency of their daily activity-travel pattern, given particular congestion pricing scenarios. Adaptation choice was modeled using the multinomial logit framework. Because of the structural role of work activities in daily activity schedules of individuals, a separate adaptation choice model was estimated for the work activity. For the work activity, the results suggest that a majority of adaptations triggered by congestion prices is a route change, followed by departure time adjustments. Changing to public transport and working at home to reduce car trips both have a small probability. Socioeconomic variables do appear to have an impact on the willingness to adapt and choice of adaptation alternatives. For non-work trips, the willingness to adapt is smaller probably because a larger share of current non-work trips takes place outside peak hours. Of the adaptation alternatives, changing route and switching to bike are the dominant responses. Also, socioeconomic variables and activity type are important factors in adaptation choice for the non-work activities. These results relate to the primary responses. Their Albatross model was then run to simulate any secondary responses that emerge when individual schedule their activities and travel using the primary responses as input (Arentz and Timmermans (2005)). Issues of acceptance and equity of travel demand management policies are addressed by Keuleers et al. (2005). They reported the results of a field experiment, in the city of Newcastle upon Tyne, UK, in which participants were given an amount of money and asked to behave and use this money as if a real road-user charging scheme was in place. This field approach differentiates their study for the typical SP approaches. The participants' behavior was recorded and changes in travel patterns analyzed using decision trees. Participants in the field experiment completed an activity-travel diary for a period of two weeks. During the first seven days, no tolls were charged to provide the 'before' data, with the toll being introduced at the start of the second week and this allows the identification of any changes in behavior between the two periods. Results suggested that the hypothetical cordon-charging scheme introduced in Newcastle upon Tyne may have a significant impact on travel patterns but less of an impact on activity participation and activity rescheduling. This study also showed that change of mode is easier for specific groups of households than change of location and time. The study described by Salt et al. (2010) evaluated comprehensive pricing and mobility-enhancing packages to improve access and offer more sustainable travel choices to and within San Francisco. A new travel demand model (based on SF-CHAMP, an activity-based model) was developed for the purpose of this study. The authors made forecasts for 2015 and 2030 to compare the long term benefits of congestion pricing in San Francisco. The pricing scenario is defined by the charge type including: area pricing, and cordon pricing, boundary of the charged area fall under three basic categories: small downtown cordon, a mid-sized cordon, and a gateway charge, time period for charging, price level, and toll discounts. The combinations of these scenarios were also examined. The RPM-9 model is calibrated with data from the 2000 Census and the Bay Area Travel Survey and validated based on observed roadway and transit volumes by time-of-day, direction, and transit line for both 2000 and 2005. In order to evaluate the feasibility of congestion pricing in San Francisco, authors compared potential benefits, impacts, and costs of a variety of congestion pricing scenarios in terms of mobility; accessibility; equity; health; financial viability, and economic impacts. The major finding from this study is that a congestion pricing program would be feasible for San Francisco, contributing to local, regional, and statewide goals for congestion management, sustainable economic growth, and reduced climate change impacts.

3. Summary and discussion

The purpose of this paper has been to review the existing literature on road pricing. As the volume of publications is very high, we selected a set of representative studies. An examination of this literature suggests that most studies have focused on only a few effects of route pricing, among which route choice and departure choice have received most attention. Moreover, often these facets have been studied in isolation. Typically these studies have applied a statistical model that did justice to the nature of the data. Most studies only consider the primary impact of road pricing, especially in terms of departure time and route choice and in some cases in terms of transport mode choice. The application of more comprehensive activity-based models of transport demand, considering a wider set of primary and secondary responses is relative scarce. This finding implies that most studies only partially deal with the modeling of road pricing as a transport demand management policy. However, changes in departure time and/or route choice may trigger other secondary responses. A shift to an earlier departure time may be in conflict with the need to bring children to school. An even more complex scenario may be that such a shift in departure time may result in an earlier completion of the work day, which in turn may be in conflict with the timing of the task to get children from school, implying that other activities need to be inserted. Similarly, a change in route choice may trigger a shift in some destination choices for some activities. More generally, road pricing may affect all aspects of activity-travel behavior, either directly or indirectly. It means the entire daily activity pattern of individuals may change, with potentially important implications for the number and chaining of trips across the entire course of the day. Activity-based analysis constitutes an integrative framework for addressing the potentially complex interdependent response patterns which may involve multiple choices. Activity-based models add the following choice facets: activity generation, travel party, task allocation, timing and duration of activities, joint activity participation and travel arrangements. Consequently, the number of explanatory variables tends to be higher. Most important however is that interdependencies in choices underlying activity-travel patterns are taken into account. Consideration of such interdependencies makes the model more sensitive to the propagation of effects. Despite these potential advantages of activity-based models, it should not be forgotten that the current generation of operational activity-based models typically considers a day as the time unit of observation and predict activity-travel patterns of individuals for a typical or average day. This approach is convenient as long as the average based on cross-sectional data of activity patterns in a population is adequate for the application of the model. To the extent that the impact of road policies involve exploration and learning and that accumulated experiences with adaptive behavior are relevant, or that activity-participation and time-use decisions are constrained by time and money budgets that are defined for longer periods of time than a day, the use of a one-day time frame severely limits the ability of the models to predict traveler response to road pricing. It seems that the only way to overcome this shortcoming is to extend the time frame from one-day to a multi-week period or perhaps even longer period of time.

Thus, we contend that road pricing policies and associated modeling approaches should ideally be embedded in the next generation of comprehensive models of transport demand: *dynamic activity-based models*. However, work on developing such models has just started. The expansion of current models into dynamics models and their application to road pricing (and other transport control management policies) should thus be high on the research agenda. Another issue that should receive further attention in this context relates to the fact that we tend to focus our analysis to single policies. However, today, households are faced with a multitude of pricing policies to manage travel demand, including carbon tax, tax reduction for fuel-efficient cars, environmental taxes for airlines, energy vouchers, expanding parking fees, etc. The combined effect of these policies on traveler response and the evaluation of the effectiveness of combined policies have to the best of our knowledge hardly received attention. This is may therefore also be included in the agenda of future research activities related to road pricing.

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