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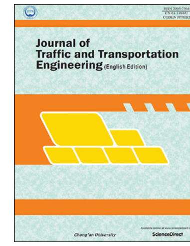

Original Research Paper

Implementation of a new network equilibrium model of travel choices

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HIGHLIGHTS

- A new combined model used more behaviorally sound model forms to represent travel choices.
- The new model allowed to be reformulated as an equivalent convex programming problem with linear constraints.
- The new model is consistently better than the commonly used logit combined model in reproducing various travel choices.

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ABSTRACT

This paper develops a new combined network equilibrium model by using more behaviorally sound mathematical forms to represent the four travel choices (i.e., trip frequency, destination, mode, and route) in a conventional travel demand forecasting process. Trip frequency choice relates to the traveler decision on “making a trip” or “not making a trip” so it is given by a binary logit model. Destination choice is formulated as a parametrized dogit model of which the captivity parameters (expressed as functions of independent variables) allow individual travelers to be captive to specific destinations. Mode choice is given by a two-level nested logit model to avoid IIA restriction. Trip assignment is based on Wardrop's “user-optimized” principle. All model forms describing travel choices are in response to the level of services incurred by the transportation system. Through the introduction of inclusive values, the traveler decisions concerning trip frequency, destination, mode, and route choices are inherently interrelated and jointly determined.

To obtain solutions of the new combined model, it was reformulated as an equivalent convex programming problem with linear constraints, a great advantage from the computational aspects. The model was applied empirically to a transportation network in New Jersey. The application results show that the new model is consistently better than the commonly used logit combined model in reproducing the observed trip flows from origin zones, origin to destination (O-D) trip flows, O-D trip flows by mode, and trip flows on the network links.

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1. Introduction

During the past ten years, many Metropolitan Planning Organizations (MPOs) in the United States have used activity-based models for the purpose of travel demand forecasting. But the conventional four step (trip frequency, destination, mode, and route) modeling process is currently still carried out in many smaller metropolitan areas. Planners in these areas customarily treat four choices of travel sequentially as a set of independent problems. The potential drawbacks of this sequential approach are twofold. First, interactions among the four choice decisions are not accounted for, and hence, the travel costs calculated from the route choice model may not be the same as the travel costs used in the trip frequency, destination and mode choice models. Second, as far as traffic equilibrium is concerned, the estimates of traffic flows are not always consistent, and, in general, do not converge to a stable solution. Although the use of improved sequential procedure with feedback loops may mitigate the above problems to some degree, important differences still persist between the sequential results and ones provided by a combined network equilibrium model whose solution ensures consistency and stability in the results (Siegel et al., 2006). This suggests that all travel choices in the conventional four step modeling process be combined into a single formulation and solved jointly.

Whereas many combined models have been developed in the past 30 years, these models typically used linear regression, entropy function, and simple logit form to represent specific travel choices in the conventional four step modeling process. The modeling effort in this paper is distinguished from previous combined models primarily by the use of more behaviorally sound models to represent these travel choices. The trip frequency choice is analyzed using a binary logit model (rather than linear regression) to determines a traveler's decision on “making a trip” or “not making a trip” for a particular time period. Destination choice is formulated as a parametrized dogit model (rather than entropy function) of which the captivity parameters are expressed as functions of independent variables and allow individual travelers to be captive to specific destinations (Swait and Ben-Akiva, 1987). The mode choice process is given by a nested logit (rather than simple logit) model formulated as that of choosing between two nests (car and public transit) and then making the mode choice within the selected nest. Regarding trip assignment, Wardrop's user-equilibrium principle of route choice occurring on both the roadway and transit networks is assumed.

This paper combined all of four different model forms into a single formulation and solved them jointly. This new combined model is called as the combined trip frequency, destination, mode, and route (CFDMR) choice model. To help incorporate interaction effects in the CFDMR model, a sequential choice structure was assumed in which (lowest level) route choice occurs after mode choice, mode choice occurs after destination choice, and destination choice occurs after (highest level) frequency choice. All model components describing travel choices are in response to the level of services incurred by the transportation system. Through the use of inclusive values (computed by aggregating the attributes in the lower level choice into the higher level choice), the traveler decisions concerning all travel choices are inherently interrelated (in the sense that the expected received utility for choice at the higher level depends on the utility of the lower level choice) and jointly determined. In addition, it is worth mentioning that the parametrized dogit model used for the destination choice can account for travel behavior of both compulsory (work) and discretionary (shopping) trips. Compulsory trips will be made even in the worst traffic conditions and, therefore, the individual choice of destination for these trips can be regarded as fixed in the short term. For discretionary trips, however, the destination choice is less regular both in time and space and highly responsive to changes in the levels of service incurred by the transportation system. To account for this diverse travel behavior, the proposed combined model allows that the number of discretionary trips between O-D pairs would respond to changing travel cost conditions occurring in both mode choice and trip assignment steps, whereas destination choice of compulsory trips would remain to be fixed, irrespective of traffic flow conditions. However, mode and route choices of compulsory trips between O-D pairs are still allowed to respond to changing travel cost conditions.

2. Literature review

Many combined models have been developed in the past to investigate personal travel choices including: destination and route (Evans, 1976; Chu, 1990, 2011); mode and route (Fisk and Nguyen, 1981; Florian and Spiess, 1983); destination, mode, and route (Florian and Nguyen, 1978; Abrahamsson and Lundqvist, 1999; Siegel et al., 2006); and trip frequency, destination, mode, and route (Safwat and Magnanti, 1988; Oppenheim, 1995; Zhou et al., 2009). Some researchers have even extended the conventional scope of the travel choice to incorporate departure time (De Cea et al., 2003), non-motorized modes (Wu and Lam, 2003), parking location (Li et al., 2007), location choice (Boyce and Mattsson, 1999; Chu, 1999), and multiple user classes (Boyce and Bar-Gera, 2004; Hasan and Dashti, 2007). In addition to the different travel choices included in the models, previous combined models also differ in the following: (a) mathematical tools used to formulate the traffic equilibrium conditions and (b) model forms used to represent travel choice behavior.

Typical approaches used to formulate combined models are equivalent optimization (Safwat and Magnanti, 1988; Chu, 1999, 2011; Zhou et al., 2009) and variational inequality approaches (Florian and Spiess, 1983; De Cea et al., 2003; Wu and Lam, 2003). An equivalent optimization approach often requires that the Jocobian matrices of link cost and travel demand functions be symmetric, and, therefore, is less realistic for a multimodal traffic equilibrium problem. However, if the equilibrium problem becomes a convex programming problem with linear constraints, it can be applied to a large-scale transportation network and solved efficiently by existing solution algorithms. The variational inequality approach enables the combined models to easily integrate the features such as multiple modes, asymmetric interactions among links, and demand functions with