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Transportation serviceability analysis for metropolitan commuting corridors based on modal choice modeling

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ABSTRACT

Major commuting corridors in metropolitan areas generally comprise multiple transportation modes for commuters, such as transit (subways or buses), private vehicles, or park-and-ride combinations. During the morning peak hour, the commuters would choose one of the available transportation modes to travel through the corridors from rural/suburban living areas to urban working areas. This paper introduces a concept of transportation serviceability to evaluate a transportation mode's service status in a specific link, route, road, or network during a certain period. The serviceability can be measured by the possibility that travelers choose a specific type of transportation service at a certain travel cost. The commuters' modal-choice possibilities are calculated using a stochastic equilibrium model based on general travel cost. The modeling results illustrate how transportation serviceability is influenced by background traffic flow in a corridor, value of comfort for railway mode, and parking fee distribution.

1. Introduction

1.1. Transportation serviceability concept for metropolitan corridor mode choice analysis

In a modern metropolitan transportation system, there usually exist one or more main corridors for commuting from residential areas to the Central Business District (CBD). As defined in FHWA (2006), a corridor refers to "a largely linear geographic band defined by existing and forecasted travel patterns involving both people and goods". In the main corridors, several major transportation modes exist and serve for commuters. The commuters may choose one specific transportation mode or a combination of the available modes to minimize their commuting travel cost and maximize serviceability provided by the corridor transportation system.

The concept of transportation serviceability can be used to assess the performances of transportation systems (Sandlin and Anderson, 2004). Berdica (2002) gave a definition of transportation serviceability as the possibility that travelers use a link/route/road network during a given time period. From the perspective of travel quality, the concept of serviceability was described multi-dimensionally as "the basic ability of a system to deliver you from where you are, to where you want to be, at the time you want to travel, at a cost…that makes the journey worthwhile" (Goodwin, 1992). Taking both of the definitions into consideration synthetically, the serviceability can be measured as the possibility that travelers choose a specific type of transportation service at a certain travel cost. Based on this definition, the serviceability can be estimated by the classic discrete choice models, such as logit model, probit model, or nonparametric models based on the comparison of travel costs between different transportation modes. Here, the travel cost should be assessed multi-dimensionally and integrated

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in terms of general travel cost, typically including travel time, travel expense and degree of comfort during travel, etc. (Meyer and Miller, 2001).

1.2. Previous studies on metropolitan corridor mode choice modeling

In the past few years, the commuting patterns through a corridor have been investigated extensively to analyze the urban economics in linear mono-centric cities. Using the deterministic queue model, Vickrey (1969) proved that an optimal time-varying toll can eliminate queuing and restore efficiency, and developed an departure time choice model which leads to cost equilibrium of all commuters. Since then, bottleneck constrained corridor models have been generalized in various directions (including toll pricing, modal choice and multi-class modeling) (Daganzo, 1985; Tabuchi, 1993; Arnott et al., 1995; Yang and Huang, 1997; Huang, 2002; Huang et al., 2007; Arnott and De Palma, 2011; Liu and Nie, 2011).

In addition to the bottleneck studies, another research focus is modeling the transportation mode choice behavior in commuting corridors. Haring et al. (1976) firstly examined the equilibrium state in transportation mode choice patterns along the corridors. In their work, the type of spatial equilibrium is defined as a "simple solution", in which both modes are used between the CBD and some locations, and only one mode (railway or highway) is used from the location to the city boundary. Latterly, the existence of the "simple solution" was verified by Jehiel (1993), who concluded that only when the capacities of the different transportation modes are constant, the "simple solution" type user equilibrium may emerge.

To investigate how to deploy park-and-ride (P&R) facilities on a commuting corridor, highway and railway were modeled as two competing modes by Wang et al. (2004). Several types of user equilibrium between highway and railway were established through the connection of P&R facilities. Furthermore, optimal location and pricing of the P&R facilities was also discussed from aspects of the profit maximization and social cost minimization. By further exploring the minimization technique, the modal-choice pattern along the commuting corridor was also investigated by Liu et al. (2009). In the study, the comfort in the transit mode was quantified as in-carriage crowding cost, accounting for commuters' general travel cost.

Additionally, the issue of P&R has been studied from various aspects. García and Marín (2002) analyzed the capacity and pricing design problem through minimizing the total travel costs. Latterly, Farhana and Murray (2008) investigated the location of P&R facilities based on the multi-objective optimization technique. From the perspective of transportation policy, Parkhurst (1995) studied the influence of P&R using a survey and interview method. Hornera and Groves (2007) discussed the P&R facilities location policy considering network flow-based strategies. In the traffic operation level, Hounsell et al. (2011) proposed an access control approach for enhancing efficiency of the P&R facilities in UK.

1.3. Motivation of this study

There are two different approaches to model the transportation systems for commuting corridors. One is the continuum modeling approach (Beckmann, 1952; Sasaki et al., 1990; Ho and Wong, 2006), and the other is discrete network modeling approach (Beckmann et al., 1956; Sheffi, 1985; Patriksson, 1994). Most of the studies on analyzing the transportation mode choice patterns along a corridor adopted the continuum modeling approach. However, there are intractabilities in characterizing transportation systems with multiple interdependent modes, including discontinuity of traffic flows and computation for Lebesgue integrals (Royden and Fitzpatrick, 2010). Therefore, the mode choice analysis for metropolitan major commuting corridors in this paper is conducted in a discrete network modeling approach. The specific motivations of this study are explained in the following.

First of all, most of the modal choice analyses for linear transportation systems in previous studies are made by using deterministic approach. In this study, a stochastic modal choice analysis is proposed since the random utility theory based approaches that treat the generalized travel costs as stochastic variables are more natural and realistic. However, dealing with the stochastic variables in continuum models may bring intractability in defining and computing the integrals of the variables. Though Wang et al. (2003) formulated the stochastic continuum model into differential equations, the problem is rather difficult to solve. Using the discrete network modeling approach, the stochastic modal choice behavior can be characterized much more easily. Furthermore, the serviceability concept can be applied to better describe the likelihood that the commuters choose a certain transportation mode in a corridor. In this paper, the logit model is intuitively applied to reflect serviceability concept and analyze the modal-choice behavior in the corridors.

Secondly, in the previous works, the commuting corridors were assumed as closed transportation systems that only allow commuters to travel along the corridors to the sole CBD destination. In reality, a commuting corridor is an open system and there are many other travelers in highways or railways who are not commuters or whose destinations are not the CBD. The background traffic may have a profound effect on the commuters' modal choices. For example, a high percentage of background traffic in highways may shift the commuters from highways to railways in order to avoid the highway congestion delay. To embody the influence of non-commuters or travelers whose destinations are not the CBD, we should address the influence of background traffic in the corridors on the commuters' modal-choice behavior through assigning the background traffic in the corridor transportation systems in this study.

Thirdly, the route flow pattern along the corridor cannot be computed accurately in previous studies since its uniqueness may not be guaranteed under the deterministic user equilibrium principle. In this study, the unique solution of the P&R traffic flow from highways to railways can be obtained in stochastic user equilibrium based on the logit model due to the strictly convexity of the objective function (Sheffi, 1985). The uniqueness of P&R traffic flow can give more meaningful com-