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Generating route choice sets with operation information on metro networks

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ABSTRACT

In recent years, the metro system has advanced into an efficient transport system and become the mainstay of urban passenger transport in many mega-cities. Passenger flow is the foundation of making and coordinating operation plans for the metro system, and therefore, a variety of studies were conducted on transit assignment models. Nevertheless route choice sets of passengers also play a paramount role in flow estimation and demand prediction. This paper first discusses the main route constraints of which the train schedule is the most important, that distinguish rail networks from road networks. Then, a two-step approach to generate route choice set in a metro network is proposed. Particularly, the improved approach introduces a route filtering with train operational information based on the conventional method. An initial numerical test shows that the proposed approach gives more reasonable route choice sets for scheduled metro networks, and, consequently, obtains more accurate results from passenger flow assignment. Recommendations for possible opportunities to apply this approach to metro operations are also provided, including its integration into a metro passenger flow assignment and simulation system in practice to help metro authorities provide more precise guidance information for passengers to travel.

1. Introduction

As an efficient transport system, the metro system has advanced in recent years and become the mainstay of urban passenger transport in many mega-cities, especially in those highly populated areas (Liu et al., 2010; Zhu et al., 2013). At present, people pay close attention to the operation and management of the metro system because its availability and service state directly influence the city's normal activity and population. As known, passenger flow is the foundation of making and coordinating operation plans for the metro system. Several research studies have been carried out on the

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development of passenger flow assignment models, which have become more and more complex in obtaining precise results. However, the route choice set of passengers also plays a crucial role in analyzing passenger flows. A variety of studies have found that the size and composition of a route choice set does matter in the choice model estimation and passenger flow calculation (Bovy, 2009; Ren et al., 2012; Swait and Ben-Akiva, 1986, 1987). Incorrect route choice sets can lead to misspecification of choice models and calculation biases passenger flow levels (Ortuzar and Willumsen, 2001; Williams and Ortuzar, 1982).

This paper focuses on the modeling and generation of route choice sets for metro networks. There are a number of completed research topics related to it, and the network type for which this subject is relevant is nearly limitless. Interesting studies and applications exist for pedestrian networks (Van Der Waerden et al., 2004), public transport (Friedrich et al., 2001), roads (Prato and Bekhor, 2006), multimodal networks (Bovy and Hoogendoorn-Lanser, 2005), inland navigation (Van Der Zijpp and Fiorenzo-Catalano, 2005), airlines (Coldren and Koppelman, 2005), and buildings (Lo and Fang, 2000). The Literature shows many different techniques for generating routes, such as recent study published by Liu et al. (2010). Typical approaches include the *K*-shortest path algorithm (Van Der Zijpp and Fiorenzo Catalano, 2002) based on link elimination or link penalties (De La Barra et al., 1993), simulation methods (Nielsen, 1996, 2002; Sheffi and Powell, 1982), and a labeling approach (Ben-Akiva et al., 1984). However, few research has been devoted to rail networks, particularly metro networks. To the best of the authors' knowledge, most methods currently used in practical demand analyses to generate route choice sets in rail networks are based on network attributes and passenger preferences (Ben-Elia et al., 2013; Kato et al., 2010; Liao et al., 2013; Nielsen, 1996, 2002; Ramming, 2002). Compared to road and other network modes, the generation of route choice sets in rail networks is based not only on the physical network topology, and passenger preferences (e.g., time, distance, etc.) but also on the train operational plans, making the problem different and more complex. For example, due to the train diagram, the accessibility of a given O–D pair in the rail network changes dynamically throughout a day.

The objective of this study is to provide an approach that can generate accurate route choice sets in metro networks considering the influences from the network topology, travel cost, and, especially, the train operational information. This paper proposes the advances as follow.

(1) Provide a route filtering method based on the travel cost difference between an alternative route and the shortest route.
(2) Propose a route filtering method based on train operational plans.
(3) Put forward a two-step framework to generate route choice sets on metro networks, based on both of the mentioned above.

To this end, the paper first explains how route choice sets play an important role in passenger flow assignments to describe this study's general scope. In Section 3, the main constraints, including the network topology, travel cost, and, especially, the train operational plan, which influence the size and, composition of route choice sets are analyzed. Then, a feasible approach to generate the route choice sets in metro networks is proposed in detail in Section 4. A numerical test is given to demonstrate the application and efficiency of the proposed approach. Moreover, recommendations for application of the proposed approach to metro operation are provided. Finally, Section 6 summarizes the paper's finding.

2. Passenger flow assignments and route choice sets

Thus far, models used to solve passenger flow assignment problems are classified according to whether Wardrop's principle is followed. One model is the non-equilibrium assignment, and another is the equilibrium assignment model. Both of them can be solved either in the space of link flows or in the space of route flows (Bekhor and Toledo, 2005). The important advantage of the link-based solution algorithms is that they can avoid explicit enumeration of the route choice sets. However, the link-based algorithms assume an implicit choice set, such as the use of all efficient paths (Dial, 2001, 2006; Maher, 1998) or all cyclic and acyclic paths (Akamatsu, 1996; Bell, 1995), which may be unrealistic from a behavioral standpoint. On the contrary, the route-based solution algorithms allow a more flexible definition of the choice set (Bekhor and Toledo, 2005; Ben-Akiva et al., 1984; Cascetta et al., 1997), but the choice set generation methods increase computation time. In any case, the route choice set does play an important role in solving passenger flow assignment problems.

To clarify the article's scope, Manski's (1977) paradigm on predicting choice, although debated in the literature, is helpful. This paradigm states that the probability of passenger i to choose alternative r from the choice set CS_i, which is also called his/her consideration set, is given by the following expression.

$$P_i(r|US_i) = \sum_{CS_i \in US_i} p_i(r|CS_i) p(CS_i|US_i) \tag{1}$$

where $P_i(r|US_i)$ is the probability that passenger i will choose alternative r from the universal set US_i of all alternatives available to i, $p_i(r|CS_i)$ is the conditional probability that passenger i will choose alternative r given that CS_i is his/her consideration set where CS_i is a subset of US_i, $p(CS_i|US_i)$ is the probability that CS_i is the consideration set of passenger i given his/her universal set US_i.

An essential element of this paradigm is that the choice set of an individual cannot, for the most part, be known with certainty nor be observed, so it is a latent concept that might be modeled as a random set as expressed by $p(CS_i)$. Although the random choice set concept seems very natural, nearly all choice modeling applications in research and practice adopt a deterministic choice set approach, $p_i(r|US_i) = p_i(r|CS_i \subseteq US_i)$. In most cases, as certainly in route choice, the choice set is a subset of a universal set of available alternatives. This subset's