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Generation and calibration of transit hyperpaths ☆

Jan-Dirk Schmöcker [a,*], Hiroshi Shimamoto [a], Fumitaka Kurauchi [b]

[a] Department of Urban Management, Kyoto University, Japan
[b] Department of Civil Engineering, Gifu University, Japan

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ABSTRACT

This paper introduces a new discrete choice model aimed at describing behaviour of public transport passengers at stops. We assume that passengers choose a set of buses from which they take the first arriving. This leads to a nested model formulation in which the upper level (choice set formation) is based on utility maximisation. The lower level choice of a specific bus from the choice set is given by the frequency distribution of the bus arrivals. We further consider hyperpath characteristics in the choice set formulation which means that the utility of the choice set in general increases with the addition of further options due to a reduction in the reduced waiting time. We discuss model properties and apply our model to some selected OD pairs of the bus network of a local city in Japan where we could observe passenger behaviour due to the availability of smart card data. We find that choice sets vary fairly significantly between some passenger groups and discuss implications for transit assignment models.

1. Introduction

Understanding and predicting travel patterns and travel demand is important for transport providers, in particular those of public transport services. Therefore there is by now a significant body of literature describing and modelling the expected demand as well as the random variation and adaptation of travel patterns over time. Assuming that choice is based on the utility concept, random variation in behaviour is usually dealt with by including stochastic factors into the model, leading to random utility models.

In particular in transit networks random variation and route selection are, however, often difficult to distinguish. A passenger might alter his/her route choice on subsequent days not because of any learning process but because of service inherent uncertainties. Whereas for drivers usually a change in route is explained with a (perceived) change in attractiveness of the road conditions (e.g. Jotisankasa and Polak, 2005), this explanation is not required for transit passengers. That is, a passenger might switch from (his/her preferred) bus A taken on day 1 to an alternate bus B on day 2 simply due to reverse order of arrival. On day 3 the passenger might, however, return to bus A if it arrives again earlier. This random variation can be usefully described with the concept of hyperpaths and strategy (Nguyen and Pallottino, 1988; Spiess and Florian, 1989).

A hyperpath of transit passengers is generally defined as a choice set consisting of a number of paths out of which any could be optimal depending on the arrival of buses that form the paths. Different strategies to choose a specific path from options among the hyperpath are possible. Spiess and Florian proposed the simple strategy "take whichever bus comes first". This strategy can be shown to be useful for risk averse passengers fearing that any bus at the stop might arrive only after a

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* Corresponding author. Tel.: +81 75 383 3239; fax: +81 75 383 3236.
E-mail address: schmoecker@trans.kuciv.kyoto-u.ac.jp (J.-D. Schmöcker).

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time equal to its headway (Schmöcker et al., 2009). Alternative more complex strategies are, however, also possible, in particular if more information about the time until the next arrival of the attractive lines are available (Nöckel and Weckek, 2009).

Though there is ample literature discussing that different passenger groups attach different values to on-board travel time, waiting time, transfers or seat availability, this has not been much reflected in hyperpath based transit assignment models. Obviously, different values will result in different path sets. Generally, higher values attached to waiting times at stops compared to on-board travel times will lead to more complex hyperpaths. That is, passengers will avoid being fixed to a specific line and rather increase their choice set (with some lines that are potentially longer) in order to reduce their expected waiting time. Kurauchi et al. (2012a,b) provide evidence for this with a stated preference survey. They show that there are some significant differences in the hyperpaths constructed by elderly. Fonzone et al. (2012) extend this line of research by providing further evidence for differences in hyperpaths among passenger groups based on a survey asking respondents to describe their actual travel patterns as well as asking them to choose their strategy in hypothetical bus networks. It appears that only some passengers choose the hyperpaths predicted by the Spiess and Florian model; a significant number of passengers appear to prefer simple choice sets. Furthermore, the choice of strategy seems to be influenced by the actual experiences made by the passenger during their daily commute.

Both of these studies have used "artificially" collected data for the estimation of hyperpaths, i.e. transit passengers have been asked to recall their travel patterns and to answer hypothetical choice situations. Through the advance in smart card data nowadays there are improved possibilities though. A large number of cities have introduced such systems offering possibilities for better understanding of passenger behaviour, service planning and evaluation (Pelletier et al., 2011). For our purposes, of importance is that such data store the actual lines boarded by passengers over longer time periods. This allows us to observe their actual choices and derive some conclusions about their strategy.

This forms the motivation for this paper. Our objective is to develop a model that estimates the choice set of passengers in dense networks where it is often optimal to form complex choice sets. Since choice sets are latent we assume that we can construct these by observing passengers repeated choice when they travel from the same origin to the same destination. We obtain such time series route choice data from the bus service provider of a local city in Japan and provide some example results for different OD pairs where we could observe that different passengers have taken different routes to reach the same destination.

The paper is structured as follows. We firstly review previous research on choice set construction and point out two important differences that make our problem different to the existing literature. We then develop our methodology, emphasising assumptions we make in the process. In the final parts of our paper we develop our case study. We first describe the bus network data, demand patterns and then apply our methodology. We discuss our model estimations as well as implications for transit assignment and further research.

2. Choice set generation methods

2.1. Introduction

Various authors have pointed out the importance of generating an appropriate choice set from the totally available options and potential errors that might arise otherwise (e.g. Swait and Ben-Akiva, 1986; Ortuzar and Willumsen, 2002). In particular Bovy (2009) reviews the generation of "consideration sets" from the "universal sets" and points out difficulties of choice set generation for route choice modelling. In comparison to for example mode choice, the universal set can be extremely large, choices can be "hidden", i.e. need to be extracted from a network and one needs to consider overlap between options. Many of these "universal options" the traveller might a priori reject and just focus his choice on a few potentially attractive options. The Dial (1971) algorithm is one common way to reduce the path set to "reasonable options" that could then be included into a choice model though the set might still be (too) large. Fonzone et al. (2013) use the term "potentially optimal" routes and show that in road networks even assuming that links have only a congested and uncongested state, the number of options can be extremely large. In large cities transit passengers sometimes face similar problems to choose between several lines that could bring them to their destination, in particular if one considers that passengers can choose their starting station as well.

Furthermore the choice set (and its size) will depend on the underlying choice behaviour. If the traveller chooses the route from the origin to the destination at once he might consider a different set than travellers choosing their path sequentially or strategically anticipating possible downstream delays. One might argue that the more uncertainty there is downstream, the more important it becomes to choose one's path sequentially and strategically in order to minimise overall travel time. This has been the main motivation for the development of optimal hyperpaths in transit assignment where waiting time at stops is the main source of uncertainty. Schmöcker et al. (2009) for example show that the most commonly used transit assignment approach following Spiess and Florian (1989) is equivilant to an optimal strategy fearing a specific type of worst case scenarios at each node.

Consequentially, this has led to the development of two sets of literature relevant to our problem and reviewed in the following, which have not been overlapping much to our knowledge. On the one side the literature emanating from authors' often based in discrete choice modelling who have developed various approaches to generate approximations to universal