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A hyperpath-based network generalized extreme-value model for route choice under uncertainties ☆

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ABSTRACT

Previous route choice studies treated uncertainties as randomness; however, it is argued that other uncertainties exist beyond random effects. As a general modeling framework for route choice under uncertainties, this paper presents a model of route choice that incorporates hyperpath and network generalized extreme-value-based link choice models. Accounting for the travel time uncertainty, numerical studies of specified models within the proposed framework are conducted. The modeling framework may be helpful in various research contexts dealing with both randomness and other non-probabilistic uncertainties that cannot be exactly perceived.

1. Introduction

1.1. The short story of route choice studies

Route choice is one of the most important issues studied in travel behavior and transportation network analyses. The comprehensive review by Prato (2009) summarizes the status quo and the future research directions of route choice studies. As Prato (2009) argued, route choice models evolved, to a certain extent, with the enhancement of random utility-based discrete choice models (Ben-Akiva and Lerman, 1985). Although the multinomial logit (MNL) model has been widely used in practice due to its simplicity, it cannot capture the complex correlation structure among overlapped routes, due to the property of independence from irrelevant alternatives (IIA). The probit model (e.g., Daganzo and Sheffi, 1977; Yai et al., 1997) or error component (mixed) logit model (e.g., Freginger and Bierlaire, 2007) could accommodate such a correlation structure; however, exhaustive Monte Carlo simulations would be required to compute the choice probabilities. Therefore, the closed-form choice model, particularly the family of generalized extreme-value (GEV) models (McFadden, 1978), would also be attractive. Nested logit (NL) models and cross-nested logit (CNL) models have helped to advance route choice studies, with application to traffic assignment (e.g., Vovsha and Bekhor, 1998). The network GEV model (N-GEV) elaborates on this idea further (Bierlaire, 2002; Daly and Bierlaire, 2006). In the N-GEV model, a broad class of networks is used to generalize the use of trees to represent (cross) NL models in the network representation. At present, the N-GEV model would be the most general operational model in the GEV-based discrete choice family. As an application in the context of route choice,

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Papola and Marzano (2013) proposed a joint-network GEV model (JNG) to capture the complex correlation (network) structure using a closed-form formulation.

In route choice modeling and its application to assignment calculations, the means by which the set of alternative routes (a route choice set) is constructed is particularly important, regardless of the approach (i.e., explicit versus implicit). Bovy (2009) provided a synthetic review of route choice modeling, set mainly from behavioral perspectives. There are two camps of route choice modeling studies. The first camp generates multiple routes as a choice set, whether deterministic or probabilistic, by explicitly using methods such as deterministic approaches (e.g., K-shortest paths of Eppstein (1998) or the labeling approach of Ben-Akiva et al. (1984)) or probabilistic generation of a set (e.g., Cascetta and Papola, 2001), and then applies the discrete choice model for the given set of route alternatives. Despite these methodological developments, new models (e.g., Freginger et al., 2009; Flötteröd and Bierlaire, 2013) continue to be developed; however, the generation of a route choice set tends to be arbitrary and is still open to debate. The second camp follows the approach outlined in seminal work by Dial (1971), albeit developed for stochastic network loading in traffic assignments that proposed avoiding explicit path enumeration. Dial (1971) defined so-called "efficient paths" involving a forward pass from the origin based on the proportions determined using the sequential MNL model, and working backward from the destination. In line with this approach, several alternative approaches to Dial's method were developed by Bell (1995) and Akamatsu (1996), among others. Both Bell (1995) and Akamatsu (1996) argued that the efficient path may ignore realistic paths that were actually attractive to drivers but were assigned zero flow. Instead, they proposed alternative methods based on the more general idea of a link-based Markov decision process. In this approach, the choice set was not limited to efficient paths but included any path that resulted in a sub-camp of the second camp that also required no path enumeration. Recently, Fosgerau et al. (2013) suggested the recursive logit model (also known as the sequential logit model) for the unrestricted (infinite) path set, along with the notion of "link size", referring to the concept of path size (Ben-Akiva and Bierlaire, 1999). In the same year, Papola and Marzano (2013) proposed the JNG model to allow implicit route enumeration using a Dial-like algorithm. Hara and Akamatsu (2012) formulated a stochastic user equilibrium (SUE) problem using the N-GEV route choice model and proposed an efficient solution algorithm without explicit route enumeration.

Route choice for transit passengers and transit assignment have proven more complicated than private vehicle networks due to transit frequencies, which make the route choice behavior more complex. Because public transportation usually operates according to schedules or predetermined service frequencies, the total travel time may vary due to the change in the waiting times. Transit assignment, as it relates to common bus-line problems (Chriqui and Robillard, 1975), provides insight into solving the transit route choice problem by suggesting a probabilistic framework in calculating the expected travel time including waiting time at transit stops. Based on this framework, the frequency-based transit assignment was established (Nguyen and Pallottino, 1988; Spiess and Florian, 1989), as well as the concept of "hyperpath" (Nguyen and Pallottino, 1988), which has since become quite popular in frequency-based transit assignments. According to the well-known assignment algorithm of Spiess and Florian (1989), a hyperpath is generated with a backward pass, followed by assignment of the proportions to the optimal strategy hyperpath with a forward pass; this approach is quite similar to Dial's algorithm. Both algorithms generate the choice set implicitly, but they have different rules in judging attractive/efficient links. Dial's rule is intuitive, while that of Spiess and Florian is based on the concept of optimal strategy.

Some studies in transit assignments have revealed the importance of discrete choice models. Nguyen et al. (1998) incorporated a Dial-like sequential logit model into the hyperpath model. Florian and Constantin (2012) modified their logit choices in strategy transit assignments by including short walks to access attractive transit paths. With the accommodation of discrete choice models, the optimal strategy models for transit networks become more behaviorally realistic. Schmöcker et al. (2013) built a two-level model in which the upper level is constrained by logit choice, while the lower level is constrained by the frequency property; the model parameters are estimated using smart card data.

1.2. Route choice under uncertainty

Although route choice behavior under some stochastic conditions of the drivers' environment, such as travel time variability, can be empirically modeled, in line with the discrete choice framework including expected utility (EU) based (e.g., de Palma and Picard, 2005) or non-EU based (e.g., Chorus, 2012; Razo and Gao, 2013; Yang and Jiang, 2014), the error term of random utility generally stands for randomness only and can be generally represented by some parametric probability distribution. However, several other uncertainties in traffic conditions (e.g., traffic incidents or network disruption) may not necessarily be modeled by a specific probability distribution and these are classified as non-probabilistic uncertainties.

The concept of hyperpath has also been applied to adaptive/policy-based routing (Miller-Hooks, 2001; Gao and Chabini, 2006; and Bell, 2009, among others). However, here, we focus on studies that dealt with uncertainties with the hyperpath methodology because hyperpath results are rooted in uncertainties. These uncertainties are interpreted differently in different studies (e.g., waiting time for transit lines (Spiess and Florian, 1989), stochastic time-dependent link travel time (Miller-Hooks, 2001; Gao and Chabini, 2006), and exposure to potential maximum delays (Bell, 2009; Bell et al., 2012)). However, the behavioral basis remains weak; thus, the link proportion results may be unrealistic.