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Integrating the mean–variance and scheduling approaches to allow for schedule delay and trip time variability under uncertainty

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ABSTRACT

Uncertainty of travel times and the impact on travel choice behavior has been recognized as an increasingly important research direction in the past decade. This paper proposes an extension to the popular scheduling approach to model traveler's departure time choice behavior under uncertainty, with the main focus on a richer representation of uncertainty. This more general approach incorporates a separate term to reflect the risk aversion associated with uncertainty. Recognizing the correlation between expected schedule delay and travel time variability, the schedule delay components in the generalized approach are defined in terms of expected travel time, which differs from the scheduling approach. This approach is developed based on the analytical investigation of the relationship between the expected schedule delay and the mean and standard deviation of travel time. An analytical equivalence was found between the scheduling approach and the general approach given a departure time *t*. To investigate the empirical performance of the generalized approach, two state preference (SP) data sets are used; one from China with a symmetric travel time distribution and the other from Australia with an asymmetric distribution. Both studies show empirical evidence of an equivalence in respect of statistical fit between the generalized and the scheduling approaches, as found from analytical investigations. The Chinese study gives support in the generalized model to including both the mean–variance and the scheduling effects; whereas the Australian study finds only the mean–variance specification has statistical merit. Despite the different travel contexts, it is noteworthy in both empirical settings, that the parameter estimate for arriving earlier than the preferred arrival time (PAT) in the generalized model is positive. This suggests that commuters tend to prefer to arrive earlier in order to guarantee he/she will not be late. This paper contributes to a better understanding of performances of different reliability measures and their relationships. The practical value of the various unreliability measures is provided showing that these indicators are easy to obtain for inclusion in project appraisal.

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1. Introduction

In transport networks, travel times and travel costs experienced by travelers within and between days are stochastic due to stochastic supply and fluctuating travel demand (Emam and Al-Deek, 2005; Tu, 2008; Tu et al., 2012). The uncertainty and heterogeneity in travelers' behavior (for instance driving behavior) also leads to variations and unpredictability in travel times, and in associated travel costs. Travel time uncertainty appears to have a significant impact on travelers' choice behavior; for instance route choice, departure time choice and mode choice. Bates et al. (2001) indicated that the reason why travel time variability is so important can be explained by at least the following sources: the anxiety or stress caused by uncertainty, additional cognitive burden associated with planning activities, and sensitivity to the consequences of the uncertainty, for instance late arrivals, etc. Modeling travel behavior under uncertainty has become an important research direction, gaining increasing attention from many researchers (Abdel-Aty et al., 1996; Bates et al., 2001; De Palma and Picard, 2005; Batley, 2007; Liu and Polak, 2007; Hensher et al., 2015a). In the context of uncertainty, departure time adaptation appears to be one of the most important behavioral changes in attempting to arrive on time at work and to reduce the probability of arriving late (Li et al., 2009a; Siu and Lo, 2013). Many studies (Abdel-Aty et al., 1996; Noland et al., 1998; Bogers and van Zuylen, 2004; Van Amelsfort et al., 2008; Li et al., 2012) have analyzed the impacts of travel time variability on travelers' departure time/route choice behavior and suggested ways to model their choice behavior under uncertainty.

These exist a number of theories designed to describe and model human choice behavior under uncertainty, such as expected utility theory (Noland and Small, 1995), prospect theory (Kahneman and Tversky, 1979), cumulative prospect theory (Kahneman and Tversky, 1979; Sumalee et al., 2009; Hensher and Li, 2012), and extended prospect theory (Van de Kaa, 2008). The difference between expected utility theory and other theories is that it does not account for the cognitive tasks in traveler's decision making. However, in general expected utility theory is sufficiently widely accepted as useful to deal with choices made under uncertainty, and can be extended to incorporate elements of prospect theory such as perceptual conditioning (Hensher et al., 2011). In this paper we set out a model form to capture uncertainty which aligns with the framework of (expected) utility theory. For research on the choice behavior under uncertainty using prospect theory, we refer to, for example, Avineri and Prashker (2006), Van de Kaa (2008) and Hensher and Li (2012). For a review of different theories for modeling traveler's choice behavior under uncertainty, we refer to, for example (Fujii and Kitamura, 2004).

Under the behavioral assumption of utility maximization, various behavioral models have been proposed in the literature to model traveler's choice behavior under uncertainty. In general, there are two common approaches, the mean–variance approach (Jackson and Jucker, 1981) and the scheduling approach (Small, 1982). The relationship and similarities between these two approaches have been investigated by several authors (Li et al., 2009b; Fosgerau, 2010). It has been shown by Fosgerau that the maximal expected utility based on the scheduling approach (without the probability of being late) is linear in the mean and standard deviation of travel time distribution under the assumption that the travel time distribution is independent of departure times. Li et al. (2009b) also found that the scheduling approach could be transformed into a linear function of the mean and the standard deviation of travel times assuming independence of travel time distributions on departure time t. They conclude that the scheduling approach is more general than the mean–variance approach in terms of modeling departure time choice behavior. Furthermore, it is found that the expected schedule delay as proposed by Noland and Small (1995), and the probability of lateness and standard deviation formulation alone, do not fully capture travel time variability – a mixture is preferred. This paper suggests that although expected schedule delay is one way of representing travel uncertainty, it is a limiting assumption, and a more behaviorally appealing form is proposed in this paper which adds in additional dimensions (e.g., standard deviation) as candidate sources of uncertainty in revealing the preferences of trip makers. In addition to the standard deviation, and in contrast to the probability of late arrival in the scheduling model proposed by Noland and Small (1995), the schedule delay in our proposed model is calculated differently based on an expected travel time. This is an extension which we refer to as the generalized utility function. The generalized behavioral model is proposed as a way of capturing and testing the fuller set of candidate influences. We use two surveys (data from China with symmetric travel time distribution, and Australia with a skewed travel time distribution) to evaluate the performance of the extended utility function specification, compared to the widely applied scheduling model.

This paper will firstly present an overview of the widely used behavioral models for departure time choice behavior under uncertainty. Then the motivation for the generalized behavioral model is provided, with a discussion of the relationship between the scheduling approach and the generalized approach. Two surveys undertaken out in Shanghai and in Brisbane are described followed by the empirical estimates obtained from four behavioral models, and the evidence is contrasted. Finally some conclusions are drawn and future research is discussed.

2. Alternative behavioral models

A number of behavioral models have been proposed in the literature as different hypotheses on choice behavior that account for uncertainty. de Jong and Bliemer (2015) provide an extensive literature review on different behavioral models accounting for the impact of unreliability on behavior, and give suggestions on how to include reliability in economic appraisal. The model forms differ in the mathematical expressions and indicators of uncertainty. For example, a hypothesis of a 'safety margin' being selected by travelers was specified by Gaver (1968) and Knight (1974), which assumed that travelers