Modeling Departure Time Choice Under Stochastic Networks

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Introduction

In transport networks, due to the stochastic supply and fluctuating travel demand, travel times and travel costs experienced by travelers within-day and over days are stochastic (Emam 2005; Tu 2008). The uncertainty and diversity in travelers’ behaviors (for instance driving behavior) lead to variations and unpredictability in travel times as well, thus in travel costs. The influence of travel time variability on travelers’ choice behavior under uncertainty has gained increasing attention. A lot of researches (Van Amelsfort et al. 2008) have been carried out on analyzing the impacts of travel time variability on travelers’ departure time/route choice behavior and on how to model their choice behaviors under uncertainty. Several empirical studies (e.g., (Abdel-Aty et al. 1996), (Kazimi et al. 2000), (Lam 2000), (Ghosh 2001)) suggest that travelers are interested not only in travel time saving but also reduction of travel time variability. Especially in the context of uncertainty, departure time adaptation appears even more significant than route choice adaptation for the sake of attempting to arrive on time at destination with high probability. Thus, the impacts of travel time unreliability on travelers’ choice behavior, especially on departure time choice behavior under uncertainty are eagerly needed to be investigated. In general, there are two approaches developed to model the choice behavior under uncertainty, namely the mean-variance approach (Jackson et al. 1981) and the scheduling approach (Small 1982). This paper will perform analytical investigations on the equivalency of the mean-variance approach and the scheduling approach. A generalized mean-variance scheduling travel cost function is derived and proposed to model travelers’ departure time/route choice behavior under uncertainty. Then a simulation-based approach is developed to model different dynamic user equilibrium with different travel cost functions from different approaches. The parameters in the travel cost functions, especially for the travel time reliability are investigated via the simulation-based approach.

Methodology and results

Analytical approach is applied to prove the equivalency between the scheduling approach and the mean-variance approach without assuming the type of the travel time distribution. If schedule delay is a linear function, then for any departure time $t$ expected schedule delay on route $p$ between OD
pair \((o,d)\) is a linear function of schedule delay with expected travel time on route \(p\) between OD pair \((o,d)\) when departing at \(t\) and standard deviation of travel time on route \(p\) between OD pair \((o,d)\) when departing at \(t\). This can be mathematical expressed as:

\[
\gamma_1 \cdot E \left[ PAT - t + \bar{\tau}_{od}^p - t \right] + \gamma_2 \cdot E \left[ t + \bar{\tau}_{od}^p - t - PAT \right]
= \gamma_1 \cdot PAT - t + E \left[ \bar{\tau}_{od}^p - t \right] + \gamma_2 \cdot t + E \left[ \bar{\tau}_{od}^p - t \right] - PAT + \xi \cdot Std \left[ \bar{\tau}_{od}^p - t \right]
\forall (o,d), p, t
\]

where \(\bar{\tau}_{od}^p - t\) denote the individual’s stochastic travel times on route \(p\) between OD pair \((o,d)\) departing at \(t\) under uncertainty. PAT is preferred arrival time. \(E[\bar{\tau}_{od}^p - t]\) and \(Std[\bar{\tau}_{od}^p - t]\) denote the expectation and standard deviation of the stochastic travel times respectively on route \(p\) between OD pair \((o,d)\) when departing at \(t\). Expectation of schedule delays can be decomposed as a linear function of expected travel time and standard deviation of travel time. A new generalized mean-variance scheduling approach is developed to model travelers’ departure time/route choice behavior under uncertainty, given by:

\[
c_{od}^p - t = \alpha \cdot E \left[ \bar{\tau}_{od}^p - t \right] + \gamma_1 \cdot PAT - t + E \left[ \bar{\tau}_{od}^p - t \right] + \gamma_2 \cdot t + E \left[ \bar{\tau}_{od}^p - t \right] - PAT + \xi \cdot Std \left[ \bar{\tau}_{od}^p - t \right]
\forall (o,d), p, t
\]

\(\xi\) is a time-dependent parameter for travel time reliability, depending on the travel time distribution at \(t\). This travel cost function is more plausible and behaviorally sound since travelers based on their past accumulative experiences perceive an expected travel time and then based on this expected travel time, they infer when they will arrive at the destination. Compared to the mean-variance approach, the travel cost function (2) accounts for the scheduling delay early and late which are not included in the mean-variance approach. Compared to the scheduling approach, the travel cost function is more general and more behaviorally sound. The scheduling approach and the mean-variance approach are special cases of the generalized mean-variance scheduling approach. In case the non-linearity in schedule delays is considered, the schedule delay costs can still be expressed as a function of the expected travel time and standard deviation of travel time.

A simulation-based approach is developed to model the reliability-based dynamic user equilibrium with travel cost functions according to the scheduling approach and the generalized mean-variance scheduling approach. Stochastic link capacities are modeled as the major factor leading to travel time variability. By analyzing the equilibrium departure patterns with different travel cost functions, the parameters in the generalized mean-variance scheduling approach are investigated, of which the relationship is also investigated with that from the scheduling approach. With the derived parameters
in the travel cost function, it can be employed for network modeling, network design problems with stochastic networks and fluctuating travel demand.

**Contributions**

1. Equivalency of the mean-variance approach and the scheduling approach is proved analytically without any assumption on the travel time distribution;
2. A generalized mean-variance scheduling approach is developed, which is more behaviorally sound compared to the scheduling approach and accounts for the schedule costs and travel time reliability explicitly;
3. A simulation-based approach is applied to model the reliability-based dynamic user equilibrium with different travel cost functions. The parameters in the travel cost functions and their relationships from different modeling approaches are investigated via the simulation-based approach.

**References**


