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A day-to-day route flow evolution process towards the mixed equilibria

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ABSTRACT

This study investigates a travelers' day-to-day route flow evolution process under a predefined market penetration of advanced traveler information system (ATIS). It is assumed that some travelers equipped with ATIS will follow the deterministic user equilibrium route choice behavior due to the complete traffic information provided by ATIS, while the other travelers unequipped with ATIS will follow the stochastic user equilibrium route choice behavior. The interaction between these two groups of travelers will result in a mixed equilibrium state. We first propose a discrete day-to-day route flow adjustment process for this mixed equilibrium behavior by specifying the travelers' route adjustment principle and adjustment ratio. The convergence of the proposed day-to-day flow dynamic model to the mixed equilibrium state is then rigorously demonstrated under certain assumptions upon route adjustment principle and adjustment ratio. In addition, without affecting the convergence of the proposed day-to-day flow dynamic model, the assumption concerning the adjustment ratio is further relaxed, thus making the proposed model more appealing in practice. Finally, numerical experiments are conducted to illustrate and evaluate the performance of the proposed day-to-day flow dynamic model.

1. Introduction

Traffic assignment models are used to predict link or route flows in the transportation networks. Traditionally, these models were formulated under the user equilibrium (UE) or stochastic user equilibrium (SUE) principle, in which no traveler can reduce his/her actual or perceived travel time by unilaterally changing routes (Sheffi, 1985). Since the UE or SUE traffic assignment models focus on the final equilibrium state, they are unable to describe driver's learning behavior and route adjustment process. As an important supplement to the traditional UE and SUE models, extensive studies have focused on the learning behavior modelling of commuters over the past decades (Cantarella, 2013; Hu and Mahmassani, 1997; Iida et al., 1992; Jha et al., 1998; Nakayama and Kitamura, 2000; Wu et al., 2013; Zhang et al., 2001) and a number of day-to-day flow dynamic models have been proposed to depict the evolution process of traffic flows before achieving the UE or SUE state (Guo and Liu, 2011; Horowitz, 1984; Smith, 1983, 1984).

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1.1. Literature review

The day-to-day flow dynamic models in the existing literature can be divided into the continuous or discrete day-to-day flow dynamic models based on their degree of time dispersion. The continuous day-to-day flow dynamic models use sufficiently short time steps, and differential equations are generally employed to formulate these models (Friesz et al., 1994; Smith and Wisten, 1995; Smith, 1983, 1984). Although they have elegant mathematical properties, they are not applicable in practice since the travel behaviors of travelers are generally adjusted in a discrete manner, e.g., daily. On the contrary, the discrete day-to-day flow dynamic models permit relatively long time steps, such as days or weekdays, and they are more reasonable from a practical point of view (Horowitz, 1984; Zhang et al., 2001). However, in order to guarantee that the discrete day-to-day flow dynamic models would evolve to an equilibrium state, some additional assumptions on the travelers' adjustment ratio are required, which will be discussed subsequently.

The day-to-day flow dynamic models can also be sorted into the route-based or link-based models. The route-based models aim to simulate the evolution process of route flows (Horowitz, 1984; Smith, 1983, 1984). They can directly reflect the adjustment process of travelers' route choice behavior. An important input parameter for the route-based models is the initial route flow pattern, and different initial route flow patterns may lead to different evolution processes. However, since the initial route flows are non-unique and unobservable in practice, the route-based models are merely limited to the theoretical studies. In order to overcome the essential shortcomings of the route-based models, the link-based models built on link flow are proposed (He et al., 2010). With the observable initial link flow pattern, the evolution process of link flows can be easily determined. However, travelers' heterogeneous route choice behavior cannot be observed in the link-based models because these models are built on the aggregate link flows.

In addition, the day-to-day flow dynamic models can be classified as deterministic or stochastic models according to the random nature of the problem being studied. Deterministic models assume that the travelers' route choice mechanism in each day is determined in advance. So the flow evolution trajectory can be explicitly predicted. On the contrary, stochastic models consider uncertainty in travelers' route choice decision-making process. They can provide the probability distribution of flow states. Obviously, stochastic models are more general than deterministic models. However, the computational burden of stochastic models prohibits their implementations in the large-scale transportation networks.

Furthermore, the day-to-day flow dynamic models can be categorized by various travelers' route choice behaviors. Prominent examples include the day-to-day flow dynamic UE models and day-to-day flow dynamic SUE models, in which travelers follow the UE or SUE behavior, respectively. We summarize the typical day-to-day flow dynamic models in Table 1.

1.2. Objectives and contributions

With the development of advanced traveler information system (ATIS), the accurate information of the road traffic condition can be provided to travelers with ease and thereby helps them make informed route choices. Hence it is reasonable to assume that travelers equipped with ATIS will follow the UE route choice behavior, whereas travelers without ATIS will choose their routes in a SUE manner. The resultant equilibria of travelers under a predefined market penetration of ATIS is referred to as the mixed equilibria of UE and SUE. From the column 5 in Table 1, it is apparent that all the existing models in the literature were formulated based on a single equilibrium concept, i.e., either UE or SUE. To the best of our knowledge, the influence of ATIS on the day-to-day flow evolution process towards the mixed equilibria has not been investigated so far. Therefore, in this paper we aim to fill this gap by proposing a discrete dynamic model to simulate the day-to-day route flow adjustment process under a predefined market penetration of ATIS.

Unlike the existing studies for a single equilibrium state (i.e., UE or SUE) in which all the travelers were assumed to follow the same route adjustment behavior, different route adjustment principles are proposed in this study for travelers with or without ATIS. Specifically, travelers with ATIS are likely to choose the shortest route under the current traffic condition for their trips in the next day, while travelers without ATIS are supposed to follow the logit-based SUE principle based on the current traffic condition. In addition, the adjustment ratio is assumed to satisfy certain conditions to guarantee the convergence of the proposed day-to-day flow dynamic model towards the mixed equilibria. Reasonable interpretations of these assumptions are presented to demonstrate that the route adjustment principle and adjustment ratio proposed in this study have rich behavioral implications other than be a mathematical expression.

The contributions of this study are fourfold: First, to simulate the evolution process of travelers' route flows with and without ATIS, we propose a discrete mixed behavior route flow dynamic model, which has not been investigated so far. Second, we specify the target flow and flow adjustment ratio, and elaborate their behavioral implications. The necessity to impose such a requirement on the flow adjustment ratio is illustrated by a counterexample in which the well-known rational behavior principle used in the continuous models is not sufficient for convergence for our discrete route flow dynamic model. Third, we show that our model may result in multiple possible route flow evolution trajectories, and present thee specific cases to refine them. Fourth, we demonstrate the convergence of our day-to-day flow dynamic model to the mixed equilibrium state even with a relaxation of the assumption on the flow adjustment ratio. Our proof essentially establishes the convergence of the partial linearization method under the (relaxation of) Goldstein rule.

The remainder of the paper is organized as follows. The mixed equilibrium behavior model and its properties are first reviewed in Section 2. We then propose a discrete day-to-day flow dynamic model in Section 3 for which the travelers' route adjustment principle and adjustment ratio are elaborated. The convergence of the day-to-day flow dynamic model is