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RESEARCH PAPER

Perception Updating Based Stochastic Dynamic Assignment Model

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Abstract: Traffic network systems endogenously display both stochasticities and dynamics with vehicle flows formed from aggregated travelers in response to their previous experiences and the information provided by Advanced Traveler Information Systems (ATIS). In consideration of the day-to-day trip-making decisions of travelers, a perception-updating-based stochastic dynamic assignment model is proposed to describe the evolution of the traffic network flow pattern. In this model, the route flows are treated explicitly as random variables and the distribution of them is proved to asymptotically converge to a stationary probability distribution. A simulation algorithm is developed for implementing the model. Numerical results under two scenarios, with and without ATIS, are also provided for comparing the stochastic dynamics of route flows.

Key Words: system engineering; stochastic dynamic assignment; perception updating; road network; ATIS

1 Introduction

In a traffic network, the decisions of travelers such as choices of departure time and routes are always random because of the uncertainty of traffic demand and supply. In addition, advanced traveler information systems (ATIS) provide travelers with various ways of accessing traffic information, such as radios, cellular phones, websites, and variable message signs. Travelers usually change their trip-making decisions according to traffic information and their past experiences. This process also involves dynamics from the view of the travel times. Traffic flow usually represents aggregated trip-making decisions of numerous travelers. Therefore a network system with traffic flow defining its state variable is essentially characterized as a stochastic dynamic system. Through recognizing the stochasticities and dynamics of the system, the evolution of the system state can be comprehensively analyzed, providing a reliable basis for traffic planning and management purposes.

Using information technologies, ATIS provide travelers with real-time and reliable traffic information, which greatly increases the convenience for travelers. Such information results in travelers making different decisions, thus the traffic flow and network conditions vary dynamically. The dynamics of trip-making decisions by travelers has attracted significant research interest from scholars all around the world. Mahmassani and Liu[1] designed several laboratory experiments to simulate travelers' daily commuting behaviors through an interactive multiple user decision simulator. They found that the provision of information would increase travelers' sensitivity to the change of travel time and travelers therefore, would switch routes more frequently. Shi[2] established a dynamic choice model based on the forecasted travel time updating process through experiences and real-time information, and found that the expected perceived travel time would stably converge after repeated trips of travelers. Liu *et al*.[3] established a day-to-day route choice evolving framework which integrated a risk aversion analysis and a perception updating process. They found that the systematic error of ATIS would affect the time needed for the convergence of route flow. He *et al*.[4] simulated the route choice behavior with mixed guidance modes and generalized the influences of different guidance modes on the route choice behavior of travelers. Xiong *et al*.[5] classified travelers by their compliances to ATIS and formulated a corresponding perceived route travel time function. Kuang *et al*.[6] confirmed that whether ATIS exists or not, travelers would unlikely acquire the exact traffic information. They established a

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stochastic assignment model based on generalized costs and found that the appropriate market penetration of ATIS and quality of information would result in a reasonable flow pattern. Nonetheless, in spite of the recognition of stochasticities and dynamics of trip-making behavior of travelers, the studies mentioned above, usually targeted one characteristic while neglecting another for simplification. Thus, the conclusions obtained are relatively restrictive. Therefore, it is necessary to consider both stochasticities and dynamics simultaneously, and use the stochastic dynamic system approach to study traffic networks and travelers' trip decision making process. Treating route choices as random variables, Cascetta[7], proposed a kind of Markovian stochastic dynamic assignment model in which the temporal route choice probability was assumed to follow Markovian characteristics. Namely, the present route choice probability could be determined by the previous finite route choice probabilities. The Markovian assignment model implies that the day-to-day trip-making decision can be explained as an accumulating process of travelers' experiences. Subsequently, Davis and Nihan[8], and Cantarella and Cascetta[9] systematically discussed the relationships between dynamics and equilibrium of traffic systems. They studied the day-to-day dynamics of traffic systems, and reached general conclusions in both theory and by using numerical cases. They also proposed a dynamic simulation algorithm different from the classical mathematical programming algorithm for the implementation of the assignment model. From the perspective of modeling, Watling and Hazelton[10–12] also studied the relationship between equilibrium and dynamic assignment models. They referred that the external information system might have influences on the stochastic dynamic model. To the best of our knowledge, however, there is very limited literature that discussed this issue in detail. Hence, in this paper, considering the stochasticities of the route flow and the perception updating process, a stochastic dynamic assignment model is proposed. In the following sections, the model is first described. It is tested using numerical examples, and finally the comparison of route flows with and without ATIS is carried out.

2 Notations and assumptions

Consider a road network $G(N, A)$ where N is the set of nodes and A is the set of links. Let W be the set of OD pairs and K_w be the set of feasible routes for any OD pair $w \in W$. Assume that the demand of the OD pair $w \in W$ is a given constant and notated as d_w. The link-route incidence is expressed as a 0-1 variable δ_{ak}, which equals 1 if and only if the link $a \in A$ is a part of the route $k \in K_w$, otherwise it equals 0, and Δw is the corresponding matrix. Let $\overline{c}_a$ be the designed capacity of link a, and $\overline{t}_a$ be the free flow travel time of that link. Let the discrete time domain L={0, 1, ···, M} be the observation time domain, where M is set to be large enough to ensure that the changes of the network state can be fully observed. Any time point $n \in L$ is assumed to represent a day.

For any OD pair w in a road network system, let S_w={0, 1, 2, ···, d_w} be the sample space of the route flow. Let the random variable $\tilde{F}_k^{(n)}$ be established on S_w, representing the flow on route k on day n, and $\tilde{\boldsymbol{F}}_w^{(n)}$ be the corresponding vector. Thus, the stochastic process $\tilde{\boldsymbol{F}}_w = \left\{\tilde{\boldsymbol{F}}_w^{(0)}, \tilde{\boldsymbol{F}}_w^{(1)}, \cdots, \tilde{\boldsymbol{F}}_w^{(M)}\right\}$ describes the stochastic dynamics of the route flow on the OD pair w. Let $x_a^{(n)}$ be the flow on link a on day n, and $x^{(n)}$ be the corresponding vector. $\boldsymbol{x}^{(n)} = \Delta_w \tilde{\boldsymbol{F}}_w^{(n)}$ holds according to the link-route incidence. Namely, the link flow vector is a function of a random route flow vector. Assume that the link cost is the function of link flow and capacity, and is notated as

$$t_a^{(n)} = \tau_a\left(x_a^{(n)}, \overline{c}_a\right)$$

Let $T_k^{(n)}$ be the route cost, it is obtained that

$$T_k^{(n)} = \sum\nolimits_{a \in A} \delta_{ak} t_a^{(n)}$$

according to the link-route incidence relationship. Let $V_k^{(n)}$ be the measurable disutility of route k and $\boldsymbol{V}_w^{(n)}$ be the corresponding vector. Let the route choice probability function be expressed as $P_k^{(n)} = P_k\left(\boldsymbol{V}_w^{(n)}\right)$ and $\boldsymbol{P}_w^{(n)}$ be the corresponding vector.

3 Utility updating and route choice

The state of a road network is usually affected by many random factors such as traffic accidents, weather conditions, road reconstruction, and maintenance. Thus it is unlikely that travelers will obtain the exact information about the network performance before their trips. But after repeated trips, travelers may accumulate abundant experiences and become familiar with the network state. Thus, travelers might form certain perceptions of the present network state based on their previous experiences and use them as their trip-making decision basis.

3.1 Utility updating

Route choice is an important part of trip-making decisions. Presently, the discrete choice model based on random utility maximization is capable of appropriately describing the route choice. In order to describe the influence of travelers' past experiences on their present perceptions, a learning mechanism with the property of exponentially decreasing linear weights needs to be introduced[12]. The measurable disutility of route k on day n can be stated as:

$$V_k^{(n)} = \frac{\sum_{i=1}^{m} \gamma^{i-1} T_k^{(n-i)}}{\sum_{i=1}^{m} \gamma^{i-1}} \qquad k \in K_w \tag{1}$$

$$= \frac{1}{\sum_{i=1}^{m} \gamma^{i-1}} T_k^{(n-1)} + \frac{\gamma}{\sum_{i=1}^{m} \gamma^{i-1}} T_k^{(n-2)} + \cdots + \frac{\gamma^{m-1}}{\sum_{i=1}^{m} \gamma^{i-1}} T_k^{(n-m)}$$

where m is the effective experience length or memory length. It means travelers would form present perceptions through the past m days' experiences. $\gamma \in (0,1)$ is a parameter with