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Exploration of day-to-day route choice models by a virtual experiment

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ABSTRACT

This paper examines existing day-to-day models based on a virtual day-to-day route choice experiment using the latest mobile Internet technologies. With the realized day-to-day path flows and path travel times in the experiment, we calibrate several well-designed path-based day-to-day models that take the Wardrop's user equilibrium as (part of) their stationary states. The nonlinear effects of path flows and path time differences on path switching are then investigated. Participants' path preferences, time-varying sensitivity, and learning behavior in the day-to-day process are also examined. The prediction power of various models with various settings (nonlinear effects, time-varying sensitivity, and learning) is compared. The assumption of "rational behavior adjustment process" in Yang and Zhang (2009) is further verified. Finally, evolutions of different Lyapunov functions used in the literature are plotted, and no obvious diversity is observed.

1. Introduction and literature review

It is believed that travelers' historical traffic experience, as well as their prediction of future traffic conditions, would influence their trip decisions from day to day. Prediction of the traffic conditions in a future time epoch (e.g., traffic volume at the morning peak on a working day) can help transportation agencies arrange appropriate management and control strategies ahead of time. Prediction is especially useful when the network structure changes (Guo and Liu, 2011; He and Liu, 2012). To model the variation of traffic flows from epoch to epoch (Cascetta, 1989; Watling and Cantarella, 2015), a substantial stream of research on day-to-day dynamics has been developed. In general, two types of trip decision, i.e., route choice and departure time choice, are considered in the day-to-day context. This paper focuses solely on route choice. Readers interested in day-to-day departure time choices can refer to the work by Hu and Mahmassani (1997), Mahmassani (1990), Mahmassani and Chang (1986), Mahmassani et al., (1986), and more recently Xiao and Lo (2016), just to name a few.

Starting from the pioneer work by Smith (1984) and Horowitz (1984), the day-to-day route choice models are established to study how aggregate traffic flow changes based on current/historical flows and travel costs. The day-to-day model is a deterministic-process model if it is formulated as ordinary differential equations or difference equations, and the steady states can be different kinds of user equilibrium (UE), including deterministic UE (DUE, i.e., Wardrop's UE), stochastic UE (Cantarella and Cascetta, 1995; Smith and Watling, 2016), and boundedly rational UE (Di et al., 2015; Guo and Liu, 2011; Mahmassani and Chang, 1987; Ye and Yang, 2017). On the other hand, the stochastic-process models formulate flow

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dynamics as stochastic processes, and the steady state is the equilibrium probability distribution (Cascetta, 1989; Cascetta and Cantarella, 1991; Davis and Nihan, 1993; Hazelton, 2002; Hazelton and Parry, 2016; Hazelton and Watling, 2004; Parry and Hazelton, 2013; Watling and Cantarella, 2015).

The interaction between day-to-day dynamic route flows and other components of the transportation system has been widely studied in an analytical way, including the traffic information system (Bifulco et al., 2016; Cantarella, 2013; Cho and Hwang, 2005; Friesz et al., 1994), fixed or responsive signal control strategies (Cantarella et al., 2012; Huang et al., 2016; Liu and Smith, 2015; Smith et al., 2015; Smith and Mounce, 2011; Xiao and Lo, 2015), congestion pricing (Friesz et al., 2004; Farokhi and Johansson, 2015; Guo, 2013; Guo et al., 2016; Han et al., 2017; Liu et al., 2017; Tan et al., 2015; Wang et al., 2015; Xu et al., 2016; Yang, 2007; Yang and Szeto, 2006; Yang et al., 2007; Ye et al., 2015), and tradable credit schemes (Ye and Yang, 2013). The day-to-day dynamics of other travel modes, such as rail (Wu et al., 2013) and transit (Bar-Yosef et al., 2013; Cantarella et al., 2015; Li and Yang, 2016), were also studied.

In addition to theoretical development, the day-to-day dynamics of route choices have also been studied through simulations and laboratory experiments. Most of these studies were concerned with how travelers' route choices are affected by factors such as information, experience, risk, uncertainty, personality factors, as well as various transportation system components mentioned above (Avineri and Prashker, 2005, 2006; Ben-Elia et al., 2008, 2013; Hu and Mahmassani, 1997; Lotan, 1997; Lu et al., 2011; Mahmassani and Herman, 1990; Mahmassani and Stephan, 1988; Rapoport et al., 2014; Srinivasan and Mahmassani, 2003; Yang et al., 1993). The laboratory experiments were also used to test static UE theories such as the Braess Paradox and Downs-Thomson Paradox (Dechenaux et al., 2014; Morgan et al., 2009; Rapoport et al., 2009).

Our paper focuses on another interesting question that has not yet received sufficient attention in the research community: Are the various route-choice-based day-to-day models proposed so far good enough to reflect the real-life situation, and, if yes, what are the relative performances of these models? Regarding this question, some early and recent empirical studies have been conducted, such as Avineri and Prashker (2005), He and Liu (2012), Mahmassani and Jou (2000), Meneguzzer and Olivieri (2013) and Rapoport et al. (2014). To answer our question, we conducted a virtual route choice experiment and collected the participants' day-to-day route choice data via smart phone apps. Using the experimental data, we study a specific group of DUE-based day-to-day route choice models in the literature, which all have good stability and convergence properties but have not yet been empirically studied. The following aspects of these models are studied. First, these path-based day-to-day models are calibrated. Second, the nonlinear effects of path flows and path time differences on route switching are investigated. Third, the participants' preferences for different paths, variation of their sensitivity over time, and their learning behavior are examined. Fourth, the assumption of "rational behavior adjustment process" is verified. Fifth, the predictive power of various day-to-day models is compared. Finally, various forms of Lyapunov functions used for stability analysis in the literature are examined.

The rest of this paper is organized as follows. Section 2 introduces the settings and processes of the virtual route choice experiment. Section 3 provides the findings from the quantitative analyses of the data. Section 4 draws the conclusions and discusses possible future directions.

2. Introduction of the virtual route choice experiment

To mimic travelers' real-life decision-making processes from day to day, the traditional laboratory or virtual experiments usually involved a relatively small number of participants and/or required the participants to repeatedly make decisions within short periods of time. In order to better mimic the real world, we managed to involve a larger number of participants and allow longer periods for decision making with the help of the social networking app *Wechat*. The network in Fig. 1 was used, where "O" and "D" are the origin and destination, respectively, and the link travel times were calculated as $t_a(v_a) = t_a^0[1 + 0.15(v_a/Y_a)^4]$, where v_a, t_a^0 and Y_a are respectively the flow, free flow time and capacity of link a; the values of t_a^0 and Y_a are given in Table 1. In our experiment, 268 participants took part for 26 rounds, where each round corresponded to a true calendar day. Most of the participants were students of Southwest Jiaotong University in China. On the first day, the route map and the free flow times on the three paths were provided to the participants at 8:00 a.m. The participants were asked to submit their route choice before 9:00 p.m. on the same day. When all the route choices were submitted, the path travel times were calculated based on the predetermined travel time functions. Notably, the travel time functions were

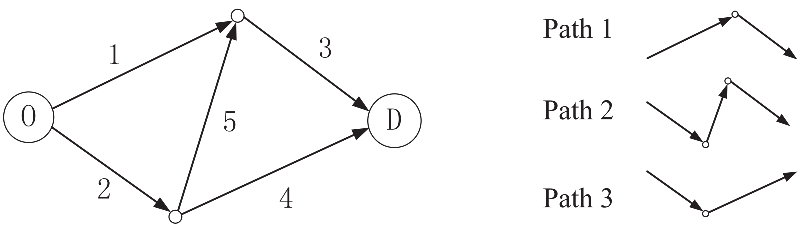

Fig. 1. Network structure and paths.

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