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Day-to-day traffic dynamics considering social interaction: From individual route choice behavior to a network flow model

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ABSTRACT

Social interaction is increasingly recognized as an important factor that influences travelers' behaviors. It remains challenging to incorporate its effect into travel choice behaviors, although there has been some research into this area. Considering random interaction among travelers, we model travelers' day-to-day route choice under the uncertain traffic condition. We further explore the evolution of network flow based on the individual-level route choice model, though that travelers are heterogeneous in decision-making under the random-interaction scheme. We analyze and prove the existence of equilibrium and the stability of equilibrium. We also analyzed and described the specific properties of the network flow evolution and travelers' behaviors. Two interesting phenomena are found in this study. First, the number of travelers that an individual interacts with can affect his route choice strategy. However, the interaction count exerts no influence on the evolution of network flow at the aggregate-level. Second, when the network flow reaches equilibrium, the route choice strategy at the individual-level is not necessarily invariable. Finally, two networks are used as numerical examples to show model properties and to demonstrate the two study phenomena. This study improves the understanding of travelers' route choice dynamics and informs how the network flow evolves under the influence of social interaction.

1. Introduction

Day-to-day traffic dynamics have attracted great attention in recent years. The most appealing feature of the day-to-day approach is its great flexibility, which allows a wide range of behavior rules, levels of aggregation and traffic models to be integrated into a same modeling framework (Watling and Hazelton, 2003). This type of dynamics focus on traffic fluctuations and the traffic flow evolution process, rather than the final (static) equilibrium state examined by traditional static traffic assignment models (He et al., 2010). Many theoretical traffic models have been proposed to study day-to-day traffic dynamics (Cascetta, 1989; Guo et al., 2015; Hazelton and Watling, 2004; Wang et al., 2014; Watling and Cantarella, 2013). Importantly, these models analyze whether and how the network flow can approach equilibrium, and whether that equilibrium is stable (Bie and Lo, 2010; Jin, 2007; Kumar and Peeta, 2015; Smith, 1984; Watling, 1999). From the individual viewpoint, travelers' route choices form the basis of day-to-day traffic dynamics. Thus, identifying and analyzing possible

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factors influencing travelers' route choices help improve traffic dynamic modeling. Existing research has focused on the influence of travelers' experience, Advanced Traveller Information Systems (ATIS), travelers' habits and risk attitudes on route choice (Avineri, 2006; Ben-Elia and Shiftan, 2010; Bogers et al., 2005; De Maio et al., 2013; Lindsey et al., 2014). In addition, significant evidence indicates that social interaction may be an important factor affecting travelers' route choices; however, it has seldom been considered in existing studies.

The powerful influence of social interaction on human behaviors has been verified in many fields, including health, economics, and psychology (Aizer and Currie, 2004; Bayer et al., 2007; Christakis and Fowler, 2007; Deutsch and Goulias, 2013; Manski, 2000). Simon (1956) identified that individual decision making is often influenced by families, friends, peers, or members of a reference group. Many studies have found that people sometimes care about others' behaviors and may rely on others' choices to support their own decision-making, especially in the face of uncertainty (Dugundji and Walker, 2005; Ettema and Kwan, 2010). Evidence has indicated that people will accelerate behavioral changes when they observe that their families, neighbors, and colleagues have changed behaviors (Jones and Sloman, 2003). Sharmeen and Timmermans (2011) found that face-to-face interaction is more likely to impact long-term decisions, such as residential mobility choice. In contrast, virtual interaction based on websites largely determines short or medium-term choices, such as daily travel. Arentze and Timmermans (2008) assumed individual utility can be determined by changes in their social links, as well as their information needs. Given this, they simulated the coevolution of social contacts and social network.

The influence of social interaction has also received increasing attention in the field of transportation research (Lin and Wang, 2014). Taniguchi and Fujii (2007) found that communication between family and friends plays an important role in promoting the use of a community bus service. Sherwin et al. (2014) found that each traveler who sustains bicycling has the potential to promote bicycle use in his or her social networks. They found the widespread use of internet-based social media accelerates the promotion process. Iryo et al. (2012) studied travelers' behavior choices when their only available information was based on other travelers' experiences, transmitted through social networks. They found that information generated by others can influence travelers' decision-making. Sunitiyoso and Matsumoto (2009) conducted laboratory experiments that confirmed social interaction can facilitate social learning. Their studies also found that when system-level aggregate behavior converges to a stable state, it does not necessarily correspond to behavioral stability at individual-level (Sunitiyoso et al., 2011a,b). Di Ciommo et al. (2014) explored the roles of individuals' social networks and trip characteristics in their choice of transport modes. Han et al. (2011) reported that travelers are usually unaware of and may not know the characteristics of certain or all alternatives. Exchanging information through social interactions updates their knowledge about the existence and attributes of alternatives. Ettema et al. (2011) studied the influence of social interaction on travelers' long-term and short-term choices by using the agent-based approach. Some scholars have used discrete-choice models to capture the role of social interaction in travelers' behaviors and applied their models to travel examples (Páez and Scott, 2007; Páez et al., 2008). Hackney and Marchal (2011) used multi-agent simulations to study the co-dependence of social factors and travel behavior in terms of travelers' social networks.

In summary, research exploring the effect of social interaction on travelers' behavior has been conducted in the contexts such as residential location choice, mode choice, and choice set composition. However, few studies have examined the influence of social interaction on travelers' route choices. Route choice is a basic and important problem in the field of transportation research. When travelers need to make repeated route choices in a complicated and uncertain transportation environment, they need other travelers' traffic information to make better choices without the benefit of other information sources (Van Lange et al., 2000). Social media greatly enhances social interactions between travelers (Sigala et al., 2012), enabling travelers to easily and conveniently obtain others' traffic experiences (Chung and Koo, 2015). In addition, research has found that information obtained through social interaction can inspire greater trust among travelers than official information (e.g., ATIS), largely because it comes from real experiences (Bartle et al., 2013).

The studies above indicate that social interaction may also be an important factor influencing travelers' route choices. Web-based social network sites (SNS) are one possible way of sharing travel experiences. An example in Bartle et al. (2013) shows how a website is used to share bicycle travel plans. Website users share comments about routes, and can also revise travel plans using others' information. Route-related information gained through social interaction differs from traditional guidance information, e.g. ATIS in several points. First, every traveler can provide information, rather than simply being a passive receiver. Second, information obtained by a traveler is partial, because he generally interacts with a limited set of travelers. Therefore, it is worth investigating travelers' route choice behaviors and network flow dynamics considering the influence of social interaction. This topic forms the motivation for this study.

This research applies a day-to-day traffic dynamic framework. Rather than directly designing flow swapping rules, a bottom-up approach is applied to first model individual route choice and then deduce the network flow dynamic by aggregating travelers' behaviors. This approach is consistent with approaches taken by Cascetta (1989), Cantarella and Cascetta (1995), Hofbauer and Sandholm (2007). Therefore, a day-to-day route choice model is firstly proposed by considering the characteristics discussed above on travelers' route choices under the influence of social interaction. The network flow model is subsequently derived based on the route choice model, and the model properties are analyzed and validated. Several numerical examples are also provided, indicating that the aggregate-level network flow model agrees well with the individual-level route choice model. This step also verified the theoretical properties of the two models.

The remainder of this paper is organized as follows. Section 2 models the dynamics of travelers' route choice behaviors under the effect of social interaction. Section 3 applies a mathematical analysis to describe network flow evolution based on the route choice model. Properties of travelers' behaviors and network flow evolution under the effect of social inter-