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Modeling route choice inertia in network equilibrium with heterogeneous prevailing choice sets

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ABSTRACT

The notion of inertia is originally a term in physics that describes the tendency of an object sustaining the same mode and its resistance of change in the state of motion. In the context of social and behavioral sciences, inertia is often understood as the endurance of stable relationships or reluctance in adjustment of status quo. In this paper, a precise definition of inertia under the criteria of route choice in the transportation network is presented. We then incorporate the concept of route choice inertia into the traffic assignment problem and propose a model of inertial user equilibrium (IUE). The inertial user equilibrium is compatible with the standard user equilibrium and extends UE with heterogeneous route choice inertia patterns. The variational inequality formulation is established. We show how travelers' heterogeneous inertia patterns may redistribute traffic flow and affect the original network equilibrium. Useful equivalent conditions for equilibrium preservation are obtained. The impact of traffic information provision to alleviate inertia is analyzed. The relationship between IUE and ε-BRUE is briefly discussed. And a number of numerical examples are conducted.

1. Introduction

The Wardrop's first principle of equilibrium (Wardrop, 1952), which is well known as user equilibrium (UE), has been solidly adopted as a norm for the traffic assignment problem in transportation networks. Travelers are assumed to be homogeneous and to choose their routes to maximize their utilities (or minimize disutilities or generalized travel costs). However, the assumption of users having perfect knowledge of travel costs by the classical user equilibrium is unrealistic. And in reality, there are many sources of uncertainty (Chen et al., 2002; Watling, 2006; Shao et al., 2013) that influence network performance. These variations, which lie in either network supplies or travel demands, may alter travelers' behaviors.

In this paper, we focus on route choice inertia and consider its effects on the transportation network. The notion of inertia, is originally a term in physics that describes the tendency of an object sustaining the same mode and its resistance of change in the state of motion. Isaac Newton in his book (Newton and Chittenden, 1848) defined that "The vis insita, or innate force of matter, is a power of resisting, by which every body, as much as in it lies, endeavors to preserve in its present state, whether it be of rest, or of moving uniformly forward in a straight line" and significantly named it "inertia, or force of inactivity". In the context of social and behavioral sciences, inertia is often understood as the endurance of stable relationships or reluctance in adjustment of status quo. "Absent other forces, inertia describes the tendency to remain with the status quo and the resistance to strategic renewal outside the frame of current strategy" (Huff et al., 1992). And individuals or organizations

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"seldom succeeded in making radical changes in strategy and structure in the face of environmental threats" (Hannan and Freeman, 1984). In a transportation network, there is also such phenomenon of inertia that people "tend to stay with the alternative that they have previously chosen unless another alternative provides sufficiently higher utility to warrant a switch" (Train, 2009). Interpretations for the motivations behind such behavior pattern are multiple. It could be the internal sunk costs or external barriers to entry and exit (Hannan and Freeman, 1984). It could because of a satisfaction level being achieved or the relationships such as habit, trust, commitment, cooperation and dependence (Bozzo, 2002). In transportation researches, inertia is usually framed as a result from the wish to save cognitive resources, which is expressed as the "effort-accuracy trade-offs" (Chorus and Dellaert, 2012).

And the behavior of choosing fixed routes can also be found in other situations. For instance, some dangerous goods transport vehicles have to take a fixed route to avoid potential hazards. Travelers using GPS navigators often seek and follow an available route of minimum physical distance prior to their trips, while not considering the real-time changing traffic conditions on the roads. Some travelers need to pass by or temporarily stop over a "transfer point" (e.g., a convenience shop, gasoline station or merely some attractions) before reaching their destinations; and some may be unwilling to enter a link such as a newly-built bridge. Such restrictions limit their route choices to a smaller set.

Despite so many diverse factors that may result in the emergence of inertial behavior, we model it purely and completely on its explicit observed behavior. That is, as inertia is exhibited as the decision maker repeatedly choosing the same alternatives, sticking to unique or some fixed choices, having regular and stable response patterns, and remaining inside a frame of familiar strategies, we simply define such observed behavior in a transportation network as route choice inertia. By this definition, implicit factors (e.g. habits, familiarity and trade-offs) that cause travelers not to switch routes out of their choice set will be included in our model. We are not to explore and explain which exact particular factor or some resulting in the inertia emergence, but to see how travelers' heterogeneous inertia patterns may redistribute traffic flow and affect the original network equilibrium.

Xie and Liu (2014) also considered stochastic networks with choice inertia. They categorized inertia and scenario knowledge levels into an inertia-knowledge matrix and then degraded it to a reduced matrix with two groups of travelers (inertial and non-inertial). In their model, travelers make route choice decisions based on long-term experience and on-going observation. The inertial travelers behave according to expectations of their perceived network scenario set and the non-inertial travelers behave according to the actual experienced network scenario information. Travelers' limited information of the traffic conditions in the current experiencing network scenario is the factor that results in inertia emergence. Comparing with their research, we first clearly state the definition of route choice inertia. And with this, we are able to handle occasions for inertia emergence other than network scenario knowledge, including factors such as habits and familiarity. Second, our model can be in general formulated as either a variational inequality (VI) problem or a mathematical program problem (when link interactions are not modeled) with rigorous proofs, while they only state the formulation of a VI problem. Third, the analytical explanation (not just numerical example experiment) for the impact of information provision is provided in our model.

With the precise definition of inertia under the criteria of route choice in the transportation network, we then incorporate the concept of route choice inertia into the traffic assignment problem and propose a model of inertial user equilibrium. The inertial user equilibrium is compatible with the standard user equilibrium and extends UE with heterogeneous route choice inertia patterns. And we establish the variational inequality (Patriksson, 1994) formulation for the inertial user equilibrium. The existence and uniqueness conditions can be guaranteed under general acceptable assumptions. Solution algorithms for the formulation are also briefly described.

We find that when there exist users being inertial, the original equilibrium state may not be preserved. Useful equivalent conditions for equilibrium preservation are obtained and examined in numerical examples. Based on equilibrium preservation conditions, we analyze the impact of traffic information provision to alleviate inertia. Media and devices that convey traffic messages and techniques of traveler information systems (Hall, 1996; Lindsey et al. (2014)) have been continuously developed in the aim of mitigating traffic congestion. It truly plays a considerable role in increasing drivers' trip knowledge and changing their decisions in departure times, travel modes, route choices and so on. However, whether the full potential of information provision can be realized to achieve its aim has been questioned and yet not in full accord (Arnott et al., 1991; Emmerink et al., 1995; Chorus et al., 2006; De Palma et al., 2012). The impact of information provision depends on many factors, such as, whether the information is pre-trip or real-time, its aim to minimize user travel cost or user marginal cost (e.g. social navigation) (van den Bosch et al., 2011), the traffic condition is low to medium demand or high demand, the percentage of drivers receiving information and their compliance with the information systems recommended (Srinivasan and Mahmassani, 2000). Thus predicting the consequence of information provision is quite complicated and the result may vary under different conditions. Chorus and Dellaert (2012) showed that inertia might not be easily broken due to unreliable information and costly provision. We demonstrate that even information provision (which improve individual drivers independently) has the ability to alleviate inertia, its impact on network performance can still be negative.

Another research track is about bounded rationality. This idea is originated from Simon (1955), which describes that rationality of individuals in decision making is "bounded" by the cognitive limitations of both knowledge and computational capacity (Simon, 1982). Yet there is still no unified and complete theory of bounded rationality in the economic literature (Gigerenzer and Selten, 2002). There are many models that allow for the assumption of bounded rationality (Conlisk, 1996). In the field of transportation, Mahmassani and Chang (1987) first brought bounded rationality into transportation systems and introduced the idea of bounded rational user equilibrium (BRUE) with particular reference to the departure time