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A mixed-behaviour equilibrium model under predictive and static Advanced Traveller Information Systems (ATIS) and state-dependent route choice

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ABSTRACT

In transportation planning and design studies it is customary to consider the network in its equilibrium state. Equilibrium conditions in the presence of Advanced Traveller Information Systems (ATIS) and recurrent congestion have been formulated either according to some behavioural principle derived from Wardrop's assumption, or as fixed-point states of day-to-day dynamic assignment processes. In the latter approach only, a differentiation has been introduced between predictive ATIS and ATIS providing static information, but the impacts on equilibrium travel times are relatively unexplored. In addition, the route choice updating model is formulated without consideration of state-dependent effects, such as inertia to change. This forms the motivation for the present paper. According to traffic information sources, three classes of users are considered: (a) users with predictive information, (b) users with static information and compliant, (c) users not equipped with ATIS or noncompliant. Users of the three classes make choices in a stochastic manner based on a logit model subject to inertia. Users of the first class have lower perception variance in view of the higher information quality. The compliance rate is endogenous and dependent on the information accuracy of the static ATIS. The fixed points in the class-specific route flows of the dynamic day-to-day processes characterise a new concept of network equilibrium, referred to as Mixed User Equilibrium (MUE), where, if each user shifts from her currently used route to her newly chosen route, the observed class-specific route flows do not change. A variant of the method of successive averages is proposed for computing MUE. The model is illustrated by an example related to the Nguyen-Dupuis network. The impacts on equilibrium travel times of the market penetration of ATIS with different functionalities as well as of inertia are examined.

1. Introduction

In transportation planning and design studies, it is customary to consider the network in its equilibrium state. The approach is suitable for the representation of recurrent congestion conditions. The recurrent condition is meant as the condition where travel demand and network characteristics are assumed constant over days, and incidents reducing road capacity are not considered. This condition, though ideal, is to an extent realistic in some cases or, at least, considered as realistic in most planning-oriented traffic models that have been developed.

In the absence of Advanced Traveller Information Systems (ATIS), the limitation of the perfect knowledge assumption of classical Wardrop's Deterministic User Equilibrium (DUE; Wardrop, 1952) has long been recognized. Stochastic User Equilibrium (SUE) has

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been proposed as alternative paradigm (Daganzo and Sheffi, 1977). Imperfect knowledge of the network and the associated heterogeneity in the perception of route travel times justify SUE providing, with the probabilistic choice models commonly used such as logit and probit, strictly positive flows for all routes. The random terms of the choice model account, at the same time, for other sources of uncertainty, such as missing attributes, zoning-related aggregation errors and supply-related attribute measurement errors.

DUE and SUE can also be seen, at the same time, as the steady states of discrete-time deterministic day-to-day assignment processes (see Bie and Lo, 2010 for DUE; Horowitz, 1984; Cantarella and Cascetta, 1995; Cantarella and Watling, 2016a, 2016b; Delle Site, 2017, among the others, for SUE; Guo and Huang, 2016, propose a new framework for day-to-day adjustment of route flows capable of accommodating as equilibrium states either DUE, logit SUE or boundedly rational user equilibrium). The adjective deterministic refers to a process where route flows are regarded as deterministic variables.

Equilibrium conditions in the presence of ATIS have been formulated either according to a combination of behavioural principles able to differentiate between equipped and non-equipped users, or as fixed-point states of deterministic day-to-day assignment processes.

In the former approach, it is customary to consider two classes of users, behaving each according to the SUE principle, with unequipped users associated with higher perception variance. The implicit assumption is that information provision reduces the heterogeneity across users of the perception of travel times. The extent of the perception variance is regarded as a measure of the information quality of the ATIS. Contributions include Koutspoulos and Lotan (1990), Lo and Szeto (2001, 2002), Huang and Li (2007), Huang et al. (2008, 2011), Li and Huang (2012), Haghani et al. (2016). In contrast, Yang (1998) assumes an idealized ATIS providing exact information on actual travel times. Thus, he models the class of equipped users according to the DUE principle, while that of unequipped users according to SUE.

The market penetration of ATIS is considered as an endogenous variable by a few authors (Yang, 1998; Lo and Szeto, 2001 and 2002), who consider that users pay for ATIS services because of their benefits. Thus, their models assume market penetration in an elastic manner. Yin and Yang (2003) and Huang et al. (2008) consider, in addition, the compliance rate as endogenous variable. They justify the possibility of non-compliance with the imperfect nature of the information provided. Thus, they propose a two-class model: the first class includes users equipped and compliant, the second class users equipped and noncompliant and users unequipped.

In the approach based on day-to-day dynamics, mention is to be made of the recent contribution by Bifulco et al. (2016) who appear to be the first to introduce a distinction between ATIS providing static information, typically on travel times in free-flow conditions (which is the case of route guidance systems available nowadays), and predictive ATIS providing information on actual travel times. The authors refer to predictive ATIS as fully-accurate ATIS. Users provided with static ATIS may be noncompliant, with compliance rate elastic with respect to the information inaccuracy, measured as deviations of suggested travel times on actual travel times. Thus, Bifulco et al. (2016) propose a three-class model including: users equipped with predictive ATIS, users equipped with static ATIS and compliant, users unequipped or noncompliant. All users make choices in a stochastic manner. Other contributions on day-to-day dynamics with ATIS are by Cantarella (2013), who proposes a model capable to analyse the impacts of ATIS and other intelligent transport systems on user surplus evolution over time, and by Zhou et al. (2017), who model the route flow evolution towards mixed (DUE together with SUE) equilibria.

The present paper adopts the distinction between predictive and static ATIS proposed by Bifulco et al. (2016), and introduces state-dependence in the underlying day-to-day dynamics. State-dependent route choice represents a realistic assumption: users exhibit inertia to change, i.e. a propensity to continue on their currently chosen route. A body of studies has provided experimental evidence supporting the assumption (see Srinivasan and Mahmassani, 2000, for a review). Inertia can be explained with habit persistence of users with satisfactory choices, and the psychological switching cost consequent to the absence of experience of alternatives. Inertia in route choice is commonly modelled by an alternative-specific constant associated with the currently chosen route (among the others: Cantillo et al., 2007; Cascetta and Cantarella, 1991; Srinivasan and Mahmassani, 2000; see Xie and Liu, 2014, for a different approach, and Zhang and Yang, 2015, for modelling inertia in the context of DUE). The impact of user inertia in the presence of ATIS has been modelled recently in the joint day-to-day evolution of departure time and mode choices by Liu et al. (2017).

Users are grouped into three classes as in Bifulco et al. (2016). All make choices in a stochastic manner based on a logit model subject to inertia. Users of the first class have lower perception variance in view of the higher information quality. The compliance rate of users equipped with static ATIS is, as in Bifulco et al. (2016), elastic to information inaccuracy.

The motivation and research objective of the present paper are to investigate the impacts on equilibrium travel times (total and class-specific travel times) of the availability of ATIS with differentiated functionalities (predictive and static), as well as of inertia. The paper is organized as follows. Section 2 presents the mathematical model, based on the day-to-day dynamics, with the associated fixed-point states regarded as mixed-behaviour equilibrium conditions. Section 3 an illustration of the model with the example of the Nguyen-Dupuis network. Section 4 a discussion of the results and directions for future research.

2. The mathematical model

2.1. Network representation and assumptions

The model is formulated according to the notation listed in Appendix.

Consider a strongly connected road transportation network. The associated graph is the couple of sets of nodes and directed arcs. Let A be the arc set and a the arc index. Origins (O) and destinations (D) constitute a subset of nodes. Let W be the set of OD pairs and w the OD pair index. Let R^w be the set of simple routes of OD pair w, and r the route index.