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Advanced traveller information systems under recurrent traffic conditions: Network equilibrium and stability

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ABSTRACT

In this paper the stability of traffic equilibrium is analysed by using a framework where advanced traveller information systems (ATIS) are explicitly modelled. The role played by information in traffic networks is discussed, with particular reference to the day-to-day dynamics of the traffic network and to system stability at equilibrium. The perspective adopted is that of transportation planning under recurrent network conditions. The network is considered to be in equilibrium, viewed as a fixed-point state of a day-to-day deterministic process, here modelled as a time-discrete non-linear Markovian dynamic system. In discussing the effects generated by the introduction of ATIS, the paper examines: changes in the fixed point(s) with respect to the absence of ATIS, how the theoretical conditions for fixed-point existence and uniqueness are affected, and the impact on the stability properties and the stability region at equilibrium. Most of the analyses are carried out with explicit theoretical considerations. Moreover, a toy network is also employed to explore numerically the effects of removing some assumptions concerning the accuracy of ATIS.

1. Introduction

Advanced traveller information systems (ATIS) are considered a powerful tool to enhance the travellers' experience and avoid wasting travel time (Bifulco et al., 2009; Khattak et al., 2003). They are mainly useful for travellers who are unfamiliar with the network (e.g. tourists), as well as for all travellers should the network be temporarily affected by some significant disruption and/or by unexpected or non-recurrent traffic conditions (Emmerink et al., 1995). Moreover, ATIS are also claimed to be useful under recurrent network congestion as they reduce the uncertainty of travellers with respect to travel times (Ettema and Timmermans, 2006).

The disaggregated effect (not considering network phenomena) of ATIS on traveller's behaviour was analysed by Ben-Elia et al. (2013) using (panel) data collected in a laboratory experiment based on a travel simulator. Both statistical analyses and calibration of a mixed-logit model were performed to show that a major role is played by the reliability of the dispatched information. Tanaka et al. (2014), basing their analysis on a different laboratory experiment and different panel

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data, confirmed the ability of information services to influence travellers' behaviour; they modelled this influence by means of a mixed-logit model as well. Previous studies by Tsirimpa et al. (2007) were based on field-collected data: both the multinomial-logit and the mixed-logit approaches confirmed that in switching between alternative routes a significant role is played by pre-trip (vs. en-route) information and by the source and content of the dispatched information. Tseng et al. (2013) also observed revealed preferences for the Dutch A12 motorway with reference to a sample of 340 participants equipped with on-board units. Switching from commuting in the morning on the motorway to alternative travel modes was analysed within a repeated choice experiment; behaviours were compared with respect to pre- and post-adoption of a smartphone-based information service, and a mixed-logit model was specified to reproduce such behaviours. Alternative approaches, not based on random utility, have been proposed for disaggregate modelling of ATIS influence on travel choices. Amongst others, Chorus et al. (2006a) integrated notions of search theory and Bayesian updating perception within a utilitarian framework, Paz and Peeta (2009) adopted a fuzzy multinomial logit structure, and Dell'Orco and Teodorovic (2009) applied uncertainty-based information theory with a fuzzy approach.

At a network level due account has to be made for the aggregate effect of travellers' behaviour, as well as interaction with network congestion and applied information strategies (which depend on current traffic conditions). The result is a *network assignment model under ATIS*, and several of such models have been developed. One was proposed, for non-recurrent traffic conditions, by Al-Deek and Kanafani (1993) and Al-Deek et al. (1998); a deterministic queuing approach was developed and applied to a two-route network to assess the benefit of providing information to travellers under incident conditions. Hall (1996) considered a dynamic traffic system with two alternative routes; he developed and discussed the traffic simulation model under different hypotheses about the reliability of the information provided and the market penetration of the information system. Interestingly, Hall defended the conjecture that ATIS are not suitable for use as control tools; unfortunately, others have since disregarded this suggestion, and the temptation to propose ATIS as a control/optimisation tool for traffic networks has been recurrent in the scientific literature. Dia (2002) combined a dynamic flow propagation model based on microsimulation with an agent-based route choice model based on the travel behaviours observed in a field experiment in Brisbane; the main aim of the work was to prove the suitability of dispatching traveller information (in simplified network conditions). Cantarella (2013) simulated the presence of the information service by appropriately modifying the value of the parameters of a day-to-day dynamic process, based on the exponential smoothing approach. Lo and Szeto (2004) considered the information services within a framework where network flow propagation is implemented by the Daganzo cell transmission model and route choice is made according to a stochastic dynamic user-optimum model. He et al. (2013) explicitly addressed the problem of real-time adapting an information strategy, rather than simulating the effects of an exogenously given (and fixed) information set; they dealt with a simplified network, explicitly simulated (dynamic) queues and discussed the extension of the proposed strategy to more complex networks.

Overall, the literature on network assignment models under ATIS is very extensive and a comprehensive review lies well beyond the scope of this paper. For a more detailed literature review we suggest Chorus et al. (2006b) and De Palma et al. (2012).

Here our focus is on the mathematical properties of the network assignment model under ATIS for recurrent traffic conditions, with particular emphasis on equilibrium stability, which is a relatively unexplored field. Previous findings, numerically obtained in Bifulco et al. (2014a) are herein extended and generalised towards identifying theoretical properties. In particular, this work shows that ATIS constitute a powerful tool for enhancing the stability of traffic systems, ensuring the stability of network configurations that are otherwise unstable, a matter of crucial importance for traffic systems planning and design. Stability properties are theoretically proved in the case of accurate travellers' information; however, some inaccuracy could affect the dispatched information. This may be due to several different factors, including the well-known anticipatory route guidance problem (Bottom, 2000). Therefore, besides the theoretical work, in discussing the theoretical results (Section 4) we also carry out some numerical simulations to show how variable levels of accuracy can affect network stability.

Our analyses are framed within the unified theory of equilibrium and day-to-day deterministic dynamic processes, as first established by Cantarella and Cascetta (1995) and then by Watling and Hazelton (2003). Recurrent conditions are considered; boundary conditions of the day-to-day dynamics are constant while the traffic system evolves, possibly towards the equilibrium. The hypothesis of recurrent traffic condition could be questioned, as both common experience and mobility studies (e.g. Schrank et al., 2012) have shown that significant fluctuations can be observed with respect to recurrent conditions, as a consequence of incidents, bad weather and other random phenomena. These fluctuations are such that travellers are subject overtime to dispersed actual travel times. The most common approach to deal with these fluctuations is to adopt probabilistic route choice models. Of course, if the fluctuations are too high, then the probabilistic approach is not adequate and non-recurrent conditions have to be explicitly considered. One way to mitigate the costs of non-recurring congestion is to provide travellers with information about actual travel conditions. This is the context in which are framed some recent papers such as Lindsey et al. (2014) and Rapoport et al. (2014). In these works a model is developed (and an experiment carried out, that broadly confirm the theory) for a two-link network; as one of the results of these works, it is shown that the way the non-recurrent conditions (e.g. incidents) are probabilistically distributed over the two alternative routes, and the difference in free-flow travel time between the two routes, can modify the effect of the information in terms of (deterministic) route choice behaviour versus system-optimum conditions. Our work, instead, is not limited to a two-link network, and adopts a probabilistic route choice approach. The approach is able to deal with non-recurring random conditions and allows for considering, if requested, covariate distributions of randomness in route travel times.