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A user equilibrium, traffic assignment model of network route and parking lot choice, with search circuits and cruising flows

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ABSTRACT

The paper provides a novel network model of parking and route choice. Parking supply is represented by parking type, management strategy including the fare, capacity and occupancy rate of parking lot, and network location, in relation to access routes along the roadway network. Trip demand is segmented according to origin–destination pair, the disposal of private parking facilities and the individual preferences for parking quality of service. Each traveller is assumed to make a two stage choice of, first, network route on the basis of the expected cost of route and parking and, second, local diversion on the basis of a discrete choice model. Search circuits are explicitly considered on the basis of the success probability to get a slot at a given lot and of the transition probabilities between lots in case of failure.

The basic endogenous model variables are the route flows, the lot success probabilities and the transition probabilities between lots. These give rise to the cost of a travel route up to a target lot and to the expected cost of search and park from that lot to the destination. Traffic equilibrium is defined in a static setting. It is characterized by a mixed problem of variational inequality and fixed point. Equilibrium is shown to exist under mild conditions and a Method of Successive Averages is put forward to solve for it. Lastly, a planning instance is given to illustrate the effects of insufficient parking capacity on travel costs and network flows.

0. Introduction

0.1. Background

Every car trip requires to park the car at the destination place or close to it; it also depends on the parking conditions at the origin place. The parking conditions in terms of price and quality of service determine the trip-maker's decisions of travel mode, network route and parking mode, especially so in dense urban areas. Abstracting from location, a parking mode involves a parking type either on-street or off-street, operating conditions such as tariffs, limit duration or special rights of access notably so for residents. Let us call "parking lot" a set of parking slots with given location and parking mode. Regular activities such as home and work will entice the car user to hold a parking space of his own, be it by ownership,

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rental or garage subscription. The associated costs (Van Ommeren et al., 2011) may push some users to park elsewhere, or to travel at another time of day, or to make their trips by another mode of travel.

Furthermore, in every place the parking capacity is limited. Thus the users compete with one another to avail themselves of the parking slots. A user that cannot get a slot immediately in a given lot has to wait for a length of time that is difficult to predict, or to divert to another lot. Not only does the quest for an available parking slot take time to the user, but it also adds ''cruising traffic'' to the core, ''through'' roadway traffic.

These phenomena have become obvious in many cities throughout the world, due to urban development, mass individual motorization and the massive use of cars by their holders (Shoup, 2005). Parking management, from capacity planning to dynamic pricing, has become a key component in the urban mobility policy and the multimodal planning of transportation networks. Yet the decision-aiding toolbox of the transportation planners still lacks a simulation model to deal with parking plans and policies over a wide area – apart from the inclusion of parking conditions in mode choice modelling and the specific treatment of Park-and-Ride (P&R) facilities at the interface between mode choice and network assignment modelling (namely the Parkride macro in the Emme/3 package).

0.2. Previous work

Models of parking supply and demand may be classified into three streams. First, a branch of economic theory has focused on parking to emphasize the social need to invest in capacity and to price for it so as to limit congestion, and also the deadweight loss of cruising traffic (Arnott and Inci, 2006). The associated theoretical models address the spatial features and the demand behaviours in a much abstract form.

Second, behavioural models for the discrete choice of a parking type and location emphasize the diversity of behavioural strategies and the linkage between parking modes and travel mode: while the first generation of behavioural models paid little if any consideration to supplied capacity and spatial configuration (e.g. Austin, 1973; Hensher and King, 2001), the next generation has addressed parking search and the associated cruising as processes of individual behaviour (Thompson and Richardson, 1998, pioneered by Polak and Axhausen, 1990), thereby leading to agent-based simulation (e.g. Benenson et al., 2008; Dieussaert et al., 2009; Martens et al., 2010; Waraich and Axhausen, 2012).

Third, parking choices are addressed in conjunction with route choice in the framework of traffic assignment to a network: models are either static (e.g. Gur and Beimborn, 1984; Li et al., 2007a) or dynamic (e.g. Bifulco, 1993; Lam et al., 2006; Li et al., 2007b). Recently, Gallo et al. (2011) provided the first macroscopic assignment model to deal with search traffic explicitly; they succeeded to model (i) public access to parking lots whatever the destination, (ii) the local lot search and (iii) the associated pedestrian path up to the destination. Yet, none of the macroscopic assignment models presented so far addressed the detailed physics of parking search, the eventuality of loops in search circuits and the resulting search time and cruising flow.

0.3. Objective and model features

The paper provides a user equilibrium, traffic assignment model of parking and route choice on a roadway transportation network including parking facilities. The model captures the following features of parking supply: by lot, the location, residual capacity available in the study period and management mode are taken as exogenous, while the lot occupation and terminal cost (by demand segment) are endogenous. The demand is modelled as a set of segments, each of which is characterized by its origin–destination pair, period flow, specific access rights to parking lots and a specific travel behaviour on the basis of individual preferences for path and lot quality of service and price.

It is hypothesized that every traveller makes a two-stage choice of, first, network route to a prior target lot on the basis of its expected overall cost (including expected parking cost) and, second, a sequence of local diversions up to parking success. At a given lot the user will succeed to park with a probability that depends on the prior capacity and the number of candidates during the study period. Upon failure, the user diverts to alternative lots according to a discrete choice model on the basis of transition costs and the expected cost of search and parking from the head lot. Thus, search loops may arise when the success probabilities of immediate parking are strictly less than one around a chain of lots. The cruising for parking flows thus result and contribute to the roadway flows and travel times. By demand segment, each parking lot is characterized by an ex-ante expected terminal cost which is endogenous and reduces to the cost of terminal pedestrian access to the destination if the lot has free capacity.

A traffic equilibrium is defined where the individual user selects only a route of minimum expected overall cost to himself. Traffic equilibrium is cast into a joint problem of variational inequality for route and target lot choice and fixed point for success probabilities as well as transition probabilities.

0.4. Contribution and approach

The model of looping is innovative in the field of macroscopic traffic assignment: it enables to capture search circuits as in the most recent agent-based simulation models, yet with simpler assumptions about user behaviour. Our macroscopic setting also captures some stochasticity in the interplay of parking capacity and demand flows, since it is assumed that the arrivals of candidate parkers as well as the delivery of the so-called prior capacity are progressive. This bears some resemblance to static traffic assignment to a transit network (Spiess and Florian, 1989).