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Transportation Research Procedia 7 (2015) 149 – 169

Transportation Research Procedia

www.elsevier.com/locate/procedia

21st International Symposium on Transportation and Traffic Theory, ISTTT21 2015, 5-7 August 2015, Kobe, Japan

A Parking-State-Based Transition Matrix of Traffic on Urban Networks

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Abstract

The urban parking and the urban traffic systems are essential components of the overall urban transportation structure. The short-term interactions between these two systems can be highly significant and influential to their individual performance. The urban parking system, for example, can affect the searching-for-parking traffic, influencing not only overall travel speeds in the network (traffic performance), but also total driven distance (environmental conditions). In turn, the traffic performance can also affect the time drivers spend searching for parking, and ultimately, parking usage. In this study, we propose a methodology to model macroscopically such interactions and evaluate their effects on urban congestion.

The model is built on a transition matrix describing how, over time, vehicles in an urban area transition from one parking-related state to another. With this model it is possible to estimate, based on the traffic and parking demand as well as the parking supply, the amount of vehicles searching for parking, the amount of vehicles driving on the network but not searching for parking, and the amount of vehicles parked at any given time. More importantly, it is also possible to estimate the total (or average) time spent and distance driven within each of these states. Based on that, the model can be used to design and evaluate different parking policies, to improve (or optimize) the performance of both systems.

A simple numerical example is provided to show possible applications of this type. Parking policies such as increasing parking supply or shortening the maximum parking duration allowed (i.e., time controls) are tested, and their effects on traffic are estimated. The preliminary results show that time control policies can alleviate the parking-caused traffic issues without the need for providing additional parking facilities. Results also show that parking policies that intend to reduce traffic delay may, at the same time, increase the driven distance and cause negative externalities. Hence, caution must be exercised and multiple traffic metrics should be evaluated before selecting these policies.

Overall, this paper shows how a parking-state-based transition matrix, despite its simplicity, can be used to efficiently evaluate the urban traffic and parking systems macroscopically. The proposed model can be used to estimate both, how parking availability can affect traffic performance (e.g., average time searching for parking, number of cars searching for parking); and how different traffic conditions (e.g., travel speed, density in the system) can affect drivers ability to find parking. Moreover, the proposed model can be used to study multiple strategies or scenarios for traffic operations and control, transportation planning, land use planning, or parking management and operations.

Selection and peer-review under responsibility of Kobe University

Keywords: macroscopic parking model; traffic congestion; parking-related traffic state; cruising-for-parking; transition matrix of traffic

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Selection and peer-review under responsibility of Kobe University
doi:10.1016/j.trpro.2015.06.009

1. Introduction

The urban parking and the urban traffic systems are essential components of the overall urban transportation structure. The interactions between these two systems, can have both, long-term effects (i.e., parking policies can affect travel demand, and vice versa), and short-term effects (i.e., parking policies can affect traffic operations, and vice versa). While the long-term effects have attracted lots of research attention (e.g. Feeney, 1989; Young et al., 1991), the short-term effects have not been well researched yet. This is unfortunate, as the short-term interactions between parking and traffic can be highly significant and influential to the performance of both systems. For example, parking availability can affect the traffic composition on the network. Shoup (2005), based on the review of 16 studies of mostly American and European cities, concluded that cars searching for free parking spaces contribute to over 8% of the total traffic in a city, reaching 30% in business areas during rush hour. Although this part of traffic is caused by inefficient parking provision, its corresponding externalities are endured by the traffic system as a whole. Such externalities have been studied from an economic point of view (e.g. Arnott and Inci (2006)) and could have a significant influence on traffic performance, causing congested or hyper-congested traffic conditions (Geroliminis (2009)).

Studies like these, all provide some insights on how the urban parking system (both supply and policies) can influence traffic performance. Nevertheless, although different parking policies including pricing schemes have been analyzed, proposed and implemented; to the authors' knowledge, no study has provided yet a generalized methodology to macroscopically model the relation between parking demand, parking availability, and traffic conditions.

In this paper, we develop a parking-state-based transition matrix that aims to model macroscopically a dynamic urban parking system. Basic assumptions for the matrix include a traffic demand over a period of time (e.g., a day), the distribution of parking durations, the length and the traffic properties of the network. Within the matrix, the likelihood of a parking searcher to access/find parking spots in an urban network is estimated, as well as other transition events such as starting to search for parking and departing from it. The model then provides an approximation of the proportion of cars searching for parking, as well as the time cars spent searching for parking, or traveling through the system. Moreover, traffic density and travel speed are also estimated over time based on different background conditions. These results are useful to evaluate both, how traffic performance (e.g., speed, density, flow) affects drivers' ability to find parking; and how parking availability affects traffic performance.

The main contributions of this paper are twofold.

1. This study looks at the relation between parking and traffic performance macroscopically. Most of the existing research looks at the problem microscopically, modeling the parking behavior of individual agents. The agent-based studies can require huge amounts of data, and high levels of detail both on the demand and the supply side. In this paper we look at the problem macroscopically, and focus only on average values and probability distributions across the whole population. This is valuable, as all data requirements correspond to aggregated values at the network level and there is no data requirement for individual drivers or parking spots. This macroscopic approach, compared to microscopic methods, saves not only on data collection efforts (e.g., drivers preferences, individual driving routes, individual parking spots turnovers) but also reduces the computation costs significantly. Such efficiencies are especially useful when the network of interest is large and/or data is scarce.
2. This study allows us to model two dynamic systems interacting with each other. For the traffic system, the model is able to analyze overcrowded situations, where time-varying traffic conditions are provided as traffic performance indicators; they are also taken into consideration for the evolution of the matrix. For the parking system, the usage and the arrival/departure rates are all dynamically updated over time. Notice that in the existing literature, with the exception of a few studies, these elements are mostly assumed without regard for past conditions. Here, however, these variables are dynamically estimated based on changing conditions to better replicate reality.

The paper is organized as follows. Section 2 reviews the existing work on the interactions between parking system and traffic performance, highlighting the differences between the work presented in this paper and the existing studies. Section 3 introduces the concept/framework of the parking-state-based transition matrix. Section 4 contains the methodology to build up the transition matrix. Section 5 shows a numerical example to explore the use of the concept and methodology proposed. Section 6 summarizes the findings of this paper.