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Abstract

Cruising-for-parking is a critical mobility issue in urban cities. The cost and accessibility of parking significantly influence people's travel behavior, such as mode choice and facility choice (on-street or garage parking). Furthermore parking affects traffic performance. Car-users may have to cruise for on-street parking space before reaching destinations and cause delays eventually to everyone, even users with destinations outside limited parking areas. Therefore, it is crucial to understand the impact of parking on mobility and identify traffic management policies to avoid the negative externalities.

Most existing studies of parking either fall short in reproducing the physics of traffic congestion in general and the cruising-for-parking phenomenon, or require data that are expensive and difficult to collect. This work aims to fill in the above-mentioned research gaps. The objective is to propose an aggregated dynamic model for multimodal mobility with the consideration of parking, and utilize the model to evaluate management policies such as parking pricing. Recent study shows that by utilizing a low-scattered bi-modal Macroscopic Fundamental Diagram (MFD), the dynamics of a bi-modal transport system can be sufficiently represented. The MFD-based bi-modal modeling framework is extended with a parking module where delay and change of choices caused by parking are taken into account. Pricing strategies of parking are then developed to influence mode choice and parking facility choice to reduce congestion.

Result of a case study shows that traffic performance under various types of parking policies can be investigated and optimal pricing scheme can be obtained.

Keywords

Parking, Cruising-for-parking, MFD, On-street parking, Pricing

Introduction

Cruising-for-parking is a critical mobility issue in urban cities. The cost and accessibility of parking significantly influence people's travel behavior, such as mode choice and facility choice (on-street or garage parking). Furthermore parking affects traffic performance. Car-users may have to cruise for on-street parking space before reaching destinations and cause delays eventually to everyone, even users with destinations outside limited parking areas. Therefore, it is crucial to understand the impact of parking on mobility and identify traffic management policies to avoid the negative externalities.

Extensive studies have been addressing how parking and parking policies influence people's mode choice and travel delay. Representative works can be found in Verhoef et al. (1995), Arnott and Rowse (1999), Calthrop et al (2000), Anderson and De Palma (2004), Arnott (2006), Anderson and De Palma (2007), and Arnott et al. (2011), Forsgerau and de Palma (2013), Yang et al. (2013) and Qian et al. (2013). These Vickrey-based studies (Vickrey, 1969) make great extension of the classical bottleneck-commute model by considering parking constraints, and reveals behavioral changes under parking-related policies. However few discuss the influence of parking on traffic flow. In case of insufficient parking capacity, for instance, cruise-for-parking flows should be treated differently than the normal running flows. Arnott and Rowse (2007) and Arnott et al (2013) took the impact of cruising into account when analyzing parking pricing policies. Martens et al. (2010) examined spatial effect on parking search. Horni et al. (2013) incorporated parking choice and searching-for-parking in an agent-based model with simplistic traffic modeling. However, these studies assumed static traffic states and did not deal with the dynamics of traffic that can be significantly different in the presence of parking limitations. The treatment of parking flow with realistic physics and how cruising-for-parking can lead to congestion remain challenging research subjects. Recent studies indeed moved toward this direction. Gallo et al. (2011) incorporated parking cost in their traffic assignment model. van Ommeren et al. (2012) carried out an empirical study on the diverse features of cruising time in the Netherlands. Guo and Gao (2012) developed a model to estimate travel time including the delay from on-street parking. Unfortunately, their models either require data that are difficult to collect or are computationally complex. Yousif and Purnawan (1999), Ye and Chen (2011) and Cao et al. (2013) analyzed delay caused by on-street curb parking at intersection level. But none of them can be readily applied on a large-scale network. Geroliminis (2014) proposed a macroscopic parking model, which was built into a Macroscopic Fundamental Diagram (MFD) framework, to capture the influence of parking at aggregated level. This work showed that the MFD-based model (i) is able to reflect the dynamics of parking flows in an urban network, and (ii) requires data that can be practically obtained. What still missing though, is to fit in a multi-modal multi-region system with the consideration of complex system-level dynamics.

This work aims to fill in the above-mentioned research gaps. The objective is to develop an aggregated dynamic model for multimodal mobility with the consideration of parking. A recent study by the authors (Zheng and Geroliminis, 2013) presents a macroscopic approach to model the dynamics of a bi-modal (cars and buses) transport system. This work shows that by utilizing a low-scattered bi-modal Macroscopic Fundamental Diagram (MFD), the dynamics of a bi-modal transport system can be sufficiently represented. Effective traffic management strategies such as allocation of dedicated-bus-lanes and area-based pricing can be developed. It is stimulating to integrate the parking module into the bi-modal modeling framework. With the integrated model, traffic performance under various types of parking policies can be represented and optimal management of parking can be investigated.

Methodology

Consider a bi-modal city divided into regions. Criteria for partitioning a region are: homogeneous distribution of congestion within each region to obtain a low scatter MFD (Ji and Geroliminis, 2012), similar topological characteristics and similar type of mode usage. Any region i can be partitioned into sub-regions j if needed. A sub-region contains a specific type of mode usage for each mode k, e.g. bus-only lanes or mixed traffic lanes, where each sub-region has its MFD or bi-modal MFD. MFD estimates the trip completion rate $O_{ijk}(t)$ of vehicles and $O_{ijk}^{p}(t)$ of passengers of the region given the accumulation of vehicles $N_{ijk}(t)$ and their occupation $p_k(t)$ in the region at time t. The city operates with two types of parking: on-street parking that has limited space available $N_p(t)$ changing over time and garage parking that has infinite capacity. Both parking facilities are priced and the prices are part of the trip cost $C(t)$, which will influence the mode choice of the demand $Q(t)$. A Nested-Logit model is utilized for mode split in the beginning of the trip. For the car-users, they are allowed to choose parking facility by the time they reach their destination based on the updated cost $C(t)$ and a Logit model. Users of on-street parking have to cruise for parking space. The flow dynamics of the traffic system, both vehicular and passenger, adapt the ones developed in Zheng and Geroliminis (2013). The aforementioned system is illustrated in Figure 1.

For the integration of the parking model, the treatment is the following. The bi-modal MFD model with unlimited parking has one family of cars, the cars moving towards their destination. It is now extended to two families: (I) cars searching-for-parking and (II) cars en-route for their destination but not yet searching for parking. The flow dynamics of cars in Family II remains the same. The searching-for-parking process is treated as a Bernoulli trial, where cars in family I continuously look for a parking space until success. The probability of successfully finding a parking sport is in direction proportion to the ratio between the current available space and the total parking space. Cars in family (I) that do not succeed in finding parking places will become cruise-for-parking flow. Cruising-for-parking brings extra delay for both family (I) and (II). This delay is estimated, and it will influence mode choices of the later-departed travelers. More detailed information on the parking model may be referred to Geroliminis (2014).

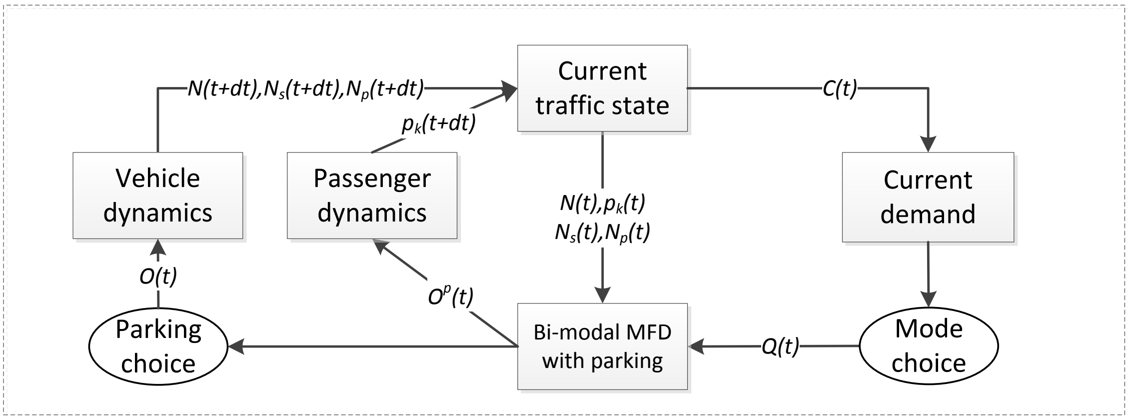

Figure 1 Dynamics of a bi-modal transport system with parking (with the indications of cruise-for-parking flow $N_s(t)$ and parking availability $N_p(t)$)

With the proposed model, the strategy of pricing the parking facilities will be investigated. Denote $p_s(t)$ for the price of on-street parking and $p_g(t)$ for garage parking. The goal for the city is to determine prices such that the total passenger cost (TPC) over time for all modes of transport is minimized.

Model Performance and Parking Pricing Scheme

A case study is carried out in an idealized bi-modal two-region city. Figure 2 displays the resulting system dynamics and traffic performance over a typical morning peak, under a fixed-pricing scheme. Figure 3 displays the same graphs but for a scenario under a time-dependent pricing scheme where the prices of parking are regulated to minimize the TPC. It can be seen that the model is capable of representing the physics of parking overcrowding, the effect of cruise-for-parking on all the users of the system, and the change of mode choices given parking constraints. By comparing the TPCs, it is found that an effective pricing scheme for parking not only reduces the delay for parking and the congestion of cars (as observed in the MFD), but also yields a positive 6% savings of TPC, i.e. the savings in system delays (13%) are larger than the extra amount of toll paid (-7%). On-going work investigates how the efficiency of parking management is affected by the competition between the two types of parking and available information on predicted parking cost. More details for the optimization procedure will be included in an extended journal version of this paper.

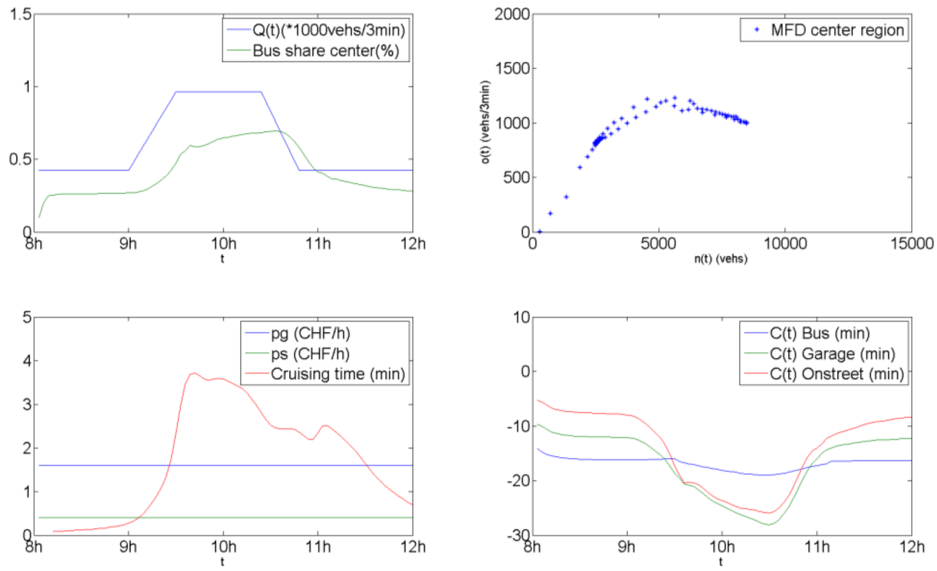

Figure 2 System dynamics and traffic performance under fix parking pricing scheme: (top left) mode share of bus and total travel demand over time, (top right) the MFD of the center region with congestion observed, (down left) the prices of p_s and p_g, and cruising-for-parking time, and (down right) the total cost of each mode C_k over time.

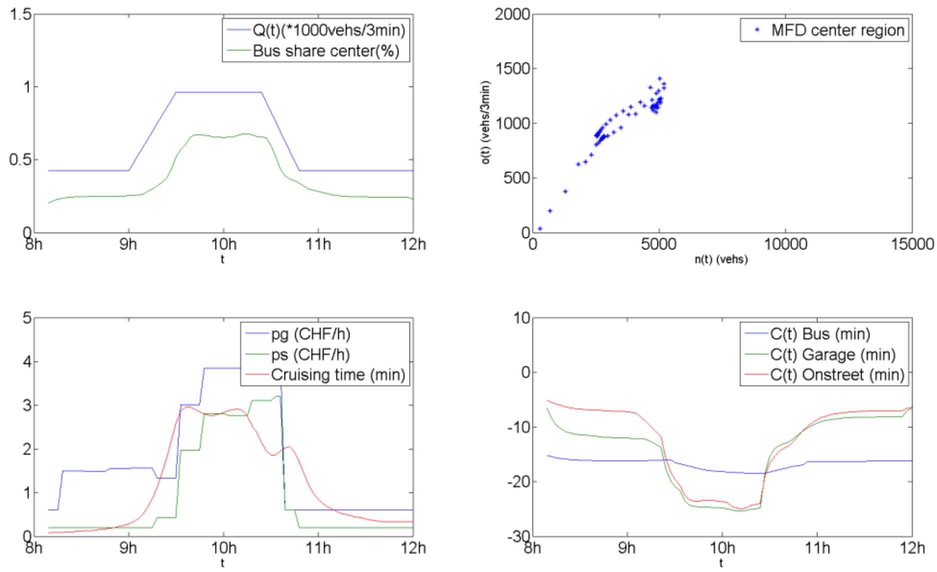

Figure 3 system dynamics and traffic performance under optimal time-dependent parking pricing scheme: same figure description as in Figure 2.

Conclusion

In this study, we proposed a macroscopic model for bi-modal traffic with the integration of parking. The proposed model incorporated the impact of limited-parking on the resultant flow dynamics and mode choice. Case study result showed that the model sufficiently reproduces traffic performance under various types of parking policies. A time-dependent parking pricing scheme was developed and demonstrated effective in improving total travel cost.

With the proposed model, parking policies can be evaluated and optimized. Furthermore, the dynamics of the competitive market between on-street and garage parking can be modeled and investigated, e.g. how local authorities (who operate on-street parking) and real-estate companies (who operate garages) respond to one another's pricing scheme. We will report these results in the extended version of the current paper.

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