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Urban parking space reservation through bottom-up information provision: An agent-based analysis

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ABSTRACT

The aim of this paper is to study the impacts of a reservation system for on-street parking. Such a system provides drivers looking for on-street parking with information on available parking spaces, thereby possibly reducing the need to cruise for parking and the accompanying negative externalities. The performance of the proposed system is studied using a highly detailed spatial agent-based simulation. The results of the simulations show that users of a reservation system benefit in terms of reduced search time and reduced walking distance under virtually all simulated circumstances. However, societal benefits are not as clear-cut. The benefit in search time for the users of the system comes at a cost to the regular drivers, which see a nearly identical increase in search time. In contrast, the positive impact on walking distance hardly influences walking distance for regular drivers. Hence, we conclude that the introduction of a reservation system for on-street parking results in a more efficient distribution of available parking spaces among drivers searching for parking.

1. Introduction

Cruising for parking has become a problem in downtown areas in major cities around the world, as was shown for several US cities (Shoup, 2005) and several European cities (Gantelet & Le Fauconnier, 2006). To overcome the unwanted externalities accompanied with cruising for parking, e.g. pollution and waste of resources (time and fuel), provision of information to drivers is regarded as a promising strategy. Facilitated by recent advances in wireless and mobile communication technologies, mainly Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication, real-time information provision to drivers has become a practically feasible possibility. These wireless communication techniques allow for highly detailed information provision, temporally as well as spatially. The potential benefits of V2V and V2I communication to overcome congestion and pollution caused by cars looking for parking has recently been underscored by the US Department of Transportation in its report *Beyond Traffic 2045* (US Department of Transportation, 2015).

Yet, contrary to the assumed advantages of information provision to drivers, previous research has shown that information on on-street parking spaces only benefits drivers under specific circumstances and only if (almost) complete information on vacant parking spaces is available through in-street parking sensors (Tasseron, Martens, & van der Heijden, 2015a). Furthermore, the most important improvements for informed drivers are not due to a reduction in search time, but are the result of reductions in the distance between parking space and final destination and the related time gains of the reduced walking distance. Moreover, drivers without information are confronted with an increase in their cruising time. Thus, information provision can be effective on the individual level, but the overall societal benefits in terms of total time savings, reductions in fuel consumption, and reductions in pollution remain unclear.

This paper continues the study of information provision in the field of parking by analyzing the impact of parking reservation, i.e. the possibility for car drivers to reserve an on-street parking space before reaching their destination. The main aim of this paper is to systematically study the effect of parking reservation on cruising for parking. Intuitively, it may be expected that a reservation system, if adequately enforced, should result in a decrease in the time needed to find a suitable parking space and thus in a decrease in pollution and waste of resources. Furthermore, parking space reservation can possibly decrease the distance between the parking location of the vehicle and the final destination of the driver, which is a clear benefit for individual users.

The paper is organized as follows. Following this introduction, we describe bottom-up information gathering and dissemination and reservation in the domain of parking (Section 2). Section 3 describes the details of the simulation: the agent-based modeling tool that has been used to run the simulations, the procedures of bottom-up information provision and parking reservation, and the simulation setup. In Section 4, the results of the simulation runs are presented. We end with conclusions and paths for future research (Section 5).

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2. Literature review

The provision of information on occupancy rates at off-street parking facilities is common practice in many cities in the world and its impacts have been investigated in a number of studies (e.g. (Ni, Sun, & Peng, 2015; Teng, Qi, & Martinelli, 2008; Van der Waerden, Timmermans, & Borgers, 2002)). The recent advances in communication technologies allow for more fine-grained gathering and dissemination of information, up to the level of single parking spaces, enabling information provision on on-street parking spaces. Various technologies are capable of providing information on these spaces: top-down and bottom-up. Traditionally, parking information is gathered top-down (i.e. centralized) by parking organizations. These organizations gather the relevant information, e.g. actual occupancy rate, and disseminate this in a top-down style. Drivers are informed by dynamic message signs on the occupancy rate of the off-street parking location. The bottom-up approach is the second way of gathering and providing information on parking places. In this case, information collection and provision is not the responsibility of a centralized organization, but information is gathered and disseminated by local entities (e.g. cars). One possibility of implementing a bottom-up approach is the application of vehicle-to-vehicle communication using so-called Vehicular Ad-Hoc Networks (VANETs) (Caliskan, Graupner, & Mauve, 2006; Prinz, Eigner, & Woerndl, 2009; Szczurek, Xu, Wolfson, Lin, & Rishe, 2010; Tasseron & Schut, 2009; Vaghela & Shah, 2011; Verroios, Efstathiou, & Delis, 2011; Wischhof, Ebner, & Rohling, 2005). VANETs are attractive for providing information on the availability of individual parking spaces as they enable a bottom-up diffusion of local data.

This paper builds on previous research on this subject in which we explored the use of VANETs in a parking context (Tasseron et al., 2015a; Tasseron, Martens, & van der Heijden, 2015b). In these papers we have compared the impacts of a Vehicle-to-Vehicle (V2V) communication strategy, in which 'smart' vehicles are able to exchange messages about parking availability, with a Sensor-to-Vehicle (S2V) communication strategy in which on-street parking sensors are capable of disseminating their vacancy status to smart vehicles. These studies showed that a V2V strategy does not result in search time improvements or reductions in walking distance, due to the inability to inform smart cars on all available parking spaces close to their final destination. The performance of a S2V strategy is somewhat better, but also in this case search time is only improved under specific circumstances (notably, a high occupancy rate). At lower occupancy rates, drivers are likely to park their car before reaching the final destination, which results in no search time. As a result, search time is on average very low, leaving not much room for improvement. Furthermore, another reason for these perhaps somewhat unexpected results lies in the fact that drivers relying on information on vacant parking spaces may find the suggested parking space occupied by another driver, forcing them to continue driving to another parking space.

Two strategies may improve the impacts of bottom-up information provision for drivers as well as society: first, providing aggregate information; second, a reservation system. For the first solution, smart cars receive information at a more aggregate level than that of a single on-street parking space (Verroios et al., 2011; Vlahogianni, Kepaptsoglou, Tsetsos, & Karlaftis, 2015). By providing information to drivers at a more aggregate level, like street segments or a city block, it may be possible to provide better estimations to drivers regarding the chance of finding a parking space close to the destination. Although this approach may improve performance, it clearly cannot provide complete certainty to drivers about finding a vacant parking space when arriving at the designated area. The second solution, a reservation system, can overcome the issue that multiple cars are heading for the same parking space and can thus reduce or even eliminate competition over parking spaces among informed drivers. Two caveats of this reservation approach are worth mentioning here. First, the reservation system requires enforcement to avoid car drivers (with or without information) from illegally occupying a reserved parking space. Second, a reservation system will require a 'booking' for a time slot that is at least slightly longer than the intended parking duration of a driver. Such a system thus de facto reduces the effective parking capacity, which may in turn increase search time, even if only marginally, for all cars looking for a parking space (Levy, Martens, & Benenson, 2013). In what follows, we will focus on the possible benefits of the second solution, a reservation system. We will explicitly assess the impacts of such a system on parking capacity, while assuming perfect enforcement of the reservation system.

Reservation of parking spaces has been studied under various conditions. A number of authors have analyzed reservation schemes for reserving a space in parking lots (Chou, Lin, & Li, 2008; Geng & Cassandras, 2012; Shin & Jun, 2014; Srikanth et al., 2009; Teodorović & Lučić, 2006; Tsai & Chu, 2012; Wang & He, 2011). These studies are less relevant to understand on-street parking, given the large differences in terms of the spatial environment in which drivers are searching for a parking space. Reservation systems for on-street parking have been studied using mathematical and game theoretic approaches (Kaspi, Raviv, & Tzur, 2014; Liu, Yang, & Yin, 2014; Zhao, Triantis, Teodorović, & Edara, 2010). Both approaches inevitably ignore the spatial dimension of the parking phenomenon. As shown in earlier research, this spatial component is crucial and cannot be neglected (Levy et al., 2013).

More recently, parking space reservation schemes and comparable initiatives have been studied using simulations. Three studies are especially relevant for our paper (Delot, Ilarri, Lecomte, & Cenerario, 2013; Kokolaki, Karaliopoulos, & Stavrakakis, 2012, 2013; Zhao, Triantis, & Edara, 2010). Kokolaki et al. (2012, 2013) compared a centralized reservation system with a V2V-based information sharing approach without reservation capabilities. The simulation setting is that of 4×4 grid, encompassing a total of 25 parking spaces. In this simulation, cars with V2V-capabilites are able to monitor on-street parking vacancies and disseminate this information opportunistically to other drivers. The results show that the V2V-approach can outperform a centralized approach, but whether this holds depends on the local circumstances, notably the spatial distribution of demand and the changes in demand over time. Delot et al. (2013) propose a distributed parking space reservation scheme, in which vehicles vacating a parking space selectively distribute this information to their proximity. Competition for parking is controlled by assigning parking spaces to drivers based on the so-called encounter probability, which denotes the relevance of the information for the particular driver. Drivers respond to all messages they receive on available parking spaces. Subsequently the coordinator of each vacant parking space, which is preferably the car that just left the corresponding parking space, chooses the 'best' car among the respondents and sends out a message of approval. To finalize the agreement, the driver also needs to confirm the reservation of the parking space. The method does not give complete certainty to the car driver, i.e., it is still possible to arrive at an allocated parking space and find it occupied. Experiments are performed for off-street and on-street parking separately. The results show that the reservation system yields positive benefits in the off-street scenario when the number of cars searching for parking exceeds the number of available parking spaces. For the on-street scenario the experiments are only varied by the number of cars in excess of the number of parking spaces. Results show that the reservation scheme yields an improvement in search time between 6 and 13%. The impacts on walking distance were not studied. Zhao et al. (Zhao, Triantis, & Edara, 2010) present the design and impact of a new travel demand management approach, namely the Downtown Space Reservation System (DSRS), using a microscopic traffic simulation. The system makes use of a central agency that handles all reservation requests. Only those cars that get permission can enter the downtown area during the requested time period. It is assumed that rejected trips are eventually carried out using other transport modes, e.g. walking, biking or public transit. In order to take into account the stochastic variations in