The potential impact of in-car information on urban parking

The case of spatial heterogeneity and heterogeneous driver behavior

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ABSTRACT

More and more municipalities and parking companies are willing to provide occupancy information to drivers. Information provision to drivers can potentially be beneficial in decreasing cruising. The aim of this paper is to study the impact of bottom-up information provision of on-street parking places under heterogeneity on performance for the different car drivers. Using an agent-based simulation, performance is compared between a bottom-up vehicle-to-vehicle communication strategy and a strategy that combines parking sensors and vehicle-to-vehicle communication. In the latter approach on-street parking places are all equipped with sensors capable of disseminating their status.
The results point out that informed cars outperform regular cars in an environment with heterogeneous demand when using sensor technology. However, introducing heterogeneous driver behavior decreases the impact of information on overall performance. The main conclusion is that societal benefits are not clear from the outset.

Keywords: Intelligent Transportation System, VANET, Parking, Agent-based modeling, Heterogeneity

1. INTRODUCTION

Studies have shown that cruising for parking is a major problem in large cities. The amount of cars that are cruising can exceed up to one third of all traffic in large crowded city centers (Shoup, 2005). Provision of information to drivers in search for parking can reduce cruising for parking and thus reduce air pollution, traffic congestion and other negative externalities related to car traffic (Van Ommeren *et al.*, 2012). Hence, cities around the world have installed technologies to provide drivers with information about off-street parking facilities. In contrast, information on on-street parking places was non-existing until recently. This is however changing rapidly due to a number of start-up companies that have entered the market to provide such information (e.g. SF Park[1]). By using the widespread penetration of smart phones and in-car navigation devices it is now possible to provide accurate information at the level of individual parking places.

There are various technologies to provide information on on-street parking places. One possibility is the use of vehicle-to-vehicle communication using so-called Vehicular Ad-Hoc Networks (VANETs). VANETs provide a way to share information among nodes in a network using bottom-up dissemination. Given their properties, VANETS are very suited for disseminating on-street parking place information. While a number of studies have analyzed the possible contribution of vehicle-to-vehicle (V2V) communication to the management of road traffic (e.g. (Wischhof *et al.*, 2005; ElBatt *et al.*, 2006; Tasseron & Schut, 2009)), and a few studies have explored the technical feasibility in a parking context (Caliskan *et al.*, 2006; Delot *et al.*, 2009; Szczurek *et al.*, 2010b, 2010a; Vaghela & Shah, 2011), till recently no research exist that has explored whether the use of V2V communication could actually lead to an optimization of parking dynamics for on-street parking. The paper builds on an earlier study (Tasseron *et al.*, 2014) in which the impacts of information provision on on-street parking was studied for a highly stylized situation, in terms of driver behavior as well as the spatial setting within which drivers search for parking. The results of this study showed that parking information had only limited benefits, both for the drivers receiving information and for other drivers. Information was mostly beneficial for drivers in terms of walking distance (between parking place and final destination) at situations with very high occupancy rates. Furthermore, the overall result was only improved when using sensor technology at on-street parking places. The question is whether these counter-intuitive results also hold under less stylized conditions. Therefore, in this study we analyze the impacts of information provision under more realistic conditions. More specifically, we explore how heterogeneity in terms of driver behavior, and in terms of spatial distribution of parking demand and supply, influence the effectiveness of information provision on on-street parking places.

The paper is organized as follows. Following this introduction, we describe the way in which car drivers are informed about on-street parking place availability using two distinct communication strategies (Section 2). In Section 3, we describe our agent-based modeling tool called PARKAGENT, as well as the simulation set up. In Section 4, the results of the simulations are presented, followed by the conclusions of the paper and paths for future research (Section 5).

2. BOTTOM-UP INFORMATION PROVISION

2.1 Information and Parking

Various technologies allow for provision of information on on-street parking places. One possibility is the use of vehicle-to-vehicle communication using so-called Vehicular Ad-Hoc Networks (VANETs). Because of their attributes, VANETS are suitable for application in a parking context. The network is formed by mobile agents (in our case, vehicles) that are capable of sending and receiving data via wireless technologies (i.e. dedicated short-range communication, DSRC). All agents in the network

[1] http://sfpark.org/

equipped with this technology contribute to the network by gathering information and distributing this information to nearby agents. Because of the limited range of this technology, as well as by the short-term nature of the information, the networks are referred to as 'ad-hoc'.

The possible contribution of vehicle-to-vehicle (V2V) communication to the management of road traffic has been analyzed (e.g. Wischhof *et al.*, 2005; Tasseron & Schut, 2009). Fewer studies have studied the viability of using V2V in a parking context (e.g. Szczurek *et al.*, 2010b; Vaghela & Shah, 2011). No research exists that systematically explored the use of V2Vcommunication and the potential effect on parking dynamics in a spatial context. This paper builds on previous research on this subject in which we started to fill this gap (Tasseron *et al.*, 2013), by studying the effect of information in a homogeneous environment. In the preceding paper a bottom-up strategy where only vehicles were able to communicate (V2V) was compared to a strategy that combines on-street parking sensors capable of disseminating their vacancy status together with communicating vehicles. This latter strategy is referred to as S2V (sensor-to-vehicle) communication. In the current paper we extend this research strand by incorporating heterogeneity, both in driver behavior as well as in the spatial distribution of demand for parking.

2.2 Implementation of Parking Strategies

In this subsection, we describe the way information is transmitted between vehicles and between parking sensors and vehicles. Important to note is that in the simulations the distinction is made between cars that are able to communicate (V2V) and cars that cannot communicate. V2V-cars are able to send and receive messages within a fixed transmission range of 200 meter (see Demmel *et al.*, 2012). Messages are broadcasted by cars and sensors to all entities in the vicinity. In the V2V communication strategy, messages are created and disseminated in two situations. First, when a V2V-car leaves a parking place it will send out a message stating the vacancy of the spot for other drivers. Second, a V2V-car disseminates a message when it occupies an empty parking place. All V2V-cars within a 200 meter radius will receive these two kinds of messages and subsequently pass them on to other V2V-cars. It is important to note that vacant parking places at the start of the simulation and departures of cars that are not able to communicate will not lead to the dissemination of a message.

In the second communication strategy (S2V), on-street parking places are equipped with sensors that are capable of sensing and communicating the occupation status (vacant or not vacant) to nearby vehicles. In the simulations, the sensors will only send out messages on a regular basis when their status is vacant, while only one message is send out if the parking place is occupied. The sensors have the same transmission range as the V2V-cars in our simulation. The important difference between both strategies lies in the fact that in the V2V communication strategy the vacancy message is transmitted only once, while in the S2V communication strategy the sensors keeps broadcasting the vacancy at regular intervals. Furthermore, initially vacant parking places at the start of the simulation are now also able to create messages about the vacancy.

A message consists of a number of attributes: (1) the timestamp at which the parking place became vacant; and (2) the location of the parking place, stored as a coordinate. Each V2V-car that receives a message on an available parking place will process the message. For this purpose, each V2V-car is equipped with three databases to store messages: a private database, a public database and a database with recently occupied parking places. If the car is looking for a parking place it will rank the message for its usefulness for own use, depending first of all on the distance between the parking place and the final destination of the car.

If it is useful, the message will be stored in the private database and ranked according to the relative value (v) of the parking place. The value is based on the distance between the final destination and the parking place and the distance between the current position of the car and the parking place. Only the messages with the best values are stored in a database according to the process depicted in Figure 1.

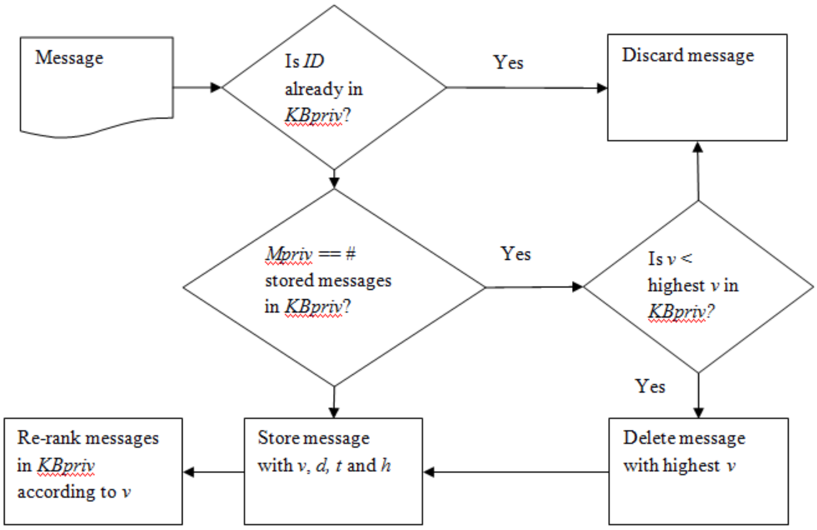

Figure 1. Processing of messages for storage in public database

In addition to the private database, each V2V-car also maintains messages in a public database for general purpose. This public database holds a limited number of messages which are ranked according to age. Similar to the process for the public database, storage of messages on occupied places are also ranked by age. When receiving such a message it is not only stored in said database, the system also deletes entries in the private and public databases that match the parking place ID and have a timestamp that is later in time than the availability timestamp (see Figure 2).

On a regular interval, all V2V-cars will broadcast the messages in their public database to cars within the transmission range. Via this method messages on available parking places can traverse the grid in a short time period and thus provide many drivers with information on parking availability. It is important to note that the above described method does not include a reservation system. Thus, it is possible to arrive at a suggested parking place and find it already occupied by another car. Furthermore, note that the private and public database can overlap, i.e. vehicles may broadcast messages to other vehicles that are also stored in the private database and, thus, to potential ‘competitors’ for the same parking place. The message protocol ensures the best parking spot is selected as the first choice for the V2V-driver which complies to the parking preferences. It is then up to the driver whether he or she wants to park at a random encountered vacant spot en route or drive on to the suggested parking place. If the car receives a message about the occupation of the parking place the driver is currently driving to, the list of available parking places is re-ranked and the destination to drive to is altered accordingly. A more elaborate description of the process of receiving and disseminating messages in V2V and S2V scenarios can be found in Tasseron et al. (2013, 2014).

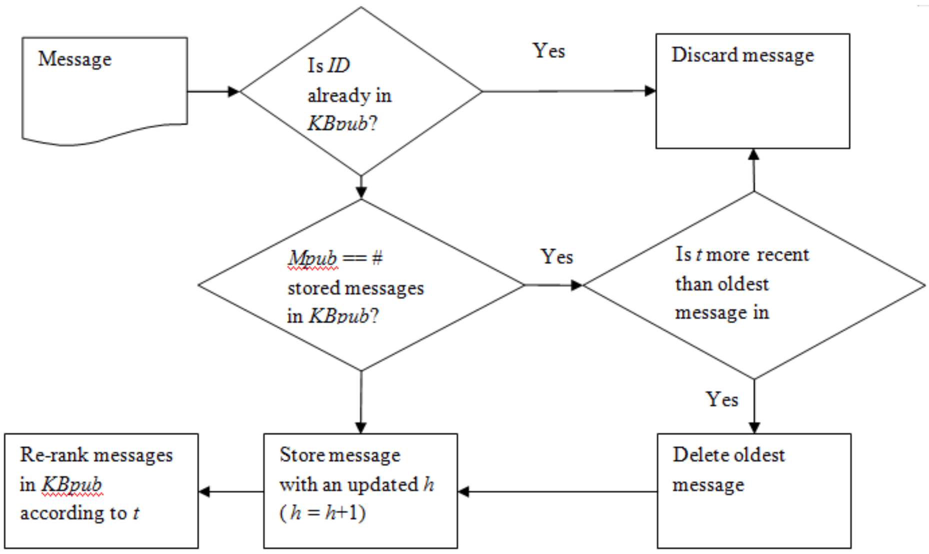

Figure 2. Processing of messages for storage in private database

3. SIMULATION DESCRIPTION

To study the impacts of bottom-up information provision on parking dynamics under heterogeneity we use PARKAGENT, an advanced agent-based parking simulation model. An extended description of the PARKAGENT model can be found in Benenson et al. (2008). By using a simulation approach we compare the impact of information provision in two different heterogeneous settings: spatial heterogeneity in demand and heterogeneity among agent preferences. The speed of vehicles searching for parking is set to 12 km/h (Benenson *et al.*, 2008), while the walking speed has been fixed at 3 km/h. This setting differs slightly from the earlier study (Tasseron *et al.*, 2014), which means that results between the two cannot be compared on an one-to-one basis. The walking speed is changed to account for the difference between the actual distance versus the air distance and to account for delays due to crossing intersections.

An agent-based model is inherently subject to stochastic variations. Running the different simulation scenarios multiple times obviated these variations. The results are averages based on five runs per unique combination for occupancy rate and penetration rate, for both the V2V and S2V communication strategy, leading to a total of 525 runs.

3.1 Spatial Heterogeneity

The simulation was based on the simulation environment representing a Manhattan grid used by Levy et al. (2012). In this environment, a city consists of 11 x 11 city blocks, with 12 destinations and 96 on-street parking places on the inner ring of each city block. On-street parking places are evenly spaced along all the streets in the network. There are no off-street parking facilities present. Destinations (buildings) are also distributed evenly over space. The study zone of our simulation is defined by the 5 x 5 city block area in the middle of the simulation environment. This zone is defined to filter out border effects, as there is less competition for parking spaces at the outer edges of the environment. The difference with Tasseron et al. (2014) is the addition of heterogeneity. For the case of spatial heterogeneity we altered the city-grid to have increased demand in the most central city block. The twelve destinations in this central block have a ten times increased demand in comparison to all other destinations.

3.2 Heterogeneous Driver Behavior

Studies on parking often use the simplifying assumption that all drivers or agents are homogeneous and assume spatial homogeneity. Obviously, this does not hold for the real world. Drivers may differ, for instance, in terms of their value of time (Shoup, 2005a) or their willingness to walk to the destination. We focus on the latter heterogeneity.

We divide the population of agents into three groups of equal size: preference for small walking distance (20 meter); preference for average walking distance (120 meter); and preference for long walking distance (220 meter). The average value of 120 meter has been proven to be a realistic population average (Benenson *et al.*, 2008). The overall driving and cruising behavior remains the same. Agents enter the simulation environment at a position that is located at 400 meter from their final destination. The shortest route to the destination, according to the Dijkstra algorithm, is chosen and the agent starts to move towards it. To be able to compare results we keep the distance, at which agents observe their environment and assess the local parking situation, the same. This means that agents all need a stretch of 180 meter to assess the local parking situation.

The decision on when and where to park has been changed in our PARKAGENT model in comparison to previous papers. The maximum allowed distance at which agents were willing to park was only used by the agents *after* passing their destination without finding a vacant parking spot and start to cruise for parking. While cruising for parking, around the final destination, the maximum distance at which agents are willing to park is increased with every increase in time. For the current study we also use this maximum preferred distance when selecting a parking space *before* reaching the final destination. Previous this decision was purely based on a risk consideration on the chance of finding an empty spot while driving closer to the final destination.

3.3 Other Independent Variables

Besides the change between environments and agent preferences, we use two additional independent variables. The simulation runs differ in terms of the initial occupancy rate and the penetration rate of cars that are able to communicate. The initial occupancy rate is the percentage of parking places that are occupied at the start of the simulation. The occupancy level remains roughly the same, as the number of cars entering the system is equal to the number of cars leaving the simulation environment during the simulation period. By varying the occupancy rate systematically we can assess the influence of occupancy rate on the impacts of bottom-up information provision on parking under heterogeneity. During the simulations only situations with an initial occupancy rate of 90% and above are considered, as these are the conditions at which the time needed to find a vacant parking spot is (rapidly) increasing (Levy *et al.*, 2012) and appears to have an effect on performance using bottom-up information provision (Tasseron *et al.*, 2013).

Besides the occupancy level and penetration rate, the turnover level also has an effect on parking dynamics. The turnover level indicates the amount of times a parking place is occupied by a different vehicle in a given time interval (Shoup, 1999). In this study turnover is not systematically changed during our simulations. Arriving cars will stay parked for the entire duration of the simulation, while the departing vehicles will be selected randomly, from the cars parked at the beginning of the simulation.

3.4 Dependent Variables

Parking performance is measured in terms of the dependent variables parking distance, search time, and overall time spent. Parking distance is defined as the air distance (‘as the crow flies’) between the final destination and the parking location. The same definition of search time (or cruising time) is used as was coined in our prior paper (Tasseron *et al.*, 2013); where search time is defined as the excess time needed to find a parking place in comparison to the most optimal travel time to the most optimal parking location. All drivers that park within that optimal time frame on the optimal parking place or on a parking place en-route to the optimal parking place, are considered to be drivers with zero search time. The third dependent variable, overall time spent, consists of the time needed to walk to and from the destination and search time (equation 1).

$$\text{Overall time} = 2 \text{ x } d_w / V_{walk} + St \qquad (1)$$

Where:
d_w = air distance between parking place and final destination
V_{walk} = walking speed
St = search time

4. RESULTS

This section describes the results of the simulation runs that have been carried out to analyze the performance of V2V-cars in different settings regarding heterogeneity. The first subsection covers the results on spatial heterogeneity. The second subsection covers the results for heterogeneous driver behavior in a uniform environment. Finally, the third subsection shows the results when combining these two kinds of heterogeneity into one simulation setting. Every subsection discusses the overall results for both the V2V communication strategy as well as the S2V communication strategy. This overall result, i.e. time spent, is composed of the elements walking distance and search time. Overall time is for every scenario compared to the base time realized per scenario without using information supply. For a more detailed look into the results of the discrete elements, which is left out due to space constraints, please contact the authors.

4.1 Spatial Heterogeneity

The overall result (Figure 1), the average difference in time spent of all vehicles (regular and V2V) together in comparison to the base situation (only regular cars), shows a similar picture as in our preceding study with homogeneous distribution of demand. The V2V strategy only works under specific circumstances. A time benefit is realized at 100% occupancy rate, and at 95% occupancy rate at high penetration rates. The S2V strategy is beneficial under all conditions, thus regardless of penetration rate or occupancy rate. The system benefits are increasing with every increase in penetration rate, this is due to the increasing number of vehicles that are able to communicate and contribute to the overall result. The time benefit is mostly realized by a shorter walking distance (which is reduced by over 20% using a S2V strategy) and only marginally by shorter search times.

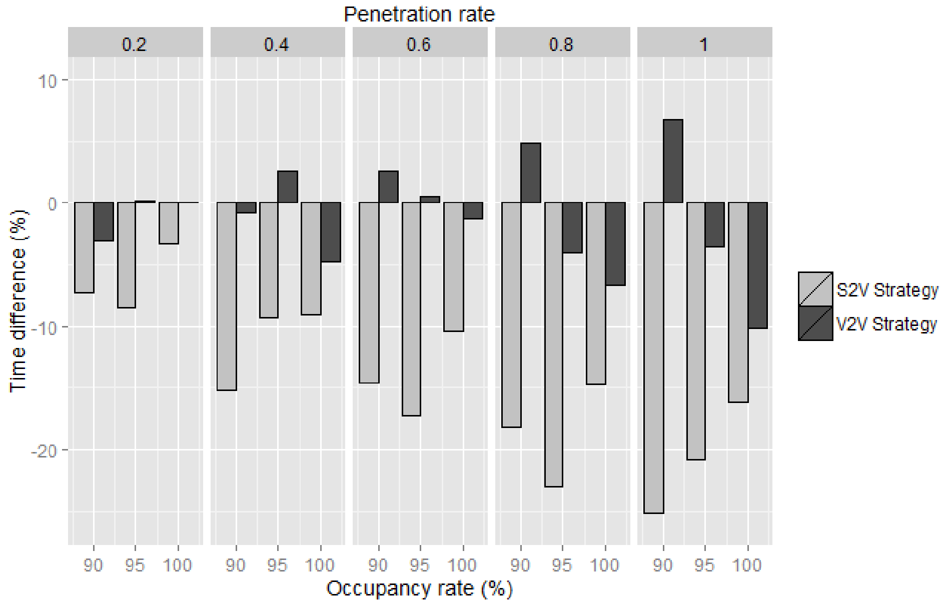

Figure 1. Overall time difference for V2V strategy and S2V strategy, for different occupancy rates and penetration rates, for spatial heterogeneity.

4.2 Heterogeneous Driver Behavior

The overall results (Figure 2) for a scenario with heterogeneous agent behavior is much different than in subsection A. The results regarding the V2V strategy only yield positive results under some conditions, and even then the difference is rather small (mostly below 5%). In contrast, the S2V strategy results in a time benefit for the overall system in all cases except one (0.2 penetration rate and 90% occupancy rate). However, the positive result is far less impressive as it was during the simulations with respect to spatial heterogeneity. This is due to the downturn in performance regarding search time and walking distance. Search time barely changes using either a V2V strategy or a S2V strategy. Only in a situation with 100% occupancy rate and a S2V strategy, the V2V-cars see a benefit in search time. Furthermore, performance regarding walking distance is less obvious. One important thing to note (not shown) is that the overall walking distance for both the regular cars as well as the V2V-cars is much lower than in simulations with a homogeneous set of agents. The average walking distance is reduced by approximately 30% to 40%.

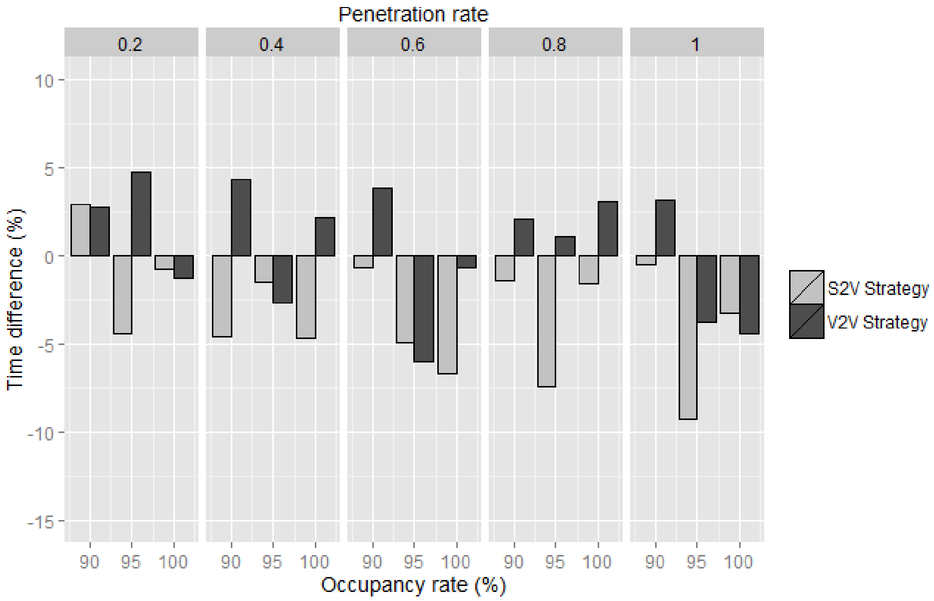

Figure 2. Overall time difference for V2V strategy and S2V strategy, for different occupancy rates and penetration rates, for heterogeneous driver behavior.

4.3 Spatial Heterogeneity and Heterogeneous Driver Behavior

The overall difference in total time spent when combining both types of heterogeneity shows a somewhat irregular pattern (see Figure 3). However, in contrast to the irregular pattern of overall results, the separate results on search time and walking distance show a stable pattern. Search time and walking distance are hardly influence using a V2V strategy. The V2V strategy shows positive results for low occupancy rates at lower penetration rates. When increasing the penetration rate the overall result is positive for both the 90% occupancy rate and the 95% occupancy rate. Important to note is that the differences are very small, in most cases between -3% and 3%.

Figure 3. Overall time difference for V2V strategy and S2V strategy, for different occupancy rates and penetration rates, with heterogeneous driver behavior and spatial heterogeneity.

The overall result for the S2V strategy shows that performance is less impressive as with spatial heterogeneity alone. Surprisingly, at a penetration rate of 0.2 the S2V strategy does not yield a positive result with respect to time spent. At penetration rates other than 0.2, the S2V strategy sees a positive impact on overall time spent for occupancy rates of 90% and 95%. At 100% occupancy rate the results are close to zero. When looking at the discrete elements, the irregular nature of the results becomes more clear. Performance regarding search time is improved for all penetration rates at 90% occupancy rate. Search time is only improved for penetration rates 0.4 and 0.6 at occupancy rates of 95% and 100%. Furthermore, performance regarding walking distance is better than in the base situation, regardless of occupancy rate or penetration rate. However, the performance increase is not as substantial as in the runs with only spatial heterogeneity.

5. CONCLUSIONS

In this paper the effect of bottom-up information provision on urban parking dynamics under heterogeneous settings was studied using agent-based computer simulations. Theoretically provision of information to drivers could decrease the effect of cruising for parking. Similar to the results in our previous studies (Tasseron *et al.*, 2014, 2013), the results of our current simulation study show that information has only a limited effect on search time. Contrary to our previous study, overall results show that a sensor strategy does not always perform better than situations where no information is used. Furthermore, results with respect to the S2V strategy are less impressive in comparison to the previous paper. In our current study time difference benefit is at most around 10% in comparison to above 20% in our previous paper. However, a 5-10% decrease in average overall time spent for all drivers is still a positive result.

Another important difference with our previous study is the positive influence of heterogeneous agent preferences on walking distance. The average walking distance decreases when introducing diversity between agents. This provides valuable insight, as it is profitable in system terms to encourage more variety between agent preferences regarding walking distance. As such introducing price diversity or encouraging distance diversity improves the overall performance. On the other hand, the effect of information on overall system performance is decreased when introducing heterogeneous drivers.

6. DISCUSSION

The results of this study should of course be placed in context. They concern a rather straightforward situation, in which the street network resembles a Manhattan grid. It is at the outset not ruled out that a more complex road network, similar to the ones that can be found in most European cities, have an impact on walking distance and search time. Moreover, the distribution of preferred walking distance over the agents is also straightforward. It is highly likely that preference regarding walking distance follows a different distribution in real life. Another side note is that this system of bottom-up information provision offers no possibility to reserve a parking place. Thus leaving the possibility open that a parking place is already occupied by another driver upon arrival at the designated location. In future research we want to overcome this issue by providing the driver with aggregate information. By aggregating information on occupancy on a higher level than single on-street parking places (e.g. street-segment level), a more accurate estimation can be made on whether a vacant parking place is available upon arrival. Furthermore, this principle it would allow for a reduction in costs when applying a sensor strategy, as not all parking places need to have a sensor to define the occupancy on an aggregate level.

In spite of these remarks, this research shows that at the outset the societal benefits of implementing a sensor-system necessarily offset the costs for such a system. Of course the benefit of such a system is dependent on the specific circumstances. As mentioned before, a more realistic environment might lead to a reduction in search time, which in turn could reduce air pollution and noise pollution and possibly increase traffic safety and congestion. Beside the impacts on walking distance and search time, drivers could potentially value the reduction in the inherent uncertainty of finding an on-street parking place.

All considered, bottom-up information provision may deliver positive societal benefits. Which is especially valid in situations with heterogeneous demand and limited diversity in agent preferences. When diversity in price is high, the positive effect of information is limited. However, the extent to which this is true requires additional analyses, including experiments with a more complex street network and ditto distribution of demand, and the dissemination of information at a higher aggregation level. These studies could potentially increase insight on the dynamics that arise when implementing parking sensor technology in the real-world situations and as such contribute to decision making whether or not to invest in a sensor system.

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