Improving Utilization and Customer Satisfaction of Parking Space with M2M Communications

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***Abstract*—The shortage of parking spaces creates a challenging problem for both drivers and parking space operators. In this research, we implement a parking simulation system to study operators' problems. The operator can use our method to evaluate different parking policies and find out the best policy. Furthermore, the operator can estimate the impact of smart parking system (SPS) on parking space management. An SPS not only tracks the number and locations of available parking spaces in a parking lot but also utilizes Machine-to-Machine communications (M2M) to provide drivers useful information. Based on the results, we are able to identify the best policy among all alternatives which achieves the highest satisfaction rate under the constraint of maintaining certain occupancy rate. Furthermore, our results show that the SPS can improve the satisfaction rate regardless scenarios under different assumptions.**

***Keywords*—M2M communications, smart parking, parking policy, satisfaction rate, occupancy rate.**

I. Introduction

The demand for parking space has increased dramatically due to the increase of vehicles in the world. At the same time, it is hard to create new parking spaces because of the continual growth of population density. The significant shortage of parking space in cities creates a challenging problem for both drivers and parking space operators.

For drivers, one problem is to search for available parking space quickly and locate the space that is the closest to the destination. Another problem is to find their car without pain in a big parking garage. For operators, the problem is how to manage parking space to satisfy needs of different customers while maintaining a high utilization rate.

The adoption of Smart Parking System (SPS) is an effort to minimize hassle and inconvenience to drivers and operators. Most research in this area only focuses on solving problems for drivers. In this research, we focus on the problem of parking space operators. We propose to use M2M technologies to improve both customer satisfaction and parking space occupancy rate. Our proposed system allows the operator to run simulations in order to choose the best policy for the parking garage and estimate the improvement of an SPS before any investment. The parking policy means how to divide parking space and drivers into different groups.

To verify our method we construct two simulation models: one without the SPS improvement and one with the SPS improvement. In the case of the SPS models, a driver subscribes to the status of parking space. When the status changes, the driver will get notifications. Based on such information, the driver can decide whether to drive to the parking garage or not, which will improve the customer satisfaction rate of the garage.

II. Background

A parking space tracking system is developed to monitor changes of parking space status over time and provide the information to drivers through parking display. This type of systems helps drivers to find a vacant parking space by providing information about the precise locations of empty parking spaces. Otherwise, drivers would need to drive around and look for an available parking space. Initially, researchers focus on the parking garages. They want to provide the number of empty parking spaces so that drivers will not waste their time driving in a fully occupied parking garage. The simplest method is to monitor traffic flow at the entrance and exit. Later, parking space occupation detection is introduced not only to provide the number of empty parking spaces but to provide the precise locations. It focuses on monitoring each parking space status and can be used for roadside parking space as well.

Recently, Due to the emergence of Machine-to-Machine communications (M2M), SPS is introduced. An SPS includes (1) a parking space tracking system which provides the number of available parking spaces in an area and the location of each empty parking space, (2) an applications which gives drivers useful information about the status of a parking area and helps find the vacant parking space for the drivers through their personal communication devices and (3) M2M between devices and applications.

III. Related work

In Kianpisheh et al.'s [1], each parking space is installed with ultrasonic sensors to detect parking space status. Fabian [2] presents an unsupervised vision-based system for parking lot occupancy detection. After retrieving raw images, the detection system will first remove shadows on raw images and then start the detection process. In Wu et al.'s [3], they use multi-class Support Vector Machine (SVM) recognition and Markov Random Field (MRF) based correction to further improve vision-based parking space occupation detection.

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A Vehicle Ad Hoc Network (VANET) allows cars equipped with On Board Unit (OBU) communication devices exchange information with each other and Roadside Units (RSUs). Lu, Lin, Zhu and Shen [4] propose a VANET-based smart parking system and create a simulation system to evaluate the proposed architecture.

In Srikanth et al.'s research [5], they chose light sensors to detect parking space status. The detection result will first be sent to the gateway through RF communications, and then delivered to the server through WiFi or Ethernet. The system provides two services: parking space guidance and reservation.

Hanif, Badiozaman and Daud [6] propose a fully reservation-based smart parking system using short message services (SMS). Each parking space is equipped with a weight sensor to detect parking space status. A driver will send a reservation to the micro-RTU (Remote Terminal Unit) through SMS. The micro-RTU will choose a vacant parking space and send back a confirmation SMS which contains a parking lot number and a security code. When a driver approaches the entrance, he must enter the security code to pass the barrier gate and park in the target parking space.

In Wang's and He's research [7], a prototype of Reservation-based Smart Parking System is proposed and a simulator is created to evaluate the proposed system. For detection part, each parking space is installed with a sensor node capable of light and vibration sensing. For parking space reservation, each sensor node is equipped with a Zigbee and a Bluetooth module. Sensors exchange parking space status and reservation information with the central server via Zigbee.

Geng and Cassandras [8] focus on how to calculate the optimal available parking space based on a driver's request. The system will then reserve the parking space based on the calculation result and send the location to the driver. Any existing parking space tracking system and vehicle location detection system could be combined with this system.

In Wang et al.'s [9], they introduce an intelligent valet parking management system that guides the cars to autonomously park within a parking lot with no waste of drivers' time.

Rajabioun and Ioannou [10] propose a multivariate autoregressive model to predict parking availability with high accuracy at the estimated arrival time of a driver.

IV. EVALUATING SMART PARKING SYSTEM WITH SIMULATION

A. *Ordinary Parking Lot Model*

We used the following assumptions to build the ordinary parking lot model: (1) the number of total parking spaces is 300, (2) the time frame is 90 days, starting from 7AM to 5PM every day, for a total of 900 hours, (3) when more than one driver competes for the same parking space, we use a First-Come First-Served policy, (4) for each driver, the length of time spent driving from the driver's original location to the parking lot is a uniformly distributed random time with a time range between 10 minutes and 30 minutes, (5) if the parking lot is fully occupied, the driver will continually retry the search process until the end of search time set for the driver. In our model, there are two important parameters: traffic pattern and parking policy.

A traffic pattern models how drivers drive to a parking garage. We used the following assumptions to create different traffic patterns: first, the maximum number of drivers every day is 600. Each driver will generate zero or one parking attempt per day. Whether the parking attempt is successful or not, the driver will not generate another parking attempt on the same day; second, we generate the arrivals of drivers based on Poisson distribution. The lambda of Poisson distribution is given hourly. A traffic pattern is defined as the 10 lambdas assigned to 10 hours in a business day.

We create five traffic patterns which are described in Table I. The row presents each hour in a business day. The column corresponding to each traffic pattern shows 10 lambdas of Poisson distribution at different hours. The name of a traffic pattern is a general description of the characteristics of the traffic pattern. For example, in the 「1 heavy rush hour + 1 rush hour」 traffic pattern, there are approximately 400 drivers coming to the parking lot from 8:00 to 8:59 (heavy rush hour) and 100 drivers coming to the parking lot from 12:00 to 12:59 (rush hour) while there are only 10 drivers coming to the parking lot for all the rest of time.

The parking policy is a set of rules established by operators to manage parking spaces. It defines different types of parking spaces and prices. The best policy for operators is to make all parking spaces reservations only as this will maximize both customer satisfaction and occupancy rates. Under this policy, a driver will only come to the parking lot when she/he has successfully booked a parking space. In our research, the case that a driver decides not to come to the parking lot when she/he knows that she/he could not get an available parking space is also treated as a successful parking attempt because it saves the driver's time and fuel. Thus, the satisfaction rate is maximized because all parking attempts are successful. This is easier and more efficient for a driver than blindly trying a parking lot for an available parking space. Moreover, the occupancy rate will be higher as well because any available parking space can be acquired by the reservation more quickly.

However, this is not practical in reality for the following reasons. First, it is hard for operators to make sure that every driver knows the reservation process, especially for drivers who come to the parking lot for the first time and who are not familiar with the service. Second, reservation service abuse is a critical problem. For example, a driver who had booked a parking space might not come to the parking lot, or a driver might park in a parking space which was not reserved by him. A practical parking policy has to offer a variety of services (beyond all by reservation) in order to satisfy different needs of drivers. A good policy can thus attract more drivers

TABLE I. TRAFFIC PATTERN

Time	1 heavy rush hour + 1 rush hour	2 similar rush hours	Equal distribution	1 heavy rush hour	5 similar rush hours
7~8	30	30	60	20	20
8~9	400	250	60	500	100
9~10	10	10	60	10	100
10~11	10	10	60	10	100
11~12	10	10	60	10	100
12~13	100	250	60	10	100
13~14	10	10	60	10	20
14~15	10	10	60	10	20
15~16	10	10	60	10	20
16~17	10	10	60	10	20

and better utilize parking spaces. In our research, we assume parking fees are the same for any types and time zones. So the price issue will not be further considered. The steps which operators traditionally take to create the best policy is illustrated in Fig. 1.

This approach has several drawbacks. First, it takes time for drivers to get used to the new policy, which may result in a lower driver satisfaction rate. Second, an operator may spend a long time to test different policies before she/he finds out the best policy for her/his parking lot. Third, an operator needs to spend money to reform the parking lot every time a new parking policy is created. With our simulation approach, operators could run traditional steps several times in a short period of time and do not need to spend money to reform the parking lot. In order to prove the concept of our simulation system, we generate five policies and pick out the best policy from the results of our simulation.

The five policies are created based on four types of parking spaces: (1) private type, (2) A type, (3) B type and (4) regular type. For a private type, each driver is assigned a dedicated parking space. For other types, each of them has a privilege level. Drivers could park in their zone or those zones with lower privilege level. As a result, the drivers with a high privilege level have more available parking spaces to use and thus their parking attempts can be satisfied more easily, which results in a higher satisfaction rate. However, parking spaces in high privilege level are shared among fewer drivers, which will lower the occupancy rate. Relationships of three types of parking spaces are described in Table II.

We create each policy by picking some or all of four types of parking spaces. Attributes of five parking policy are

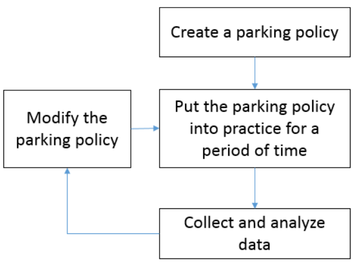


Fig. 1. Traditional steps for creating a best policy

described in Table III. There are two attributes of each policy: group of parking spaces and group of drivers. In most real world parking lots, operators would like to reserve a small amount of parking spaces for high privilege level drivers because the number of regular drivers is usually larger than the number of high privilege level drivers. As a result, we assume that if an operator would like to provide more than 2 types of parking spaces, the number of regular parking spaces is a fixed number, which is 200. The naming rule for a policy is the concatenation of all first letters of the types adopted. For example, a policy named "A.R." means there are two types of parking spaces: A type and regular type.

Finally, how drivers interact with the parking lot is illustrated in Fig. 2. The "Drive" state is the default state of a driver. The driver will enter the "Search" state when they arrive in the parking lot. When a driver is in the "Search" state, if he finds an available parking space, he will enter the "Park" state. If there are no available parking spaces, the driver will circle in the parking lot in order to find an available parking space for a period of time (search time). During this time, he will enter the"Park" state (p_drive time) once he finds an available parking space. At the end of the search time, if he could not find any available parking space, he will enter the "Leave" state. In the "Park" state, the driver will park his car for an occupation time and then enter the "Leave" state to indicate his departure from the parking lot.

The lower the type number of a parking space pool is, the higher its privilege level is. A driver will first enter the "Search" state at the highest privilege level they had been approved for. When a driver used out the search time but didn't find an available parking space, he would enter the "Search" state at the next privilege level. This search process continues until none can be found at the lowest privilege level. If so, the driver will enter the "Leave" state. In each resource pool, the search time is different. It is in increased order because the lower the privilege level is, the more the parking spaces are.

B. M2M-enabled SPS Model

In this model, an SPS driver can check the status of the parking space remotely and in real time. The system will

TABLE II. RELATIONSHIPS OF DIFFERENT TYPES

Privilege level	A type > B type > Regular type
The number of drivers for each type	A type ≤ B type ≤ Regular type
The number of parking spaces for each type	A type ≤ B type ≤ Regular type
The number of available parking spaces	A type ≥ B type ≥ Regular type

TABLE III. ATTRIBUTES OF FIVE PARKING POLICIES

Policy	Group of parking space				Group of drivers			
	Private	A type	B type	Regular	Private	A type	B type	Regular
R.	0	0	0	300	0	0	0	600
P.A.B.R.	30	35	35	200	30	70	100	400
A.R.	0	100	0	200	0	200	0	400
P.A.R.	30	70	0	200	30	170	0	400
P.R.	100	0	0	200	100	0	0	500

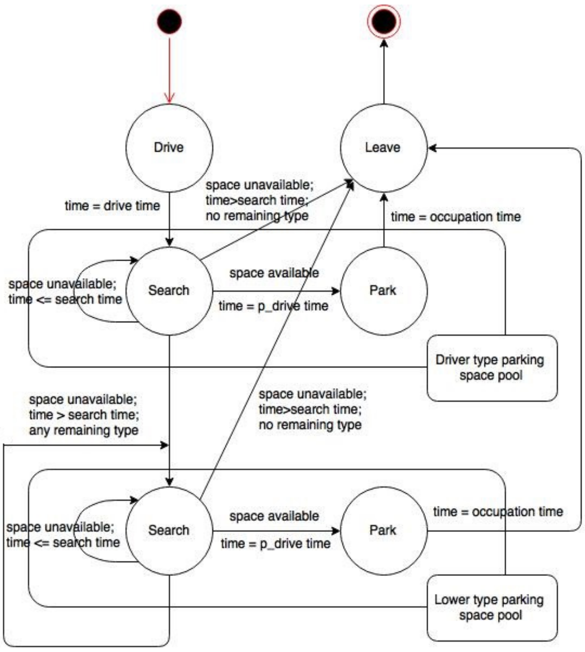


Fig. 2. Regular driver behavior

update parking space status based on parking space occupation detection. We assume that any existing parking space occupation detection method could be used in our system. A driver could subscribe to the status of the parking lot. The system will send a notification when the parking lot is fully occupied to help the driver decide whether or not to go to the parking lot. The system will also provide navigation services to reduce the time spent driving to the parking space. We assume any existing driver navigation system could be used in our system.

The high-level architecture of the simulation system is illustrated in Fig. 3. In the real world, it is hard to spread the smart parking service to all customers. Some drivers are just ad hoc users of the parking lot so they may not subscribe to the smart parking service. Yet another set of drivers may not apply to any mobile network, such as 3G or 4G, to use the smart parking service. Nevertheless, for operators these drivers are still important customers to meet a certain level of occupancy rate. Thus, it is normal that regular drivers and SPS drivers will coexist.

It is expected that the more drivers use smart parking services, the better customer satisfaction rate and occupancy rate will be. The reason is that drivers can avoid blind attempts that worsen the satisfaction rate. In our system, the

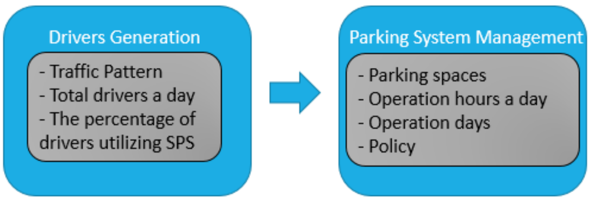


Fig. 3. Architecture of the simulation system

drivers of the regular parking model and the drivers of the SPS model coexist. Our model allows the modification of the percentage of SPS drivers to see how these two groups' interaction affects overall customer satisfaction and occupancy rate. In our experiments, we first calculate the number of SPS drivers based on a percentage. Then, we randomly distribute them to different privilege levels according to the parking policy used. As a result, each privilege level may consist of both regular drivers and SPS drivers.

Differences between the SPS driver behavior and the regular driver behavior are as follows: in the "Drive" state, if a driver receives a notification, he will decide not to come to the parking lot and thus enters the "Leave" state; in the "Search" state, the search time will be reduced because the driver now knows there is no partking space left through the SPS. Furthermore, the time spent driving to the available parking space after the driver found it (p_drive time) will be reduced as well because the SPS will navigate the driver to the space.

V. Experimental Design and Results

We create three sets of experiments to study operators' problems. The performance metrics used for the evaluation of each experiment are the satisfaction rate and the occupancy rate. The satisfaction rate is defined as the number of successful parking attempts divided by the number of parking attempts. Successful attempts include the cases in which the driver either gets a parking space or decides not to come due to the notification about the unavailability of parking space. The occupancy rate is defined as the total occupied time divided by the total available time of all parking spaces.

For satisfaction rate calculation, we first calculate the satisfaction rate of each privilege level in a parking policy. After the simulation is ended, each privilege level will record data of n satisfaction rates, where n is the number of business days. Then, we calculate the average satisfaction rate of each privilege level. Finally, we use weighted average to calculate the overall satisfaction rate. The reason is that although the number of drivers in high privilege is smaller than the number of drivers in low privilege level, the satisfaction rate of high privilege level is considered more important than the satisfaction rate of low privilege level. Weights are equally distributed based on the number of privilege level.

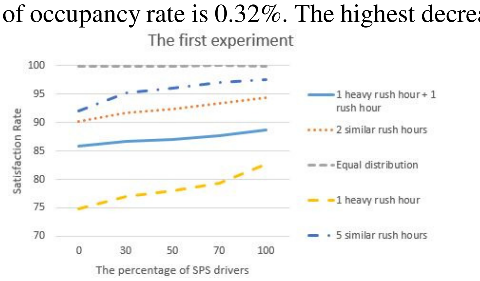
For occupancy rate calculation, we treat all parking spaces as equal because we assume parking fees are the same for any types and time zones. The total available time of all parking spaces is the number of parking spaces multiplied by the amount of open hours in the parking lot. As a result, the overall occupancy rate is the total occupied time divided by the total available time of all parking spaces. For non-commercial parking lot operators, the most important goal is to improve the customer satisfaction rate while maintaining certain level of occupancy rate.

In the first experiment, we simulate the operations of the parking lot using five traffic patterns. We investigate whether a higher percentage of SPS drivers for a parking lot would imply a better overall satisfaction rate regardless the types of traffic patterns and without much loss in the overall occupation rate. For each traffic pattern, we use different percentages of SPS drivers to run simulations. We assume the P.A.B.R. policy is used in all simulations. Results of the first experiment are illustrated in Fig. 4.

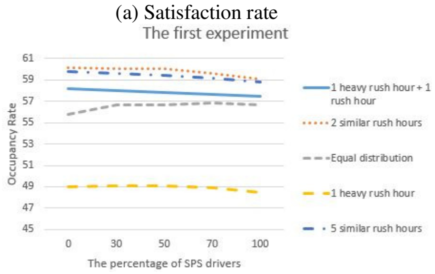
The satisfaction rate is increased along with the percentage increase of the SPS drivers. The highest increase of satisfaction rate is 7.87%, which appeared in the "1 heavy rush hour" traffic pattern, while the decrease of occupancy rate is about 0.56%. The reason is that during the rush hour, the parking space is mostly congested. As a result, SPS drivers will not come to the parking lot and this results in a lower occupation rate. However, the occupancy rate is decreased, but its decrease is smaller than the increase range of satisfaction rate. The highest decrease of occupancy rate is 1.01%, which appeared in the 2 similar rush hours traffic pattern, while the increase of satisfaction rate is 4.26%. The reason is that there would be some available parking spaces left when SPS drivers decided not to come to the parking lot. This results in the slight decrease of occupancy rate.

In the second experiment, we investigate whether a higher percentage of SPS drivers for a parking lot would imply a better overall satisfaction rate regardless the parking policies used. Also, such better satisfaction rate would not significantly decrease the occupancy rate. We simulate five parking policies. For each parking policy, we used different percentages of SPS drivers to run simulations. We assume the "1 heavy rush hour + 1 rush hour" traffic pattern in all simulations. Results of the second experiment are illustrated in Fig. 5.

The satisfaction rate is increased when the percentage of SPS drivers is increased. The highest increase of satisfaction rate is 3.08%, which appeared in the P.R. policy, while the decrease of occupancy rate is 0.32%. The highest decrease of occupancy rate is 0.78%, which appeared in the P.A.R. policy, while the increase of satisfaction rate is 1.84%.

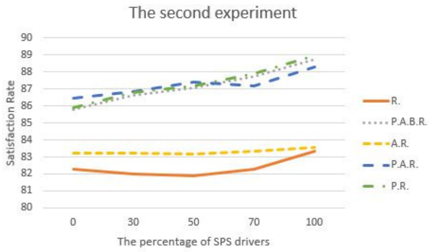


(a) Satisfaction rate

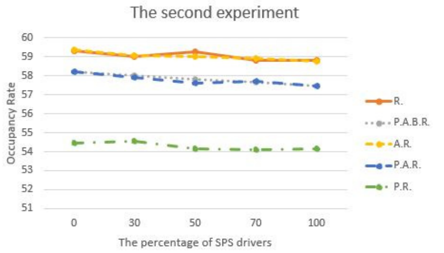


(b) Occupancy rate

Fig. 4. Results of the first experiment



(a) Satisfaction rate



(b) Occupancy rate

Fig. 5. Results of the second experiment

In the third experiment, for each percentage of SPS drivers, we will test five parking policies and find out the best policy among them. The best policy is defined as the one with the highest satisfaction rate while achieving the above-average occupancy rate among five parking policies. The traffic pattern of "1 heavy rush hour + 1 rush hour" is used in all simulations. For each percentage of SPS drivers, experimental results are described in Table IV. If the occupancy rate of a policy is equal or greater than the average occupancy rate, the policy is qualified and the occupancy rate of the policy is written in italics and bold in the table. Among all qualified policies, the one with the highest satisfaction rate is the best policy for that percentage of SPS drivers and its satisfaction rate is written in italics and bold in the table.

The P.A.R. policy is the best policy among 0%, 30% and 50% of drivers utilizing SPS, while the P.A.B.R. policy is the best policy among 70% and 100% of drivers utilizing SPS.

In conclusion, the policies with 3 or 4 privilege levels can achieve the highest satisfaction rate under the constraint of occupancy rate. The reason is that if there are more privilege levels, a high privilege level driver could find an available parking space at a higher probability. If the satisfaction rate of high privilege level drivers becomes higher, the overall satisfaction rate will be increased. Although the highest satisfaction rate is the P.R. policy because parking attempts of private type drivers will never fail, it has the lowest occupancy rate as the parking spaces of a private type cannot be shared by multiple drivers.

VI. Conclusions

In this research, we investigate the impact of an SPS on parking space management under different parking policies and traffic patterns. An SPS utilizing M2M not only tracks

TABLE IV. RESULTS OF THE THIRD EXPERIMENT

(A) 0% SPS DRIVERS

Policy	Occupancy Rate (%)	Satisfaction Rate (%)
R.	***59.32***	82.3
P.A.B.R.	***58.2***	85.79
A.R.	***59.39***	83.22
P.A.R.	***58.24***	***86.43***
P.R.	54.47	85.91
	Average: 57.924	

(B) 30% SPS DRIVERS

Policy	Occupancy Rate (%)	Satisfaction Rate (%)
R.	***59***	82.01
P.A.B.R.	***58.02***	86.62
A.R.	***59.08***	83.21
P.A.R.	***57.91***	***86.82***
P.R.	54.53	86.81
	Average: 57.708	

(C) 50% SPS DRIVERS

Policy	Occupancy Rate (%)	Satisfaction Rate (%)
R.	***59.25***	81.88
P.A.B.R.	***57.8***	87.08
A.R.	***59.03***	83.15
P.A.R.	***57.63***	***87.4***
P.R.	54.17	87.2
	Average: 57.576	

(D) 70% SPS DRIVERS

Policy	Occupancy Rate (%)	Satisfaction Rate (%)
R.	***58.83***	82.28
P.A.B.R.	***57.66***	***87.75***
A.R.	***58.92***	83.34
P.A.R.	***57.72***	87.19
P.R.	54.12	87.89
	Average: 57.45	

(E) 100% SPS DRIVERS

Policy	Occupancy Rate (%)	Satisfaction Rate (%)
R.	***58.83***	83.31
P.A.B.R.	***57.45***	***88.76***
A.R.	***58.79***	83.55
P.A.R.	***57.46***	88.27
P.R.	54.15	88.99
	Average: 57.336	

the number and locations of available spaces in a parking lot but also provides drivers with the real-time status of a parking lot. Next, we evaluate different parking policies in order to identity the best policy. All these are accomplished by developing a method of discrete event simulation with two models: ordinary parking lot model and M2M-enabled SPS model. Our parking simulation system is implemented by SimPy.

We create three sets of experiments. The first and the second experiments estimate the impact of SPS under different parking lot situations. Based on simulation results, we conclude that independent of what traffic pattern and what policy are used, the satisfaction rate is always improved when the percentage of smart parking drivers rises. The third experiment identifies the best policy that achieves the highest satisfaction rate under the constraint of a minimum occupancy rate among many alternatives. Based on simulation results, we conclude that policies with 3 or 4 privilege levels are the best in terms of satisfaction rate.

These results provide good insights to operators on how to best manage their parking resources. Although the M2M-enabled SPS may slightly decrease the revenue during a short period of time because of the little loss of occupancy rate. But in the long run, more drivers will be attracted back to the same garage if the operator implements the SPS.

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