Smart parking solutions for urban areas

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***Abstract*—Finding a parking place in a busy city centre is often a frustrating task for many drivers; time and fuel are wasted in the quest for a vacant spot and traffic in the area increases due to the slow moving vehicles circling around. In this paper, we present the results of a survey on the needs of drivers from parking infrastructures from a smart services perspective. As smart parking systems are becoming a necessity in today's urban areas, we discuss the latest trends in parking availability monitoring, parking reservation and dynamic pricing schemes. We also examine how these schemes can be integrated forming technologically advanced parking infrastructures whose aim is to benefit both the drivers and the parking operators alike.**

Keywords – smart parking; parking reservation; parking availability; smart cities

I. INTRODUCTION

The increase in vehicle traffic in city centers, is one of the effects of the recent rapid population growth in urban areas. In addition to the negative impact on the environment, the increase in city traffic has multiple other consequences which as expected, include the increasing demand on parking infrastructures accessible to the general public. As a result, finding a vacant parking spot during peak hours is in many cases impossible. Drivers keep circling around wasting time and fuel while hoping that a spot will be vacated as they drive by; this creates further traffic delays and aggravation for other drivers.

Recognizing the need to resolve the above issues and at the same time satisfy demand for parking spots and better services, parking management organizations are striving to implement solutions that work towards a more streamlined parking experience. Recent technological advances are bringing forward major changes in the traditional parking model. As a result, we see a variety of payment methods becoming widely available in conjunction with the dissemination of parking availability information.

The fact that parking availability is monitored in real time, opens up an opportunity for the provision of smart parking solutions that facilitate advance parking spot reservation and dynamic pricing. By making such services available to the drivers, the operators offer an enhanced level of service to their customers while at the same time have the opportunity to increase their revenues.

In this paper we present the latest developments in public parking infrastructures along with the outcomes of a relevant driver survey. We describe the technologies around parking availability monitoring, parking reservation and dynamic pricing and see how they are utilized in different settings while highlighting the importance of mobile applications.

This rest of this paper is structured as follows: in section II we describe parking related infrastructures and present the results of a driver survey on smart parking. In section III we describe parking information system technologies. In section IV, we analyse the latest trends in smart parking technologies and present our conclusions in section V.

II. PUBLIC PARKING INFRASTRUCTURES AND DRIVER SURVEY

Public parking infrastructures are available in all urban areas. Here, we provide a brief description of their current status from a technological perspective and present the results of a driver survey about smart parking facilities.

A. Public parking infrastructures

Today, there is a large variety of parking lots available for public use which can be broadly categorized as on-street and off-street. On-street spaces are on the roadside and offer convenient access to nearby locations; they are primarily operated by local authorities. Off-street parking spaces are larger areas that can accommodate tens or hundreds of vehicles. They are operated by local authorities as well as private companies and are either found at street level or in multi-storey arrangements (underground and/or elevated) which allow for significant vehicle capacities.

As expected, the total number of off-street spaces is usually much higher than the number of on-street spaces. As such, we often see some usage limitations applied at on-street spaces (e.g. a two hours maximum stay duration) as well as higher fees. The main purpose of these rules is to allow fair usage of these limited spaces.

Various payment policies and technologies are also being utilized. For on-street spaces, parking meters that accept

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coins are still widely used along with "pay and display" machines. In order to alleviate the well known issues associated with the use of coins, alternative forms of payment were introduced including: scratch cards, text messaging (SMS) and advanced pay and display machines which accept credit cards or prepaid cards. In uncontrolled entry and exit off-street spaces, we also find pay and display machines that are in some cases used along with the other payment methods just mentioned.

For revenue protection purposes, in many off-street spaces, barriers control the car park entrance and exit. Depending on the policy applicable, payment may take place on entry (e.g. if there is a fixed fee irrespective of the duration of the stay) or exit (i.e. the fee is determined by the duration of the stay).

The use of barriers allows for more advanced access control and payment technologies to be deployed that rely on Automatic Vehicle Identification (AVI). One such method is based on Radio Frequency Identification (RFID). A tag is attached to the vehicle's windscreen or license plate and is automatically detected and identified by long range RFID readers installed at the entry and exit points [1]. Another AVI method uses Automatic Number Plate Recognition (ANPR) technology. Cameras installed at entry and exit points capture the car's image. Image processing techniques are then used to locate the license plate region and recognize the characters [2]. In simpler setups, drivers use magnetic cards or short range RFID tags to identify themselves to the system and gain access.

B. *Driver survey*

To assess the need for smarter parking systems, we carried out a driver survey as part of the activities of the 'e-PARK' project [3]. The aim of 'e-PARK' is the design and evaluation of an integrated and expandable smart parking solution that can play a key role in urban areas.

The survey took place in the cities of Nicosia in Cyprus and Chania in Greece. The questionnaire included a variety of questions that aimed to gather demographic data, information on the potential use of various payment methods as well as the drivers' needs from smart parking solutions. A total of 1,400 questionnaires were completed and processed and here we only present data that is relevant to the scope of this paper.

Figures 1 and 2 provide information on how quickly drivers can find a vacant parking spot and how they react if their preferred location is not available. We see that a significant percentage (37%) spend more than 10 minutes searching for a vacant spot. When drivers go to their preferred parking location and no places are available, we observe 'negative' behavior in 34% of drivers: some park illegally somewhere nearby risking a fine and probably causing traffic problems, whereas others become frustrated and leave the area cancelling their activity. As expected, drivers leaving imply lost revenue for parking operators as well as local businesses; fortunately, the majority (55%) search for a spot nearby but as mentioned, some face delays while doing so.

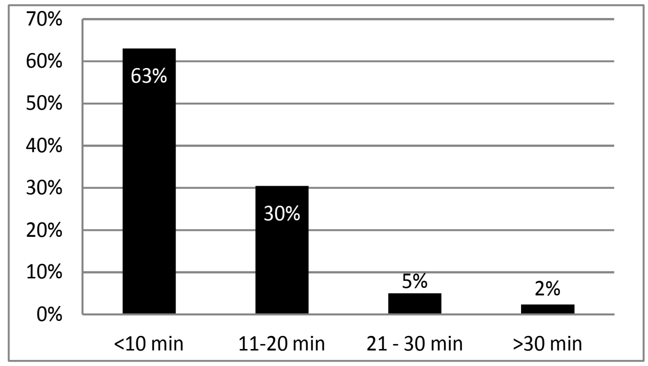

Figure 1. Time spent searching for a vacant parking spot

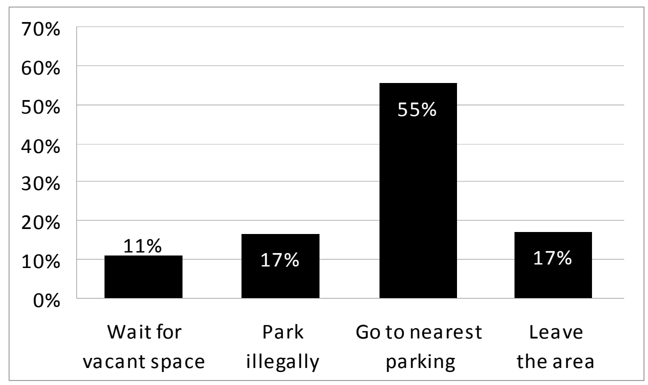

Figure 2. Driver actions when preferred parking lot is full

To save them from searching, we observe (Fig. 3) that most drivers are interested in using a smartphone application that guides them to the nearest parking with available spaces.

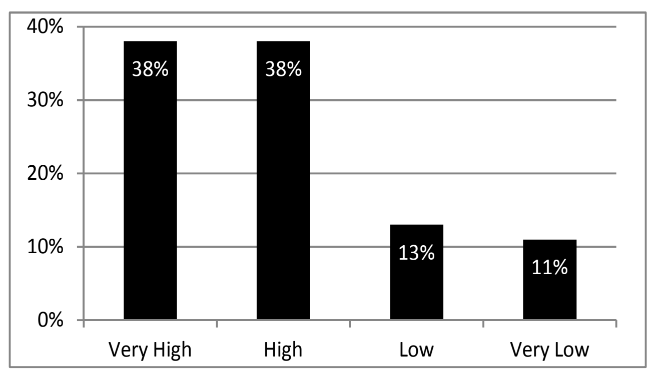

Figure 3. Use smartphone application providing availability information

Finally, in figures 4 and 5 we examine the potential application of advance reservations as well as variable pricing. We see that 43% of the participants in the survey are potential users of a fee-based reservation feature. As expected, the majority (64%) of drivers would prefer to have lower parking fees during periods of low demand and fees that are higher than normal during peak periods.

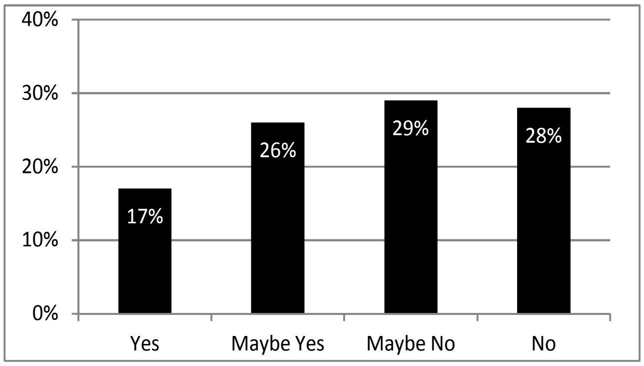

Figure 4. Interested in reserving a parking space for a fee

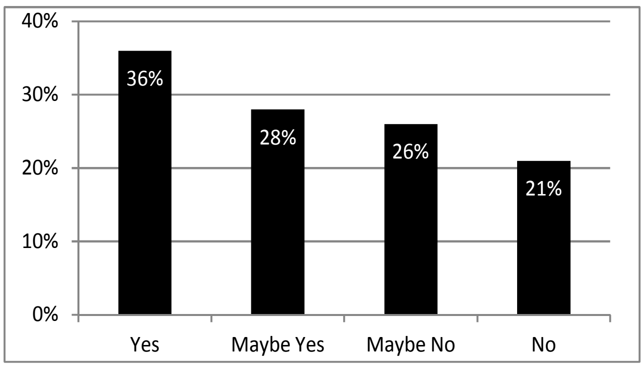

Figure 5. Prefer low fees during off-peak periods and high during peak

The overall conclusion from the survey is that drivers face some problems with regards to the availability of parking spaces and they are willing to exploit technology to reduce their impact. It is important to note that at present, none of the two cities has any smart parking facilities other than the possibility of payment through text messaging.

III. PARKING INFORMATION SYSTEMS

Knowing the availability at parking lots allows for the dissemination of this information to drivers. In this section, we see how this can be achieved and why it is highly useful.

A. Monitoring parking availability

As mentioned, finding a parking spot during peak hours causes inconvenience to drivers and has negative consequences for the environment. In busy areas, it is imperative that parking availability is somehow monitored. This data collection is possible through a number of methods which are often dictated by the type and arrangement of the parking lot. The level of information also varies from a general calculation of availability, to accurate data about the availability of specific parking spots.

In its simplest form, availability monitoring at off-street parking lots occurs by counting the number of vehicles entering and leaving. A variety of technologies is used to achieve that, with inductive loops (installed at entry and exit points) being the one most frequently used.

At a more detailed level (i.e. within a parking lot), information on the status of each individual parking spot is also very useful. To achieve this, a sensor is placed at each spot; this is either on the ceiling (in covered/multi-storey parking lots), or in the ground (in open air spaces). Note that by installing devices to monitor every parking spot, both the number of vacant parking spaces and their position are known. Obviously, the type of sensor used depends on the parking type, installation location, cost, connection type (wired or wireless) and sensitivity to external factors (that may affect accuracy). The economic benefits of installing a parking sensor network were analysed in [4].

For overhead installations, ultrasonic sensors are usually deployed, one above the centre of each parking spot. The sensor measures its distance from the nearest surface which in the case of a vacant space is the ground. When a vehicle enters the space, the distance reported by the sensor is reduced indicating the presence of a vehicle. Instead of ultrasonic sensors on the ceiling, a magnetic sensor can be placed on the floor in the centre of each parking spot; it readily detects a vehicle's presence as it causes a big change in the earth's magnetic field. In addition to ultrasonic and magnetic sensors, infrared, luminosity, weight and acoustic sensors have also been suggested for vehicle detection purposes. Sensor combinations can also be used for more accurate information; this way, the system has the ability to make correct detections in various scenarios and variable ambient conditions [5]. Data gathered from the sensors is processed to recognize if a spot is occupied.

Other options include a solution that does not require sensor installation at every parking spot; instead, it uses a robotic overhead system [6] to detect and identify empty spots. A solution that is cost effective when applied in larger (open space) car parks, involves the use of CCTV cameras and image processing techniques. By comparing consecutive frames the software identifies differences between vacant and occupied spots [7].

Through the expanding use of Internet of Things technologies, it is possible to collect parking availability information even from on-street parking spots. Magnetic sensors installed at each parking spot [8] detect the presence of a vehicle; at regular intervals (and every time the status changes) they transmit a wireless signal with the current occupancy status to a nearby gateway. This transmission is usually achieved through a multi-hop wireless network.

B. Parking Guidance and Information systems

Information on the availability of parking spaces is disseminated to drivers through Parking Guidance and Information (PGI) systems. We often find large variable message signs (VMS) installed at various locations that display the number of parking spaces available at nearby or city centre parking lots. Modern PGI systems are a major improvement on the first installations that took place during the 1970's; they incorporate web and mobile applications providing remote access to real-time availability data for multiple parking locations as well as navigation instructions to these locations.

The information provided by PGI systems can even include individual parking spot status. Once inside a parking lot, suitably placed electronic maps, signs and overhead lights, guide drivers to the vacant spots and hence save them from searching for them [9, 10]. Also, at the entrances of multi-storey car parks we often find information on the current availability at each floor. Information regarding the availability of on-street parking spots can also be available in real time usually via a mobile application that also features a map and navigation facility (Fig. 6).

The provision of availability information during periods of high demand may result in multiple cars chasing the same space(s) [11]. To reduce the probability of this occurring, and ensure that all drivers who used the information will find a place to park, the number of vacant spaces published is lower than the actual one. However, a small difference between the two figures does not solve the problem (and causes frustration) whereas a large difference may result in vacant spots which mean reduced utilization and revenue.

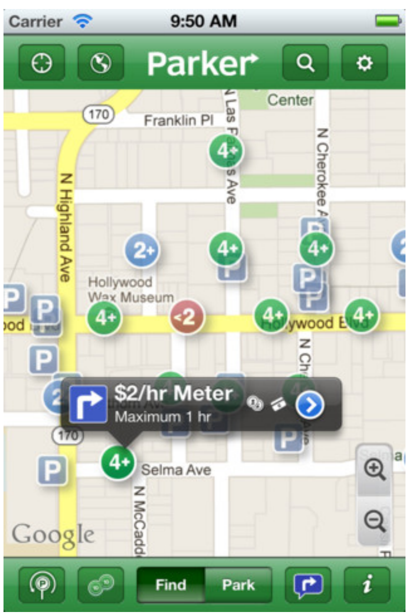

Figure 6. Real-time parking availability application

A number of advanced solutions that combine monitoring with other features were also proposed. The SPARK system [12] uses vehicular communication (via on-board units) and roadside units to monitor the availability in the parking lot. At the same time, it protects vehicles from being stolen; an alarm is triggered if the vehicle starts moving and its driver has not provided a password to the on-board unit. Avoiding the cost of the roadside infrastructure, IPark [13] enables the formation of clusters between vehicles through which parking spot occupancy status is exchanged. Based on this information, the system generates a map of the current status of the parking lot. A vehicle that enters the parking lot receives this map on which the locations of available parking spots are indicated.

In another solution, specifically designed for monitoring on-street parking spots [14], occupancy data is collected from drive-by vehicles. The monitoring vehicle is equipped with a GPS device and an ultrasonic sensor that is installed on the passenger's side. The sensor yields a short distance reading if a vehicle is present in the parking spot the monitoring vehicle currently passes by. The GPS locations associated with these readings, help the system deduce the location of vacant spots. This low-cost method, achieves reasonably accurate readings and utilises vehicles that travel round the parking areas as part of a daily routine (e.g. taxis).

After looking at various solutions, researchers defined [15] three different types of parking search: Non-Assisted Parking Search (NAPS) where the driver's decisions are solely based on his observations, estimations and experience, Opportunistically Assisted Parking Search (OAPS) where availability information is provided through a wireless ad hoc network and Centrally Assisted Parking Search (CAPS) that also allows for parking spot reservation. Their evaluation shows that the latter two methods reduce searching time and route length but in some cases a good location may also be discovered by NAPS.

Finally, we observe that parking availability information is used in transit-based information systems where it is combined with public transportation schedules, traffic conditions and other relevant data. One of the aims of such systems is to encourage drivers to use park-and-ride facilities. This increases public transportation use and at the same time reduces traffic and parking demand in city centers. Similar to PGIs, drivers receive information via VMS signs in roads near transit stations, mobile phones, in-car systems, the internet, radio broadcasts etc. Transit-based information systems are successfully operating in many countries.

IV. SMART PARKING CONCEPTS

The concepts of parking reservation and dynamic pricing are among the latest trends within the smart parking/transport and smart city contexts. They are deemed as highly important as they can collectively increase customer satisfaction and increase revenue from parking services.

A. Parking reservation

The ability to reserve a parking slot in advance is highly desirable especially during peak hours. Advance reservations ensure that drivers will find an empty parking spot upon arrival to their destination; reservations effectively eliminate the negative impact of searching for a vacant spot. Manni [16] proposed a Parking Management and Payment Service which indicates that it is highly valuable for the users and the environment if drivers can book parking spaces in advance.

In general, in order to make a reservation, drivers must send a request and receive a confirmation. Upon arrival to the parking location, the driver or vehicle associated with the reservation must somehow be identified to ensure that the reserved parking space won't be occupied by someone else. The whole reservation process initially appears to be overly simple; however, when examined in more detail, a number of issues are identified. These mainly stem from the different arrangements and policies at parking lots.

The first issue regards reservation location: is the reservation request generic (e.g. to reserve a space in the city centre), subject to criteria (e.g. distance, cost) [17] or for a specific parking lot? It is essential that accurate availability information is available to the system in order to identify and allocate available parking spaces. Once a reservation is accepted, one has to define how long it remains valid for. To reduce the effect of 'no shows' a small reservation fee could be charged in advance (and perhaps refunded upon payment of the parking fee). Also, taking full payment at the time of the reservation would help in covering for cancellations; this requires the duration of the stay to be estimated which would help operators reduce time gaps between reservations. In [18] we defined a parking spot as a resource and defined reservation policies that aim to maximize its utilization. A system could also set criteria for prioritization among current reservation requests e.g. select to fulfill those originating from drivers who will arrive at a parking lot the soonest [19].

Perhaps the most complex issues concerning parking reservation relate to the verification and enforcement of the reservation. In gated parking lots where a random space has been reserved, it is enough to verify reservations at the entrance and let drivers find a vacant space once inside the parking lot. This can be achieved using AVI or a code provided to the user when the reservation was made [20, 21].

The system must 'enforce' reservations and guarantee that when a driver arrives, the space reserved will be available. Reservation verification for on-street parking spaces or when a specific parking spot has been reserved can take place via a mobile application. In this scenario, enforcement is not so straightforward. It could theoretically be achieved by small barrier systems but such a solution may not be cost effective. Instead, lights can be used to indicate the status of each slot [20] and drivers should refrain from parking at empty but reserved slots. Finally, overstays (i.e. drivers exceeding the duration of their reservation) can result in subsequent reservations not being honored; some parking slots should be left empty in order to cover for such cases.

B. *Dynamic pricing*

Demand for parking spots obviously varies. In some areas it peaks during business hours, in others during the weekend etc. At the same time, convenient parking spots may cost more than those located further away from popular places of interest. The current and historical data collected by availability monitoring systems, can be used to provide an estimate for future demand. As such, different parking tariffs for different time periods of the day, different locations and even different customers can be applied.

Dynamic pricing can serve a number of purposes. The most obvious, is that it can maximize revenue for the parking operator by setting higher fees during peak times and lower during periods of reduced demand (to attract drivers). When parking prices are high, people may opt for public transport or change the time/place of their activity; this immediately results in reduced traffic [22]. Also, an evenly distributed arrival of cars during the day leads to an evenly distributed availability of parking spaces; drivers are satisfied since they can find a vacant parking space everywhere and are able to choose where to park depending on the price. Along these lines, Shoup [23] suggests that fees must be set so that a couple of vacant parking spots at each block always exist. Wang [24] designed a reservation-based smart parking system that exploits dynamic pricing based on the parking conditions in an entire area, instead of a single parking lot.

Parking rates can be defined and published in advance in order to inform drivers via websites and applications. This is appropriate when an event in an area will take place and attract many people; prices will be higher in cases of known peak demand. Alternatively, prices can vary in real time as a result of current demand and supply, or be set at regular intervals based on statistical information.

The first large-scale application of demand-based pricing is found in San Francisco [25] where prices range from $0.25 to $6 per hour. Pricing varies between blocks and is also different during different times of the day, during weekdays, weekends and when events are scheduled to take place.

C. *Smart parking deployments*

We already mentioned a few cases where individual technological concepts described in this paper were used. As integrated smart parking systems are being deployed in various parts of the world, useful conclusions can be drawn with regards to their success.

In Oakland California, a smart parking system was installed for the Rockbridge Bay Area Rapid Transit (BART) station. Drivers have access to real-time parking availability information, schedules and traffic conditions via VMS on an adjacent highway and other means (mobile phones, internet etc) and they can make advance and short-notice parking reservations. An evaluation revealed some issues with prices and parking capacity, but the usage of the station increased and users were satisfied from the benefits gained by reserving a parking space and using public transport; commute time and vehicle miles travelled per driver were reduced [26]. Similar installations are found in many other places; the general consensus is that the pre-trip and on-trip information received helps in trip planning especially during peak periods and when traffic disruptions occur.

PGIs and advance parking reservations seem to operate quite well in airport car parks. One reason is that drivers know their schedules and hence the start time and duration of their stay can be readily provided. Advance reservations benefit drivers with outbound flights as they do not lose any time searching for a vacant parking spot.

As mentioned, variable pricing was first applied in San Francisco. In a similar fashion, in the Los Angeles ExpressPark program [27] prices are adjusted once a month and are announced via the internet, electronic signs and a mobile application. Pricing strategies combine local event information with data collected from smart meters.

Mobile applications already play a key role in smart parking environments. As a prime example, the Parker mobile application is part of the ExpressPark service. Parker combines the concepts of PGI, dynamic pricing and reservation. It guides drivers to downtown streets where spaces are available, provides rate information, allows reservations, mobile payments, and even provides directions to the user's car so that it is easily found in large car parks. In addition to the end user applications, we also find applications used by parking operators and law enforcement agencies e.g. to locate violations such as non-payment [25].

V. CONCLUSION

Drivers in today's modern society begin to demand more intelligent services and smart parking is inevitably becoming an inherent service in urban areas. The smart parking features presented in this paper are gradually finding their way in advanced systems resulting in improved user services and increased revenues. Monitoring parking availability in real time, enables operators to gain a competitive advantage through PGI systems, reservation services and dynamic pricing. Users utilize these services via mobile applications which enable them to access location-based information in real time and request system services.

We also observe many isolated trials of different smart parking solutions indicating that there are still some issues that need to be resolved. In that respect, a middleware layer integrating components from the various vendors must be defined e.g. to enable processing the data generated by different availability monitoring systems.

Concluding, we believe that smart parking infrastructures should be interoperable in order to scale and cover larger geographical areas. Well defined and integrated services will result in common gateways for multiple service providers within urban areas, simplifying the lives of today's citizens.

ACKNOWLEDGMENT

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