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Architecture for parking management in smart cities

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Abstract: Parking is becoming an expensive resource in almost any major city in the world, and its limited availability is a concurrent cause of urban traffic congestion, and air pollution. In old cities, the structure of the public parking space is rigidly organised and often in the form of on-street public parking spots. Unfortunately, these public parking spots cannot be reserved beforehand during the pre-trip phase, and that often lead to a detriment of the quality of urban mobility. Addressing the problem of managing public parking spots is therefore vital to obtain environmentally friendlier and healthier cities. Recent technological progresses in industrial automation, wireless network, sensor communication along with the widespread of high-range smart devices and new rules concerning financial transactions in mobile payment allow the definition of new intelligent frameworks that enable a convenient management of public parking in urban area, which could improve sustainable urban mobility. In such a scenario, the proposed intelligent parking assistant (IPA) architecture aims at overcoming current public parking management solutions. This study discusses the conceptual architecture of IPA and the first prototype-scale simulations of the system.

1 Introduction

Nowadays, the term 'smart city' is very widely used in spatial planning literature or urban research. The term is used for various aspects involving an urban area, which range from smart city as an IT-district to a smart city regarding the education (or smartness) of its inhabitants. Focusing on smart mobility features, local and international accessibilities are important aspects investigated in this work as well as the availability of information and communication technologies and modern and sustainable transport systems. Smart mobility can contribute to the design of smart cities in order to answer to users' request in terms of transport network efficiency and social sustainability. In this context, reducing urban traffic congestion and public transport policy is a main goal, and intelligent management of public parking is fundamental aspect. Indeed, public parking is becoming an expensive resource in almost any major city in the world, and its limited availability is also a concurrent cause for air pollution and detriment of the quality urban mobility. From the specific standpoint of environmental conditions, the search of the parking area is able to generate the so-called 'traffic parasite', specifically vehicles in the traffic flow that are actually seeking for free parking stalls. These conditions result in a 20–45% increase in the pick of the traffic flow, and the generation of queues and of traffic crashes causing the total deterioration of the level of service available. More and more often, lack of parking stalls in a certain area of the city can also determine illegal double parking, which is a key contributor to congestion on major corridors. The impact on the emission levels of pullulating gas is also severe, for example, the presence of 800 vehicles per hour (veh/h) and illegal parking between two closely signalised junctions for over 18 min determine extra CO emissions about 20%. If the number of vehicles increases up to 1200 veh/h, the extra CO emissions become about 26.5% [1].

In [2], a study regarding parking management over the course of a year in a small business district in Los Angeles shows that vehicles seeking for a parking stall waste an amount of gasoline and produce an amount of CO_2 emissions equivalent to either 38 trips around the earth or four trips to the moon. The endless searching for a parking stall in a crowded city thus causes driver frustration. To ease driver frustration, it would be much more efficient and environmentally friendly if a parking stall could be made available on driver's arrival to the destination.

The above considerations suggest improving actual parking policies in order to contribute to environmental protection in urban areas and to perform better road traffic issues. The parking management involves supply and organisation of the private parking in designated areas or along the public roads. SPARK management represents an important strategic measure, and in addition it implies specific action plans for control and management of urban traffic. In general, the parking supply management must find the tools to control the number and nature of requests for parking and thus create actions that affect the spatial–temporal allocation of parking spot (stalls). Such activity surely affects traffic conditions by determining a reduction of the urban congestion.

The paper discusses a novel-parking model referred to as intelligent parking assistant (IPA) that provides drivers with information about on-street parking stall availability and allows drivers to reserve the most convenient parking stall at destination before their departure. That in turns easies traffic circulation because of the search for an available parking stall. IPA evolves current on-street parking management solutions and aims at becoming the leading paradigm for next generation public parking management system.

In this work, the IPA software and hardware modules are presented and described in detail; furthermore, a point-to-point comparison with the standard Italian off-street parking management system is carried out. The experimental evidence demonstrates the feasibility and effectiveness of the proposed approach along with the positive effects on air pollution. The contributions of this work compared with other systems are: IPA allows to manage and reserve road-side parking spots, whereas existing parking system focuses on parking lots [3, 4]; no devices have to be installed in the driver's vehicle [4, 5], and no internet connection is required to get into the parking spots after this has been reserved; the reserved spots can be easily given to other people (such as other family members) simply handing a small radio frequency identification (RFID) tag; miss-parking are avoided by a retractable bollard that prevents unauthorised drivers to get into a parking spot; users can complete the check-in process without stopping the car avoiding queues formation and reducing gas emissions; furthermore, no personnel to patrol the IPA stalls are needed.

The paper is organised as follows: Section 2 discusses related works; Section 3 presents the IPA system; Section 4 shows the hardware and software architectures of the proposed system; Section 5 shows a parking design model; and Section 6 illustrates experimental results. Finally, Section 8 concludes the paper.

2 Related works

Parking guidance information [6] systems were provided in the early years to minimise parking search traffic by dynamically monitoring available parking and directing drivers to a vacant parking spot. Current solutions focus on parking lots and are concerned with the application of wireless network and sensors communication. However, these systems do not provide a reservation mechanism to secure a parking spot in one of these lots during the pre-trip phase.

Tang *et al.* [3] describe an intelligent car park management system based on wireless sensor networks. The wireless sensors are deployed into a car park field to detect and monitor the occupation of the parking lot. The data collected by the sensors are reported periodically to a database that can be accessed to perform various management functions, such as finding vacant parking lots, security management and statistic report. Yan *et al.* [4] focus on 'secured' wireless network. In their system, each vehicle is equipped with a short-range wireless transceiver and a simple processor. The hardware infrastructure for the parking lot consists of wireless transceivers that transmit parking and reservation information, parking belts, infrared device and a control computer that keeps a map of empty spot in the parking area. The terminals (e.g. PDAs and cell phones) of drivers can receive messages sent from the base station and the drivers can reserve an empty spot only when they are near the parking lot.

Another technology widely used to manage parking lots is the RFID. Pala and Inanç [7] use RFID for check-in and check-out procedures. The authorisation on entrance to the car park depends on the registrations of the vehicle. The use of RFID allows a considerable reduction in costs [7, 8].

The basic infrastructure of a parking system relies on devices to detect if parking spaces are occupied or available. Different detectors are currently used [9]: loop detectors, machine vision, ultrasonic, infrared, microwave and lasers. Chinrungrueng *et al.* [10] propose to employ optical sensors in wireless sensor network (WSN) to replace commonly used loop detectors. Optical WSN is easy to install and maintain with the same or better accuracy, but these sensors are very expensive. Wolff *et al.* described a system based on passive magnetic field sensors in [11] to provide occupancy information for the car park. These sensors support a wide range of temperatures (-55 to 200°), which are cheap, light and small, and hence versatile in placement. For these reasons, they have been widely employed for vehicle detection.

The development of a vehicular ad-hoc network (VANET) [12] has provided another option for smart parking (SPARK) systems [13–15]. In [13], the authors present a new SPARK based on VANET to provide drivers with real-time parking navigation service, intelligent anti-theft protection and friendly parking information dissemination in large parking lots. The SPARK scheme is characterised by employing parking lot roadside units (RSUs) to manage the whole parking lot using VANET communication technology. After the vehicle enters a large parking lot, the RSUs first chooses a proper vacant parking space, then chooses the shortest path and navigates the vehicle to the vacant parking space.

In this short review, it has been demonstrated that there exist technically advanced solutions for parking management focus on parking lots. Nonetheless, one key factor contributing to traffic congestion is the lack of information about roadside parking availability. Occupancy data for parking garages are relatively straightforward to obtain through entry/exit counters, yet important information is generally unavailable for roadside parking. The SF-park project [16] tries to detect roadside free parking space using fixed sensors (magnetometer) installed in the asphalt in the centre of each parking spot. Sensors deliver the data to a centralised parking monitoring system. Park Net [5] employs vehicles equipped with a global positioning system receiver and a passenger-side-facing ultrasonic range finder to determine roadside parking spot occupancy. The data collected by the vehicles are aggregated at a central server, which builds a map of parking availability and could provide this information to clients that query the system in search of parking, but the same free spots are displayed for all users. This might cause that multiple users drive to the same spot and find it occupied when they get there causing traffic congestion if available spaces are less than the spaces in demand.

IPA aims at showing roadside parking availability information to the drivers, but it also provides a reservation service. The reservation system avoids driver's frustration in the endless search for a parking space in a crowded city and reduces traffic congestion. The reservation is guaranteed by a retractable bollard that prevents unauthorised drivers to get into a parking spot. The IPA system is based on wireless sensor networks similarly to

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previous approaches [3, 4, 17, 18] in conjunction with an RFID system, yet (e.g. [4]) no devices have to be installed in the driver's vehicle like in previous, and similar systems. By the utilisation of RFID readers and retractable bollards parking-spot, check-in and check-out controls have been achieved. Furthermore, no personnel to patrol the IPA stalls are needed.

3 Intelligent parking assistant

The public parking system developed within the IPA project will partially remodel the public off-street parking system, so that only authorised users can use parking spaces on reservation. An authorised user is a customer registered at the IPA website that has booked a parking stall. In the rest of the paper, we will refer to an on-street public space managed by IPA as IPA parking spot/space.

To establish the IPA architecture, the following business rules have been defined:

(B1) Reservation confirmation numbers can be delivered only to authorised customers.
(B2) A reservation is held for a 'grace period' (e.g. 15 min) after the start of the reserved interval in order to account for customers who does not show up in time. If the customer arrives within the grace period, he/she will be billed for the full reserved period. If the customer does not show up within the grace period, a message (e.g. SMS or email) will inform him/her about the expiration of his/her reservation.
(B3) If the customer arrives any time after the regular grace period, a vacant and unreserved spots will be offered for the remaining period of the original interval of reservation. The customer will be billed from the start to the end of his/her original reservation.
(B4) No-show customers will be billed for the entire duration of their reserved interval.
(B5) Customers who fail to clear their parking spot as scheduled will be billed at a higher rate for the overstay duration. The overstay rate will be increased progressively with the duration of overstay. A message (e.g. SMS or email) will be sent to the customer to notify these events.
(B6) Each customer is allowed to have multiple standing reservations on his/her name, but these reservations cannot be contiguous. A minimum of 1 h gap is imposed between any consecutive reservations, and consecutive reservations made by the same customer will be merged into a single reservation.
(B7) If a customer arrives and his or her reserved spot is still occupied by a previous customer who failed to depart as scheduled, but there are other available spots, the arriving customer will be offered to park on an available spot. This information will be sent through an SMS.
(B8) The system cannot overbook the parking-space reservations. IPA business policies do not allow overbooking, since IPA is thought for customers who are willing to pay for an on-street parking stall in order to have the absolute certainty to find a parking spot at their arrival in a high-density trafficked areas of the city. If IPA allowed overbooking, there will be no difference between a regular parking spot and an IPA stall. Furthermore, IPA parking stalls must be paid in advance independently of whether the customer uses or not his/her reserved spot, so there is no loss on revenues.
(B9) Reservation must always be warranted. To fulfil this rule, some special IPA parking spaces are left at the disposal of the IPA. These parking spaces are referred to as back-up parking spots.
(B10) If some customers failed to depart as scheduled, the authorised customer who finds his/her spot occupied will be assigned to one of the backing-up parking spots. This change will be notified with an SMS to the customer. If all backing-up IPA spaces are unavailable, the customer will be asked to leave without parking, and will be given a rain check.

4 IPA: software and hardware

Fig. 1 shows the main components of the IPA system, which will be shortly described in major details. In the IPA architecture, the customers can reserve a parking space online, via a computer, a tablet, a mobile phone or other pervasive computing devices. All they need to do is to log onto a specified website, look for an available parking spot near their destination and reserve it. They must pay their reservation in advance.

The hardware devices installed inside each IPA parking stall monitor the status of the parking space (available or occupied), manage vehicle access control and send parking space information to central server through a wireless network. The central server aggregates information coming from IPA parking spot, keeps a real-time map of empty spots, provides this information to clients that query the system in search of parking and manages users' reservation.

4.1 IPA architectural model

The IPA architecture consists of five modules, as shown in the deployment diagram shown in Fig. 2.

(1) User interface module: this subsystem is a core module of the IPA system. It manages the communication with the customer, for example, accounting, reservation, cancellation and billing. This module communicates with the function module through the communication module.
(2) Communication module: this module simplifies the communication process and performs error control, for example, verifying the checksum and correcting errors. In general, the purpose is fast communication speed and

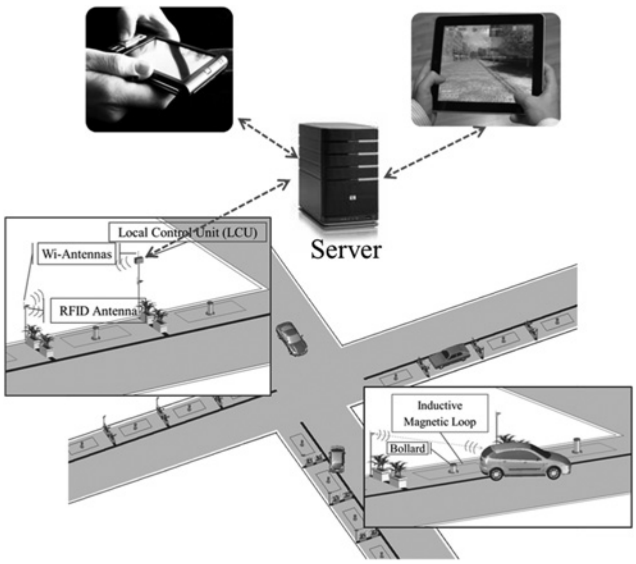

Fig. 1 *IPA: system overview*

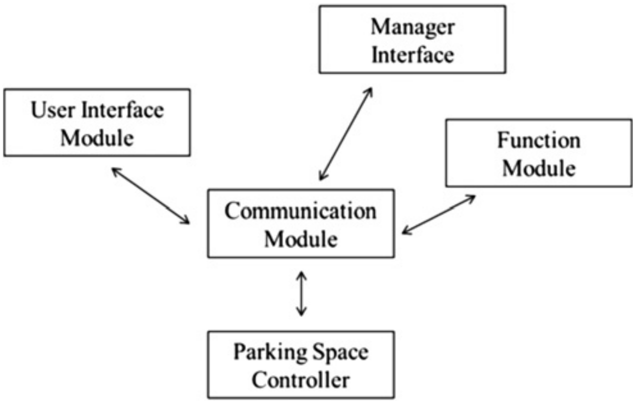

Fig. 2 *Block scheme of the IPA architecture*

enhanced message correctness because the communication response time is strict.
(3) Function module: it consists of some servers, and a relational database. The database contains various information, including:

- Information about the registered customers.
- State of each parking spot: 'available', 'reserved' or 'occupied'.
- Current parking reservations.
- Record of transactions for each customer, such as past reservations, usages, whether the customer showed up late, or failed to show up during their reserved period etc.
- Various statistics about the IPA usage.

(4) Parking space controller module: it consists of sensors, and a unit controller. This system is triggered when a car parks or leaves the parking spot. When a customer parks/leaves his/her car in/from the parking space, the sensor detects the action and sends information to the unit controller that triggers proper actions (e.g. ascent/descent of retractable bollard). The unit controller receives the information and sends information to the function module.

4.2 IPA software module

The functional organisation, server-side, of the IPA software is shown in Fig. 3. It consists of several modules:

(1) User computer interaction: it manages customer registration, requests for parking-space reservation and general account management, for instance, showing the list of recent user's transactions with the IPA parking system. This module has been implemented to comply with the business policy (B8); therefore overbooking will not be allowed.
(2) Parking spot access control: this processes the data generated by either the customer and the IPA system (e.g. data generated by the sensors) in order to implement the business policies (B1), (B5), (B7) and (B10).
(3) Monitoring module: Fig. 4 shows the state transition diagram for each individual parking spot. An IPA parking spot can be only in one of the following four status: 'available', 'reserved', 'occupied' and 'out-of-service'. The

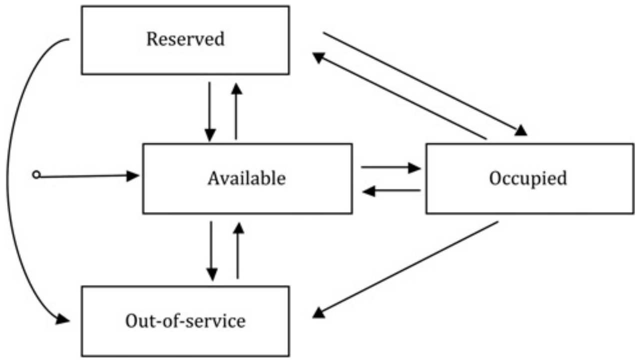

Fig. 4 *State diagram for an individual parking spot*

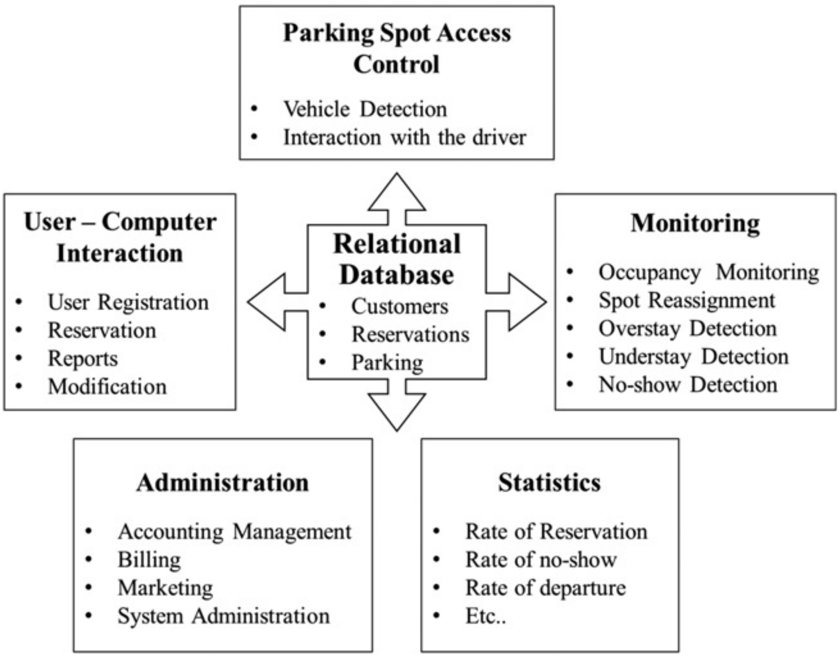

Fig. 3 *Functional organisation of the server-side of the IPA parking software*

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current status for each individual parking spot is recorded in the relational database. This module ensures that only the allowed state transitions shown in Fig. 4 will occur. This module periodically queries the database for reservations and determines if some customers did not arrive as scheduled by their reservation. Reservations are held for a limited 'grace period', as per the business policy (B2). The reservation is released after the grace period expires by changing the database status of the reserved spot to 'Available'. The system also applies the business policies (B3) and (B4) for late-arriving or no-show customers. Each event, such as 'arrived late' or 'no-show', is recorded in the record of customer's transactions. The module periodically queries the database for current occupancies and determines if some customers failed to free the parking spot as scheduled. The system applies the business policies (B5), (B7), (B9) and (B10), and it records the customer's transactions with the system, such as extension of the reservation, overstay etc.
System administration: the IPA managers should be able to configure the system with parameters such as:

- total capacity of the parking spaces;
- rates for parking usage as reserved; and
- special fees for overstays.

This module implements a system for billing reserved occupancy time, extensions and overstays. Management of malfunctioning and regular maintenance of the IPA parking stalls is implemented in this module.

4.3 IPA hardware components

The following devices will be installed inside each IPA parking space in order to properly deploy the IPA architecture:

(a) a retractable bollard for each parking spot to guarantee the reservation and prevent unauthorised drivers from entering an IPA parking space;
(b) a magnetic loop to detect the occupancy of the spot by a vehicle;
(c) an RFID reader to identify the TAG of who has booked and constantly check the TAG to verify the presence of the car;
(d) a unit controller embedded into the retractable bollard to manage IPA parking functionalities, for example, status of the parking spot;
(e) a wireless transceiver to communicate with the local control unit (LCU) (see Fig. 5). The transceiver is a zigbee device.

The unit controller is an electronic circuit board with a central processing unit, a memory block, an internal clock that is periodically synchronised with the server, a power supply circuit connected with the electrical net, an interface for the communication with the RFID reader, a self-calibrating amplifier adjusting the amplitude of the signal coming from the loop, an interface for the Wi-Fi connection and an input/output adapter for the connection with the control unit of the bollard automation.

An LCU (Figs. 1 and 5) acts as a gateway between the central server and the unit controller of each IPA parking spot of a parking area. The roadside parking spaces are located on various parts of the city. Each LCU controls a restricted area.

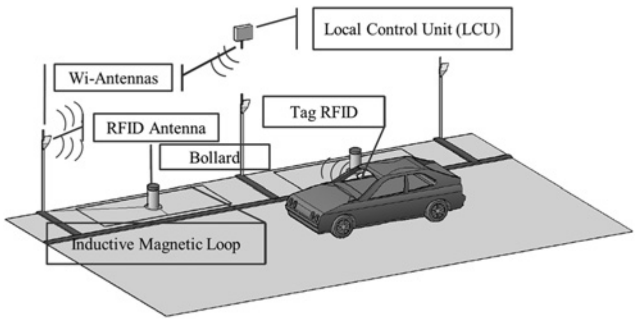

Fig. 5 *IPA- hardware components*

LCU forwards data from the central server (e.g. the TAG code and the reservation information as the time of arrival/departure of user) to unit controller, notifies the central server about the arrival and the departure of the car and about faults (e.g. power failure or breakdown). It has been made a prototype of the system in small scale (Fig. 6).

Check-ins and check-outs processes are under control with RFID readers, tag and retractable bollard. When an authorised user (a customer that is registered at the IPA website and has a reservation confirmation number) is near the assigned spot, the RFID reader detects the TAG and the unit controller queries the central database, through the LCU, looking for vehicle's identification information. Then it compares reservation data (time and user's identification tag) sent from the server with those acquired in real time; only if the comparison is positive, the bollard goes down.

The RFID reader has a detection radius of about 8 m that allows users to complete the check-in process without using their mobile telephone, which is one of the most dangerous things for a driver to do and without stopping the car. This avoids queues formation and reduces gas emissions. The use of RFID tag also allows to easily assign the reserved spot to other people (such as other family members) simply by handing the RFID tag from one family member to another. Finally, the use of RFID tag allows people who do not have a smart device to use the IPA system (a regular PC can be used to reserve the parking spots, whereas the tag RFID allows drivers to complete the check-in process).

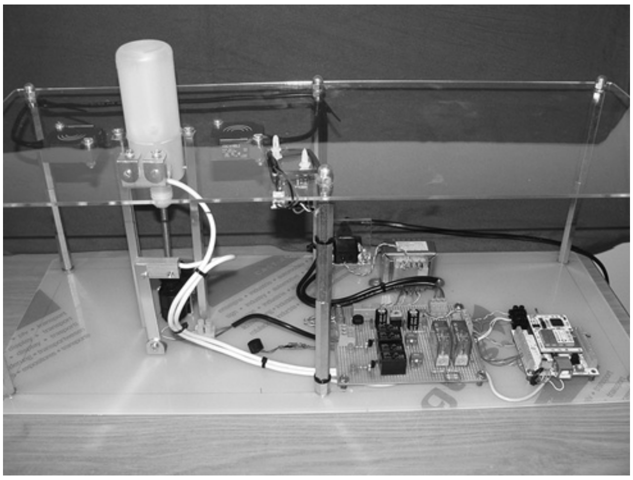

Fig. 6 *Prototype*

During the operations of entrance or exit from the IPA parking spot, the magnetic loop placed around the bollard detects the vehicle and the unit controller maintains the bollard lowered in order to prevent risk of collision between the vehicle and the bollard.

When the car leaves the IPA parking spot, the RFID reader and the magnetic loop detect the action and send these information to the unit controller that triggers the ascent of the bollard and sends the check-out information (TAG code, time of exit and the IP address that identifies the IPA parking spot) to the LCU. Finally, the LCU forwards these data to the central server.

The IPA system also detects unauthorised parking. For instance, a car parked between two bollards of two adjacent empty spaces can be detected through the combined use of magnetic loops installed in the ground and the RFID reader. The parking space controller sends a proper alert message to the unit controller when the magnetic loops detect the presence of a car, but the RFID reader does not detect an authorised customer. On such an alert message, the parking agency takes the proper set of actions to clear the unlawfully occupied spots.

5 Parking design model

For the analysis and evaluation of the parking management strategies, the following parking design model has been adopted. The model is based on optimisation techniques that aim to minimise the total distance that users need to walk from parking areas to the areas of destination. This is to minimise the objective function disutility or total impedance $U(p_i, t)$ of a parking p_i, for a duration time unit t, subject to the constraints of supply and demand, expressed as

$$U(p_i,\ t) = \beta_1 w(p_i) + \beta_2 f(p_i,\ t) + \beta_3 s(p_i) + \beta_4 \tau(p_i) \quad (1)$$

where:

– $w(p_i)$ represents the time needed to walk more and leave the car park to reach the nearest bus stop (or directly to proper destination if continue walking);
– $f(p_i, t)$ is the price paid for the car park p_i for time duration t;
– $s(p_i)$ is the search time (and expectation) of a free-stall once arrived at p_i;
– $\tau(p_i)$ is the time of access by road network to the parking lot p_i;
– β_I are the parameters of the utility function, which is considered positive and known [19, 20].

If the probability of finding an available stall in a parking lot is given by

$$\Pr(p_i) = 1 - \sum_j \frac{\eta_j}{k_j} \quad (2)$$

where η_j is the number of parking spots employed in p_j at the time when the route origin/destination is selected by the user and k_j is the capacity of the parking p_j, then $s(p_i)$, or the average waiting time that a user spends looking for a stall from the begin of search to the leave of the car, depends on both the capacity and the demand for car park itself through the expression

$$s(p_i) = \frac{(\eta_i - 0.9k_i)^{2\omega_i}}{2k_i\eta_i} \quad (3)$$

where ϖ_I is the average parking time at p_i.

6 Experimental results

To illustrate some advantages of the IPA solution compared with the conventional parking management systems, different traffic scenarios have been studied. In these studies, we assume that either all vehicles in the traffic flow use IPA, or that the area under consideration has a significant disparity between demand and parking supply. In these scenarios, estimates for usual efficiency parameters related to transport [delay, travel time, fuel consumption (FC) etc.] are estimated. Fig. 7 displays the structure of segment of the urban road considered; the structure of this segment is such that it is possible to stop at the edge of the carriageway. The capacity of on-street parking depends on many variable parameters. For the present investigation, the design parameters defined by the Italian Road Policy for

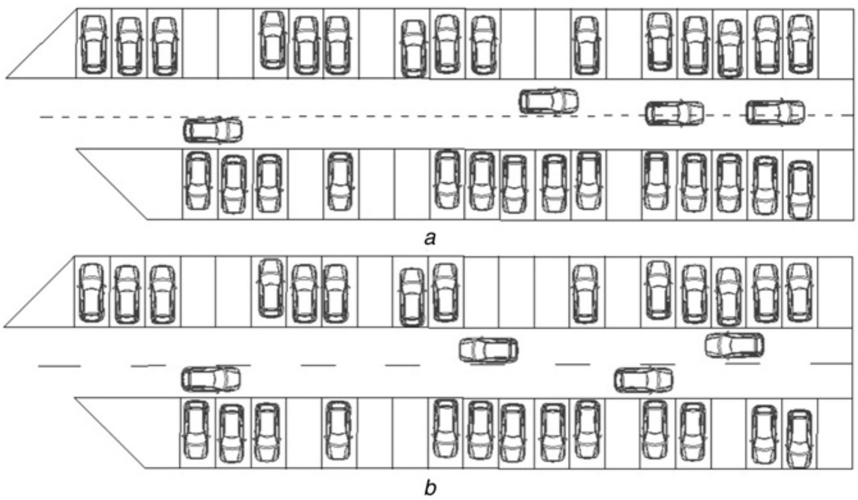

Fig. 7 *Experimental results*

a Scheme of urban road segment with parking stall on both edges of carriageway
b Scheme of urban road segment with parking stall on both sides of the carriageway and two ways traffic flow

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Table 1 Estimates of main efficiency parameters

Q, veh/h	L, m	SP_{av}, km/h	TTT_{un}, s/h	S_a	S_r	S_f	Pr(p)	$s(p)$, s/veh	D_1, s/h	D_2, s/h	TTT_D, s/h	FC, m^3
500	40	40	1.800	30	10	6	0.20	54.19	65	325	2.190	1.96
500	80	40	3.600	60	20	12	0.20	35.75	86	429	4.115	4.25
500	120	40	5.400	90	30	18	0.20	28.03	101	505	6.005	6.89
500	200	40	9.000	150	50	30	0.20	20.63	124	619	9.743	11.55
800	40	40	2.880	30	16	6	0.20	54.19	163	325	3.368	3.14
800	80	40	5.760	60	32	12	0.20	35.75	214	429	6.403	6.59
800	120	40	8.640	90	48	18	0.20	28.03	252	505	9.397	10.85
800	200	40	14.400	150	80	30	0.20	20.63	309	619	15.328	17.66

Case of traditional parking management.

design and management have been used. With that respect, the stall size for off-street parking spots is fixed at 5.50 m long and 2.50 m large.

In the scenario depicted in Fig. 7*a*, it is assumed that: the one-way hourly flow (Q) is equal to 500 veh/h; the number of vehicles seeking for a parking stall (S_r) is equal either to 2% of Q or to 10 vehicles in an hour; the rate of rotation of parked vehicles (S_f) is equal to 20% in the hour through the use of (2), that is, for 30 stalls available (S_a) the number of stall that become free (S_f) in an hour is equal to 6. In this way, the road segment considered is approximately 40 m (L) length and it determines an unsatisfied stop demand equal to 40% (S_r–S_f) or 4 vehicles on 10 looking for a stall cannot be satisfied. The delay of current vehicular determined by the traffic parasite produces a delay (D_1) that must be added to the delay determined by the vehicles that finding a stall free perform the parking manoeuvre (D_2). To carry out an estimation of D_2 be determined by calculating the average waiting time $s(p)$ through (3) and for the value of D_1, reference was made to reports in [21].

Starting from these estimates, Table 1 shows:

– Total travel time (TTT_{un}) for the traffic flow Q without delay for park searching.
– Total travel time (TTT_D) for the traffic flow Q because of delay D_1 and D_2.
– FC for all vehicles travelling along L, as calculated from [22].

In case of use of the IPA solution for the scheme of Fig. 7*a*, the unsatisfied demand for parking is zero because the vehicles that slowdown to search for a stall and to perform the parking manoeuvre are only those who carried out the reservation of the stall. Therefore the unsatisfied demand for parking expressed by vehicles (S_r–S_f) will not slowdown the traffic flow along the segment as knowing a priori the location of their parking stalls to previously booked and situated in a later section of the trunk road. It has the elimination of delay in the rate of D_1 and the decrease in the value of the TTT_D much more sensitive than the more extended is the road section in question (see Table 2).

In the second scenario, the following assumptions are made: the two-way hourly flow (Q) is equal to 500 veh/h; the number of vehicles seeking for a parking stall (S_r) is equal either to 3% of Q or to 15 vehicles in an hour; the rate of rotation of parked vehicles (S_f) is equal to 20% in the hour through the use of (2), that is, for 30 stalls available (S_a) the number of stall that become free (S_f) in an hour is equal to 6.

Table 2 Estimates of main efficiency parameters

Q, veh/h	L, m	SP_{av}, km/h	TTT_{un}, s/h	S_a	S_r	S_f	$s(p)$, s/veh	D_1, s/h	D_2, s/h	TTT_D, s /h	FC, m^3
500	40	40	1.800	30	6	6	54.19	0	325	2.125	1.94
500	80	40	3.600	60	12	12	35.75	0	429	4.029	4.06
500	120	40	5.400	90	18	18	28.03	0	505	5.905	6.52
500	200	40	9.000	150	30	30	20.63	0	619	9.619	10.34
800	40	40	2.880	30	6	6	54.19	0	325	3.205	3.07
800	80	40	5.760	60	12	12	35.75	0	429	6.189	6.21
800	120	40	8.640	90	18	18	28.03	0	505	9.145	9.3
800	200	40	14.400	150	30	30	20.63	0	619	15.019	15.88

Case of IPA solution for parking management.

Table 3 Estimates of main efficiency parameters

Q, veh/h	L, m	SP_{av}, km/h	TTT_{un}, s/h	S_a	S_r	S_f	Pr(p)	$s(p)$, s/veh	D_1, s/h	D_2, s/h	TTT_D, s/h	FC, m^3
500	40	40	1.800	30	15	6	0.20	130.49	352	783	2.935	2.47
500	80	40	3.600	60	30	12	0.20	113.60	613	1.363	5.577	6.09
500	120	40	5.400	90	45	18	0.20	104.75	848	1.885	8.134	9.32
500	200	40	9.000	150	75	30	0.20	94.58	1.277	2.837	13.114	14.75
800	40	40	2.880	30	24	6	0.20	130.49	705	783	4.368	4.41
800	80	40	5.760	60	48	12	0.20	113.60	1.227	1.363	8.350	9.4
800	120	40	8.640	90	72	18	0.20	104.75	1.697	1.885	12.222	13.05
800	200	40	14.400	150	120	30	0.20	94.58	2.554	2.837	19.791	21.12

Case of traditional parking management.

Table 4 Estimates of main efficiency parameters

g	L, m	SP_{av}, km/h	TTT_{un}, s/h	S_a	S_r	S_f	$s(p)$, s/veh	D_1, s/h	D_2, s/h	TTT_D, s /h	FC, m^3
500	40	40	1.800	30	6	6	130.49	0	783	2.583	2.39
500	80	40	3.600	60	12	12	113.60	0	1.363	4.963	5.79
500	120	40	5.400	90	18	18	104.75	0	1.885	7.285	7.92
500	200	40	9.000	150	30	30	94.58	0	2.837	11.837	12.98
800	40	40	2.880	30	6	6	130.49	0	783	3.663	3.27
800	80	40	5.760	60	12	12	113.60	0	1.363	7.123	7.78
800	120	40	8.640	90	18	18	104.75	0	1.885	10.525	11.85
800	200	40	14.400	150	30	30	94.58	0	2.837	17.237	18.98

Case of IPA solution for parking management.

In this way, the road segment considered is approximately 40 m (L) length and it determines an unsatisfied stop demand equal to 60% (S_r–S_f) or 9 vehicles on 15 looking for a stall cannot be satisfied. To carry out the estimation of D_2, determined by calculating the average waiting time $s(p)$ through (3), it has been considered an increase of ϖ_I (the average parking time) because of the possibility of parking just at one side of carriageway for each direction. For the value of D_1, reference was made to reports in [21] as for scenario 1.

Starting from these estimates, Table 3 shows test findings as for scenario 1.

In case of use of the IPA solution for the scheme of Fig. 7*b*, the unsatisfied demand for parking is zero because the vehicles that slowdown to search for an available parking spot and perform the parking manoeuvres are only those with a valid reservation. Our findings show that IPA is even more beneficial than the standard solution for scenario 2 because of an increase on the waiting time average, $s(p)$, (see Table 4), which depends on both the major average parking time (ϖ_i) and the growth difference between S_a and S_r.

7 Conclusion

In this paper, we have presented a novel SPARK system, called IPA, for the management of the off-street parking spots in consolidated cities. IPA puts the management of parking spots into a different perspective that goes beyond the simple engineering (or automation) of parking system through the use of advanced ICT solutions, such as wireless networks and sensor communication. In fact, IPA is concerned with (i) the quality of life in modern cities, in terms of amount of pollution and effects of the urban traffic congestion on the abilities of the drivers and (ii) the quality of mobility in urban areas. Although IPA is still in a preliminary stage and the effects of its deployment on the environment and quality of life in the urban city have not be evaluated, simulation results seem to show that IPA may perform better that the conventional parking management solution when the demand for a parking spot is greater than the available parking spots. Future work includes more extensive investigation and modelling about parking allocation model, that is, calibrating parking disutility function for IPA solutions depending by neighbourhoods features. Further considerations would be made about evaluation of the revenue of the parking site.

Future releases of the IPA system will include:

– a module for the Smartphone App to navigate the users to the assigned parking spots using a vocal guide and
a module to use Bluetooth technology to complete the check-in process.

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