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A novel architecture of Parking management for Smart Cities

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Abstract

Parking is becoming an expensive resource in almost any major city in the world. Current technically advanced solutions for parking management are concerned with the application of secured wireless network and sensor communication for parking reservation. Moreover 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.
The paper discusses the conceptual architecture of IPA (Intelligent Parking Assistant) which aims at overcoming current parking management solutions and thereby becoming a leading paradigm for the so called "smart cities".

Keywords: Infrastructure management; Evaluation of operating conditions;Environmental policy.

1. Background

Nowadays, the term "Smart City" is very widely used in spatial planning literature or urban research. From literature the term is used for various aspects, which range from smart city as an IT-district to a smart city regarding the education (or smartness) of its inhabitants. In association with economy or jobs, smart city is used to describe a city with a "smart" industry. That implies especially industries in the fields of information and communication technologies (ICT) as well as other industries implying ICT in their production processes. In other literature the term smart city is referred to the relation between the city government responsible administration and its citizen. Good governance as an aspect of a smart administration often also referred to the usage of new channels of communication for the citizens, e.g. "e-governance" or "e-democracy". Smart city is furthermore used to discuss the use of modern technology in everyday urban life. This includes not only ICT but also, and especially, modern transport technologies. Logistics as well as new transport systems as "smart" systems that improve the urban traffic and the inhabitants' mobility. Moreover various other aspects referring to life in a city are mentioned in connection to the

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term smart city like security/safe, green, efficient & sustainable, energy etc. Finally, it can to identify six characteristics, see Fig. 1, as a roof for explanation of smart cities, which should allow an inclusion of additional factors:

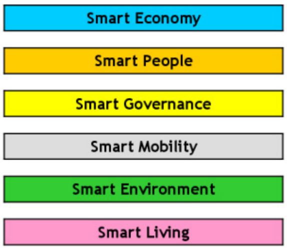

Figure 1. Factors contributing to Smart City definition, Centre of Regional Science (2007) [1]

Focusing on smart mobility features, local and international accessibility are important aspects 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 user request in terms of transport network efficiency and social sustainability. Because of urban traffic congestion and public transport policy, parking is becoming an expensive resource in almost any major city in the world, and its limited availability is a concurrent cause air pollution and detriment of the quality urban mobility. Further details about principles and weakness of urban mobility registered today in many consolidated cities will be discussed in section 2.

Current technically advanced solutions for parking management focus on parking lots. These techniques are concerned with the application of secured wireless network and sensor communication for parking reservation to avoid frauds to the parking company or administration. On the other hand, 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 paper will discuss a novel parking model called Intelligent Parking Assistant (IPA). It overcomes parking companies aims and it can be considered well embedded on smart cities architecture, because it evolves current parking management solutions and thereby could become a leading paradigm for next generation public parking management system.

2. Main characteristics and rules of urban mobility related to parking instances

The concern of mobility in urban areas in recent decades has become an increasingly serious problem and difficult to manage: the quality of life, not only of drivers, is strongly influenced due to inefficiencies and diseconomies of urban congestion. This raises also serious problems of pollution and noise and wide spaces of the city are occupied by parked cars. To this must be added that the costs and travel times are always increasing and that the mortality rate due to accidents in urban areas is very high. From a macro-economic point of view, the society "pays" a very high cost for urban mobility and each user adapts its travel patterns in order to reduce the structural deficit of the transport network. From the scientific point of view, the North American and European literature [2], [3] have approached the matter with the goal of mitigating the consequences of individual mobility trying to model the feature of traffic that occur during peak hours.

As it well known, Hensher and Button [4] traffic models allow both to analyze the current mobility scenario and, secondly, to evaluate the hypothesis of evolution of the network infrastructure and transportation system as a whole. A typical example is the analysis of the impact of new traffic and parking policies for vehicles through the introduction of so-called "Limited Traffic Zone (LTZ)" in the central parts of an urban area. In high density urban areas, cars represent a significant proportion of the total discomfort of the journey for a driver. The analysis of parking features is therefore relevant in determining the drivers' behavior assuming that they are eager to reach a target parking areas as close as possible to their own final destination. Therefore, in order to evaluate the effects of the main parking management strategies, it is necessary to estimate:

- Difficulty in reaching a parking lot;
- Level of use of a particular parking lot (occupancy rate);
- Impact of changes in demand for parking (number of arrivals and duration);
- Changes in the provision of parking areas (locations and number).

Parking areas are places of change of transport modality where user switch from vehicle to pedestrian mode, or from car to public transport mode, where the destination of the vehicle is the parking lot but it is not univocally determined. In fact, the motorist in making their choices of path takes account of a subset of parking spot and where possible the choice of parking that will access depends on the availability of parking stall when user enters.

In the static predictive models, the model simulates the assignment of drivers to the road network where each parking lot is assigned to the respective capacities and for different time periods is possible to determine the filling level of the parking lots at various times of the day, providing for the parking of a newly designed prediction on usage.

In dynamic predictive models, the model wants to predict the saturation of the parking lot. Usually, it is available the historical data on the number of stalls occupied (eg. every 10 minutes) in the working day average winter and sensors for the control of vehicles on the road network and / or at access points to the entry and exit, in the case of private parking lots, to update continuously the potential demand for parking. The model applies the temporal evolution of historical data to traffic measured in real time at a given time of the day, and determine an hypothesis of parking lot usage, usually with an advance of 20-30 minutes. This hypothesis is iteratively corrected every 10 minutes. The prediction provided by the models is used as input for addressing the parking of a dynamic type, that "guide" motorists to parking spaces available via variable message panels creating a dynamic navigation system search for parking.

Models used to address parking lot management provide decision support to each driver who being in the area of origin wants to reach a place of destination in the shortest possible time, having the need to park his car [5]. The optimal path can provide both car parking directly at the place of destination and also in the area of origin or in an intermediate zone and reaching the destination with a different mode (public transport, pedestrian, etc.). The itinerary provided by these models is optimal with regard to traffic conditions and the availability of parking observed at the time of the request of the move [6] making it very sensitive to the time interval considered (e.g. at peak hours).

Therefore, the parking management involves supply and organization of the private parking in designated areas or along the public roads. It represents not only an important strategic measure, but also 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 actions that affect the spatio-temporal allocation of stalls. Such activity is evident that influence traffic conditions on roads, determining an appreciable quality of flow and congestion. Traditionally, the actions undertaken in the parking management in an urban area include:

- Eliminate the parking stalls along some roads and regulation of parking only a few hours (e.g. peak hours);
- Adjust the number of stalls in public areas already equipped or be devoted to parking;
- Determine and differentiation parking rates depending on the length of time for parking,
- Define the location of areas suitable for intermodal transfer.

The choice in the parking management about different spatial charge, particularly in central urban areas, can, for example result in:

- A decrease in the number of parking spaces occupied in an area;
- An increase of parking spaces occupied in the surrounding areas;
- Changes to the areas of congestion,
- A change in the average walking time,
- A change of modal split,

3. Main weakness in stratified urban area

Private mobility in urban areas has several critical aspects on its own which are worsen by the critical issues typical of cities consolidated with respect to town planning and transport networks

In fact, as it can often be found in medium and large Italian cities, the evolution of the urban fabric is characterized by a stratification and hierarchy both of buildings and roads that is not suitable to functional and / or structural changes. That determines to one side in the concentric localization of residential, economic and trade activities; to the other side into a constant gap between increasing demand and strengthening the infrastructure of public transport. In other words, the economic and social development of a medium-sized cities in Italy is only manageable through the increase in private transport with subsequent failure of the road network, deterioration of the sustainability of road traffic and inability to meet vehicle parking demand.

A famous example of what described above can be observe in the city of Milan, where over the past 50 years urban and infrastructure growth has been characterized by the search for solutions that make a balance between city sustainability and people and goods mobility. Of course the discussion of the characteristics of urban mobility in the city of Milan is beyond the scope of the paper, but merely observing that only data which in the past decade (2001-2010) are referred to the planning of parking areas, it can draw significant conclusions about the limits placed on the car parking management in many Italian urban contexts. From the data of the total parking supply in the town of Milan in 2001, is possible to observe the high incidence of overall parked outside platform (approximately 19%). In 2001 has been estimated that less than one third of this amount (about 6% of total) was regular and that the remainder (13% of the total) must be considered to be irregular or excess capacity to stop. These data are shown in summary in Figures 2 and 3 respectively, and for case day and night, [7] .

The spatial distribution of the regulated parking ranged from 100% in the central city to 7-10% in areas of the city arranged on concentric circles gradually peripheral. The density range of parking stalls per km of road network showed strong territorial discontinuities, from 90 stalls / km of network in the central areas, to 180 stalls / km in the intermediate areas and 277 stalls / km in the outer zones. This distribution highlights how in the areas of highest potential demand for parking inversely match the available supply. This is verified even if one considers the density of stalls in function of the residents (reference overnight stop), in that the share of off-road parking shows a high variability linked to the urban structure, the availability of parking on private areas surface or groundwater.

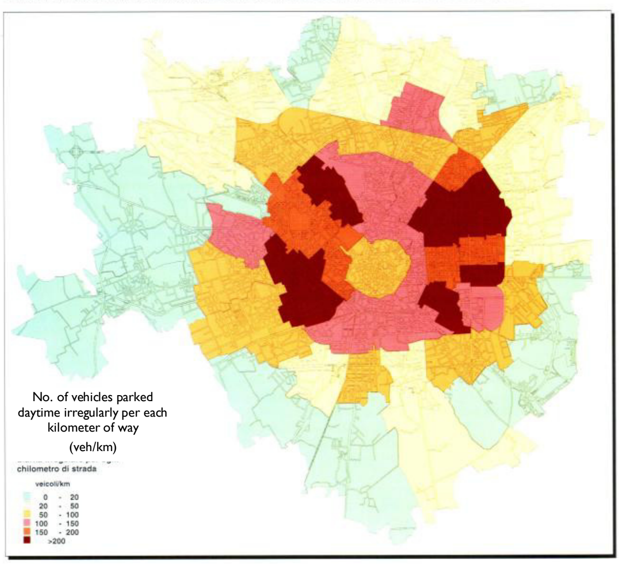

Figure 2. Parking demand during the day throughout Milan neighborhoods (year 2001), [7]

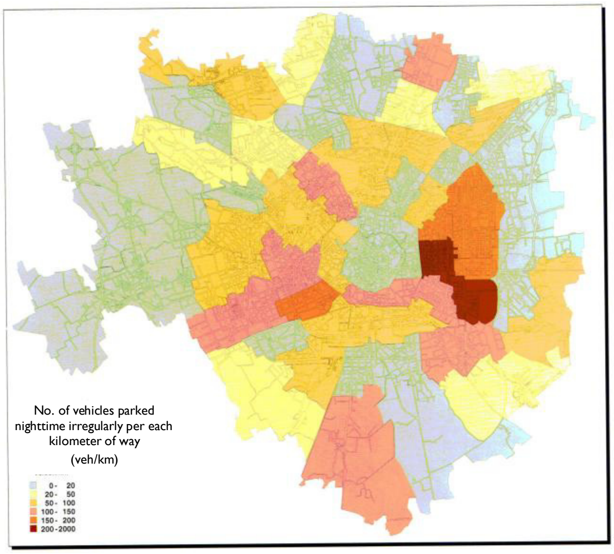

Figure 3. Parking demand during the night throughout Milan neighborhoods (year 2001), [7]

The car parking management, as demonstrated by the example of the city of Milan, certainly raise significant problems regarding environmental sustainability and urban quality of life. From the specific standpoint of environmental, the search of the parking area is able to generate the so-called "traffic parasite", exactly vehicles that are present in the traffic flow but searching free parking stall. These conditions result in a peak increase of about 25-40% of the traffic flows, the formation of queues and of traffic crashes causing the total deterioration of the level of service available. More often, parking research could determine illegal double parking which is a key contributor to congestion on major corridors. Whilst local congestion is inevitable there is often a wide-ranging impact on the network. Simply lane blocking reduces the capacity of the street to handle the normal traffic flow and has particularly detrimental effects when the double parking occurs during peak commuting hours. Illegal double parking creates other negative impacts:

- increased traffic on residential streets when motorists rat-run to avoid congestion on major corridors;
- degradation in the quality of bus services in the locality;
- increase accident risk for pedestrians when double-parked cars block sight lines;
- safety concerns for motorists and cyclists manoeuvring around double-parked cars;
- elevated pollution levels;
- unnecessary use of fuel and elevated carbon emissions.

A research released by Bell and Galatioto [8] observing many arterials in the city of Palermo has provided the evaluation of the illegal parking impact in terms of congestion. Principal considerations were:

- congestion levels increase generally over 50% with peaks of 200% in function of the illegal double parking duration;
- negative effects are quantify for illegal double parking durations over 5-6 minutes (in single events or cumulative);
- capacity reduces about 15-30%,

About impact on emissions level, effects length normalised with a flow 800 veh/h and illegal parking between two closely signalised junctions for durations over 18 minutes determine extra CO emissions about 20%. Emission effects length normalised with a flow 1,200 veh/h and illegal parking, determine extra CO emissions about 26.5 %.

In order to calculate the specific contribution of delay and cruise events due to parking lot management, it is possible to aggregate speed/acceleration frequency distributions (SAFDs) elements with regard to idle, acceleration, deceleration and cruise modes. Emission factors related to each elementary event can then be obtained using partial aggregation of distributions as input to Comprehensive Modal Emission Model (CMEM) [9]. Moreover, a decision criterion has been stated for the analysis of SAFDs - both for uncongested and congested conditions - as well as for intermediate volume-to-capacity ratios. Application of this criterion for the arterial SADFs analysis in the different traffic conditions (from uncongested to congested situations) lead to identify proportion of time spent by vehicles in each modal activity as shown in Table 1 [10]

Table 1. Proportion of time spent by vehicles in each modal activity

Average Speed/Free-flow-speed	% time spent by traffic event			
	Idle	Acc	Dec	Cruise
0,65	20,99	10,77	8,01	60,23
0,50	34,41	11,16	8,31	46,10
0,40	43,59	11,43	8,51	36,45
0,30	52,76	11,70	8,72	26,80
0,28	53,88	11,74	8,75	25,63

All above considerations suggest to improve actual parking policies in order both to contribute to environmental protection in urban areas and to perform better road traffic issue. The proposed Intelligent Parking Assistant (IPA) showed in section 3 could address environmental and road traffic features.

4. Parking design models

For the analysis and evaluation of strategies for parking management can adopt two classes of parking design models. The first is based on optimization techniques that aim to minimize the total distance that users need to walk from parking areas to the areas of destination. This is to minimize the objective function disutility or total impedance U(pi, t) of a parking pi, for a duration time unit t, subject to the constraints of supply and demand, expressed as:

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

where:

- $w(p_i)$ represents the time needed to walk more and leave the car park to reach the nearest bus stop;
- $f(p_i, t)$ 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, [11], [12].

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

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

where η_j is the number of stalls employed in p_j at the time when the route O/D 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:

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

where ϖ_i is the average parking time at p_i.

The second class consists of models in which balance demand and supply of parking lot until it reaches a state of equilibrium. Therefore, in this case the stalls are allocated according to the users destinations and according to a function based on the repulsion distance. So by means of a distribution function of type Logit multinomial, it is determined the probability with which a driver associated with the *k-th* pair O/D uses the parking $p \in P(k)$, or the set of the parking lot useful for the pair O/D, by the expression:

$$\Pr(k, p) = \frac{e^{-\alpha c_{kp}}}{\sum_{q \in P(k))} e^{-\alpha c_{kp}}}, \forall k \in K \qquad (4)$$

where c_{kp} represents the generalized cost of transportation of the shortest path associated to the pair (k, p).

From the demand t_k of *k-th* O/D pair to get the number of users x_{kp} wishing to use the parking p through the expression:

$$x_{kp} = \Pr(k, p) \cdot t_k, \forall p \in P(k), k \in K \qquad (5)$$

which yields the number of x_p users who want access to the parking lot p:

$$x_p = \sum_{k \in K} x_{kp}, \forall p \in P \qquad (6)$$

where the sum is extended only to the O/D pairs that have parking p as useful and P denotes the set of all the parking area of destination. The iteration of the model can converge towards a solution "stable" in which the choice of parking and route can be considered equilibrium.

5. Intelligent parking assistant

Public off-street parking spaces are currently managed across Italy without any semi-automatic mechanism. The Parking Agency has therefore concerns about inefficiencies of sub-optimal usage of parking space (lost opportunity/profit). Currently, the Parking Agency monitors the parking spaces occupancy by having employees walk around the decks to inspect the occupancy of individual spots. This is obviously a time-consuming and not efficient patrolling method that has a severe effect of the revenues, for example, a not authorized driver may been able to leave the irregularly occupied parking space (i.e., he/she has not paid the due fee) before that any of employees has had the chance to control his/her parking ticket. The public parking system arranged by IPA project will be partially remodeled, so that off-street public parking spaces can be used only by authorized users upon reservation. An authorized user is a customer that is registered at the IPA website and has a reservation confirmation number. In the rest of the paper, we will refer to an off-street public space managed by IPA as IPA parking spot/space. The IPA system will mostly based on Wireless sensor networks similarly to previous approaches deployed for an intelligent management of parking lots [13], [14], [15]. The following devices will be installed inside each IPA parking space in order to properly deploy the IPA architecture:

- a sensor that detect the occupancy of the spot by a vehicle. The sensor could be based on visible or infra-red light, ultrasound, or a similar sensing technique;
- a rollway post/barrier for each parking spot to guarantee the reservation and prevent unauthorized drivers from entering a IPA parking space;
- a wireless transceiver allows communication with the other IPA modules. The transceiver is a zigbee devices; the wireless transceiver can be Wi-Fi wireless network or a Wireless Lan (WLan) network.
- a unit controller (a processor) embedded into the rollway post that manages IPA parking functionalities, e.g., status of the parking spot.

The IPA architecture will be developed to comply with the following business rules:

- B1. Reservation confirmation numbers can be delivered only to authorized customers.
- B2. A reservation is held for a “grace period” (e.g., 15 minutes) 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, an SMS 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. An SMS 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 one-hour 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 a SMS.
- B8. The system cannot overbook the parking space reservations.
- B9. Reservation must always be warranted. To fulfill 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 authorized customer who find 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.

6. IPA architectural model

The IPA architecture consists of five modules, as shown in the deployment diagram shown in Figure 4. These modules are the user interface module, the function module, the manager interface module, the parking space controller module, and the communication module.

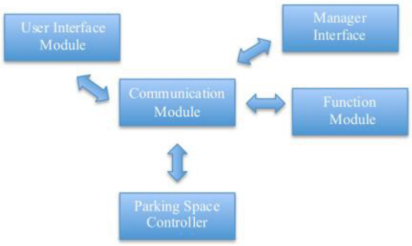

Figure 4. A block scheme of the IPA architecture.

User Interface Module: this subsystem is a core module of the IPA system. It manages the communication with the customer during all phases requiring an interaction with the user, for example, accounting, reservation, cancellation, and billing. This module communicates with the function module thanks to the communication module.

2) Communication Module: this sub-module receives and transmits messages between sender and receiver. 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 enhanced message correctness because the communication response time is strict.

3) Function Module: this functional block is a core module of the IPA system. It consists of servers and a relational database that records all the events the system goes through every day. The database contains various information, including:

- information about the registered customers;
- the occupancy state of each parking spot: “available,” “reserved,” or “occupied”;
- current parking reservations;
- the 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;

The function module communicates to hard devices and transmit/receive data without having to know the detail of the driving protocol through the communication module.

4) Parking Space Controller Module: it is responsible for the communication with hardware devices and sensors. It consists of sensors, and 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. the rollway plunger is opened/close). The unit controller receives the information and sends information to the Function module to record the action.

7. IPA software module

The functional organization, server-side, of the IPA software is shown in Figure 5. There are several modules that will be described in the following sections.

1) User Computer Interaction: 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, are supported by this module. This module is implemented as a Java server-side application that accepts client connections and interacts with the relational database to process the client requests.

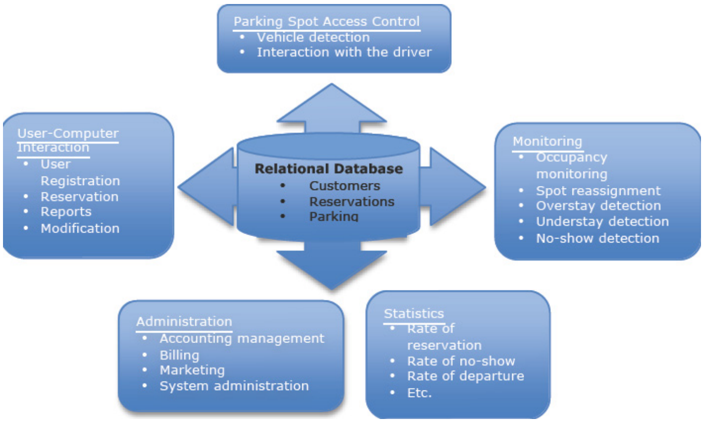

Figure 5. Functional organization of the server side of the IPA parking software

This module has been implemented to comply with the business policy (B8); therefore, overbooking will not be allowed. Some implementation issue considered during the design of this module were: a) Remote reservation can be accomplished using a remote client running on either a regular computer, or a smart-phone (or another small smart device); therefore, the number of data entries required by the user should be kept at a minimum. A regular computer connected to the Internet has to be used for all other activities, such as registration of new customers and general account management; b) this module queries the relational database and seek for the available spots during the interval that the customer specified in order to support requests for parking space reservation.

2) Parking Spot Access Control: this functional module manages the access to the IPA parking spaces. This functionality includes processing the data generated by users and by the IPA system (e.g., data generated by the sensors) in order to implement the business policies (B1), (B5), (B7), and (B10).

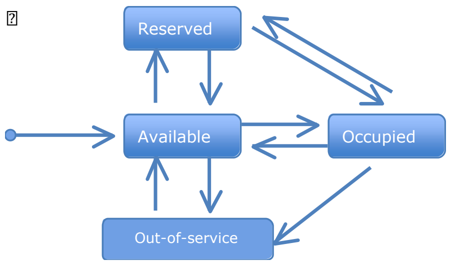

Figure 6. State diagram for an individual parking spot

Monitoring Module: Figure 6 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 current status for each individual parking spot is recorded in the relational database. This module ensures that only the allowed state transitions shown in Figure 6 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.

4) 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;
- special fees for overstays.

This module implements a system for billing reserved occupancy time, extensions, overstays. Periodically (e.g., once a week), the system examines the list of transactions for all customers and generates a weekly statement. IPA managers should be able to view various statistical charts about IPA spots occupancy over different periods (day, week, month, etc.), number of overbooked reservations, number of customers who were turned away because of overbooking, number of customers who do not show up, depart earlier than booked, or overstay, average duration of overstays, etc. Management of malfunctioning and regular maintenance of the IPA parking spaces will be implemented in this module.

8. Preliminary evaluation of IPA solution

In order to illustrate some advantages of IPA solution compared to the conventional parking management system, different traffic scenarios have been studied. In these studies, we assume that either the system IPA is used by all vehicles in the traffic flow, 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, etc.) are estimated. Figure 7 display 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.

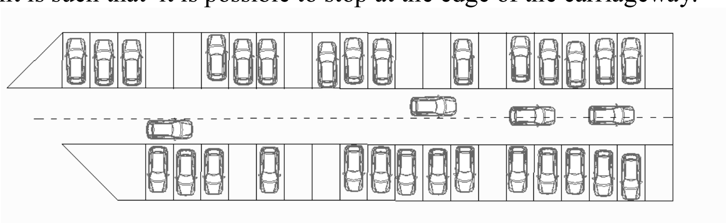

Figure 7. Scheme of urban road segment with parking stall on both edge of carriageway

The above scenario assumes 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 Eq. (2), i.e., 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) which must be added to the delay determined by the vehicles that finding a stall free perform the parking maneuver (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 Thompson and Richardson [16].

Starting from these estimates, Table 2 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 due to delay D1 and D_2;
- Fuel consumption (FC) for all vehicles traveling along L, as calculated from the Laboratory of Applied Thermodynamics (1998).

Table 2 shows the estimates of the efficiency parameters for different values of Q considered.

Table 2. Estimates of main efficiency parameters. Case of traditional parking management

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

In case of use of the IPA solution for the scheme of Figure 7, the unsatisfied demand for parking is zero because the vehicles that slowdown to search for a stall and to perform the parking maneuver 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 3].

Table 3. Estimates of main efficiency parameters. Case of IPA solution for parking management

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

9. Conclusions

In this paper, we have presented a novel smart parking 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 (1) 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 (2) 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 seems 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 modeling about parking allocation model, i.e. calibrating parking disutility function for IPA solutions depending by neighborhoods features. Further considerations it would be make about evaluation of the revenue of the parking site.

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