ADVANCES IN CYBER-PHYSICAL SYSTEMS

Vol. 2, No. 2, 2017

CYBER-PHYSICAL SYSTEM OF PARKING LOT OPERATION

Andriy Salo

Lviv Polytechnic National University, 12, S. Bandera str., Lviv, 79013, Ukraine
Authors e-mail: *ansalo@yahoo.com*

Submitted on 09.11.2017

Abstract: **Multilevel structure of cyber physical parking lot operation system. Classification of the ways of driver identification has been given. The functions and algorithms of parking lot equipment unit's work have been described. The succession of cars entering the parking lot has been shown. Structural scheme of parking equipment control board has been suggested. The calculation methods of the configuration parameters for cyber physical parking lots operation system have been produced.**

Index Terms: **vending, cyber physical systems, vending cyber physical systems, parking lot operation, processing, monitoring, vending machines, server system, database, transaction, configuration, physical world, automated system.**

I. INTRODUCTION

Increase in vehicles in cities leads to the lack of parking places and transport collapse. Parking lot gives the country and city council an opportunity to get additional payments from cars owners. That is why the issue of parking arrangement every year is getting more and more attention.

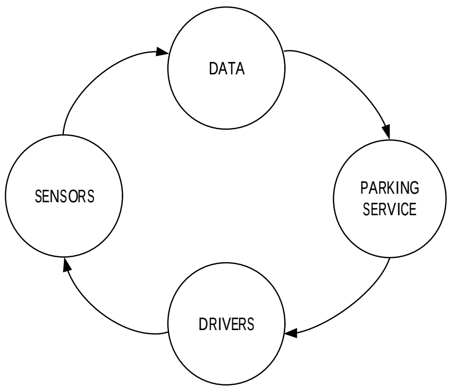

Fig. 1 Parking functioning process

Parking lots can be open and close. In open parking lots a parking meter is used for payment. There is no limiting equipment for entering or leaving the parking. For close parking lots automated parking systems (APS) are used. There are special racks with barriers, which give an opportunity to fix entrance and leaving time and to check if the payment was done. ASP are set on the territory of malls, markets and special municipal areas, parking lots near houses etc. Next we are observing systems for close parking lots. To choose the correct equipment configuration for ASP there must be information on the regime of parking functioning namely: intensity of car arriving and leaving, time of being on the parking lot, parking lot capacity, queue length, parking cost, public transport routes. On the first stage when infrastructure is not developed and there is lack of information on real processes forecasting methods are used. To use forecast models mathematical statistics and probability theory must be used. Almost all methods and models are used for the assumption that arriving to the parking lot is subject to the Poisson distribution, and duration of being on the parking lot is described by negative exponential distribution [6]. During the exploitation statistical information, which gives an opportunity to correct equipment configuration, must be used. As it is shown in the Fig. 1, using parking equipment and sensors drivers give the data that we can analyze and provide high quality parking service.

II. FORMULATION OF THE PROBLEM

To suggest cyber-physical parking control system (CPPCS) of close type, which allows managing parking lots effectively within a city. To show a model of close parking work, to describe functions of each CPPCS unit, to suggest the ways of customer identification. To provide the methods of parking lot configuration parameters calculation. Hard– and software complex equipment of close parking operation is supposed to keep track of present on the parking vehicles, to fix the time of arriving and leaving and the term of the vehicle stay at the parking lot, to define the fee and the number of free places at the parking lot, and to register settlement operations.

III. ORGANIZATION OF PARKING IN BIG CITIES AND EQUIPMENT FUNCTIONS

Fig. 2 shows organizational hierarchical structure, which allows to build one cyber-physical system of parking operation within a city, and anticipates cooperation within public-private partnership. Such system is to let exploitation of separate parking lots by different organizations, and data is transmitted to the central server that will enable town hall to make adjustments. Having the data the city hall will make more effective decisions on creating new parking lots, tariff formation, etc.

IV.WAYS OF A DRIVER IDENTIFICATION

Customer identification is crucial for parking functioning. On logical level identifications (cards) are used. Guest card – a single card – is used within parking zone to provide customer entrance/exit. Permanent cards are divided into debit and service. Debit (replenishing) card – is a multiple card with unique number that is put in car park data base. The card is beneficial for a customer who regularly uses the car park. It is also beneficial for an operator as, in fact, a customer pays in advance. Debit cards give an opportunity to launch loyalty system for customers. Service card is a multiple one with a unique number and provides free access to the car park for the staff. In physical execution card codes (identifiers) and information can be contained on paper as a bar code QR code, on plastic cards written on special RFID marks or in mobile phone (Fig. 3). On this stage for identification most parking systems use paper parking ticket that is rather ineffective decision regarding price and comfort of use. RFID (Radio frequency identification) uses electromagnetic fields to identify and track attached to the objects marks [3]. Analyzing disadvantages and advantages of each way, we can conclude that for guest and permanent cards the best option is to use Mifare-technology. Additional perspective technology is Ibeacon with its own special application for a mobile phone.

V. STRUCTURE OF CYBER-PHYSICAL SYSTEM OF PARKING LOT OPERATION

According to modern demands cyber-physical system of parking lot operation must have such functions:

– to administrate parking lot functioning (all data accumulation, storage and analysis);
– configuration for the given parking lot;
– analysis, which allows CPPCS improvement during operation;
– management of temporary customers parking;
– management of permanent customers parking;
– payment control;
– electronic journal keeping;
– accounting and statistics;
– control of permanent clients' cards use;
– equipment service and monitoring;
– information Import (export) in different accounting system.

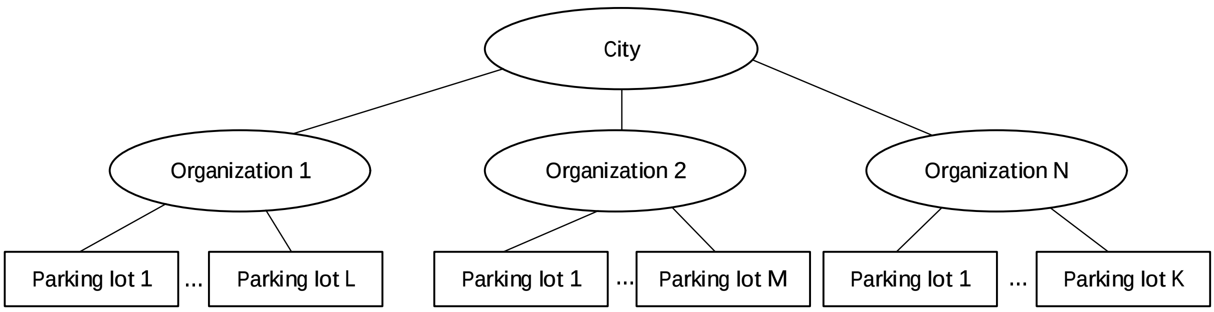

Fig. 2. Organizational structure of parking lots in a city

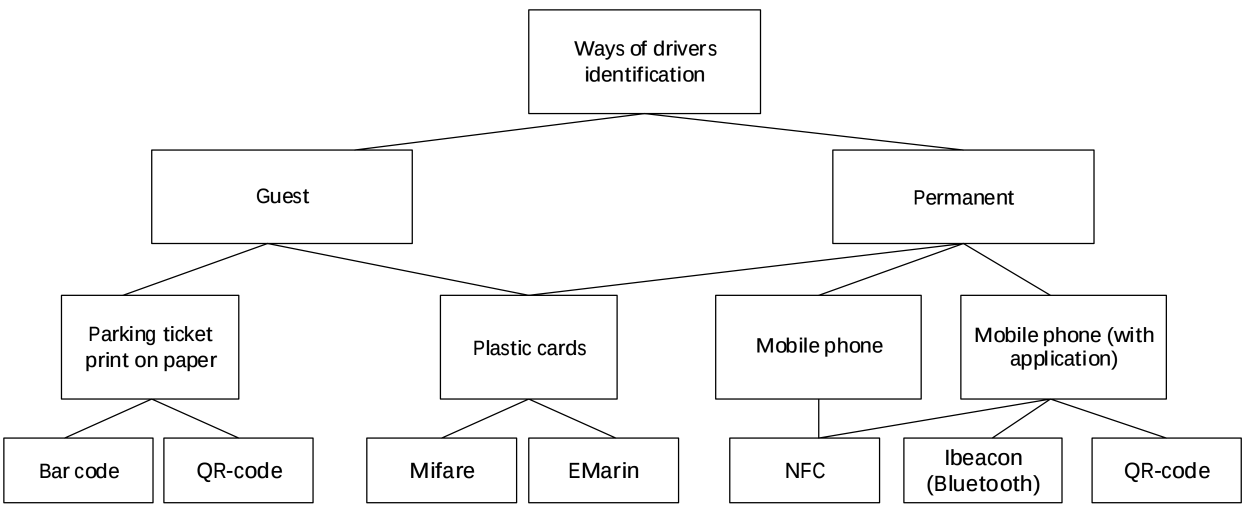

Fig. 3 Ways of drivers identification on parking lots

To create CPPCS based on the principles of build-up and scalability and to provide minimal lifetime and execution of the above mentioned functions. It is suggested to use multilevel basic cyber-physical system platform [1, 2, 4]. We are to show the position of each CPPCS component:

0-level. Physical world (a driver, parking service, money, service department, collector, analysts, managers, officials);

1-st level. Means of interaction with the physical world (parking equipment, barriers, parking meters, counters, inductive loops, traffic lights, etc.);

2-nd level. Means of information collection and delivery (GSM, WIFI, LAN modules, the Internet, etc.);

3-rd level. Means of information processing (server hard– and software complex);

4-th level. Means of decision making (analytical system);

5-th level. Means of personal service (Visualization means based of PC and smartphones).

In Fig. 4 there is general structure of soft– and hardware complex of a close parking lot, developed basing on multilevel cyber-physical system platform.

A. Parking equipment

Entry counter functions (EC):

– guest cards delivery;

– entrance by subscription and service cards;

– entrance barrier control;

– information record on entry time and other events into the database;

– notification that the cards number in the counter is less than the defined one;

– reaction on induction loops condition.

Exit counter functions (ExC):

– guest cards reading and capturing, or a guest card returning with the notification on the board about the need to pay;

– subscription and service cards reading;

– record of information on exit time and other events into the database;

– exit barrier operation;

– reaction on induction loops condition.

Server software functions:

– parking lot ACS elements condition control.

– transactions operation;

– providing the procedure of the system software units update;

– providing the access to remote working cabinet.

Payment terminal functions (PT):

-payment for parking services by guest cards with Ukraine National Bank banknotes, receipt delivery;

– subscription cards sale;

– payment of fines, e.g. for card loss;

– information record on payment and other events into the database.

Software functions in a parking lot administrator's office:

– reading, with display on the board, current card data;

– display of information on the status of ACS elements on the information board;

– record of service cards into the system and, if necessary, their deletion (blocking);

– service reports formation.

Functions of the monitoring system remote working cabinet:

– output of close parking lot ACS equipment condition.

– financial reports formation;

– all card types accounting;

– parking lot equipment configuration formation;

– upgraded terminal software firmware;

– collection accounting.

Further entry counter work is described. Other equipment configuration and work algorithms are the same.

B. Entry counter work algorithm

Parking lot entry organization is shown on the Fig. 5.

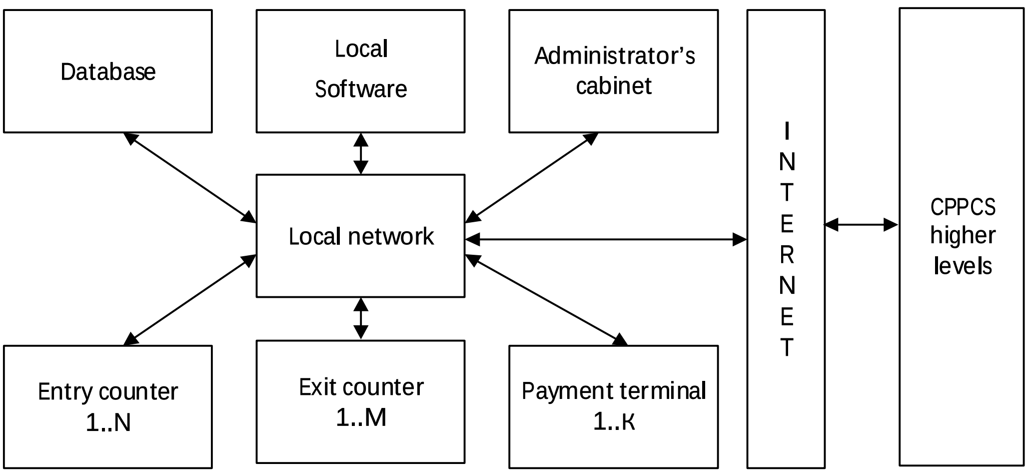

Fig. 4. Close parking lot general structure

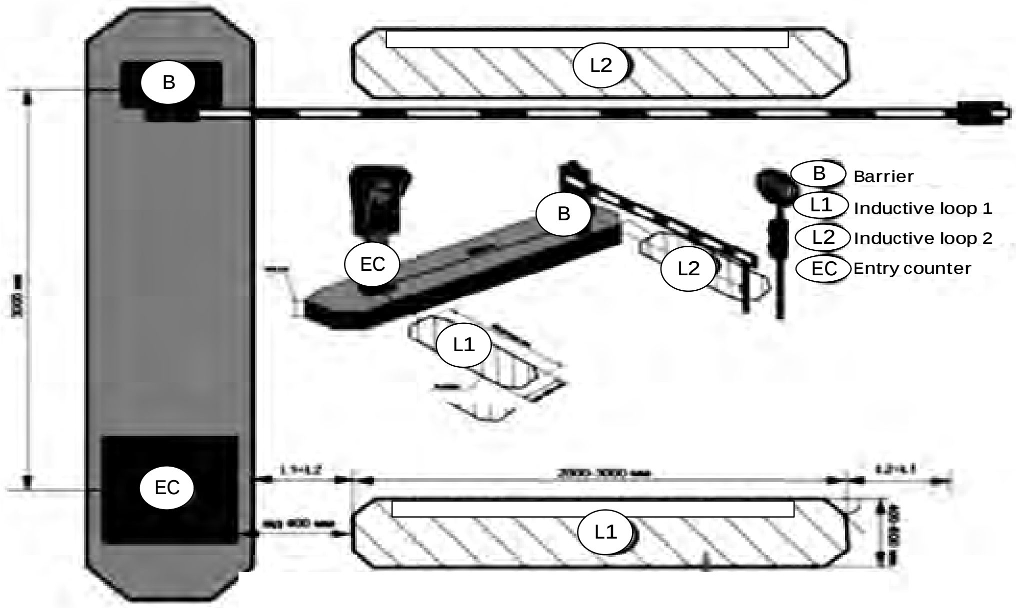

Fig. 5. Parking lot entry organization

For example, we will observe organization of interaction between drivers and CPPCS with the use of contactless plastic cards. A driver approaches an entry counter (EC). The car is over an induction loop (L1). On the entry counter indicator a request to present the card or to press the button to get a card appears. The driver presses the counter button and gets an identificator: guest contactless electronic plastic (CEP) card. The system fixes entry time by the card in the database (or on the card). Traffic light automatically turns green. The barrier (B) opens and lets a car into the parking lot. If the car did not enter during 30 seconds, the barrier automatically closes. The traffic light turns red. The given card is included into the stop-list. Exit by this card is blocked. If the car enters the parking lot, the barrier automatically closes. Crossing of the second induction loop (L2) by the car informs the system about correct entry. Countdown of the time, the car spends on the parking lot, starts. Also all necessary entry data are noted:
entry time, card that enabled the entry and other parameters. All the data is transmitted to the database of the parking lot server and to the parking lots data processing center. For permanent parking lot customers use of CEP special type cards that will always be by the customer is possible. They can be subscription cards for some period, debit cards for certain sum of money, service cards. A user, who has such active card presents it to the system while entering and exiting. At the same time the system defines this card legality, checks presence of money on the debit card and reduces account balance at the exit by the sum of parking services. For such visitors' entrance, there is a reader in the counter. While entering a parking lot a driver inserts the card, making it active for this specific parking lot. At the same time on the information board there is 'Account balance e.g. 10 UAN' and entry barrier opens.

VI. METHODS OF DEFINING CPPCS EQUIPMENT CONFIGURATION AND PARAMETERS.

Order of parking lot equipment configuration search:

1. To define efficiency of each equipment type.
2. To define traffic intensity and average time of car presence at rush hours (in Fig. 7 there is the intensity of supermarket parking lot filling up, obviously, it is enough to measure the stream from 5 to 8 pm).
3. We directly define this specific parking lot equipment configuration.

Let us find one car pass time using EC (Fig. 6).

$$t_{EC} = t_{st1} + \max(t_{st2}, t_{st0}), \qquad (1)$$

where t_{sts} – car's pass time of stages s={0,1,2}.

Cars pass efficiency through EC:

$$m_{EC} = \frac{1}{t_{EC}} \qquad (2)$$

According to formula (1) time of barrier opening/closing, card issue, car speed (individual, depends on the driver's skills and character) influence EC efficiency. Using formula (1) and statistical data and equipment characteristics, we can find one car pass time, which is from 12 to 18 seconds. Card issue time is 1 second due to previous preparations at the moment of barrier opening. Correspondingly, we can define other parking lot terminal equipment.

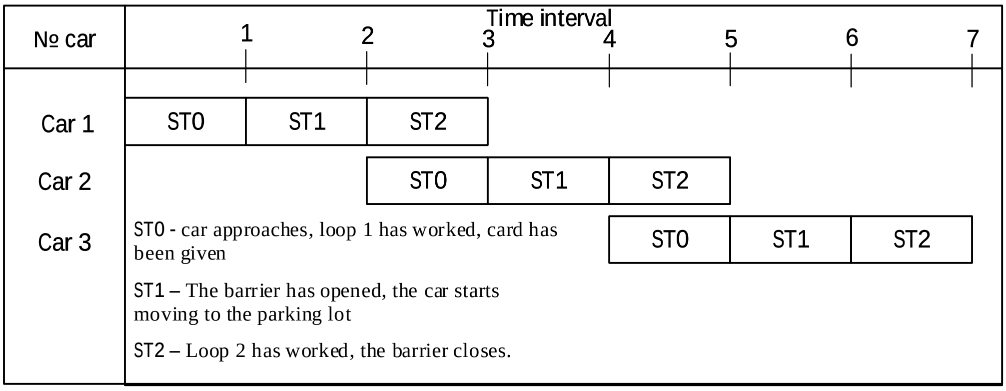

Fig. 6. Sequence of car entry to the parking lot through EC

Next step is to measure average time of a car's being at the parking lot and the intensity of a parking lot filling up. Experimentally we define that one supermarket parking lot has 140 places, the highest intensity, almost 100% we can observe from 5 to 8 pm, and average time, spent there is 30 minutes.

Let us look at a parking lot as multi-canal mass service system with unlimited queue (MCMSS). In fact, there are four subsystems that can be described by MCMSS rules. If we count parameters of each of them, we will get CPPCS configuration. Each MCMSS is characterized by such parameters [5]:

1) λ – intensity of cars coming to the parking lot (cars per hour);

2) μ – service traffic intensity (number of cars that park for an hour; number of cars that can be serviced by the terminal for an hour);

3) n – number of service canals (number of places at the parking lot; number of counters; number of payment terminals);

4)
$$r = \frac{l}{m}, \tag{3}$$

parking lot (equipment) commitment factor;

5)
$$j = \frac{r}{n} < 1, \tag{4}$$

condition of permanent mode existence.

Probability of car absence at a parking lot:

$$P_0 = \frac{1}{1 + \frac{r}{1!} + \frac{r^2}{2!} ... + \frac{r^{n-1}}{(n-1)!} + \frac{r^n}{(n-1)!} * \frac{1}{n-r}}. \tag{5}$$

Average number of cars in the queue:

$$Lq = \frac{p^{n+1}}{n!} * \frac{n}{(n-p)^2} P_0 . \tag{6}$$

Average time spent at the parking lot:

$$t_n = \frac{Lq}{l} + \frac{1}{m}. \tag{7}$$

In table 1 there is possible EC configuration for t_{EC} = 15 sec (a barrier with ordinary characteristics).

Correct choice is 2 EC. Correspondingly to the given parking lot, it was defined that 2 PT and 3 ExC are necessary.

VII. SYSTEM WORKING CAPACITY CHECK

Practical system implementation has shown configurational parameters choice correctness. As it is shown in the Fig. 8, real number of cars present at the parking lot absolutely correlates with the graph in the Fig. 7.

Fig. 7. Intensity of parking lot filling up during the day (theoretically)

Fig. 8. The intensity of parking lot filling up during the day (practical realization)

Other parameters also state that they do not exceed the calculated ones. If usage of CPPCS gives information that equipment does not cope, it is necessary to change the configuration.

Table 1

Possible equipment configurations

Number, n / Parameters	1	2	3
φ	1.125	0.5625	0.37
P_0	-0.125	0.3247	0.61
L_q	-10.125	0.6039	0.14
t_p, sec	-120	23.052	16.87

VIII. CONCLUSIONS

Multilevel cyber-physical system of parking lot operation structure has been suggested. The methods of its configuration parameters calculation have been presented. It has been shown that theoretical results coincide with practical ones with quite high probability. Means of drivers' identification classification at a parking lot has been presented. Parking equipment units functions and algorithms have been given.

REFERENCES

[1] Melnyk A. O. Multilevel basic cyber-physical system platform // Cyber-physical systems: achievements and challenges. First scientific seminar materials (June 25–26). – Lviv, 2015. – p. 5–15.

[2] Salo A. M., Kravets O. I. Vending machine architecture // Lviv Polytechnic National University Herald. Series "Computer systems and networks". – 2014. – No. 806. – p. 240–246.

[3] A. Barsegian, M. Kupriyanov, I. Holod, S. Elizarov, M. Tess. Analysis of data and processes: from standart to realtime data mining. ReDi Roma-Verlag. – 2014/ – 300 p.

[4] Salo A. M. The principle of monitoring vending machine creation. Lviv Polytechnic National University Herald. Series "Computer systems and networks". – 2013. – No. 773, pp. 112–118.

[5] Ventsel E. C. Operation research. – M.: Nauka, 1980. – 206 p.

[6] Klinkovstein, M. B. Afanasiev. – 5-th ed., improved and supplemented. – M.: Transport, 2001. – 231 p.

[7] Kaur, M., Sandhu, M., Mohan, N., Sandhu, P.S.: RFID technology principles, advantages, limitations & its applications. Int. J. Comput. Electr. Eng. 3, 2011. – 151–157 p.

[8] RFID Journal. Available online: http://www.rfidjournal.com/ healthcare (accessed on 17 August 2017).

Author received the B.S. degree in computer engineering in 1999. M.S. degree in specialized computer systems was received in 2000 and the Ph.D. degree in computer systems and components in 2008. All degree was received in National University "Lviv Polytechnic", Lviv, Ukraine. From 2001 to 2011 he was an assistant(2001 to 2005) and senior lecturer (2005–2010). Since 2011, he has been an Assistant Proffesor at the Department of Computer Engineering in National University "Lviv Polytechnic", Lviv, Ukraine. He is getting the DSc degree in computer systems and components. He the author of more than 33 articles and has developed more than 11 big IT projects. His research interests include the design and manufacture of embedded systems, high-performance computer systems, vending cyber-physical systems.