Parking Management System with Dynamic Pricing and Personalized Assistant Application

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1. Introduction

Nowadays, urban mobility demands are not primarily satisfied with the extension of the transport network, but with the **development of transportation management**. More and more attention is paid to devices and procedures that aid travellers with intelligent solutions. A significant part of urban road traffic is caused by vehicles cruising for car park (Allen, 1993), (Shoup, 2006). These vehicles not only make confused unnecessary movements, but their uncertainty induces disturbances and enhances the risk of accidents as well. There are two main types of measures to manage this problem:

1. pricing policy and/or
2. **intelligent transportation systems.**

Volume of cruising traffic can be moderated by introduction of parking charge and increasing fees (Simićević et al., 2013). This measure is not a primary solution, because only the symptoms and not the source of the problem is treated (Verhoef et al., 1995). Origin of the problem: the travellers do not receive personalized information aiding their decisions regarding (among other transportation related issues) parking at the right time.

Microscopic methods that are more flexible and effective on a certain area have been superseded by macroscopic policies that are simplified and aggregated (Arnott et al., 2007).

Ideally, travellers are supported by route planners that plan the ETC and assist its realization. Such complex route planners are still not in widespread public use. Their realization has been hindered by several obstacles (often conflicts between the transportation operators). For individual travellers, one of the **most critical phases** of the ETC is accessibility to free parking spaces (Shoup, 2006). Successful execution of this phase greatly facilitates the optimal (personalized) realization of the ETC.

Urban road traffic volume can be significantly reduced by dynamic (using real-time data) parking management (Ommeren et al., 2012), (Klappenecker et al., 2014), (Caicedo, 2010) (Giuffrè et al., 2012). This statement has also been proved by results from the San Francisco real-time parking management system (Rodier et al., 2010). Real-time parking space occupancy can be effectively collected by local sensors. Conception of intelligent parking management using sensor network has been already realized (Tang et al., 2006). Parking management is part of the entire infrastructure management. State of the art booking theory regarding the infrastructure elements has already been devised (Soltész et al., 2011). The dynamic capacity and usage level of the parking systems greatly depend on their accessibility, which is affected by both physical barriers and a lack of information. The accessibility of information can be significantly improved by personalized information, parking facility booking and advanced fee collection (payment) functions (Heckenast et al., 2008).

Our recent research focused on parking planning and the related traveller habits. Modern and widespread applied **parking assistant applications (PAA) have been investigated and compared**. It has been kept in mind that parking management should be integrated into the entire transportation management (Sándor et al., 2013).

It is an existing problem that travellers are provided with collective information instead of personalized information. The revealing of travellers' demands should be considered with higher importance during the development of the PAS (Thompson et al., 1997). For this purpose **travellers' parking habits and expectations have been surveyed**. Personalized PAAs may also reduce travel time and energy consumption (Jong-Ho et al., 2014).

Based on these results structural and functional **conception of the advanced PAS has been framed**. The information provision service has been devised in details and a **muster application has been developed**. It aids travellers before and during their movements. The applied terminal is a **mobile smart device** (for example smartphone).

2. Situation analysis

Situation analysis has been executed in the following regards:

1. 11 PAAs have been analysed and compared.
2. 160 people have been interviewed to get to know their expectations and habits as well as

the characteristics of their decisions.

These tasks have been performed in parallel. Based on the results, the most important requirements towards PAAs have been identified. The innovative properties have been derived from these requirements. Presence of these properties in the existing applications has been reviewed and the obstacles of their spread have been identified. Methods of demand-responsive pricing have also been reviewed in order to identify the temporal attributes and calculation procedures of the fees. Demand-responsive pricing means rates may vary by occupancy of parking facilities.

2.1 Comparative evaluation of PAAs

Criteria for selection of applications:

1. **market leaders** in a particular area and/or
2. having some **promising properties**.

Table 1 shows the evaluated PAAs and their URL. Among them, Park Plus and SF Park use demand-responsive pricing.

Park Me	http://www.parkme.com
Park Me Right	http://parkmeright.com
Best Parking	http://www.bestparking.com
Park Up	http://www.park-up.com
Parkopedia	http://www.parkopedia.co.uk
Park Plus	https://www.calgaryparking.com
Neoparking	http://en.neoparking.com
TRANS Park	http://www.iru.org/transpark-app
Voice Park	http://www.voicepark.org
Central Parking	https://find.parking.com
SF Park	http://sfpark.org

Table 1. Compared PAAs and their URL

Table 2. shows the evaluation criteria of PAAs. A 4-point rating scale (0 – 3) has been applied to assess the presence of criteria in the applications. Figures indicate the following:

- 0: not specific,
- 1: hardly specific,
- 2: rather specific,
- 3: mostly specific.

Evaluation aspects	Description
I. Multimodality	Planning with consideration to several transportation modes (e.g. private,
II. Real-time/estimated	For example: occupancy level of parking facility, indication of unoccupied
III. Personalization	Selecting car parks by various personalized criteria.
IV. Free of charge	The application can be downloaded and used free of charge; data supply is
V. Availability for mobile	The mobile device limits are not exceeded by the application requirements. It
VI. Visualization on map	Input data and/or results are displayed on map.
VII. Compact user	Application menu is simple. All necessary information appear on one side.
VIII. Crowd sourcing	Travellers share their information (opinions) with community (active mode).
IX. Outdoor navigation	Navigation on the planned route to the entrance of the car park.
X. Indoor navigation	Navigation inside car park (from entrance to free parking space and return).
XI. Booking	Booking a parking space is possible before arrival.

Table 2. Evaluation criteria of PAAs (source: own)

Scores have been summarized by evaluation aspects. Total scores regarding each aspect indicate prevalence of the certain aspects. Figure 1. shows the proportion of total scores and maximum possible scores as a percentage. **The most significant deficiency is multimodality.** PAAs tend to not have assistance in planning the rest of the ETC. Booking is only possible in a few cases, which increases uncertainty. Navigation is also not common, because most of the PAAs do not have a route planning function. The main reason for the deficiencies is that organizations managing the transportation modes have different interests. Due to the development of infocommunication technology (e.g. smart phones, internet) the „crowd sourcing“ function becomes more and more common.

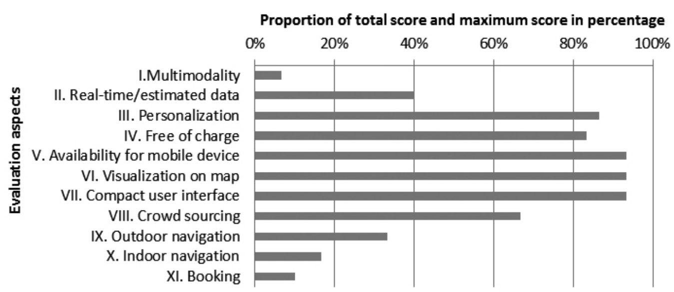

Figure 1. Prevalence of evaluation aspects in PAAs (source: own)

3.2 Revealing travellers' habits and expectations

Owing to the **online questionnaire**, a high proportion of the respondents had the necessary computer knowledge and/or were frequent users of existing route planners, therefore they may be potential users of PAAs as well. Consequently, potential users' habits and expectations have been surveyed in our questionnaire. The questions related to the parking habits and the process of parking movements, which almost all people have an opinion about, regardless of whether they have a driving license and usually drive or not. Both drivers' and potential drivers' opinions have been considered.

A significant amount of the respondents were students and employees of Budapest University of Technology and Economics, Department of Transport Technology and Economics. The questionnaire consisted of the following question groups:

a. age,
b. employment,
c. disability,
d. travel motivation,

e. the importance of security, cost and time,
f. the expected properties of PAA,
g. the expected operational functions of PAA and
h. potential parameters of PAAs’ algorithm.

There were some multiple choice questions (a.-e. groups consisting of 5 questions) with single or multiple answers. Most of the questions (f.-g. groups consisting of 38 questions) had a 5-point rating scale (1 – 5) to rate the importance each of the aspects. The most important question group is h. group regarding the key issues: algorithm parameters’ importance. Personalized information packages are selected based on these results. The remaining question groups have been considered to the PAAs’ **database and user interface** design.

User groups have been formed by b., c. and d. question groups, whose answers have been examined separately. If definite differences between certain user groups’ expectations had been noticed, group-specific settings would have been developed in the application. However, the results showed just the opposite: the survey did not reveal such significant differences. **User groups’ expectations are similar to the common expectations rather than to the individual expectations.**

Answers from travellers with dissimilar travel motivations are illustrated using an example (regarding the most important questions, namely the h. question group). For example, there has been little difference between the travellers’ answers with dissimilar travel motivation and the average of all the traveller’s answers on the key issues. The key issues are the following:

26. planned duration of parking,
27. fee rate,
28. street parking,
29. park and ride,
30. parking garage,
31. other types of parking,
32. transport hub
33. distance between parking facility and destination,
34. travel/walking time between parking facility and destination,
35. popularity of parking facility among other travellers,
36. actual parking availability,
37. safety and
38. parking facility pre-booking.

These issues have been assessed by a 5 point rating scale (1 – 5), where ‘5’ means it is very important and ‘1’ means it doesn’t matter. Figure 2. shows differences between answers of traveller groups with dissimilar travel motivation and the mean value of answers. Considering the range of scoring as 5-points; it is not worth separating groups according to their motivation, because the differences are unremarkable. This statement is also true for all other user groups.

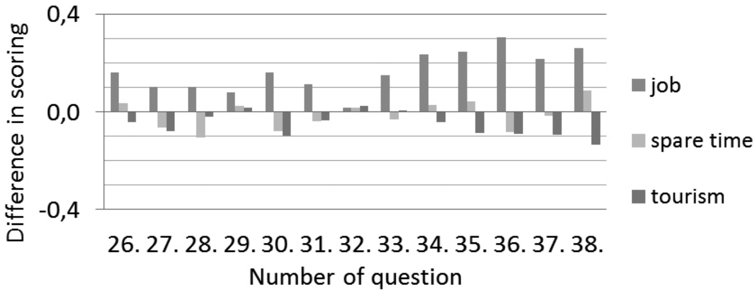

Figure 2. Differences between answers of traveller groups with dissimilar travel motivations and mean value of answers (source: own)

Table 3. shows the mean values of the answers regarding the key issues.

Question number	26.	27.	28.	29.	30.	31.	32.	33.	34.	35.	36.	37.	38.
Average value of answers	3.4	3.8	3.3	3.5	3.4	3.3	3.6	3.8	3.9	2.8	3.7	3.7	3.3

Table 3. The mean values of the answers regarding the key issues (questions 26-38.) (source: own)

3.3 Innovative properties of the proposed PAA

The research has revealed important properties, which are clearly necessary in an advanced PAA. These properties are widely applied in the examined applications and/or being particularly important for the travellers by the survey. These innovative properties are the following

1. **personalized information**,
2. **map display**,
3. **parking fees** information and
4. **simple user** interface, which can be easily used on mobile device.

Accordingly, **quality perceived by travellers** is influenced by several interrelated aspects.

3. Results

Result of the research is the conceptual design of PAS. It contains:

• structural and functional plan of proposed PAS,
• design of functions and user interface of the proposed PAA.

Planning of parking must not be separated from planning of other phases of ETC. Therefore, architecture of the PAS is opened for both public transportation and private transportation.

3.1 Proposed PAS

The two main features of the PAS are the following:

- assigns parking demands to the available parking capacity in real time,
- influences traveller's decision with **demand-responsive pricing**.

The proposed PAS assigns travel/parking demands to the available parking capacity in real time. Figure 3. represents our PAS model, with the key components and information management operations. PAS has two „outer" components, namely travellers and parking facility operators. Information is exchanged between the two. The „core" subsystem is **Parking Management Centre (PMC)**, where data flows from the mentioned components are coordinated and raw data is processed. Supply and demand data of parking facilities are met in PMC. Ideally, PMC is both functionally and in some cases also physically part of the transportation management centre. In this way parking management is not an isolated process, but can be coordinated by the information management of ETC. PAS transmits data in general via internet (Yanfeng et al., 2012).

PAA requires a feasible mobile device with internet access (e.g. 3G mobile network or faster, Wi-Fi) to provide real-time data for the traveller. **The planning is performed on the mobile device.** An internet connection is primarily required to update real time occupancy data. Secondly, collecting anonymous information about travellers and updating static parking information also require internet access. In online mode relevant data is updated during the parking search process initiated by traveller. Only data around the destination should be updated. The destination surroundings (and relevant parking facilities) are defined by maximal walking distance assigned by traveller. In this way volume of updated data can be significantly decreased. PAA can be operated also in offline mode, but in this case real time data is unavailable of course. To let PAS provide reliable information it is recommended to update static data on the PAA regularly (e. g. every few days). Data collection about travellers' expectations and habits in the PMC is useful for statistical purposes and improvement of the PAS.

Parking facility operators collect event-driven data by sensors installed at car parks and/or parking facility's entrances and exits. For this purpose a **Wireless Sensor Network (WSN)** is the most appropriate solution. Sensors detect vehicles being in car parks or vehicles passing through entrances and exits. Currently, a wide range of WSN solutions are available (Akyildiz et al., 2002). In the entire system the radio access technologies and C-ITS solutions might play substantial role; an LDM-based mobility management architecture for C-ITS applications/services has been elaborated and tested in (Varga et al., 2015).

The following data sources are to be used to measure actual occupancy in the parking facilities:

- data from sensors of parking spaces,
- data from sensors of parking facility entrances/exits,
- payment data from parking meters,
- data of camera system,
- manual collection of data.

In order to measure the **actual occupancy** of parking facilities, the mobile phone payment data can also be used. In the case of indoor parking facilities automatic registration of vehicles passing through entrances and exits is also an effective solution, because it is not tied to the payment procedure, so it can be used also in free of charge parking facilities (Hössinger et al., 2014). This kind of "registration" cannot be applied in the case of outdoor parking spaces (on street).

Raw data of parking facility operators are stored in their own database and are transmitted to the PMC with about 5 to 15 minutes frequency in order to realize the real-time information service. Static data is transmitted only after occasional changes.

PAS sums collected occupancy data by parking facilities and by time bands in order to determine rates. The recommended time s are the following:

- weekend,
- weekdays,
- dawn (3:00 – 6:00),
- morning (6:00 – 9:00),
- forenoon (9:00 – 12:00,
- afternoon (12:00 – 15:00),
- late in the afternoon (15:00 – 18:00),
- evening (18:00 – 21:00),
- night (21:00 – 3:00) and
- the combination of these time bands.

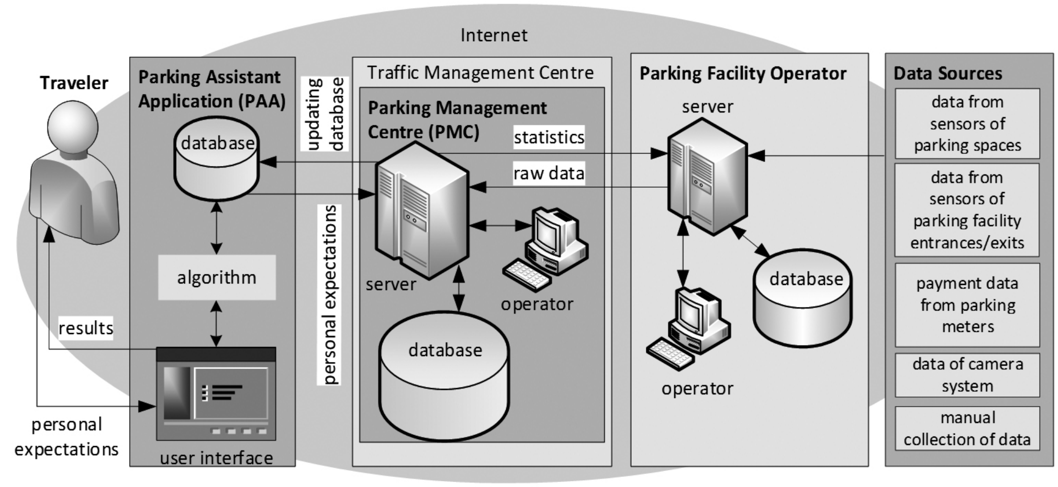

Figure 3. Structural model of PAS (source: own)

The information provision is **free of charge** for travellers. Since personal data is also collected in PAS, they are to be treated anonymously. Detailed, personalized information provision is beneficial also for parking facility operators, because their parking facilities are preferred as a consequence. Both the real time information about actual occupancy of parking facilities and the prebooking result in additional benefits.

3.2 The method of determining demand-responsive rates

The calculating of demand-responsive rates have two inputs:

1. Categorization of parking facilities by travellers' willingness to accept.
2. Estimated occupancy values of parking facilities for the next month.

1. **Categorization of parking facilities by travellers' willingness to accept:** Figure 4. shows the distribution of travellers' WTA (willingness to accept) and actual hourly rate. Traveller's WTA means the maximum value of hourly rate (adjusted in the PAA), which is acceptable by the user. The PAA filters parking facilities by this maximum hourly rate, so traveller can only select a parking facility that has a lower actual hourly rate then his or her maximum hourly rate. Parking facilities can be categorized (for each time band) by the rate of these deviations:

   1. payment category: average WTA is at least 30% higher than actual hourly rate.
   2. payment category: average WTA is at most 30% higher than actual hourly rate.

The 30% value is our estimation.

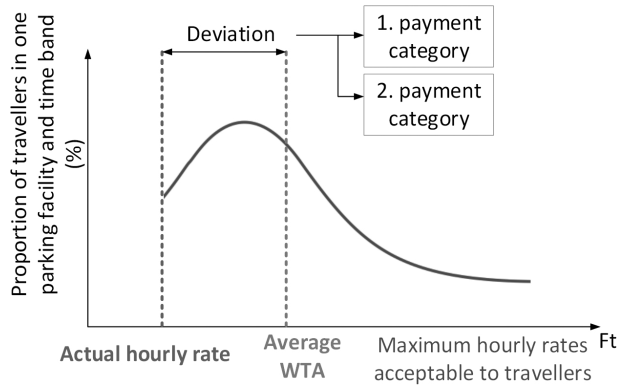

Figure 4. Distribution of travellers' WTA (willingness to accept) by actual hourly rate in case of one parking facility and one time interval (source: own)

2. **Estimating the occupancy of parking facilities:** Estimating of occupancy does not require complex solution. The changes of occupancy is well balanced in each time bands (for example, occupancy is low at night and high in the morning).

The aim of the method is keeping the average occupancy of the parking facility (for each time band) in a specified interval (from 50% up to 80% is recommended).

The average occupancy values of parking facilities for each time band (f_{ij}) is provided by the data collection method. Figure 5. shows these values.

Month (h)	Time band (l_j)			
Parking facility (P_i)	f_{11}	f_{12}	...	f_{1j}
	f_{21}			
	...			
	f_{i1}	f_{i2}	...	$\mathbf{f_{ij}}$

Figure 5. Average occupancy values of parking facilities for each time band in one month (source:own)

The estimated values of occupancy ($f_{ij,e}$) are calculated monthly in parking facilities (P_i) for each time band (I_j). Table 4. shows the used values of the method and equation 3.1 - 3.5. show the method of estimating occupancy. The base data is the average values of occupancy (f_{ij}) in the last three months. Equation 3.1 - 3.3. shows the differences of these values. The method estimates the difference between the actual month's average values (f_{ij}) and the next month's estimated values ($f_{ij,e}$): the estimated difference is the average of the last three month's differences. Equtation 3.4. shows this average. Equation 3.5. shows that the estimated values of occupancy ($f_{ij,e}$) is the sum of the estimated differences ($\Delta f_{ij(e,t)}$) and the actual month average values ($f_{ij,t}$).

$$\Delta f_{ij(t-2,t-3)} = f_{ij(t-2)} - f_{ij(t-3)} \quad (3.1)$$

$$\Delta f_{ij(t-1,t-2)} = f_{ij(t-1)} - f_{ij(t-2)} \quad (3.2)$$

$$\Delta f_{ij(t,t-1)} = f_{ijt} - f_{ij(t-1)} \quad (3.3)$$

$$\Delta f_{ij(e,t)} = Avg\left(\Delta f_{ij(t-2,t-3)}, \Delta f_{ij(t-1,t-2)}, \Delta f_{ij(t,t-1)}\right) \quad (3.4)$$

$$f_{ij,e} = f_{ijt} + \Delta f_{ij(e,t)} \quad (3.5)$$

Parking facilitiy (P_i) and time band (I_j)					
Month (h)	$h_{(t-3)}$	$h_{(t-2)}$	$h_{(t-1)}$	h_t (actual month)	h_e (next month)
Average values of occupancy	$f_{ij(t-3)}$	$f_{ij(t-2)}$	$f_{ij(t-1)}$	f_{ijt}	**$f_{ij,e}$**
Differences between average values		$\Delta f_{ij(t-2,t-3)}$	$\Delta f_{ij(t-1,t-2)}$	$\Delta f_{ij(t,t-1)}$	$\Delta f_{ij(e,t)}$

Table 4. The used values of the estimation method (source: own)

Calculating demand-responsive rates: the inputs of the function are the estimated values of the occupancy ($f_{ij,e}$). In all parking facilities for each time band one **rate modification** (Δp_{ij}) is calculated. Figure 6. shows the function of the rate (p_{ij}) and its first derivatives (rate modification).

The rates are between a minimum (p_{min}) and a maximum (p_{max}) value. The rates may vary between these two values depending on the estimated occupancy. If occupancy falls within the target occupancy range ($[f_a, f_f]$), then modification is not required. Otherwise, rates are modified.

Equation 3.6. shows the function of the rate modification.

$$\Delta p_{ij} = \begin{cases} (f_{ij,e} - f_a) \cdot m, & if\ f_{ij,e} \leq f_a \\ 0\ , & if\ f_a < f_{ij,e} < f_f \\ (f_{ij,e} - f_f) \cdot m, & if\ f_f \leq f_{ij,e} \end{cases} \quad (3.6)$$

$m \in R^+$ is slope of the rate modification.

The other input of the function is the payment categories for parking facilities. The slope of the function (m) is determined by them. Parking facilities with 1. payment category has a higher value of m than with 2. payment category. The value of m is to be calibrated during the test run of the PAS.

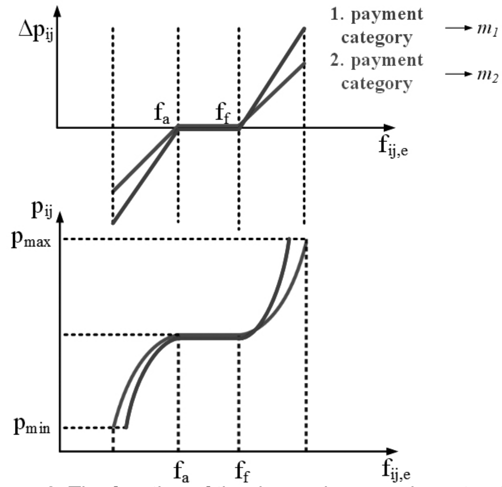

Figure 6. The function of the demand responsive rates (source: own)

3.3 Proposed PAA

Travellers can access to the services of the PAS by an application called PAA. Personal expectations of travellers are managed by this application.

The **application** executes a multi-criteria analysis during operation, where the traveller adjusts the values of the criteria. Parking facilities are the possible alternatives. **Data filtering** has been found to be the most efficient method for selection of the appropriate alternatives. Namely travellers feel more confident about the results filtered by different criteria at the same time, rather than results computed by weighted criteria. Traveller can adjust extreme values to the following criteria:

- distance between parking facility and destination,
- actual occupancy,
- popularity of parking facility,
- incidence rate of crime,
- outdoor/indoor parking facility,
- arrival and departure time,
- the rate of the fee depending on the duration of parking.

The range of data and frequency of data collection depend on these criteria. For example actual occupancy is real-time data, which has to be collected periodically, with an appropriate sampling time cycle. Transmission time between parking facility and the PMC as well as the data updating time cycle in the PMC have also been taken into account.

The application has to have an **ease of use** considering it will be usually run on a mobile device during travel. The menu contains a minimum

number of items; travellers can save their destinations and personal settings for later use.
Figure 7. illustrates the menu options of the PAA. Blue boxes represent the forms (1. and 2.) with input and output data. Functions and data management operations (A-G) are indicated by arrows between boxes. The open and close (A, B) functions are available on the initial form, called “Favourites” (1). The traveller can create (C) favourites based on the regular travel motivations and the actual parking attributes. When editing a favourite, values of the filtering criteria are adjusted. Only one favourite can be selected (D) for one data filtering. After selection of a favourite, data filtering (E) can be performed. Search results for parking appear in the next form (2). After one parking facility has been selected from the results, its data can be also saved (F). When data filtering does not result in any appropriate parking facility, the traveller may return to the initial form (G), where the filtering criteria may be readjusted.

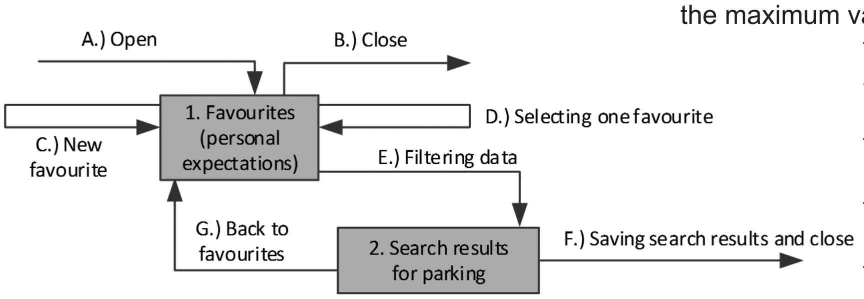

Figure 7. Menu options of the personalized PAA (source: own)

For testing the operation of the PAA, a prototype has been developed using Microsoft Access. As a result of the development so far the prototype can manage the following data:

- basic **expectations of travellers**,
- data of **parking facilities** and
- data of **destinations** (location coordinates, address).

Sample data of the database is originated from the city of **Győr**. All options in the application can be demonstrated by this data. Results of our survey have also been considered for default settings.

Data elements on the initial form appear in the following format:

- **Name of favourite:** name of the travel motivation.
- **Destination:** name of the destination.
- **Maximum hourly rate:** maximum value of hourly rate acceptable to the traveller.
- **Maximum distance between parking facility and destination:** maximum value of distance acceptable to traveller. (Straight line distance is calculated between parking facility and destination by GPS coordinates.)
- **Minimum security:** minimum value of security required by traveller. It may vary among the following 3 values:
    - o high security (value: 3),
    - o medium security (value: 2),
    - o low security (value: 1).
- **Arrival and departure time:** arrival and departure times can be set with hour accuracy.
- **Day of the parking:** the day of the parking demanded by the traveller.

Following attributes of the parking facilities are used in the PAA:

- **GPS coordinates:** for calculation of straight line distances between parking facility and destination. If the calculated value is less than the maximum value acceptable to the traveller, the parking facility is appropriate in this regard.
- **Opening and closing time:** these time values are compared to the time appointed by the traveller.
- **Security:** if the value is less than the minimum value of security required by the traveller, the parking facility is not appropriate in this regard. Its value can vary among the following 3 values:
    - o high security (value: 3),
    - o medium security (value: 2),
    - o low security (value: 1).
- **Hourly rate:** if the value is less than the maximum value of the hourly rate acceptable to the traveller, the parking facility is appropriate in this regard. The actual fee is calculated by the hourly rates.
- **Actual occupancy of a parking facility:** if this value is higher than or equal to 90% occupancy, the parking facility doesn’t appear in the result list.

Only the parking facilities that meet all expectations of traveller are listed.

3.4 Further development opportunities of the PAA

The input and output forms can be integrated into a map interface. The traveller can define a starting place (A) and a destination (B). Clicking on the starting place, the traveller can adjust his or her expectations (maximum hourly rate, maximum walking distance, minimum desired security). Clicking on the destination, the traveller can define his or her arrival and departure time and the day. The results of the filtering (recommended parking facilities) appear on the map interface. Clicking on a parking facility, its properties and the booking function appear. The application plans routes to each parking facility from the starting point and to the destination. Navigation is also available.

4. Conclusions

Urban mobility management requires the use of advanced infocommunication technologies. Aiding the ETC with information in real time is a rather complex task, requiring extensive integration of the subsystems. One crucial phase of this task is the parking management. PAS is an effective solution in passenger transportation, which requires relatively low operational costs compared to other management systems or measures. Our proposed PAS and its services can be integrated into the information system covering ETC.

The proposed PAS provides real time information before and during travel, also considering personal expectations. A limited number of personal setting options in the PAA may already sufficiently aid travellers. Results of our survey have clearly highlighted the promising features that can significantly improve traveller satisfaction during the search for a parking space.

Estimating of occupancy does not require complex calculations. The changes of occupancy is well balanced in each time bands. The demand–responsive rates can be calculated with simple methods. Simplicity and efficiency are not mutually exclusive.

Our future research work will focus on integrating parking management into traffic management.

Acknowledgement

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