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The Location of Park and Ride Facilities Using the Fuzzy Inference Model

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***Abstract*—**The paper presents a method in which the expert knowledge is applied to fuzzy inference model. Even a less experienced person could benefit from the use of such a system, e.g. urban planners, officials. The analysis result is obtained in a very short time, so a large number of the proposed locations can also be verified in a short time. The proposed method is intended for testing of locations of car parks in a city. The paper shows selected examples of locations of the P&R facilities in cities planning to introduce the P&R. The analyses of existing objects are also shown in the paper and they are confronted with the opinions of the system users, with particular emphasis on unpopular locations. The results of the analyses are compared to expert analysis of the P&R facilities location that was outsourced by the city and the opinions about existing facilities users that were expressed on social networking sites. The obtained results are consistent with actual users' feedback. The proposed method proves to be good, but does not require the involvement of a large experts team and large financial contributions for complicated research. The method also provides an opportunity to show the alternative location of P&R facilities. Although the results of the method are approximate, they are not worse than results of analysis of employed experts. The advantage of this method is ease of use, which simplifies the professional expert analysis. The ability of analyzing a large number of alternative locations gives a broader view on the problem. It is valuable that the arduous analysis of the team of people can be replaced by the model's calculation. According to the authors, the proposed method is also suitable for implementation on a GIS platform.

***Keywords*—**Fuzzy logic inference, P&R facilities, P&R location.

I. Introduction

CONTEMPORARY cities are facing serious congestion and parking problems. This phenomenon was caused by the surge in the number of cars in cities that had not been designed for so much traffic. As a result, one has to face the problem of traffic jams, slow movement, difficulty in finding parking space in the down-town area, etc. This situation requires rapid and effective actions to be taken in the fields of transport and parking. Best practice is to introduce significant limitations in the development of individual communication and replace it with a well-functioning public transport system with the ability to use park and ride (P&R) complex interchange nodes. This solution requires an individual approach to designing a system of such nodes. In urban transport policy the introduction of the P&R system is an increasingly popular way of limiting vehicular traffic. Finding of P&R facilities location is a key aspect of the system. Practice and research [6] show that P&R facilities are not used if they are not located conveniently from the point of view of potential users, even if a level of congestion is high. Criteria for assessing the quality of the selected location are formulated generally and descriptively. Research outsourced to specialists is expensive and time consuming. Most focus is given to the examination of a few pre-selected places [5]. The practice has shown that choosing locations of these sites in an intuitive way without a detailed analysis of all the circumstances often gives negative results. Then the existing facilities are not used as expected. Methods of locating are also widely taken in the scientific literature as a research topic. Built mathematical models often do not treat the problem comprehensively, e.g. it is often assumed that a city has linear organization and has been developed along one important communications corridor [2]. This direction of analysis is continued by the authors of the paper [4]. The authors of [3] define locations in a very precise way on the basis of the input data. The use of such a model is very limited because obtaining such detailed and precise data requires additional effort and research means. It is also time consuming. There is another group of papers where authors' studies are based on Geographic Information Systems (GIS) using statistical research [7], [8]. GIS can be very helpful but the authors do not use imprecise, estimated information, such as acoustic map which can be utilized by using methods based on fuzzy logic. Similarly to the example [3] possibilities of analysis are limited to the field in which exact parameters can be determined. Fuzzy logic, which is one of the newest areas of mathematics, is commonly used for inference in such cases. In particular, it is often used when the parameters on the basis of which the assessment is made are difficult to determine and are based on intuitive expert knowledge. The examples of such applications can be found in publications [9], [10].

For many socio-economic reasons it is often not possible to carry out lengthy, costly, and detailed analyses based on collected long-term data. The dynamics of changes in communication hinders this process and forces making quick decisions based mostly on a superficial, often intuitive analysis of the phenomenon. In the method presented in this paper, the authors apply expert knowledge to fuzzy inference model of P&R car parks locating [1]. Even a less experienced person could use such a system of location evaluation, e.g. urban planners, officials. The system is friendly for users and allows getting results in a short time. As a result, a large number of the proposed locations can be evaluated quickly.

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Using currently being built P&R system hubs in selected Polish cities, practical solutions were confronted with assessment obtained with the help of modelling process of inference using fuzzy logic.

II. Analysis of P&R System Conditions

In a city's transport policy a P&R system plays an important role. Its very essential aspect is locating parking lots in good places. Appropriate placement of a P&R facility in the communication system makes it more popular, and thus, increases the capacity of the major roads. The P&R facilities offer convenient access to down-town which is usually the most attractive area [6], [11]. Communication overload currently affects all the big cities of Western Europe. The growing number of cars in the cities, the problem of environmental pollution, and the lack of an efficient transport system require a comprehensive approach. The environmental factor is also important. Its importance has increased in the 90's as a result of the growing public awareness. It influences the choice of location of a P&R in order to reduce air pollution [11]. There are no clear criteria for the distance from a P&R facility to the city center. On the basis of the analysis of the existing locations, it is possible to identify different criteria and types of locations, used by researchers from different countries. In [12] and [13] three categories of P&Rs on the basis of the proximity between urban areas and locations can be distinguished:

1) Remote P&R – this location is designed to intercept drivers close to the source, tend to be localized near their homes in the suburbs
2) External P & R – a model typical for the UK and the US. It aims at intercepting travelers for the last stage of their journey.
3) Local P&R – these car parks are designed for intercepting travelers at many points along the major transport corridors.

The authors of [6] cite other location examples:

1) [17] suggests to locate P&R facilities on the outskirts of congestion, but not less than 4 miles (6.5 km) from the Central Business District (CBD),
2) [18] suggests to locate the object at least 3.1 miles (1.6 km) from the CBD
3) [19] considers location that should not be less than 10 miles (16 km) from the CBD.

All researchers are consistent on three issues pertaining to the location of a P&R facility. The proximity of major roads is important; P&R should be visible from the road, moreover: a location on the verge of congestion seems ideal as it allows the users to use their cars on the less crowded part of the road. It also must be noted that the location of a P&R can cause previously unforeseen effects. Such an example was described by Giuliano Mingardo [12] on the basis of research he conducted in the Netherlands. He noticed the following phenomena: „abstraction from bike" and „park and walk users". Concerning the former, some people commuting to work by bike resigned from previous means of communication and returned to car transportation and then P&R interchange. Even if it could be considered as a phenomenon that is not equally important for most countries, it should not be underestimated, especially taking into account the positive health effects of the regular use of bicycles. In the case of the latter, namely „park and walk users" phenomenon, for some travelers P&R facility (built as a place of interchange) has become a destination point. Inhabitants walked the rest of the way to work, occupying parking places for road users who wanted to benefit from the hub.

III. The Methodology of Research

The presented method can be used as an aid in determining the location of parking places in the city. The paper presents analysis and evaluation of a number of selected examples. These are the existing car parks in a city where the system is already working and potential sites for locating car parks in a city that is planning to introduce the P&R system. For the tests we have chosen two Polish cities - the capital city of Warsaw and Poznan. Warsaw is a city in which the P&R system has been functioning for several years and it has been gradually developed. Therefore, the analyses shown in the paper are confronted with the feedback of the users of this system. In Poznan, the system is in the planning stage. The analysis therefore relates to the planned facilities whose locations have been qualitatively analyzed by experts. We have confronted the results of the expert studies with our research performed with the help of the fuzzy inference model which was described in more detail in [1]. The model is intended to be a tool both for cities that have already a P&R system or have decided to introduce it. The results of the analysis were compared with the documentation of P&R facilities location prepared by experts at the request of the city authorities and the opinions of users of the system.

A. The Model Description

Usefulness of the chosen place for the location of P&R facilities results from the features and objectives of P&R system. There is a number of conditions and parameters that testify to the value of a place. They can be grouped into two main fields. The first one is related to the territorial conditionality and the second one to the public transport which is expected to take over the passenger load of individual traffic. Using this expert classification the inference has been divided into two local models of inference. The first local model counts the indicator of territorial conditions (IOTC). The second local model (IOPQ) counts the indicator of the public transport quality. The final result is calculated by the complete inference model (IOCM). Such an approach gives a clear assessment of the proposed location. On the basis of the results of the intermediate local models, it indicates the components of the final result factors. The schema of the fuzzy inference model of P&R car parks location is in Fig. 1.

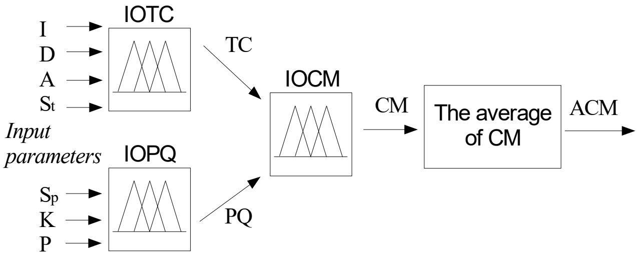

Fig. 1 The schema of the fuzzy inference model of P&R car parks location

B. The First Local Inference Model – the Indicator of Territorial Conditions

According to expert assessment, three parameters that are linguistic variables in the model are specified. All parameters have gained numerical values in the range from 0 to 100.

The first variable is the location in a context of the road transport system. The best is a location near the entry road to the city which is connecting residential areas located outside the city and the city center. This parameter is strongly correlated with the number of vehicles flowing into the city whose drivers are interested in using the car park. The authors have marked this parameter as *I*. The more potential users ride the chosen corridor, the higher the value of *I*. The value of this variable is determined on the basis of the size of catchment area of the city, i.e. the number of housing units (settlements, towns, villages) connected to the city by the chosen corridor. The statistics data for this area can be used as a basis for to estimate its value. Traffic studies are sometimes carried out for some places, the results can also be the basis for the estimation of this parameter. An expert can estimate its value utilizing an acoustic map of the area as well. Another variable determining the attractiveness of a given location is the quality of the access to the car park by car (*D*). This parameter encompasses the time and convenience of travel related to the quality of the road itself (number of lanes, width, surface quality), as well as the number of intersections and other obstacles slowing down the traffic and bandwidth of the road.

P&R facilities are often indirectly supported by the road which is the main city entrance. For various organizational reasons, car parks may be spaced from the road and connected with it by a street of lower technical class which is used as direct service. This combination also affects the drivers' decisions of making use of the facility or not. If the object is accessible from the main road, clearly marked and with clear indication of the entrance, as well as conveniently located (near and on the right side of the main road) is more likely to be used. This parameter has been denoted as *A*.

The last parameter of territorial conditions is the distance from the parking lot to the city center which is the target zone of traffic. City governments make different decisions about the minimum distance. However, there is a rule that car parks placed too close to the city center become a destination point, not a place of transfer to public transport. In this case, a factor of a decrease in congestion does not exist. Medium-sized towns often hold the ring of car parks in comparable distances from the central zone. Big cities sometimes opt for several zones of distance for P&R facilities location. The authors have decided to divide the distance parameter *S* into two separate parameters S_t and S_p. The first one is related to the territorial conditions and the second one to the public transport quality. The reason for this is that the distance between the location and the city center from the users' point of view is something different than the distance resulting from means of public transport. The best situation is when the distance is big but the connection by public transport is very fast.

After determining the value of each parameter, the fuzzy inference model rules presented in [1] were used to assess locations in terms of territorial conditions. These rules define relationships between different parameters depending on the value they adopt. An example rule looks as follows:

If *I* is *big* **and** *D* is *low* **and** *A* is *good* **and** *S* is *long* **then** *TC* is *sufficient*

The result is *TC* - territorial indicator of location which gains value in the range from 0 to 100%. The following scale has been adopted:

- 0% *bad*
- 25% *mediocre*
- 50% *sufficient*
- 75% *good*
- 100% *very good*

This scale means that membership functions look like in Fig. 1, e.g. if we have a value of *TC* in point A, that is 35%, the score for this point is in two membership functions *mediocre* and *sufficient*. The result is 60% of *mediocre* and 40% of *sufficient*. The same rule is adopted for the next scales of indicators.

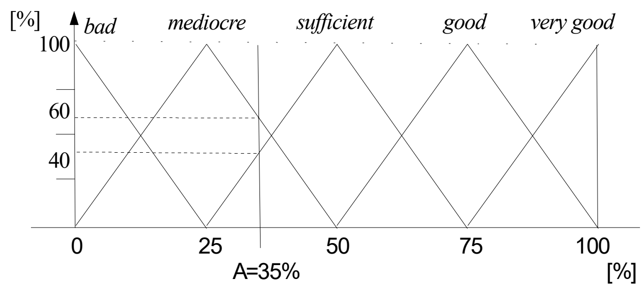

Fig. 2 The membership functions of *TC*

The value of *TC* is "*bad*" in two situations. The first is when *I* is small and *D* is low and second when *S* is short. In the first case it is not worth building a car park because there would be no potential users of the system. In the second case a location of a P&R facility is too close to the city center so the car park would not be use as a transfer place but it would become a destination point.

The value is "*mediocre*" when the number of vehicles flowing into the city is big but the quality of road is low and the distance to the city center is medium or not short. Then it would be difficult to reach the P&R facility because of great congestion. The value is "*mediocre*" also when *I* is small, *D* is big and *S* is long. This is due to the fact that the location is not good when there are no users.

The value is "*sufficient*" in three cases. The first is when *I* is big, *D* is low, *A* is good and *S* is long. That means a lot of cars and a proper distance to the center and easy access to car park but low quality of road that results in congestion problem. If *I* is medium, *D* is low, *A* is bad and *S* is not short the value of *TC* is also "*sufficient*". In this case the number of cars is smaller but the access is worse, which gives the same level of location quality. The third situation is when *I* is small, *D* is high and *S* is medium, independently of the access to the car park. The car park is then too close to the city center and it is in the place of the small number of users.

The first condition for the value "*good*" is that the distance to the city center cannot be short. Then there are two cases. The first is when *I* is not small, *D* is high and *A* is bad. This means a good proportion of the quality of the road up to the number of cars. Poor quality of the access is not so important in this case. The second rule assumes that *I* is medium, *D* is low and *A* is good.

The value is "*very good*" only in one case when *I* is not small, *D* is high, *A* is good and *S* is not short. The condition of a sufficiently large number of cars with good quality of the road and availability of space must be met.

C. The Second Local Inference Model – the Indicator of the Public Transport

From the users' point of view, the connection between the object's location place and the public transport is an extremely important factor. P&R facilities should become transfer spaces located near bus or rail lines. This is represented by the linguistic variable *K* in the model. It contains a number of conditions indicating the attractiveness of the transfer node. First of all, it is the number of possible means of transport to choose from (bus, tram, subway, train, etc.). The quantity of various connections as a part of each mode of transport is also important. It determines the flexibility of choosing the target point of the trip. In addition, the quality and frequency of services (rolling stock and clocking) affects the complete travel time.

The parameter, which is the value *P* in the model, is the distance that a traveler must overcome after leaving the car in order to change to public transport. It also affects the travel time. This is primarily a consequence of the way of the organization of P&R facility as a transfer hub, the adopted distance between the platforms and the way of organizing of pedestrian traffic.

The distance parameter *S* has been divided into two separate parameters: S_t and S_p. The parameter S_p is the relative distance to the city center by means of public transport.

After determining the value of each parameter, the fuzzy inference model rules presented in [1] were used to assess locations in terms of the public transport quality. The result is *PQ* - indicator of the public transport quality. The analysis of experts showed that every place in the city has some communication value. Therefore, it is difficult to evaluate the worst place as 0%. In [1], a scale was proposed according to which the lowest value was evaluated as 25% in a similar way to *TC*. However, the broader expert analyses showed that such a scale of assessment is difficult to accept in an intuitive way. For this reason, we have decided to modify the percentage evaluation scale of parameter *PQ*. Such treatment may be more readable for the user. The following scale of the indicator *PQ* has been adopted:

- 10% - *mediocre*
- 40% - *sufficient*
- 70% - *good*
- 100% - *very good*

The value is "*mediocre*" when *S* is long and *K* is small and *P* is long. That means a long distance to walk, a lot of time spent waiting for the means of public transport and a long ride.

The value is "*sufficient*" in four cases. Two cases include situations when the distance to the public transport stop is long and there are not many means of transport. These situations differ in the distance to the city center that takes values "short" and "medium". The third situation is when *S* is not short, *K* is small and *P* is short and the similar case when *S* is not short but *K* is medium and *P* is long. In both cases the distance to the city center is not comfortable for users.

The value is "*good*" in three cases. The first one is when *S* is short, *K* is small and *P* is short. Then the time spent on the move is not too long. The second case is similar - *S* is also short, *K* is not small and *P* is long. The third one assumes that *S* is not short, *K* is medium and *P* is short. That means comfortable way from the car park to the public transport stop, a sufficient amount of means of public transport and not too long distance to the city center.

The value is "very good" in two cases. The first is independent from the distance to the city center and assumes that *K* is big and *P* is short. The time for waiting and riding is very short then. The second case is when *S* is short, *K* is medium and *P* is short. It is still comfortable situation since riding to the city center is very short and the time for waiting for the means of public transport is not long.

D. The Complete Inference Model

The inference results from both local models (IOTC, IOTQ) are used as input data for IOCM. On the basis of IOTC and IOTQ models the final indicator of location quality (CM) resulting from the fuzzy model IOCM is inferred. Due to the fact that the parameter *I* is often not constant the expert is also interested in the assessment of the location in the perspective of the various values of this parameter. Therefore, in order to determine the indicator, the indicator simulation depending on the parameter *I* is computed. At the same time the complete indicator is calculated as the average value of the results of the simulation (*ACM*) according to the formula (1). The use of ACM in the fuzzy inference model of P&R car parks location was shown in schema in Fig. 1.

$$ACM = \frac{\int_{I_{\min}}^{I_{\max}} CM\, dI}{I_{\max} - I_{\min}} \tag{1}$$

A similar scale as for *TC* is used for *CM* - the final indicator of the location quality. The same scale is adopted for *ACM* – the average indicator of location quality.

- 0%- *bad*
- 25% *mediocre*
- 50% *sufficient*
- 75% *good*
- 100% *very good*

Territorial conditions are very important and have much greater influence on the quality of the location than public transport. This is because they are not easy to change as opposed to transport. Therefore, when *TC* is bad, mediocre or sufficient and *PQ* is mediocre or sufficient the final indicator has the value "*bad*". The *CM* value is also "*bad*" when *TC* is bad even if *PQ* has the value good or very good.

The value of *CM* is "*mediocre*" in two cases: *PQ* is mediocre and *TC* is sufficient and in the opposite - when *PQ* is sufficient and *TC* is mediocre.

The value of *CM* is "*sufficient*" in several cases. The first cases are when *PQ* is good and *TC* is mediocre or sufficient. Such facilities are not very popular because of poor quality of location, even if public transport is not bad. The next three cases concern locations with the sufficient value of *PQ*. Then *TC* may adopt values: sufficient, good, very good. If *PQ* is mediocre and *TC* is good or very good *CM* also adopt the value "*sufficient*". Low quality of the public transport is not satisfactory for users. The last situation is when *PQ* is very good and *TC* is mediocre.

The value of *CM* is "*good*" when both *PQ* and *TC* are good. The next case is when *PQ* is very good and *TC* is sufficient.

The value of *CM* is "*very good*" in three cases. The first is when both *PQ* and *TC* are very good. The next cases are when *PQ* and *TC* alternately take values good and very good.

IV. Description of Research Facilities

Two cities: Warsaw and Poznan have been objects of research. We have chosen seven planned P&R facilities in Poznan (Fig. 3) and seven existing P&R facilities in Warsaw (Fig. 4). The selected objects have been tested by the fuzzy inference model and their locations have been evaluated.

A. Poznan

Poznan is the capital of the Wielkopolska Region. The city is located in western Poland, situated on the Warta River, at the mouth of the Cybina River. Poznan is a strong economic, scientific and cultural center. Poznan is one of the biggest cities in Poland. The city population is about 550 000, while the continuous conurbation with Poznan County and several other communities is inhabited by almost 1.1 million people. The Larger Poznan Metropolitan Area is inhabited by 1.3-1.4 million people and extends to many satellite towns making it the fourth largest metropolitan area in Poland. There is a strong trend of migration of city dwellers to areas adjacent to the city in the region. These people remain at the same close relationship with the city. Such phenomenon will be accompanied by intensification of the trip to the agglomeration. Poznan today is the metropolitan center that attracts residents of neighboring towns and villages. The city is an important road and rail hub, also international airport operates there. It is one of the biggest airports in the west of Poland.

The road system of the city is based on a radially-ring net of streets. It consists of road rings called the framework and the outlet streets radially extending from the center.

The basis of public transport in the city is 20 tram lines, which are complemented by 53 regular urban bus lines, 46 suburban bus lines and 1 fast bus. Due to the many changes it is necessary to reorganize the transportation system of the city and to integrate the public transport with the communication system. The city authorities have decided to introduce a P&R system. There are three studies defining the location of car parks [14]-[16]. Locations designated in various studies do not always coincide. In this paper we have analyzed seven locations designated in the document [16] using fuzzy inference model.

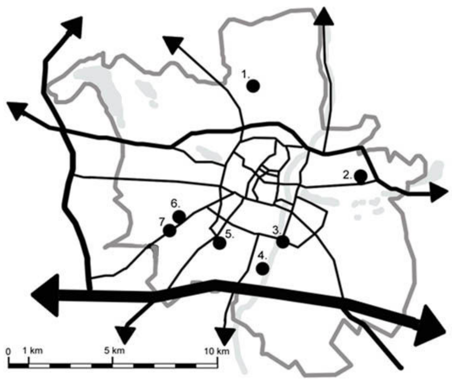

Fig. 3 The examples of planned P&R facilities in Poznan

The list of selected P&R facilities in Poznan:

1. Os. Jana III Sobieskiego, Tram Loop
2. Milostowo, Tram Loop
3. Staroleka Traffic Circle
4. Poznan Staroleka Station
5. Gorczyszyn Tram Loop
6. Grunwald Budziszynska Tram Loop
7. Junikowo Tram Loop

B. Warsaw

Warsaw is the capital and largest city of Poland. Its population is estimated at 1.740 million residents within a greater metropolitan area of 2.666 million residents, which makes Warsaw the 9th most populous capital city in the European Union. The city limits cover 516.9 square kilometers, while the metropolitan area covers 6,100.43 square kilometers. The population of Warsaw represents approximately 4.5% of the population of the whole country. The population is steadily, slightly increasing, which is mainly due to positive migration balance.

Warsaw is located in the middle course of the Vistula River, in east-central Poland. The city shape is slightly elongated along the riverbanks. Because of this the city faces communication problems in river crossings. Warsaw is the largest hub in terms of passenger car traffic, rail and air transport. The river is a communication barrier; bridges are places which slow down the traffic. Thus, one of the most important city tasks is the development of public transport structure which could be an alternative to private car transport whose role in the city center will be limited. So far, the city authorities have established a down-town zone of paid parking and the introduction of fees for entry to the center in the future is being considered. From the beginning of the twenty-first century, the city takes steps to integrate different means of transport. The most important idea is introducing the P&R system. Places to locate parking lots were determined on the basis of expert studies [5]. They are mostly located near transportation hubs. In order to encourage users to make use of the system and to facilitate getting around the city a single ticket for public transport has been established. Its range was extended to suburban communes. The city is trying to give priority to public transport which is an important aspect of the P&R system. There are formed separate lanes for buses on the streets without tram transport.

Fig. 4 The examples of P&R facilities in Warsaw

The list of selected P&R facilities in Warsaw:

1. Anin SKM
2. Krakowska Ave.
3. Metro Imielin
4. Metro Marymont
5. Metro Mlociny
6. Metro Wilanowska St.
7. Polczynska St.

V. The Evaluation Criteria of Input Parameters of the Model

The parameter I specifies the amount of traffic at the location of the car park. It is assessed on the basis of an analysis of the acoustic maps compared to congestion maps. Such a comparison is important because cars standing in traffic generate little noise, and these fast moving generate a large noise. When the traffic jam is small and the noise is big the influx of cars is big. The small noise and traffic means the small influx of cars. An additional criterion is the size of the road and its catchment area.

The parameter D determines the quality of access to the car park by car. The value 100% has been adopted for the beginning of the agglomeration. The value is reduced with a decrease of quality of the road and quantity of intersections and other obstacles slowing down the traffic and bandwidth of the road. The traffic is also taken into account, as in (2):

$$D_{n+1} = (100\% - k_n)D_n \tag{2}$$

Parameters of (2) are: $D_0=100\%$, n- the number of the next obstacle, k_n – the percentage weight of the next obstacle, D_n – indicator of the road quality, taking into account the obstacles from 1 to n.

The parameter k_n was determined on the basis of the changes in the quality of the road, the size of the intersection capping or other obstacles (crossings, road narrows, etc.). For example, for the full intersection with a left turn and degree of capping 4 on a scale 1-4 (read from a website traffic map) k_n=8

For the junction with 4-lanes route k_n =8 and additionally, when the road narrowed to a 2-lanes road k_n was increased twice.

The parameter A is the availability of the parking facility from the main road. 100% implies a situation in which the facility location is right next to the road that is the main inlet corridor, on the right side of the road and the object is visible from the road and from the moment of seeing one can have a direct access to it. The parameter value is reduced when the object is not visible or when there is a need to use an additional road of a lower technical class that supports entry. A facility situated close to the road but having the big difficulty of access would have low value, e.g. after the moment of seeing one has to drive on 600-900 meters and next leave the main road to the lower class road and cross a few intersections to reach the object. Such a situation experts have also considered as little comfortable.

The parameter S has been divided into two parameters S_t and S_p. In the category of territorial indicators, the value 100% was determined in a place situated on the border of the traffic jam area during peak-traffic hours. The closer to the city center the lower the value of the parameter. The value 0% is in the place where the car park could be the destination point which means 5 minutes to the center on foot.

In the category of public transport, the parameter S_p takes the value 100% when the travel time to the center by means of public transport does not exceed 10 minutes. The value of the parameter decreases with extending the time of arrival.

The parameter K describes the quality of public transport - the number of possible means of transport and the frequency of their running. The situation when the frequency is not less than 30 vehicles / hour has been accepted as 100%.

The parameter P determines the distance between parking and public transport stops. The value 100% has been adopted for the situation when the distance does not exceed 50 meters and stops are located in one covered place.

VI. The Research Results

The results of simulation studies for Poznan are shown in Table I. Locations indicated in Poznan have been consulted with residents and representatives of Housing Estate Councils [14]-[16]. Residents have expressed concern about the public transport system. According to them there are not many public transport connections, which can affect the aversion to the use of the P&R system. Well-functioning public transport and location near rail transport plays a key role.

TABLE I
THE RESULTS OF SIMULATION STUDIES FOR POZNAN

	I	*D*	*A*	S_t	*TC*	*K*	*P*	S_p	*PQ*	*ACM*
1. Os. Jana III Sobieskiego, Tram Loop	60-70	55	50	50	64	90	90	80	87	84
2.Milostowo, Tram Loop	80	86	60	50	100	55	90	90	70	100
3. Staroleka Traffic Circle	70-80	65	90	40	61	60	65	90	66	62
4. Poznan Staroleka Station	40-50	60	90	50	61	75	60	60	72	61
5.Gorczyszyn Tram Loop	60-70	88	80	55	100	65	65	70	69	98
6. Grunwald Budziszynska Tram Loop	50-60	49	90	60	81	80	90	70	83	77
7. Junikowo Tram Loop	50-60	49	90	70	81	60	80	70	70	66

TABLE II
THE RESULTS OF SIMULATION STUDIES FOR WARSAW

	I	*D*	*A*	S_t	*TC*	*K*	*P*	S_p	*PQ*	*ACM*
1.Anin SKM	50-60	41	90	65	75	40	80	40	70	63
2.Krakowska Ave.	90-100	68	90	70	77	90	90	60	87	89
3. Metro Imielin	50-60	53	80	80	84	90	85	70	85	80
4. Metro Marymont	80-90	61	85	50	68	90	75	90	83	78
5. Metro Mlociny	80-90	69	60	80	78	95	70	80	89	90
6. Metro Wilanowska St.	70-80	47	80	60	55	90	90	90	87	72
7. Polczynska St.	80-90	68	95	60	77	30	50	50	55	65

Locations have been evaluated well by the respondents; some interviewees expressed concerns in relation to the three locations. According to the opinion of 25% of the surveyed persons, the locations No.3, No.4 and No.7 are located too close to the city center. This means that drivers who reach this place will prefer slightly extend the journey and drive to city center their own car without using the public transport.

The fuzzy inference results of model for Poznan are convergent with the potential users' opinions. Locations No.3, No.4 and No.7 obtained 62, 61 and 66% *ACM*, respectively. That means they are between the values *sufficient* and *good*. The distance to the city center has a significant impact on it, especially in case of locations No. 3 and No.4.

The results of simulation studies for Warsaw are shown in Table II. The P&R system is very popular in Warsaw, which is attested not only by experts but also by users. Most P&R facilities have good opinions but some of them are located too close to the city center in users' opinions. Such a car park is Anin SKM (No.1 in Table II). The inference fuzzy model has evaluated it as 63% *ACM* which means the value between sufficient and good. Low value is caused by low value of parameter *D*. Thus, the fuzzy inference results are convergent with the users' opinions. Similar situation is for Polczynska St. car park (No.7 in Table II). In the opinion of experts [5], the facility has been assessed as very good but the results of our simulation tests indicate the value of *ACM* 65%. That means 40% *sufficient* and 60% *good* which is definitely less than in experts' opinions. Our evaluation is closer to the reality. The location is good from the territorial conditions' point of view but in terms of public transport the result is 50% sufficient and 50% good which shows the lack of public transport quality. These results are in accordance with the opinions of current users. The drivers find that parking too close to the city center and not comfortable because of insufficient public transport. Organizing a convenient transport is one of the important elements indicated in the literature.

VII. Conclusions

Results of studies of most locations were consistent with the opinions of commercial team of experts. In one case it was divergence but the confrontation with users' feedback showed that the results of our fuzzy inference method are closer to reality than the result of the team of experts' analysis. The presented examples of studies have confirmed the effectiveness of the method based on fuzzy inference. The method can be applied in urban planning of the P&R facilities location in relation to the accompanying functions. The presented method is easy to use, which is its advantage because it enables simplification of the professional expert analysis. The ability to analyze multiple locations in a short time gives a broader view on the problem. The model's calculation can replace the laborious analysis of the team of people, which is very valuable. In the authors' opinion, the proposed method could be suitable for implementation on a GIS platform.

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