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THE MULTIMODAL APPROACH TO THE MODELLING OF MODAL SPLIT

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Abstract: *Transport in cities plays a crucial role in the lives of inhabitants. Development of cities affects the functional aspects of the network include the emergence of new areas of traffic generators. Unsuited infrastructure causes many negative effects that outraged the standard of living in cities. In this paper the concept of Park and Ride was presented as a way to cope with the growing volume of traffic. Full procedure for estimating the contribution of different modes of transport including the Park and Ride was presented. Additionally, an important part of the article is devoted to a description of full Delphic approach, applied for membership function (MF) shape definition of chosen function, estimating linguistic variable.*

Key words: *modal split modelling, Mamdani Fuzzy Inference System, Park and Ride*

1. Introduction

The development of city substances, observed especially during last decades has strong influence on functional aspects of street network. New living areas, shopping malls or industrial areas are significant traffic generators which imply changes into functioning both public and private transport system. Very often existing street network, especially in historical cities, is not prepared for high level of traffic. Those problems refers also to districts which are placed outside the downtown – in the suburbs. Many housing estates are connected with street network through few streets with low technical parameters. It implies on increasing lost time of passengers (and drivers), increase operating costs, influence on modal split (by decreasing share of public transport) and decrease level of life in cities.

Park and Ride is one of the way how to solve traffic problems and mitigate the process of urban sprawl. The system tries to join the advantages of public transport in high-density areas and the advantages of the private car in the outskirts. In Polish conditions Park and Ride system is not widely developed (Warsaw and Krakow are implementing parking lots and also national rail operator is involved with its implementation). However, the decision makers are aware that P&R can be treated as a tool for improvement of downtown accessibility, but they cannot decide whether implement the system or not. Main reason of such situation is caused by lack of knowledge about effects of P&R implementation. Furthermore, it is very important to determine number of users interested in P&R trips. This knowledge can help to define size of P&R lot and evaluate its economic efficiency.

Application of Fuzzy Inference System for modal split modelling is used in many cases [1], [2], [6], [7], [9], [14]. Fuzzy approach [3], [15] could be helpful, when human factor has strong influence on undertaken decisions. In mode choice process, there are few parameters hat could be used in modelling process, e.g.: travel time (quotient of travel times of different modes), cost of the trip, motorization level, car access, yearly income, household size etc. In spite of the fact, that it is possible to estimate mentioned parameters, the final decision undertaken by the users is always affected by their way of perceiving travel conditions. That is why, Fuzzy Inference System could be treated as a proper tool in modal split estimation process.

In fuzzy approach, crucial role plays shape of membership function (MF). There are plenty of approaches, which are helpful in definition of the MF [8]: methods based on heuristics, probability to possibility transformations, histograms, nearest neighbor techniques, feed-forward neural networks, clustering, and mixture decomposition. The shape of MF usually can be estimated as a result of data set collected during survey process. The size of accessible sample has strong impact on obtained further results of Inference System. Because in Poland P&R system operates in limited range which cases insufficient input data, it was assumed, that it would be acceptable to provide proper shapes basing on experts' knowledge. It was designed special procedure of cooperation with experts to define shape of MF. The procedure, was based on Delphic approach [12] - the same group of experts received results of first questionnaire and then had to create their own membership function based on experiences collected within first round of questionnaire. Similar approach was applied by Ping-Teng [5]. The method employs the fuzzy statistics and technique of the conjugate gradient search to fit membership functions. In presented approach, shape of MFs will be estimated according to transport experts estimations. Proposed shapes were digitalized and using approximation tools parameterized as different functions (Gauss, bell etc.). As a result it was obtained final shapes of function, which state the base for whole FIS procedure. Within the paper it will be described full procedure of estimating share of different modes of transport, taking into consideration Park and Ride trips. Additionally, important part will be devoted to description of full Delphic approach, applied for MF shape definition of chosen function, estimating linguistic variable.

2. Research approach

In traditional approach of determining probability of mode choice, as an influence factor it is used quotient of travel times – private transport (*PrT*) and public transport (*PuT*). However it will not take into consideration subjective impression of the users connected with time of individual parts of trip chain (e.g. access time, waiting time, egress time, dwell time). That is why, within this approach as a base for further analysis there will be taken generalized cost of the trip [10]. Generalized cost is a total cost which user should cover to travel from origin to destination [11]. This value consider not only operating costs (e.g. cost of the fuel, insurance, public transport ticket) but also monetary equivalent of travel time:

$$K_{P\&R}=K_{PrT}+K_{PuT}+U \quad (1)$$

where:

$K_{P\&R}$ – generalized cost of P&R trip,

K_{PrT} – cost of private car trip,

K_{PuT} – cost of public transport trip,

U – cost equivalent of trip time inconvenience.

The cost of private car and public transport riding is relatively not complicated to find. The problem is, how to estimate cost equivalent of trip inconvenience. Access time, riding time, waiting time and egress time (Fig.1) has the same unit, but there is no possibility to add directly all those values. Each element of trip chain has different weight for its time and to make this value additive with operating costs, subjective time of the trip is multiplied by monetary value of time. During first step of proposed approach it will be necessary to define value of generalized cost of the trip for selected modes of transport (private car, public transport and Park and Ride).

It is worth to emphasize, that generalized cost must concerns each origin-destination (O-D) trips, and it should be estimated for all possible O-D relations which can be realized through analyzed P&R lot (separately for each P&R lot). Afterwards it will be possible to use methodology, which can be divided into following stages:

1. Procedure of split estimation between private and public transport (1st Stage).
2. Comparison results with accessible logit models, calibrated for Polish cities. Positive comparison of proposed fuzzy approach with traditional logit models can be treated as a confirmation of chosen methodology.
3. Procedure of section off P&R trips from private and public modes of transport (2nd Stage). Share of analyzed modes of transport can be estimated using following formulas:

$$U_{PrT} = U'_{PrT} - U^{PrT}_{P\&R} \quad (2)$$

$$U_{PuT} = U'_{PuT} - U^{PuT}_{P\&R} \quad (3)$$

$$U_{P\&R} = 100 - U_{PrT} - U_{PuT} \quad (4)$$

Where:

U_{PrT} – total share of private transport trips;

U'_{PrT} – share of private transport trips from bimodal approach;

U_{PuT} – total share of public transport trips;

U'_{PuT} – share of public transport trips from bimodal approach;

$U^{PrT}_{P\&R}$ – share of P&R trips among trips initially carried out by private transport;

$U^{PuT}_{P\&R}$ – share of P&R trips among trips initially carried out by public transport.

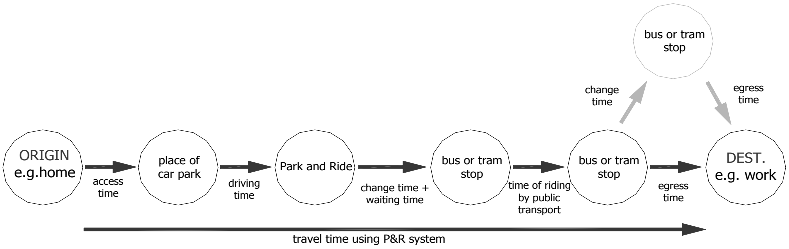

Fig. 1. Trip chain for Park and Ride

3. Variable definition

For the purpose of the estimation of different mode shares (defined above), it will be used Mamdani's Fuzzy Inference System with one input and one output set [15]. Share of *PrT* among non-pedestrian trips depends on value of quotient Δ (5):

$$\Delta = \frac{K_{\Pr T}}{K_{PuT}} \tag{5}$$

where:

K_{PrT} – generalized cost of the trip of private car;

K_{PuT} - generalized cost of the trip of public transport;

For further analysis as a symbol of quotient of generalized cost of the trip will be used symbol "*quotient PrT/PuT*". Assumed input data ("*quotient PrT/PuT*") requires choice of linguistic variable. In this case it is proposed as follow:

Δ ("*quotient PrT/PuT*")=["*very small*", "*small*", "*equal*", "*large*", "*very large*"]

As an output data there will be taken linguistic variable *U* ("*share*"), described by following terms:

U ("*share*")=["*small*", "*medium*", "*large*", "*very large*"]

All linguistic variables will be defined by membership functions, estimating their strength in fuzzy process. Shape of membership function will be define as a separate procedure.

4. Estimation of membership function

To estimate shapes of membership functions, it was applied procedure, based on questionnaire. However, it was quite hard to collect information from daily users – the concept of fuzzy analysis is not understandable and it is not possible to have high quality data. Due to the fact, that shape of membership function has strong impact on final results, it was decided to find other was, where shape could be estimated according to transport experts knowledge. As a supporting tool it was applied Delphic methodology developed by O. Helmer and Dalkey [14]. It is inquiry approach with closed questions, possible to estimate by special group of chosen professionals working separately, with no possibility of discussion. The inquiry is divided into two (sometimes three) rounds of questions, and panelists got information about results from previous round – this helps to decrease dispersion of the obtained results.

Within proposed approach, the shape of membership function was estimated according to inquiry results. The group of experts were chosen among transport professionals in Poland (41 persons). The questionnaire contain explanation of the purpose of the survey and initial shape of the membership function (without suggestions about its location). All collected shapes were digitalized and each shape was saved as a vector of coordinates. Figure 2 presents results of chosen shape (for "*large quotient*" linguistic variable).

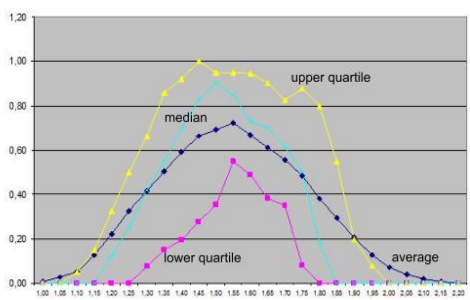

Fig. 2. The example of membership function – results of first round of inquiry for linguistic variable "*large quotient*"

Due to the fact, that membership functions should have height equal to 1,0, so it was necessary to normalize obtained set of functions (some results were subnormal). Then, during next step of questionnaire, results of the first round were presented to the same group of experts. The questionnaire form contained normalized shapes estimated for each linguistic variable with following data: lower quartile, average value, median and upper quartile. The experts were asked to fill up the questionnaire again, but their proposal should be located between upper and lower quartile. That assumption imply on decreasing of results dispersion and support the process of finding common understanding between experts. On figure 3 it is presented final results of the questionnaire for chosen linguistic variable "*large quotient*".

After transformation of the functions, it was chosen mathematical formulas, approximating obtained results. For the whole modelling process it was used Matlab software [14], where following function are possible to apply: *trimf, trapmf, gaussmf, sigmf, dsigmf and psigmf*. For the purpose of the modal split analysis it was chosen gauss function with parameters of average value and standard deviations:

$$f(x,\delta,c) = e^{\frac{-(x-c)^2}{2\delta^2}} \qquad (6)$$

where:
x – average value
δ – standard deviation

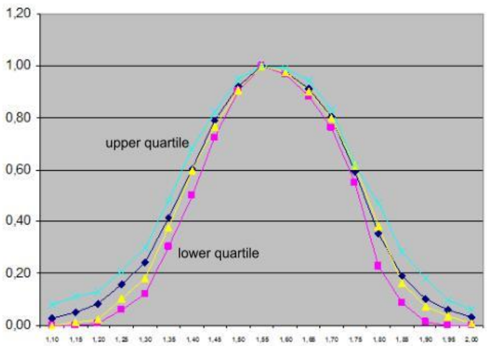

Fig. 3. The results of membership function normalization for linguistic variable "*large quotient*"

For the verification of chosen functions, to compare a sample with a reference probability distribution it was conduct Kolmogorov – Smirnov test and proposed shape of membership function for chosen linguistic variable "*large quotient*" could be estimated with following formula:

$$f(x,\delta,c) = e^{\frac{-(x-1{,}56)^2}{0{,}05}} \qquad (7)$$

Presented formula is valid only for:
$x \in \langle 1{,}45;3{,}00\rangle$

The way of estimating membership functions were applied also for other linguistic variables:
For variable "*very small quotient*":

$$f(x,a,c) = \frac{1}{1+e^{11{,}84(x-0{,}44)}} \qquad (8)$$

Valid for: $x \in \langle 0{,}00;1{,}00\rangle$

For variable "*small quotient*":

$$f(x,\delta,c) = e^{\frac{-(x-0{,}67)^2}{0{,}05}} \qquad (9)$$

Valid for: $x \in \langle 0{,}15;1{,}15\rangle$

For variable "*equal quotient*":

$$f(x,\delta,c) = e^{\frac{-(x-1{,}01)^2}{0{,}03}} \qquad (10)$$

Valid for: $x \in \langle 0{,}55;1{,}45\rangle$

For variable "*very large quotient*":

$$f(x,a,b,c) = \frac{1}{1+\left|\frac{x-3{,}00}{1{,}09}\right|^{7{,}21}} \qquad (11)$$

Valid for: $x \in \langle 1{,}45;3{,}00\rangle$

On figure 4 it is presented final membership function for linguistic variable "*share*".

Last element of Fuzzy Inference System is to define semantics rules which are based on implication IF…THEN. It was created set of all possible rules and in next step rules which are not possible or illogical were rejected. Then for some less important rules there were assumed weights. Defining process of whole set of rules was based on experts analyses. The scheme of applied Fuzzy Inference System is presented on Fig. 5.

The effect of running fuzzy inference process is presented as a two dimensional chart. To compare results of fuzzy process with existing logit models it was necessary to approximate it.

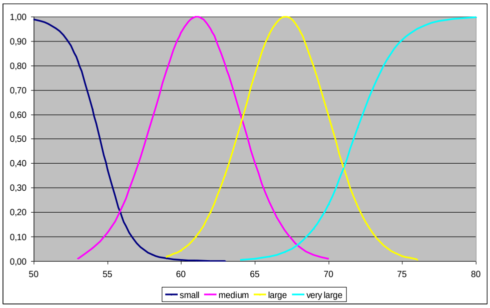

Fig. 4. Example of membership functions for linguistic variable "*share*"

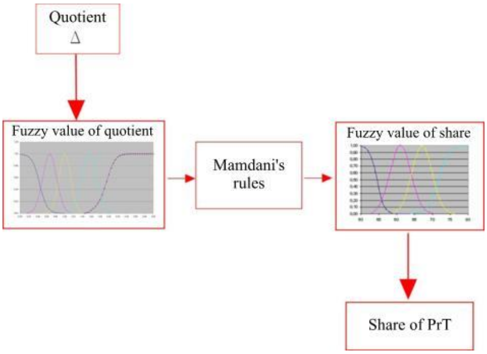

Fig. 5. Scheme of FIS defining share of private transport

Using Mathematica software [13] there was proposed empirical function – formula 11:

$$U'_{PrT} = 65{,}2 * \Delta^{0,1} \qquad (12)$$

To verify obtained results it was necessary to compare "fuzzy" approach with existing logit models. For comparison there was used modal split formulas for chosen cities in Poland: Katowice, Warszawa, Siemianowice Slaskie and Poznan. All functions are based on Comprehensive Travel Studies conducted in those cities during last few years. Figure 6 presents functions of modal split for selected cities.

Obtained result of fuzzy approach (which was received with completely different way than other models) do not significant diverge from dominance of graph bundles – especially in the range of *Δ* 0,4-1,5. It is impossible to use statistical tools (e.g. goodness-of-fit test) to compare those functions. Mostly they are logit ones but the way how the function were obtained, in spite of appearances, are different.

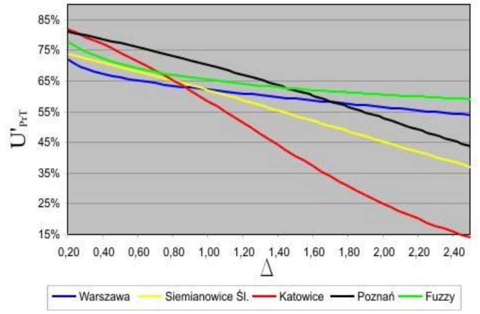

Fig. 6. Comparison of existing modal split models with "fuzzy" model

There is no common procedure taking into consideration surveys of travel behavior (differences concern e.g. definition of trip, formulating questionnaires or result analysis). Moreover dispersion of presented models can prove strong influence of local behaviors on travelling. However similar results of fuzzy approach with traditional models can be treated as a proof of chosen methodology. This assumption states base for further analysis.

5. Estimation of P&R trips share, among car users

Share of Park and Ride refers to two groups of non-pedestrian trips: private cars and public transport. For car drivers it is obvious – some of them will choose P&R as a way of travelling. For second case – public transport passengers – P&R can be chosen only for those, who have driving license and car access. Both groups of users require special procedure to section off potential P&R users. As it was in bimodal approach, base for estimation share of P&R users will be quotient of generalized cost of the trip by car and P&R. However cost is not the only variable during process of choosing mode of transport. In the case of Park and Ride it is important to know, how parking lot is localized, if it is comfortable and safe for users and if it is possible to arrange other business (e.g. shopping). All those elements can affect the decision process during mode choice. It is the reason, why it should be implemented additional variable "*P&R*

attraction". As the input data there will be used two linguistic variables:

Δ ("*quotient PrT/P&R*")=["*very small*", "*small*", "*equal*", "*quite large*", "*large*", "*very large*"]

and

A ("*P&R attractiveness*")=["*small*", "*medium*", "*large*"]

To estimate shape of membership function, there were used results of questionnaire for linguistic variable "*quotient PrT/PuT*". Initially there were the same shapes but afterwards they were modified. During conducted questionnaire surveys it was added question concerning arduousness of changing modes of transport (from private car to P&R). This knowledge will help to determine proper shape of membership function. Because changing mode of transport is connected with arduousness, it means that function should part – left side for membership functions for terms "*very small'* and "*small*" (if it is more difficult to left car and choose P&R it means that mentioned terms should have less value) and right side for terms "*large*" and "*very large*". In the result of function parting it was obtained empty area between terms "*equal*" and "*large*". It is important from operational point of view to have crossing level similar to 0,5 (value for which adjacent functions are crossing) [3]. According to this it is important to add new function describing term "*quite large*".

For shape of "P*&R attraction*", it was chosen Gauss function according to literature studies. It was assumed, that level of attraction for each P&R lot will be assessed individually and range of values will be between 0-10 (0 – the worst location, 10 – the best one). Proposed shapes of membership functions for linguistic variable "*attractiveness*" is presented on figure 7:

As the output data there was used the same shapes as in the case of bimodal approach. The only difference refers to assumed range of share. According to results of P&R study in western countries it was obtained, that share of P&R trips is not higher than 10% - it was assumption for the data range. Because share of P&R users is not higher than 10% it confirms meaning of "*large*" as a linguistic variable. It is worth to emphasize, that assumed values refers only to single O-D trip. In the scale of whole city P&R will have less significance.

The scheme of fuzzy inference system is presented on fig. 8 (semantic rules were defined in the same way as it was described in bimodal approach).

After application of fuzzy process, there were obtained results which can be presented in three dimensional chart (fig. 9).

To make results more accessible, it was made the approximation. The formula describing obtained surface can be presented as follows:

$$U_{P\&R}^{PrT}(x,y) = -0{,}3x^2 + 2{,}4x + 0{,}17y + 0{,}82 \quad (13)$$

where:

x – quotient of generalized cost of the trip PuT/P&R;

y – attractiveness of P&R location.

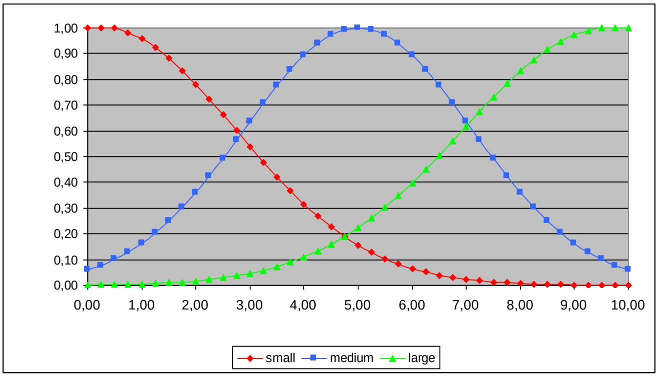

Fig. 7. Example of membership functions for linguistic variable "*attractiveness*"

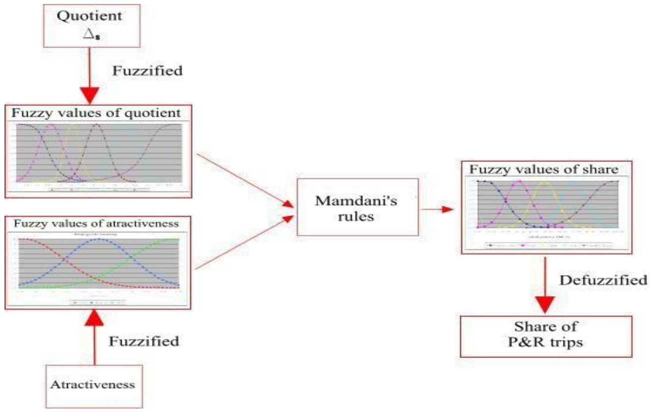

Fig. 8. Scheme of FIS defining share of P&R among private transport trips

Obtained results can help to estimate potential share of P&R trips among private transport. This value refers only to analysed OD relation and cannot be directly treated as a total split. Share of P&R trips fluctuates between 1,5% - for extremely unfavourable conditions and 6,4% for the most favourable ones. It can be strangely high value of share for the worst conditions, but fuzzy procedure rejects extreme input values (in this case close to 0% and 10%), and thanks to this it brings closer to way of noticed of phenomenon by human mind.

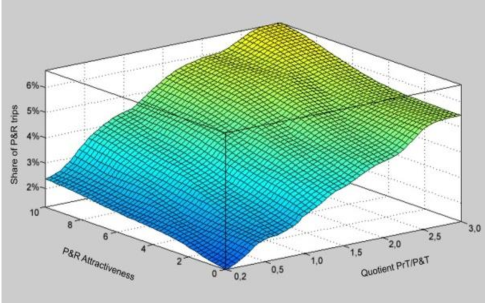

Fig. 9. Results of FIS – share of P&R users among private transport

6. Estimation of P&R trips share, among public transport users

Last element of presented approach refers to share estimation of P&R trips among public transport users. This refers only to group of persons which have possibility of mode choice i.e. they have driving license and car availability.

Proposed approach has the same character as presented above – the input and output data, rules and membership functions are the same. The only difference refers to shape of membership functions of linguistic variable "*quotient PuT/P&R*". In this case it was necessary to difference "slenderness" of MF and its positioning. It refers to relationship between changing modes of transport – it is easier to change public mode of transport into P&R than private car into P&R. If it is easier, it means that MF should be more "slenderness" ("squeezed"). It can explained the fact, that if it is easier to change PuT into P&R the impulse to do it for the user can be smaller. Figure 10 presents proposed shapes of membership functions for input data "*quotient PuT/P&R*".

After run of fuzzy procedure obtained results can be presented in three dimensional chart. The surface represent share of P&R trips among public transport (Fig. 11).

The surface has different character in comparison with private transport approach. The main reason is completely different layout of membership functions of input data. In this case MF are concentrated on value 1,0 and it is the reason of significant growth of share. It can be explained, that according to taken assumption (it is easier to change mode of transport from PuT into P&R than from PrT into P&R) small changes of "*quotient PuT/P&R*" is enough to convince user to change mode into P&R. For higher/smaller values of "*quotient PuT/P&R*" the share of P&R has more stable character.

Because surface has complex shape, one has decided to divide it into three parts. For each of them there was approximated functions using Mathematica software.

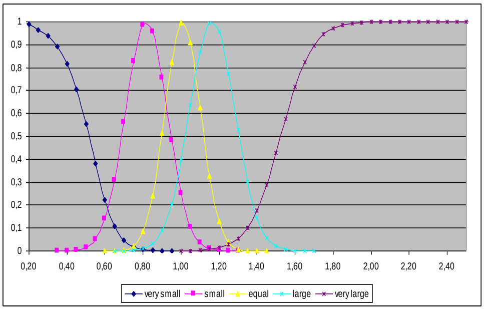

Fig. 10 Example of membership functions for input data

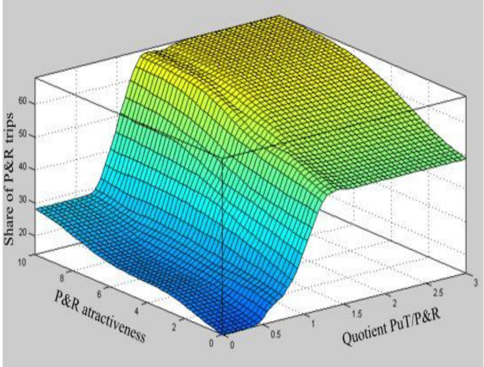

Fig. 11. Results of FIS – share of P&R users among public transport

Formulas for each part is presented below:

For $\Delta_{PuT/P\&R} \in (0,2;0,8)$

$$U^{PuT}_{P\&R}(x,y) = -0,01y^2 + 0,15y - 0,1xy + 1,7x + 1,1 \quad (14)$$

For $\Delta_{PuT/P\&R} \in (0,8;1,4)$

$$U^{PuT}_{P\&R}(x,y) = -0,03y + 0,2xy + 72,6x - 12,9e^x - 34,9\ln x - 33,5 \quad (15)$$

For $\Delta_{PuT/P\&R} \in (1,4;2,5)$

$$U^{PuT}_{P\&R}(x,y) = -0,1x^2 + 0,3x + 0,1xy - 0,2y^2 + 0,4y + 4,5 \quad (16)$$

where:

x – quotient of generalized cost of the trip PuT/P&R;

y – attractiveness of P&R location.

7. Conclusions

Presented methodology of estimation P&R trips share users is quite circuitous and complicated. It requires interpretation of potential travel behaviors and its transmission into fuzzy procedure. Proposed formulas can be used as a tool for estimation of size of future parking lots and it can be also used to evaluate economic efficiency of the system (e.g. in the frame of Feasibility Study).

The system is not well known in Poland (practically, on large scale the system operates only in Warsaw) and it is difficult to estimate (also calibrate) modal split function based only on Stated Preferences survey. Krakow has two P&R lots, but share of that kind of trips do not exceed 0,1% of total trips in the city. Fuzzy approach can be justified in the case of rough data and moreover in this case, existing human factor is difficult to estimate using traditional mathematical approach, it is seemed, that fuzzy methodology can be treated as a proper way to describe choice of mode of transport. The proposed approach is based on the Mamdani Fuzzy Inference System where, as the part of the model, the membership functions estimation, states one of the most important part. Presented methodology of MF estimation requires interpretation of potential travel behaviors and its transmission into fuzzy procedure. The survey had two level verification using Delphic approach and final results were obtained as an approximation of shapes of the functions proposed by experts. The cooperation between transport experts could have significant impact on obtaining reliable results, especially when modelled object has hypothetical character for users.

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