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The Model of Correspondence of Passenger Transportation on the Basis of Fuzzy Logic

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Abstract. The article dwells upon possibilities of the implementation of smooth calculation methods for predicting the demand for passenger transportation. The developed model which is based on fuzzy logic successfully solves the problem with traffic assignment – formation of passenger throughput for each traffic route. The model of correspondence takes into account such defining factors as fare on the route, average headway on it and fullness of the vehicle saloon. Different combination of these factors forms attractiveness as a criterion of an optimal route for a prospective passenger. It is determined that the lower saloon fullness, transportation fare and headway, the higher attractiveness is. Using the reasoned criterion, it is possible to allocate the total number of prospective passengers according to each existing route.

Key words: fuzzy logic, transportation correspondence, membership function, basis of fuzzy rules, route attractiveness.

INTRODUCTION

The system of passenger transportation in cities has to be regarded as difficult and changeable one. The initial information used for the development of project decisions concerning improvements of traffic system functioning is the demand of citizens for transportation services. Prediction of the demand for passenger transportation is indispensible part of traffic planning in big cities.

One of the powerful characteristic features of demand due to its resource-intensiveness of calculations is considered to be correspondence of passenger transportation of the citizens. Results of its calculations characterize the mobility pattern on the territory of planning in spatial and quantitative dimensions.

ANALYSIS OF THE LATEST FINDINGS AND SCIENTIFIC PUBLICATIONS

The issue of passenger transportation allocation on a street and road network of a city or town was investigated by a number of scientists [1 – 9]. In their works, the initial information for matrix correspondence evaluation is a number of passengers who gets on and off a vehicle on each stop. The research in this field was carried out mainly for routes of public transport. Among foreign scientists who worked on this subject the following ones can be distinguished: N. Oppenheim, Y. Sheffi, J. Ortuzar, C. Winston, D. Loze, D. Drew and others [10 – 14].

The analysis of scientific publications has defined the requirements for passenger correspondence patterns: flexibility (possibility of additional parameters input in order to take into account traffic situation in cities); universality (possibility to describe different types of road trips); relative simplicity (broad application under various conditions of planning with and without computing technologies) [15, 16].

Models of defining transportation capacity with the use of fuzzy logic are qualitatively distinguished among others in terms of minimizing necessary resources for collecting initial data and simplicity of calculating. Due to their structure, such models represent a “black box” which allows to enter input data, formed in a certain way, and receive outcomes [17].

OBJECTIVE

Since passenger transportations are characterized by ambiguity of information concerning main features of a particular route type and preferences of an active part of the population, the objective of the research is to develop a model of passenger transportation correspondence on the basis of mathematical apparatus of fuzzy logic which enables choosing the most suitable options of a route which at the same time are the most time and cost effective and the most comfortable ones.

MAIN OUTCOMES OF THE INVESTIGATION

In the course of certain investigations [18] the survey of citizens was carried out with the aim to detect factors which do not allow people to satisfy their needs in using public transport. Among them there is transportation fare, headways, boarding denial, saloon fullness, time spent on the way to a stop, necessity in transfers, transportation safety. Outcomes of processed data have shown that passengers belonging to the main population groups are not satisfied, first and foremost, with transportation fare. Other factors that follow in order of importance are: headway, boarding denial, saloon fullness [18].

Taking into consideration the above, for allocation on the routes of transportation of the total number of people who waits to be transferred from point A to point B, it is reasonable to build the model with the initial data concerning total transportation fare, average headway of the vehicle on the route and average fullness of the vehicle. Initial (resulting) data will be attractiveness.

Considering a set of alternative connective routes, each of them corresponds to a particular value which is called attractiveness and depends upon parameters which characterize this route.

Therefore, methodological approach to evaluation of alternative attractiveness (choice of a route option) is considered in this paper:

$$P = f\left(V, I, N\right), \tag{1}$$

where: V – transportation fare on the route;
I – average headway on the route;
N – fullness of vehicle saloon.

In order to fulfill the set task there has to be created a database of rules for fuzzy logic with three inputs and one output. The task was to form fuzzy rules for the basis of the control module which, when receiving input signals (transportation fare (*V*), average headway on the route (*I*) and fullness of the vehicle (*N*)), would generate valid (with the least error) output signals (attractiveness of the route (*P*)) [19].

Let us suppose that we know the minimal and maximal value of each signal. According to these data it is possible to define intervals of admissible values. For instance, for input signal of transportation fare on a route (*V*) this interval is denoted as $\left[V_{\min}; V_{\max}\right]$ in monetary units.

Similarly let us set an average headway on a route (*I*) as $\left[I_{\min}; I_{\max}\right]$ in minutes, for vehicle fullness (*N*) – [0;100] on a percentage base. Accordingly, we choose the interval for an output signal of a fuzzy system – route attractiveness (*P*) [0;10], where 0 means that this route will not be used, 10 – the route will definitely be used.

Let us divide each interval defined in this way into areas which can be of the same or different length. Selected areas will be denoted as *M* (small), *S* (middle), *B* (big). One membership function will be defined for each interval. Fig. 1 depicts allocation of input and output signals into intervals. Each interval is divided into three areas.

Each membership function of input signals has triangular shape. One of the vertices is located in the center of the area and corresponds to the function value of 1. Two other vertices are in the adjacent areas and correspond to the function value of 0. The membership function of the output signal (attractiveness) is circumscribed, for example, by Gaussian curve.

The next step in creating the transportation correspondence model is setting fuzzy rules. To do this we define the degree of data membership in each of highlighted areas.

This membership is expressed by the membership function values of respective fuzzy sets for each data group [19]. The initial information was a testing selection in which the researcher had estimated in grades the degree of attractiveness of suggested routes with different characteristics.

Let us relate data to the areas in which they have the highest degree of membership. For instance, for the route with such characteristics:

$$V = 0{,}1 \cdot V_{\max},\ I = 0{,}4 \cdot I_{\max},\ N = 40\%,\ P = 8$$

it is possible to record the following fuzzy rule (there are 27 of them in total):

$$\begin{aligned} &(V = 0.1 \cdot V_{\max}, I = 0.4 \cdot I_{\max}, N = 40\%;\\ &P = 8) \Rightarrow V = 0.1 \cdot V_{\max}\,[\max: 1\ in\ M],\\ &I = 0.4 \cdot I_{\max}\,[\max: 0.6\ in\ S],\\ &N = 40\%\,[\max: 0.6\ in\ S],\\ &P = 8\,[\max: 0.9\ in\ B] \Rightarrow\\ &ruleR:\\ &IF\,(V\,is\,M\ AND\,I\,is\,S\ AND\,N\,is\,S)\\ &THEN\,P\,is\,B. \end{aligned} \tag{2}$$

As a result of processing of these samples some compiled rules appeared to be controversial (e.g. the rule with the same conditions but with different outcomes). Elimination of controversy meant attributing to each of them a degree of verity with further selection of the rule where this indicator is the highest [19].

In this way there were found and discarded 5 pairs of controversial rules. The procedure was carried out according to this formula:

$$SP(R) = \mu_M\left(V\right) \cdot \mu_S\left(I\right) \cdot \mu_S\left(N\right) \cdot \mu_B\left(P\right), \tag{3}$$

where: $\mu_M\left(V\right), \mu_S\left(I\right), \mu_S\left(N\right), \mu_B\left(P\right)$ is membership degree of the value of fare, headway and fullness of the vehicle in respective areas.

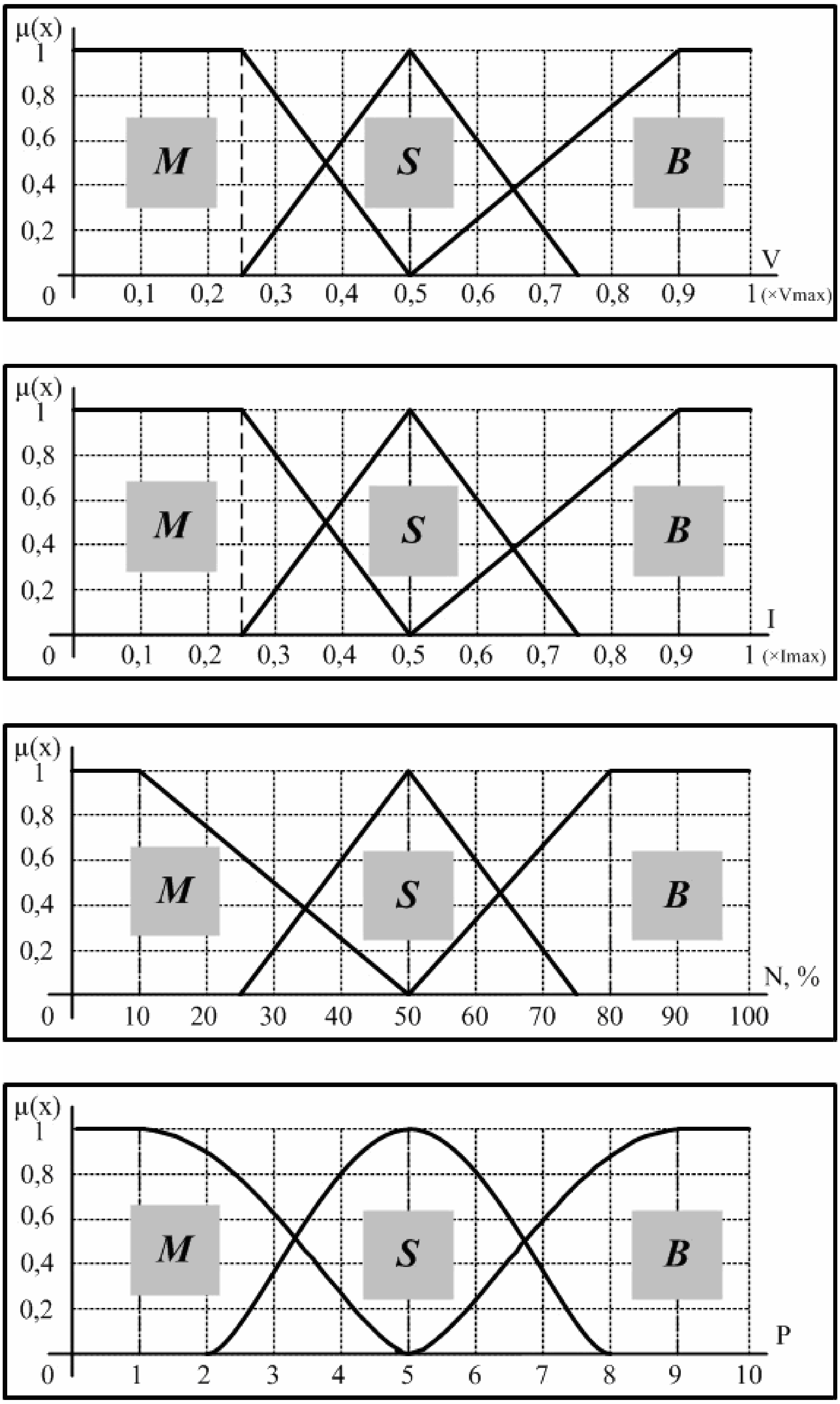
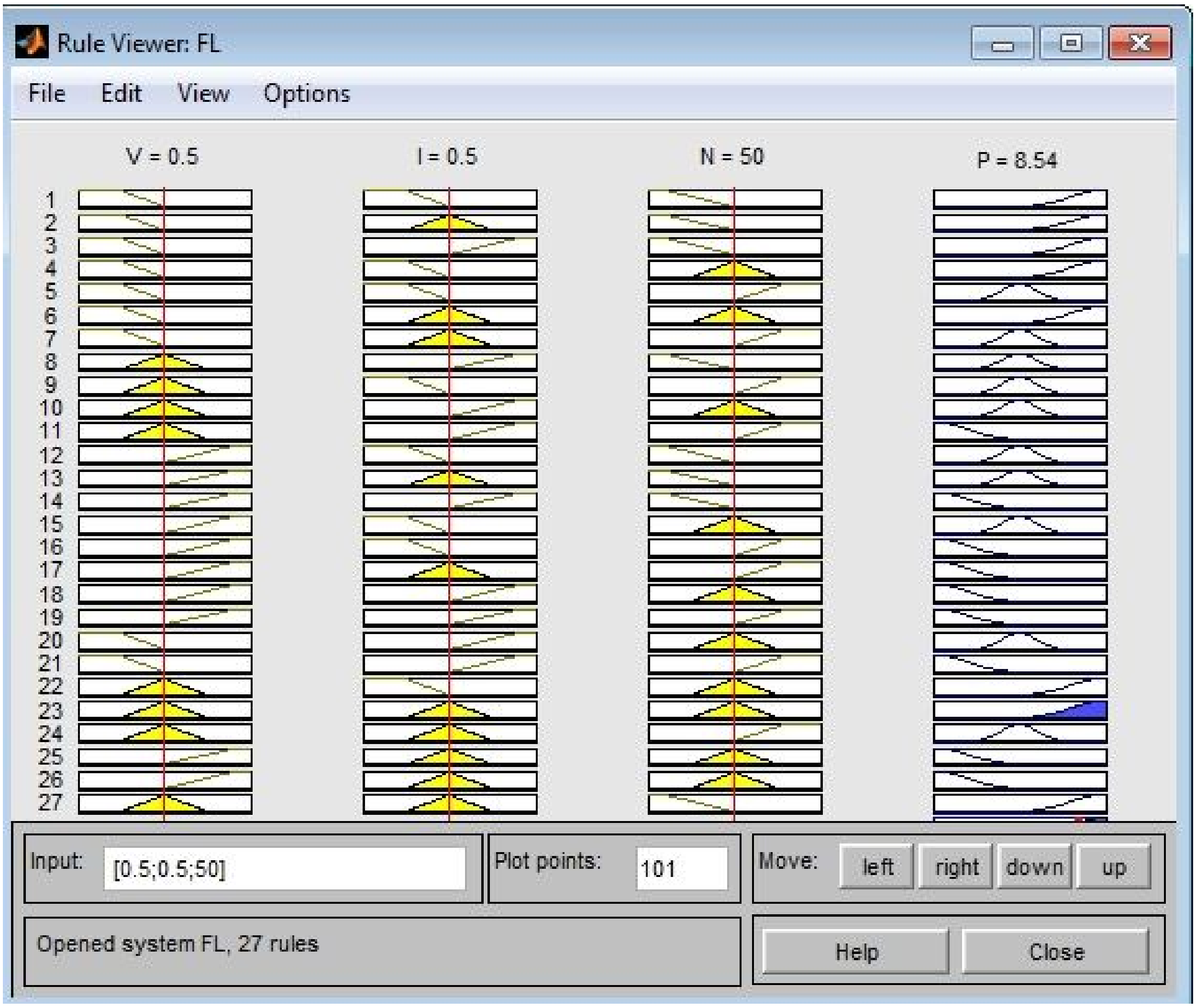


Fig. 1. Space allocation of input and output signals on the area and respective to them membership functions



Input: [0.5;0.5;50]

Plot points: 101

Opened system FL, 27 rules

Fig. 2. View window of the rules of fuzzy inferences in MATLAB software environment

Therefore, the whole database of rules consists of 27 fuzzy statements (3 input signals which are divided into three areas). With its help and having used one of defuzzification methods (barycentric method, Center of Area method, left/right modal value method) we gain accurate output value of a fuzzy system, i. e. attractiveness of an option in grades.

Manipulating the data of passenger throughputs between two points among available route options which connect them and attractiveness of such alternatives, it is possible to calculate the number of passengers which will use each of these routes:

$$q_i = \frac{Q}{\sum_{i=1}^{n} p_i} \cdot p_i, \qquad (4)$$

where: q_i is a number of passengers which will use i-option;

Q - passenger throughput between two points;

p_i - attractiveness of i-option among total n-number.

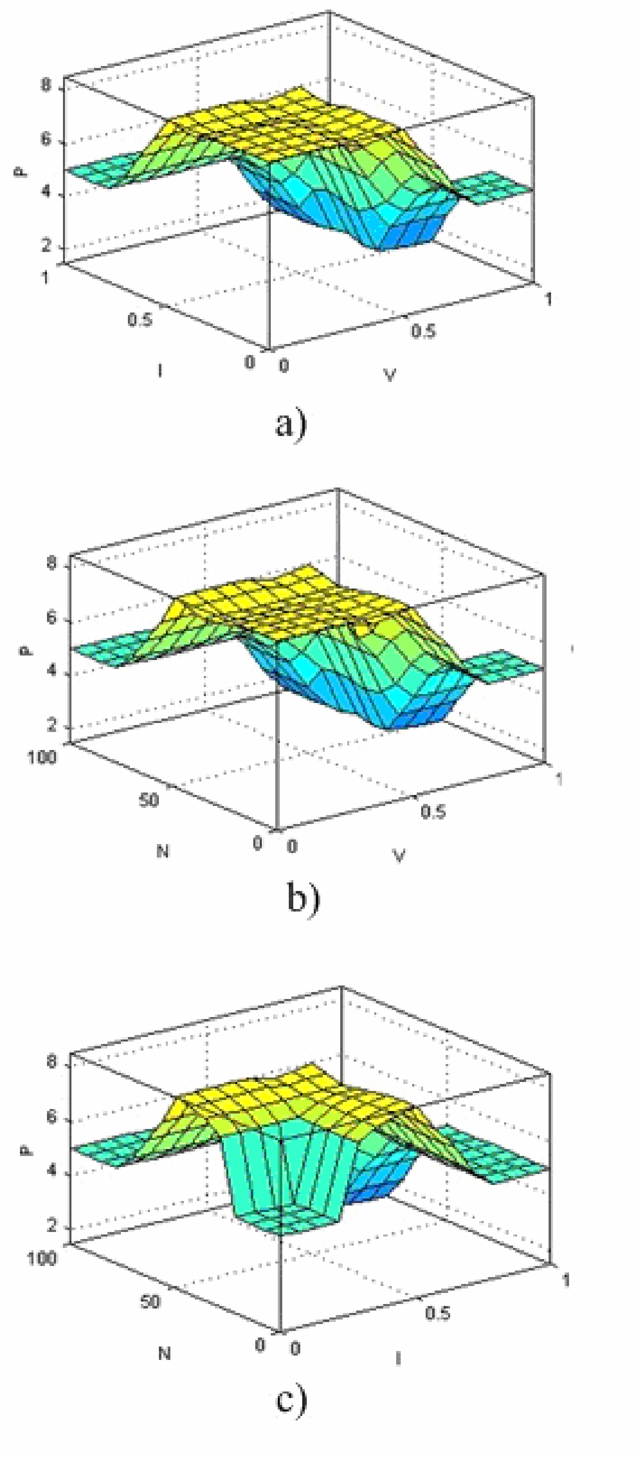


Fig. 3. Response Surfaces in relation to attractiveness level of alternative variants of transportations

The developed model is implemented in MATLAB software environment with the use of Fuzzy Logic Toolbox package [20, 21]. The program uses Mamdani algorithm of fuzzy inference and centroid method of defuzzification (reduction to neatness) [19]. Fig. 2 shows the view window of the rules for fuzzy inferences (red lines depict transportation fare *V*, headway on the route *I* and fullness of a vehicle saloon *N*; in the fourth column the output value, i. e. attractiveness *P*, is calculated automatically).

Dependence of attractiveness of alternative options for passenger transportation on transportation fare and vehicle headway (a), transportation fare and vehicle fullness (b), headway and fullness (c) are depicted as response surfaces in fig. 3.

Therefore, the outcomes of the application of developed correspondence models based on fuzzy logic has proved that they can be used further in forming matrixes of passenger throughput on specific routes. The information from databases of cellular communication on recording of transactions carried out by citizens will also be used.

CONCLUSIONS

Obtained results enabled drawing the fallowing conclusions:

1. The analysis of scientific publications on functioning systems of passenger transportation has revealed main demands to transportation correspondence models.
2. Correspondence models take into account the following defining factors: transportation fare on the route, average headway on it and fullness of a vehicle. Attractiveness of a route type is considered as a defining criterion for the selection of a rational option of transportation.
3. With the help of application of the fuzzy logic method and respective membership functions, the full database of rules (27 in total) for finding attractiveness of alternative route options was established.
4. The transportation correspondence model is implemented in MATLAB software environment with the use of Fuzzy Logic Toolbox package. On the basis of this (as a specific example shows) it is possible to choose optimal options of correspondence allocation on the routes according to their attractiveness.

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