

## **The Formation of Transportation Route Selection Model of the Urban Population in Matlab Software Environment**

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**Summary.** The article dwells upon the possibilities of the implementation of smooth calculation methods for predicting the demand for people movement. The developed model based on fuzzy logic allows to solve the problem of transportation allocation - the formation of passenger traffic for each type of route. Transportation route selection model takes into account the following defining factors: transportation fare on the route, average headway on it and fullness of a vehicle. Different combination of these factors form the attractiveness as a criterion of an optimal route for a prospective passenger. The article describes the gradual creation of passengers' allocation model accordingly to the routes in the software environment Matlab using the Fuzzy Logic Toolbox package. The example of model implementation is given.

**Key words:** fuzzy logic, software environment Matlab, graphical interface, model parameters, the attraction of route, membership function.

### **INTRODUCTION**

The determination of population's transportation characteristics as key indicators of the city areas development is the subject of many studies conducted in domestic and foreign urban planning and transport planning practices.

In order to develop and adopt effective management decisions in the public transport organization and exploitation, the determining issue is constant (according to the monitoring results) information on the correspondence of movement within the territory covered by this network. It is used for both service level improvement and current users of public transportation (the updating of timetables offers maximum convenience for the users) and for encouraging more users (the coordination of different types of work schedules). The implementation of this important task requires first of all the development of mathematical (computer) model for an adequate reproduction of the actual route options of population transportation. On this basis, the relevant criteria for the route are suggested.

### **ANALYSIS OF THE LATEST FINDINGS AND SCIENTIFIC PUBLICATIONS**

The issue of passenger transportation allocation on a street and road network of a city was investigated by a number of domestic scientists [1-9], among which there are Braylovskiy N. O., Hranovskiy B. I., Horbachov P. F., Dolia V. K., Hetsovykh S. M., Zablotskiy H. A., Vdovychenko V. A., Liubiy Ye. V., Honcharenko S. Yu., Rossolov O. V., Pohrebniak E. B., Skaletskiy V. V. and

others. 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 main 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].

In order to design systems based on fuzzy logic Matlab Fuzzy Logic Toolbox package is used, containing appropriate tools [18-21]. The package allows you to create expert systems, conduct clustering with fuzzy algorithms and also design neuro-fuzzy networks.

### **OBJECTIVE**

Since population's transportation is characterized by ambiguity of information concerning main features of a particular route type and preferences of its active part, the objective of the research is to develop a model of the transportation route selection model on the basis of mathematical apparatus of fuzzy logic which is realized in software environment Matlab by using Fuzzy Logic Toolbox package.

### **MAIN OUTCOMES OF THE INVESTIGATION**

Fuzzy logic and fuzzy sets theory underlie many methods of research and system modeling that relate to artificial intelligence. To implement the process of a fuzzy modeling in Matlab environment a special bump package Fuzzy Logic Toolbox is used [18-21].

For the development and further application of the transportation route selection model of population in interactive mode are used such graphical tools, included in Fuzzy Logic Toolbox package:

- Fuzzy inference systems editor FIS (FIS-editor);

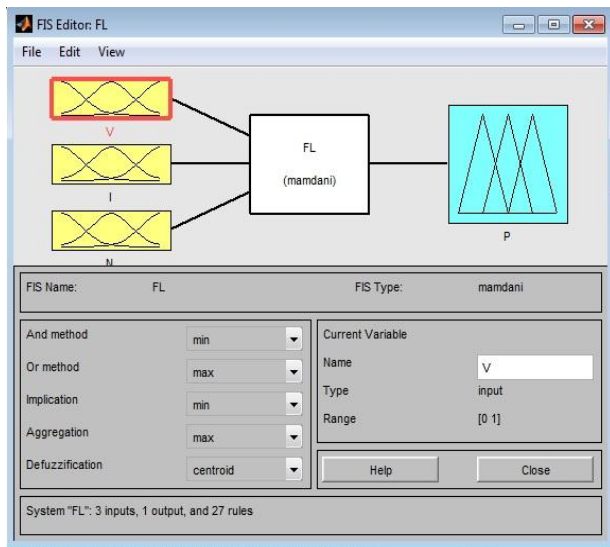
- Membership function editor of the fuzzy inference systems (Membership Function Editor);
- Rule Editor of the fuzzy inference systems (Rule Editor);
- Rule Viewer of the fuzzy inference system (Rule Viewer);
- Surface Viewer of the fuzzy inference system (Viewer).

FIS Editor is the primary means used for creating and editing fuzzy inference systems in a graphical mode and is started by entering a function *fuzzy* in a command line. This function provides an opportunity for the user to set and edit on a high level properties of the fuzzy inference system. In particular, the number of input and output settings, the type of fuzzy inference system, the method of defuzzification that will be used in a future model.

In our previous studies we justified the initial parameters of the transportation route selection model of passenger [22, 23]. Among them, the total transportation fare ( $V$ ), average headway on the route ( $I$ ) and average fullness of vehicle saloon ( $N$ ) are the input parameters of the model; route attractiveness ( $P$ ) is resulting data. The model uses Mamdani algorithm of fuzzy inference and centroid method of defuzzification [23, 24]. Enter the above information on the initial parameters of the model in FIS Editor. Fig. 1 shows the view window of graphical interface FIS with given initial parameters of the model.

FIS Editor possesses a graphical interface and allows to induce all the other editors and programs of fuzzy inference systems view.

Membership function editor of the fuzzy inference systems is used to set and edit membership functions of the individual parameters of the fuzzy inference system in graphical mode. It is possible to change name, type, and parameters of each membership function. The editor provides an opportunity for the user not only to select any of the 11 built-in membership functions but to create your own.



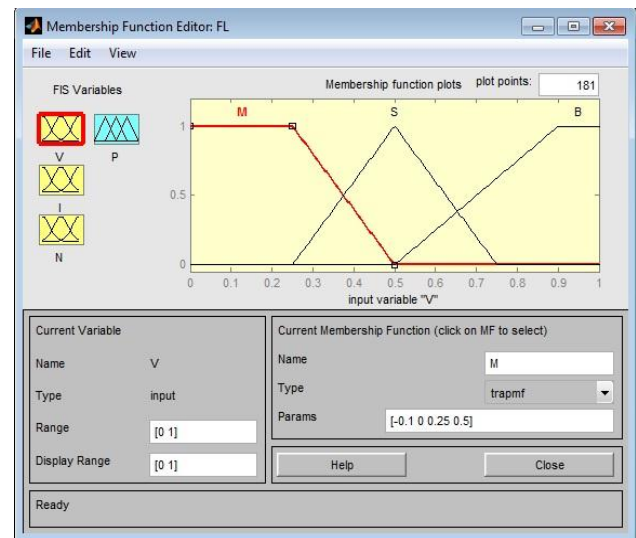
**Fig.1.** GUI view window of FIS Editor with given initial parameters of the transportation route selection model.

Previous studies for each of the model parameters defined a band for permissible values [23]: for the input

signal of transportation fare on the route ( $V$ ) such interval is defined  $[V_{\min}; V_{\max}]$  in monetary units; average headway on the route ( $I$ ) such interval is defined  $[I_{\min}; I_{\max}]$  in minutes; for fullness of the vehicle – ( $N$ )  $[0; 100]$  in percents, for the attractiveness of route ( $P$ ) –  $[0; 10]$  in points. Each defined in this way headway is divided into areas  $M$  (small)  $S$  (average),  $B$  (large). Each membership function of the input signals has a trapezoidal shape. Membership function of an output signal (attractiveness) is described by Gaussian curve.

Let us consider the example of membership function creation, for instance, the input parameter - the total fare of transportation ( $V$ ) in software environment. Let the maximum transportation fare  $V_{\max}$  be 1, thus the average transportation fare is  $0,5 \cdot V_{\max} = 0.5$ . In *Range* window enter the range of parameter changes  $[0; 1]$ . In *Type* window select the desired type of membership function (in our case *trapmf*). In the field *Membership function plots* with the help of a mouse draw the appropriate membership function. Similar actions are performed for three other model parameters. Membership function editor window of the input parameter of the total transportation fare is as follows (Fig. 2).

Rule Editor of the fuzzy inference system is designed to create and edit individual rules of the fuzzy inference system in graphical mode and can be opened by Main Menu Editor FIS (by menu command *Edit-Rules*). To enter the rule choose in the menu an appropriate combination of the terms and click *Add Rule*.



**Fig. 2.** Membership function editor window of the input parameter "total transportation fare".

As an example, let us consider a creation of the following rule in Matlab environment: If the total transportation fare is small and the average headway on the route is small, and fullness of the vehicle is small, the attractiveness of route is great. With the help of appropriate terms and logical operators this rule can be written like this:

**IF**  $V$  is  $M$  and  $I$  is  $M$  and  $N$  is  $M$  **THEN**  $P$  is  $B$ .

Fig. 3 shows the editor window of the rule base after entering all 27 rules [23]. At the end of each there are their weight coefficients in brackets.

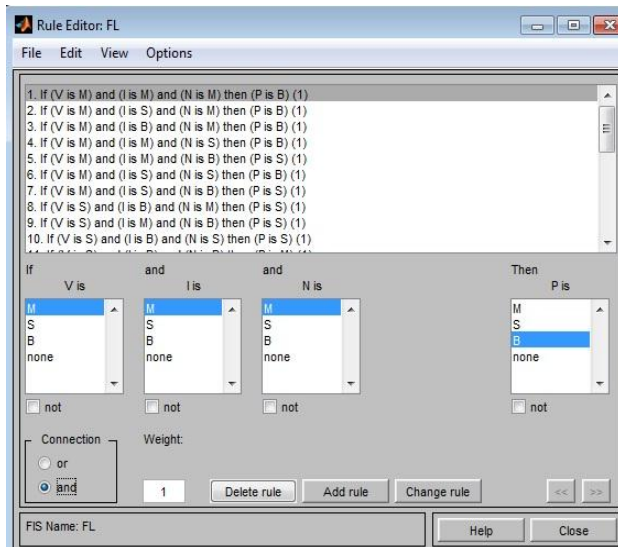


Fig. 3. The fuzzy rule base in *Rule Editor*

The main purpose of rule review program is the ability to visualize the results of fuzzy inference and get the values of output parameters (in our case attractiveness on the route) depending on the initial values of input parameters (total transportation fare, average headway on the route and fullness of the vehicle). The program is invoked with the help of main menu FIS Editor, Membership function editor or Rule editor menu command *View - Rules*.

Rule review program does not allow to edit rules and membership functions of the terms parameters and is used after developing the fuzzy inference system during the phase of its analysis and evaluation. The program is also suitable for using when you need to represent visually all fuzzy inference process from the beginning to the end. The user has the opportunity to assess the value of output parameters of the fuzzy model, and the impact of each rule on the result of fuzzy inference by changing values of input parameters. The graphical interface of Rule review program is shown on Fig. 4.

In the center of graphical interface of the Rule review program are placed rectangles that correspond to the separate input (yellow membership functions) and the output parameters (blue membership function) of the fuzzy inference rules. Each rule corresponds to a separate line of these rectangles. The value of input parameter which was obtained as a result of defuzzification is indicated at the top of the column with the name of this input parameter. Rectangles of the input parameters are crossed by a vertical red line, the allocation of which corresponds to a particular value of the input parameter of the appropriate column. The line can be moved by changing the parameter values. Fig. 4 shows a situation where total transportation fare  $0,5 \cdot V_{\max}$ , average headway on the route –  $0,5 \cdot I_{\max}$ , fullness of the vehicle – 50%. Hence we obtain the value of output parameter – attractiveness of the route reaches 8.54 points.

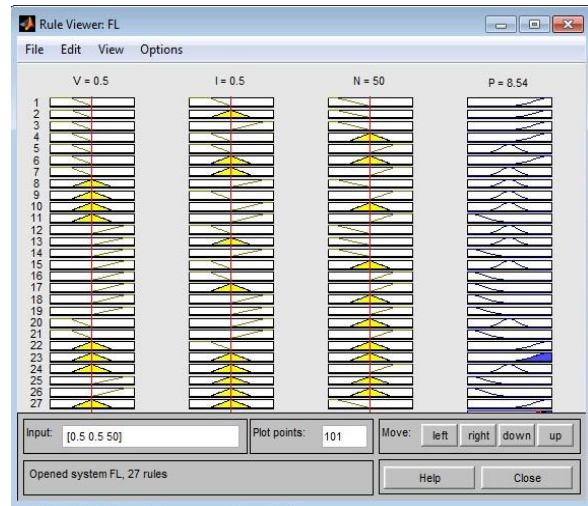


Fig. 4. View window of the Rule review program of the fuzzy inference system.

The surface review program of fuzzy inference system allows to view it and visualize dependency graphs of the output and separate input parameters. GUI can be invoked with the help of main menu FIS Editor, membership function editor or rule editor menu command *View - Surface*. The program does not allow you to make changes to the fuzzy inference system and its corresponding structure the FIS. The user can choose the input variables and the corresponding horizontal coordinate axes (X and Y), the output variables with vertical axis Z, viewing angle of the response surface.

Screen viewer surface of fuzzy conclusion attractiveness of the passengers alternative transportation options on transportation fare and headway of the vehicle is shown on Fig. 5.

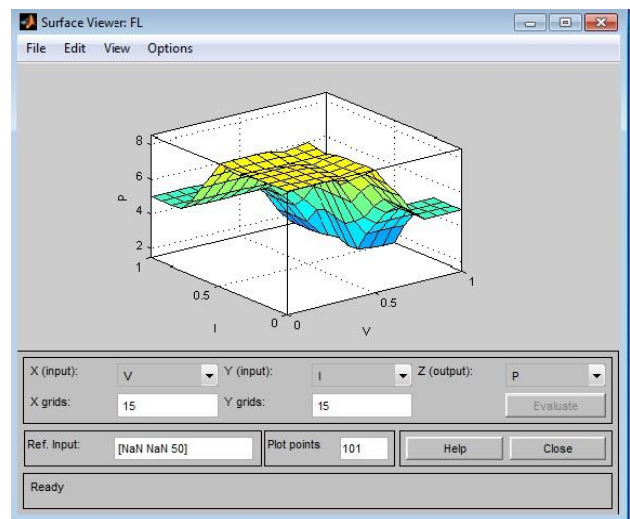


Fig.5. Example of response surface in dependence the level of attractiveness of the transportation fare and headway of the vehicle.

It should be emphasized, that this method is effective for complex fuzzy models with a large number of parameters and rules of fuzzy inference. In that case the setting of parameters and membership functions of their

terms in graphical mode, and also visualization of rules can significantly reduce the labor fare of fuzzy model development, the number of possible errors and total time of fuzzy modeling.

To check on the adequacy of the developed model we will give a specific example. Let us consider the fragment of urban area, the total area of which is covered by 5 routes: 3 bus routes, 1 trolleybus route, 1 tram route. Evaluations of overall characteristics of each of them with the possibility of a transfer are shown in Tab. 1. 90 prospective passengers expect for the transportation from point A to point B. Defined points connect, for instance, a direct tram route №5, and a bus route with a transfer from №3 on №1. The task is to distribute passengers according to each of proposed routes options.

**Table.1.** Estimates of the general characteristics of urban routes

Route №	Type	Far, UAH.	Headway, min.	Fullness of the vehicle, %
1	bus	4	5	80
2	bus	4	10	40
3	bus	4	15	60
4	trolleybus	3	5	90
5	tram	2.5	10	50
1-2	transfer	8	10	80
1-3	transfer	8	15	80
1-4	transfer	7	5	90
1-5	transfer	6.5	10	80
2-3	transfer	8	15	60
2-4	transfer	7	10	90
2-5	transfer	6.5	10	50
3-4	transfer	7	15	90
3-5	transfer	6.5	15	60
4-5	transfer	5.5	10	90

The first step in solving this problem is the conversion of indicators of the overall (in the case of transfer) transportation fare and the maximum headway on the route into parts from their maximum values. After the appropriate calculations have been done, we enter the information received into the Rule viewer program of fuzzy inference system, moving the red line in the columns of the relevant parameters (see. Fig. 4). Over the last column is displayed the resulting value of the output parameter - the attractiveness of the route in points. The more is the value of route attractiveness, the more passengers will take advantage of it and vice versa. Tab. 2 outlines the estimated input and output parameters of the passengers allocation model according to the routes.

**Table 2.** Input and output parameters of the model

Route №	Part of maximum fare, $\times V_{max}$	Part of maximum headway, $\times I_{max}$	Fullness of the vehicle, %	Attractiveness, points
1	0.5	0.33	80	5
2	0.5	0.66	40	6.5
3	0.5	1	60	3.8
4	0.38	0.33	90	5
5	0.31	0.66	50	6.5
1-2	1	0.66	80	2
1-3	1	1	80	1.5
1-4	0.88	0.33	90	1.6
1-5	0.81	0.66	80	1.9
2-3	1	1	60	1.7
2-4	0.88	0.66	90	1.9
2-5	0.81	0.66	50	1.9
3-4	0.88	1	90	1.5
3-5	0.81	1	60	1.7
4-5	0.69	0.66	90	3.1

On the basis of table data analysis it is possible to calculate the number of passengers by the received in previous studies formula [23] for which options of transportation will be optimal:

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

where:  $q_i$  – is a number of passengers which will use  $i$  - option of the route;  $Q$  – passenger throughput between two points;  $p_i$  – attractiveness of  $i$ -option among total  $n$ -number.

Thus:

$$q_{\text{№5}} = \frac{90}{6,5 + 1,5} \cdot 6,5 = 73,$$

$$q_{\text{№3, №1}} = \frac{90}{6,5 + 1,5} \cdot 1,5 = 17.$$

Hence, 73 passengers will take the direct tram route №5, other 17 bus route № 3 and №1 with the transfer. For these routes parameters are the following (see. Tab.1): the route №5 – transportation fare is 2.5 UAH., the average headway of vehicle is 10 min., the fullness of saloon is 50%; for the route with the transfer from №3 to №1 the total value is 8 UAH., the average headway is 15 min., fullness is 80%.

The fuzzy model of passenger allocation in accordance to the routes developed in software environment Matlab will be used for constructing matrices of the passenger traffic according to each of them. This will allow to adjust timetables of the city transport to the needs of the population more adequately.

## CONCLUSIONS

1. The analysis of scientific publications on functioning systems of passenger transportation has revealed main demands to transportation correspondence models: flexibility, versatility, ease.
2. The developed model of transportation route selection takes into account the following defining factors: transportation fare on the route, average headway on it and fullness of a vehicle. For the optimality criterion in the selection of a variant of the route taken input (resultant) indicator - its appeal.
3. The transportation correspondence model is implemented in Matlab software environment with the use of Fuzzy Logic Toolbox package. The gradual procedure of this model creation is provided and its practical application is shown by a concrete example.

## REFERENCES

1. **Shvetsov V. 2010.** Problems of Transportation Modeling in Traffic Networks. Proceedings of MFTI, Vol. 2, N. 4, 169-179. (in Russian).
2. **Brailovsky N., Hranovskyy B. 1978.** Modeling of Traffic Systems. Moscow, Transport, 124. (in Russian).
3. **Horbachov P. 2009.** New Conception of Modeling Needs of the Population in Commuting. Journal of Science of Dnipropetrovsk Lazaryan University of Railway Transport, N. 27, 210-214. (in Ukrainian).
4. **Horbachov P. 2009.** Modern Scientific Approaches to the Management of Passenger Transport of Fixed-Routes in Cities. Kharkiv, KhNAHU, 196. (in Ukrainian).
5. **Zablotskyy H. 1968.** Methods of Calculations of Passenger and Traffic Flows in Cities. Moscow, Central science technical institute of civil engineering and architecture, 92. (in Russian).
6. **Vdovychenko V. 2004.** Functioning Efficiency of Urban Passenger Transportation System. Ph.D. dissertation, 05.22.01. Kharkiv, KhNAHU, 193. (in Russian).
7. **Lyubyy Ye., Horbachov P., Havrylyshyna O., Siromolot A. 2011.** Patterns of Allocation of Transportation Correspondences in Towns. Visnyk of Dal Eastern Ukraine University, N. 5 (159), 89-94. (in Ukrainian).
8. **Pohrebniak Ye., Samoylenko N. 2006.** Analysis of Methods of Forming the Matrix of Transportation Network Correspondences in a City. Municipal property of cities, N. 69, 121-126. (in Russian).
9. **Hetsovykh Ye., Zasyadko D. 2010.** Traffic Zoning of Megalopolises and Estimation of the Routes for Correspondence Realization. Proceedings of conference "Improvement of the traffic engineering and passenger and cargo transportation", 26-33. (in Russian).
10. **Oppenheim N. 1995.** Urban Travel Demand Modeling. John Wiley and Sons Ltd, 480.
11. **Ortuzar, J. de D., Willumsen L. G. 2006.** Modelling transport. Third edition John Wiley & Sons Ltd., 499.
12. **Winston C., Small K. 1998.** The Demand for Transportation: Models and Applications California, Univesity of California, 51.
13. **Drew D. 1972.** Theory of Traffic Flows and Traffic Management. Moscow, Transport, 423. (in Russian).
14. **Lose D. 2006.** Modelling of Traffic Supply and Demand for Passenger and Official Vehicles. Proceedings of conference "Traffic engineering and Safety in Cities", Saint Petersburg, 170-186. (in Russian).
15. **Horbachov P., Dmitriyev I. 2002.** Fundamentals of Traffic System Theory. Kharkiv, KhNAHU, 202. (in Russian).
16. **Ohay V. 1978.** Models for the Analysis of Passenger Throughputs on Routes of the Public Transport. Thesis of Ph.D. dissertation, 05.22.10, 22. (in Russian).
17. **Bilous A., Demchuk I. 2014.** Analysis of Methods and Models of the Calculation of Passenger Correspondence Capacity. Eastern-European Journal of Enterprise Technologies, Issue 3/3 (69), 53-57. (in Ukrainian).
18. **Stovba S. 2007.** Designing of Fuzzy Systems with MATLAB. Moscow, Telecom, 288. (in Russian).
19. **Leonenkov A. 2003.** Fuzzy Modeling in MATLAB and fuzzy TECH Environment. Saint Petersburg, Solving Master, 72. (in Russian).
20. **Tarasyan V.S. 2013.** The package Fuzzy Logic Toolbox for Matlab. Ekaterinburg: UrHUPS, 112. (in Russian).
21. **Sivanandam S.N. 2006.** Introduction to Fuzzy Logic Using MATLAB / Sivanandam S.N., Sumathi S., Deepa S.N. – Springer, 2006, 430.
22. **Demchuk I. 2015.** Justification of the choice of model parameters correspondence of population movements. Abstracts of scientific-practical conference "New ways of creation, technical operation, repair and service of cars," Odessa-Koblevo, 71-73. (in Ukrainian).
23. **Fornalchyk Ye. 2015.** The Model of Correspondence of Passenger Transportation on the Basis of Fuzzy Logic / Ye. Fornalchyk, A. Bilous, I. Demchuk - Econtechmod : an international quarterly journal on economics in technology, new technologies and modelling processes. - Lublin ; Rzeszow, 2015. - Volum 04, N. 2, 59-64.
24. **Rutkovskaya D., Pilinskiy M., Rutkovskiy L. 2006.** Neural Networks, Genetic Algorithms and Fuzzy Systems. Moscow, Telecom, 382. (in Russian).
25. **Slobodyanyuk M., Tararychkin I., Nechayev G. 2013.** Structural analysis of an interregional transport network and assessment of capability for its multi-level optimization, TEKA Commission. Motorization and Power Industry in agriculture, Vol. 13 (4), 250-258.
26. **Kravchenko A., Medvediev Ie. 2013.** Diagnostics of the regional transport and logistic system's functioning (in the case of Luhansk region), TEKA Commission .Motorization and Power Industry in agriculture, Vol. 13 (4), 115-126.

# ФОРМИРОВАНИЕ МОДЕЛИ ВЫБОРА МАРШРУТА ПЕРЕДВИЖЕНИЯ ГОРОДСКОГО НАСЕЛЕНИЯ В ПРОГРАММНОЙ СРЕДЕ MATLAB

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Аннотация. В статье рассматриваются возможности применения мягких методов вычисления для прогнозирования спроса на передвижение населения. Разработанная модель на основе нечеткой логики позволяет решить проблему распределения поездок - формирование пассажиропотоков по каждому виду маршрута. Модель выбора маршрута передвижений учитывает такие определяющие факторы: стоимость проезда на

маршруте, средний интервал времени движения на нем и наполненность салона транспортного средства. Различные сочетания этих факторов между собой формируют привлекательность маршрута, который принят в качестве критерия выбора оптимального варианта для потенциального пассажира. В статье описано поэтапное создание модели распределения пассажиров по маршрутам в программной среде Matlab с использованием пакета Fuzzy Logic Toolbox. Приведен пример реализации модели.

Ключевые слова: нечеткая логика, программная среда Matlab, графический интерфейс, параметры модели, привлекательность маршрута, функция принадлежности.