Zorica Milanovic[1], Sinisa Rankov[2], Marko Vulic[3]

MODELLING COMMUTER BEHAVIOUR WITH FUZZY LOGIC: AN EXAMPLE OF RAILWAY PASSENGER BEHAVIOUR IN BELGRADE AREA

The development of fuzzy concepts and techniques has contributed to the development of tools that may be used for resolving problems in both technical sciences and humanities. In recent years, traffic experts have applied fuzzy techniques to solving numerous traffic-related problems. This paper presents the results of a complex research on railway commuter behaviour in the Belgrade area modelled by applying fuzzy logic. Since commuters are the largest group within the total number of railway passengers, research and modelling of their behaviour and attitude have significant importance in transportation services planning. The fuzzy model based on approximative reasoning has been developed through the MatLab Fuzzy Logic Toolbox software. The input assumptions have implied that railway service in the Belgrade area would be improved if the demands of commuter passengers were appreciated to the maximum extent. The services planned in this manner should be acceptable for commuters and profitable for the operator.

Keywords: *fuzzy modelling, commuter behaviour, railway service.*

Зоріца Мілановіч, Сініша Ранков, Марко Вуліч

МОДЕЛЮВАННЯ ПОВЕДІНКИ ПРИМІСЬКИХ ПАСАЖИРІВ ІЗ ЗАСТОСУВАННЯМ НЕЧІТКОЇ ЛОГІКИ НА ПРИКЛАДІ ПАСАЖИРІВ ЕЛЕКТРИЧОК В РАЙОНІ М. БЕЛГРАД, СЕРБІЯ

У статті показано, що розробка понять нечіткої логіки сприяла розвитку методів, які можуть бути використані для вирішення проблем у технічних і гуманітарних науках. В останні роки нечіткі методи застосовуються у вирішенні дорожньо-транспортних питань. Представлено результати комплексного дослідження поведінки пасажирів приміських залізниць у районі Белграда із застосуванням нечіткої логіки. Оскільки приміські пасажири - найбільша група серед загальної кількості пасажирів залізничного транспорту, дослідження та моделювання їхньої поведінки має важливе значення в плануванні транспортних послуг. Нечітка модель, заснована на апроксимативних міркуваннях, була розроблена в програмі "MatLab Fuzzy Logic Toolbox". Початкове припущення: залізничне сполучення в районі Белграда можна поліпшити, максимально задовольнивши вимоги приміських пасажирів. Покращене планування послуги має бути вигідним як споживачам, так і перевізнику.

Ключові слова: *нечітке моделювання, приміські пасажири, залізничні перевезення.*
Рис. 3. Літ. 13.

Зорица Миланович, Синиша Ранков, Марко Вулич

МОДЕЛИРОВАНИЕ ПОВЕДЕНИЯ ПРИГОРОДНЫХ ПАССАЖИРОВ С ПРИМЕНЕНИЕМ НЕЧЕТКОЙ ЛОГИКИ НА ПРИМЕРЕ ПАССАЖИРОВ ЭЛЕКТРИЧЕК В РАЙОНЕ Г. БЕЛГРАД, СЕРБИЯ

В статье показано, что разработка понятий нечеткой логики повлекла развитие методов, которые могут быть использованы для решения проблем в технических и гуманитарных науках. В последние годы нечеткие методы применяются в решении дорожно-транспортных вопросов. Представлены результаты комплексного исследования

[1] PhD, Department of Transport Economics & Technology, Institute of Transportation, Belgrade, Serbia.
[2] Associate Professor, Faculty of Computer Sciences, University of Megatrend, Belgrade, Serbia.
[3] PhD Student, Faculty of Organizational Sciences, University of Belgrade, Serbia.

поведения пассажиров пригородных железных дорог в районе Белграда с применением нечеткой логики. Так как пригородные пассажиры - самая большая группа среди общего количества пассажиров железнодорожного транспорта, исследование и моделирование их поведения имеют важное значение в планировании транспортных услуг. Нечеткая модель, основанная на аппроксимативных рассуждениях, была разработана в программе "MatLab Fuzzy Logic Toolbox". Изначальное предположение: железнодорожное сообщение в районе Белграда можно улучшить, максимально удовлетворив требования пригородных пассажиров. Улучшенной планирование услуги должно быть выгодным как потребителям, так и перевозчику.

Ключевые слова: *нечеткое моделирование, пригородные пассажиры, железнодорожные перевозки.*

1. Introduction. The fuzzy set theory (Zadeh, 1965) has influenced the development of mathematically-oriented concepts and techniques of human cognitive processes which are considered imprecise, ambiguous, uncertain and inexplicit according to classical mathematical interpretations. These concepts have been widely recognized by engineers, mathematicians, linguists and philosophers and therefore they are becoming frequently applied in both technical and social sciences nowadays.

Fuzzy logic is often confused with the probability theory. The basic difference between fuzzy logic and the probability theory is that fuzzy logic deals with deterministic uncertainties while the probability theory deals with credibility of stochastic events (Teodorovic & Kikuchi, 1991). "Fuzzy" and "probable" are 2 different attributes that describe different aspects of uncertainty. Fuzzy logic deals with the subjectivity of human thought, perception and language while probability shows objective statistics in natural sciences (Teodorovic & Vukadinovic, 1998).

Mamdani & Pappis (1977) published the first paper in which practical traffic and transportation issues were resolved by applying fuzzy set theory. During the past 3 decades, numerous experts, including Serbian ones, have applied different methods of the fuzzy set theory to solving different traffic and transportation problems. Recenlty published papers on traffic problems were analysed (Serrano & Cuena, 1998) in order to determine the applied techniques (fuzzy, fuzzy mixed theories, probability theory and hypothesis testing). The analysis indicated that the application of fuzzy techniques was 4 times greater compared to the application of non-fuzzy techniques. The most frequent application of fuzzy techniques is identified in traffic control and management, vehicle operation and traffic signalling (Kikuchi, 2012). In addition, the application of fuzzy and fuzzy-mixed techniques is identified in behavioural researches in traffic and transportation. These techniques are also successfully used in decision-making processes related to modal split (Jovic & Popovic, 2001), employees performance appraisal (Manoharan, Muralidharan & Deshmukh, 2011), behaviour-based safety management (Dagdeviren & Yuksel, 2008), evaluation of passenger services on terminals (Yeh & Kuo, 2003), solving scheduling problems (Olaru & Smith, 2005) etc.

Research goals. This paper shows the results of complex research on the attitudes, needs and demands of railway passengers (mainly commuters) in the Belgrade area. Commuter behaviour fuzzy modelling was done based on these results. An interview was performed to collect the subjective experiences of passengers about total trip time as well as passenger opinions on the quality of traffic services. Since the obtained data were characterized by subjectivity they can be modelled on the basis of the fuzzy set theory, fuzzy logic and related techniques. Subjectively assessed values were treated as fuzzy numbers. The purpose of the commuter behaviour fuzzy modeling was to develop a fuzzy model for estimation of the transport service quality based on approximative reasoning. The model has been developed within the MatLab (MATrix LABoratory) software package, modul FLT (Fuzzy Logic Toolbox). The basic assumption was that modelling results may be used to help traffic planners understand what users opinions are based on when evaluating service quality. These results may be used as additional arguments for railway commuter service planning and solving urban-suburban railway rescheduling problem on the observed railway line. Incorporating these data into urban-suburban railway service planning, the service should become acceptable for the majority of passengers and should be profitable for the operator.

The presented research is a part of a complex research done for the author's doctoral dissertation case study (Milanovic, 2012).

2. Problem definition. Traffic planning problem. Numerous data are used in timetable and other transportation services planning. Transportation services may be planned using only the company data (internal data). However, the new planning approach is based on both internal and external data, especially those external data obtained through market and passenger demands research. Behaviourial researches provide data that can be used as an additional argument for passenger transport service planning. New techniques, technologies and methods may be used for processing this type of data. These contribute to the planning process becoming more complex. However, lots of benefits could be obtained if the planned services are in compliance with passenger demands.

Urban and suburban railway passenger transport system in Belgrade was established in 1988. The number of passengers had a growing tendency until 2001. Various factors caused the decrease in the number of passengers, between 2001 and 2010. One of the most significant reasons was that the timetable had not been in compliance with the basic commuter demands. Urban-suburban railway traffic planning process didn`t include external data, especially the data that describe commuter behaviour and demands.

One of the main railway lines in Belgrade urban-suburban railway transport system is the Pancevo-Belgrade line (17 km long). The greatest passenger flow in the system is annotated on this line (1/3 of all the passengers). Around 40 000 passengers a day travel between these two cities in both directions. In 2001, the railway participates in the "modal-split" with around 25%, and in 2011, with less than 10%. It is obvious that passengers, mostly commuters, are not satisfied with the railway service on this line.

Commuter demands. Commuters are the most sensitive group of passengers. Especially concerning some traffic quality elements, such as timetable and travel time. By interviewing commuters, researchers provide data and information of great importance for the traffic planning process, such as:

- O/D (origin/destination) matrices;
- Total travel time from an origin to a destination;
- The reason for travelling;
- Motives for travel mode choice;

- Travel demands and opinions regarding traffic service quality.

Passenger tolerance to travel time depends on the activities which are the primary cause of the travel. For example, for commuters the timetable is extremely important only when they go to work or school, while in other periods during the day, when they travel due to other purposes, it is less important. For instance, the total travel time of "about 60 min" may be considered as "very long" for commuters, "medium-long" for those who travel periodically and "insignificant" for those who travel for leisure purposes. Commuters need the total travel time from an origin to a destination to be as short as possible.

Commuter behaviour researches in Serbia are very rare. The results of these researches were poorly used in planning. The reason for that could be found in an inadequate method applied in processing and presentation of this type of data, so planners and decision-makers didn't properly understand their significance and what the purpose of this data is.

The main goal of this research is to provide the analytical data on railway commuter behaviour and demands that could be used, as additional arguments, for railway service replanning and rescheduling. It is expected that the new way of exploring and analyzing passenger behaviour, by fuzzy modelling, will be of great help to traffic planners.

The input assumptions. Obtaining and processing useful data for railway urban-suburban service planning is a complex problem. Behavioural data can be obtained by interviewing passengers. Data, in general, should be processed and analyzed using mathematical and statistical methods. Data with fuzzy characteristics could be modelled using fuzzy logic and techniques. The appropriate fuzzy model has to be developed for the purpose of estimation of railway passenger demands to transport service quality. Solving this problem is based on the following assumptions:

- Researches of commuter behaviour and demands provide data important for the purpose of traffic and transportation services planning;
- Behavioural data is characterised by subjectivity, so it can be modelled on the basis of fuzzy set theory, fuzzy logic and techniques;
- Fuzzy modeling is necessary to obtain formalisation of descriptive and lingually expressed data;
- Output data from the fuzzy model are understandable and precise, therefore they can be considered as additional arguments for decision-making in urban-suburban railway traffic planning process;
- Railway passenger service should be in compliance with the requirements of commuter passengers to the maximum extent;
- Commuter behaviour fuzzy modelling insignificantly increases the price but not the duration of the planning process time.

Based on the defined problem and the input assumptions, it is expected that the collected data on passenger behaviour would be useful in the traffic planning process. Fuzzy model outcomes should be considered as valid arguments to support the sustainable urban-suburban railway traffic planning on the observed Belgrade-Pancevo railway line.

3. Description of the interview. An electronic questionnaire was created using the BLAISE system. The questionnaire consists of 19 questions in total. The questions are referring to the following:

- Travel route (railway station/stop where a passenger gets on/gets off a train);
- Transportation mode and travel time in arrival to the railway station where a passenger gets on a train;
- Transportation mode and travel time from the railway station where a passenger gets of a train to a destination (place of work, school etc.);
- Opinion and attitude of a passenger towards the total travel time;
- Attitude of a passenger towards transport modes connectivity;
- Transportation mode in return to a passenger's origin;
- Reasons for traveling (work, school, shopping, tourist and other);
- Reasons for travel mode choice (why a passenger decided to travel by train);
- Attitudes of a passenger towards the elements of railway transport service quality;
- The need for train timetables (the desired time of departures/arrivals);
- Possibility for transportation mode choice.

The interview was performed in April 2010, during the period from 6:00 AM to 7:00 PM. Around the same number of passengers were interviewed in the mornings and afternoon. Passengers who got on trains in Pancevo railway stations and railway stops (2 railway stations and 2 railway stops) were interviewed. The interview was conducted with the same number of women and men of all ages.

All the answers have been entered into the electronic BLAISE questionnaire, and then they were transformed into the Pascal programme and compiled. The database formed in this way was converted into SPSS PC format (SPSS for Windows - Software package for statistical analysis).

4. The main results of the interview. The main results of the data analysis are presented below:

- For the majority of passengers (around 73%) the point of origin is in the close proximity of the railway stations/railway stops at which they get on the train, and the point of origin for around 27% of passengers is in remote settlements;
- From the point of origin to the railway stations/stops around 68.5% of passengers go on foot, 25.7% travel by bus, 3.2% by car, 2.1% by train and 0.5% by bicycle;
- Travel time from the point of origin to the railway station was subjectively assessed. Most passengers (29.4%) travel between 10 and 15 minutes, 24.3% of passengers travel between 15 and 20 minutes, 19.9% travel between 5 and 10 min, 16.4% travel between 20 and 30 minutes, and 10% travel more than 30 minutes;
- The average travel time from a point of origin to a railway station is around 16.9 minutes;
- From the railway stations/stops where the passengers get off the train to a destination about 20.7% of passengers go on foot, 55.8% travel by bus, 17.9% travel either by bus, or tram, 3.2% travel by tram, while 2.4% take a train on another railway line. Even 76.9% of passengers use public transportation after getting off the train;
- Travel time from the railway stations/stops where the passengers get off the train to the destination for 1.9% of passengers is around 5 minutes in maximum, for 7.5% of passengers is between 5 and 10 minutes, for 19.5% – between 10 and 15 minutes, for 25.1% – between 15 and 20 minutes, for 21.9% of passengers it is between 20 and 25 minutes, for 15.7% – between 25 and 30 minutes and for 7.5% – longer than 30 minutes;

- The average travel time from railway stations/stops to a destination is around 19.4 minutes;
- On the return to Pancevo, about 86.4% travel by train, while 10.4% travel by bus and 3.2 travel by car;
- The percentage of commuters is around 76.8% (41.8% are workers and 35.0% are pupils and students);
- The majority of passengers (56.6%) travel by train due to travel time (speed of train), 12.7% because of the ticket price, 12,3% because of comfort, 7.96% because of reliability;
- Only 3.98% of passengers are satisfied with the timetable;
- Around 63.3% of passengers have some remarks on railway schedule (they considered the timetable "bad");
- The passengers with remarks on the timetable either arrive to the destination long before the start of their activities, or they are late;
- The passengers that characterized the timetable as "acceptable" or "partially acceptable" said that the waiting time for the beginning of their activities is "short" or "medium";
- The main commuter demands are related to the timetable. If the timetable was rescheduled, the majority of them would continue to travel by train. However, if there were no changes in the timetable, most of them would consider other means of transportation;
- The average total travel time from an origin to a destination is about 70.3 minutes (train delays are not included).

5. Description of the fuzzy model development. The first attempt of passenger behaviour fuzzy modeling was performed in 2007 on the basis of the data obtained from the small-scale survey (Milanovic, 2007). The results of that research showed that fuzzy modelling of passenger's behaviour is useful and that outcomes could be applied in traffic planning process in an appropriate way.

The fuzzy model described herein (Milanovic, 2012) is defined with 2 input and 1 output variable. The input variables are subjectively and lingually expressed attitudes of passengers towards travel time parameters, such as:

- Travel time from the station where the passenger gets-off the train to a destination — T_{odl} (min) subjectively estimated as: "short", "medium" and "long";
- Waiting time (period of time between the arrival to a destination and the beginning of their activities) — T_{cek} (min) subjectively estimated as: "short", "medium" and "long".

The output variable is the attitude referring to the quality elements of transportation service (in this case the observed quality element is the suitability/convenience of arrival time to a destination — T_{dol}). The attitude is created according to the input variables and is expressed through a numerical scale for the estimation ranging from 1 to 10, where 1 is referring to the lowest quality level (the least suitable arrival time) and 10 is referring to the highest quality level (the most suitable arrival time).

The fuzzy process of approximative reasoning in Fuzzy Logic Toolbox (FLT) consists of 5 parts, the so-called steps:

Step 1. Fuzzification of input variables.

Step 2. Selection, introduction and application of fuzzy operator (AND or OR) for assumption purposes (antecedent).

Step 3. Application of implication method (rules setting).

Step 4. Aggregation of outcomes (aggregation of all consequences via defined rules).

Step 5. Defuzzification.

Step 1: Fuzzification of input variables. Fuzzification of input variables has been defined by membership functions. For each of the selected fuzzy set, a membership degree has been defined via a membership function, for example:

1. Travel time from the station where the passenger gets off the train to a destination – T_{odl} (min):

– Rank [0 35]

- "short" (0 0 15) – Trigonometric membership function (trimf);
- "medium" (10 15 25) – Gaussian membership function (gaussmf);
- "long" (25 35 35) – Sigmodial membership function (smf).

2. Waiting time at the destination (to start with the activities) – T_{cek} (min)

– Rank [0 30]

- "short" (0 0 10) – Trigonometric membership function (trimf);
- "medium" (5 12) – Gaussian membership function (gaussmf);
- "long" (15 20 30) – Trigonometric membership function (trimf).

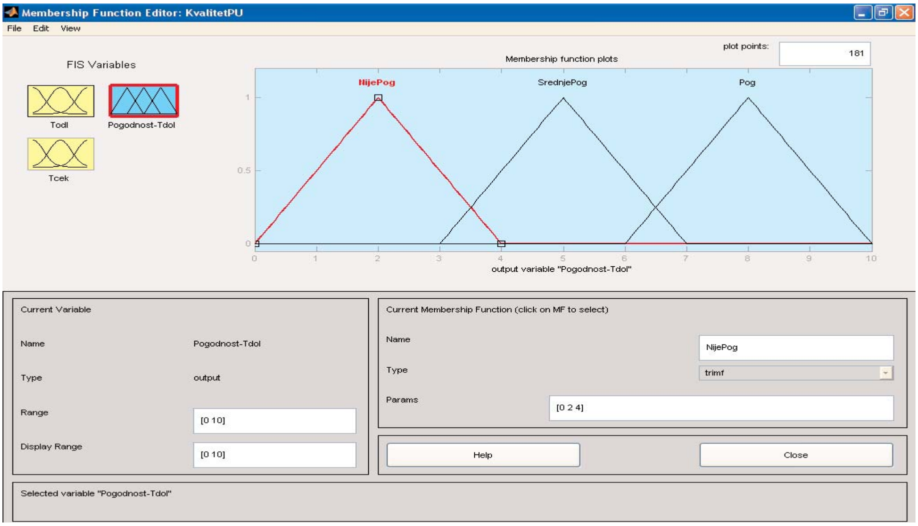

Figure 1. **Membership functions for the output variable "Suitability of T_{odl}"**

The output variable, the suitability/convenience of arrival time to a destination- T_{dol}, has been defined by fuzzy sets, for which the membership degree has been defined via the trigonometric membership functions:

– Rank [0 10]

- "Not suitable" (0 2 4) – Trigonometric membership function (trimf);
- "Partially suitable" (3 5 7) – Trigonometric membership function (trimf);
- "Suitable" (6 8 10) – Trigonometric membership function (trimf) (Figure 1).

Step 2: Selection, introduction and application of fuzzy operators. After fuzzification, we know the membership degree for all the input data. The "AND" method: min (minimum) has been adopted as a fuzzy operator (it provides one number representing the results of assumptions for the given rule). 7 "If – Then" rules have been set up for the given assumptions:

- Rule 1: If T_{odl} "short" and T_{cek} "short" Then T_{dol} "suitable".
- Rule 2: If T_{odl} "short" and T_{cek} "long" Then T_{dol} "not suitable".
- Rule 3: If T_{odl} "short" and T_{cek} "medium" Then T_{dol} "partially suitable".
- Rule 4: If T_{odl} "medium" and T_{cek} "short" Then T_{dol} "partially suitable".
- Rule 5: If T_{odl} "medium" and T_{cek} "medium" Then T_{dol} "not suitable".
- Rule 6: If T_{odl} "long" and T_{cek} "short" Then T_{dol} "partially suitable".
- Rule 7: If T_{odl} "long" and T_{cek} "medium" Then T_{dol} "not suitable".

Step 3: Application of implication method (rules setting). Prior to application of the implication method (rules setting), the rule weight of each rule must be precisely specified (number between 0 and 1, i.e. closed unit interval [0, 1]). The rule weight is introduced for the given number of assumptions. The rule weight for each defined rule is specified as value 1. That means that all the rules have the identical weight and influence. When a rule weight is specified, the application of implication method is completed.

The consequence of the set rules is a fuzzy set represented via the membership function whose weight is determined according to lingual characteristics with assigned attributes. The consequence is sharpened by applying the function which is associated with the assumption (one number). Thus, the input of the reasoning process is one number defined by the assumption and the output is a fuzzy set.

Step 4: Aggregation of all outcomes. Since decisions are based on testing of all rules, the rules have to be combined in a defined sense to enable decision-making. Aggregation is a process where a fuzzy set that represents an output of every rule is compressed into one fuzzy set. Aggregation appears only once for each output variable, just prior to the fifth and the last step – defuzzification. An output from the aggregation process is one fuzzy set for each output variable. As long as an aggregation method satisfies the commutativity characteristic (which is always the case), an order in which the set rules will be executed is irrelevant. The max (maximum) method was selected as an aggregation method.

Step 5: Defuzzification. The input of defuzzification process is a fuzzy set (fuzzy set as a result of an aggregation process), and the output for each variable is one number. The aggregation process extends the rank of output values, and therefore, they must be defuzzificated in the exact order to resolve the unit value of the output set. For defuzzification purpose the "centroid" method was chosen (this method finds the center of an area under the curve).

6. The main results of the fuzzy modelling. FLT diagram of fuzzy reasoning consists of all small diagrams that appear in the system. They simultaneously show all the parts of the observed fuzzy reasoning process.

T_{dol} within the set characterized as "Not suitable". If a passenger travels 17.5 minutes from the station where he/she gets off the train to a destination, and waits for

15 minutes at the destination to start with activities (time loss of 32.5 minutes), then T_{dol} = 2, i.e. it is within the set of values "not suitable" (Figure 2).

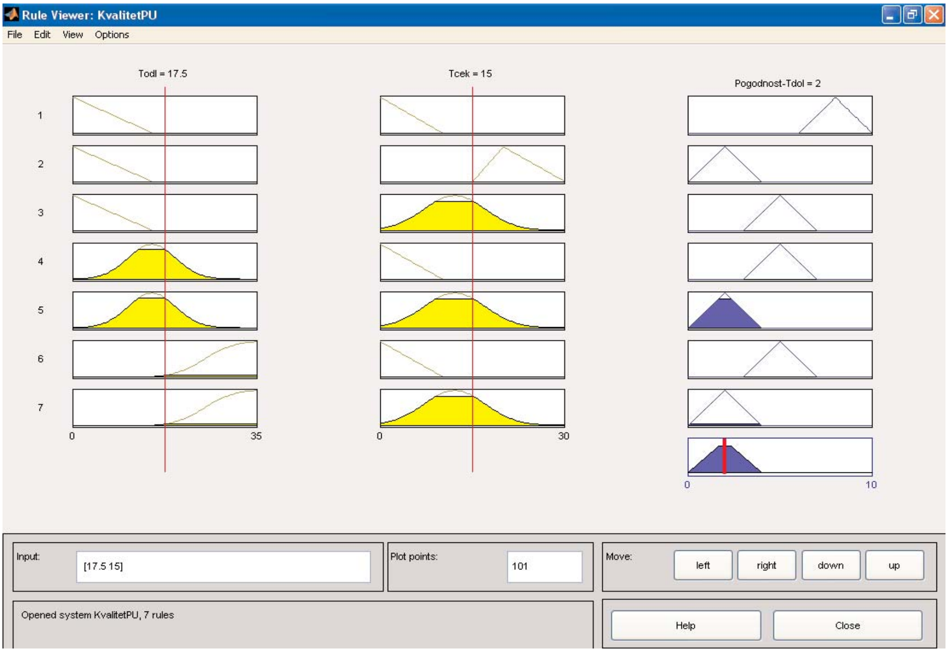

Figure 2. **Value of output variable T_{dol} = 2**

If it is known that the average travel time by train is about 28 minutes, and the average travel time from the point of origin to the railway station is around 17 minutes, and the waiting time on the station for a train is around 7 minutes, then with the above mentioned time loss, it can be concluded that a passenger from the origin to a destination has the total time loss of over 84 minutes. This is the reason why passengers consider transportation service as "bad".

The information indicates that it may be expected that these passengers could choose other mode of transportation if there are no changes in the train schedule according to their requirements. According to this knowledge planners should consider the following:

- to reschedule the timetable so the waiting time at a destination would be as short as possible;
- to work on synchronisation of timetables of train and public transportation in order to minimize time losses.

T_{dol} within the set characterized as "medium suitable". If a passenger travels 5 minutes from the station where he/she gets off the train to a destination, and waits for 15 minutes at the destination to start with activities (the time loss of 20 minutes), then T_{dol} = 4.75, i.e. it is within the set of values "partially suitable". In this case, a passenger from the origin to a destination has the total time loss of around 70 minutes.

According to this, planners should consider rescheduling the timetable so the waiting time at a destination is as short as possible.

T_{dol} ***within the set characterized as "suitable".*** If a passenger travels 5 minutes from the station where he/she gets off the train to a destination, and waits for 5 minutes at the destination to start with activities (the time loss of 10 minutes), then T_{dol} = 6.22, i.e. it is within the set of values "suitable". In this case, a passenger from the origin to a destination has the total time loss of around 60 minutes, and considers the travel service as acceptable.

According to this knowledge planners should consider rescheduling the timetable, so the majority of passengers find travel service acceptable.

As stated above, 63.3% of the passengers have complaints on the timetable, it is obvious that planners should replan the service according to the passengers' demands.

The value of the outcome variable (Figure 3) is presented in FLT Surface Viewer.

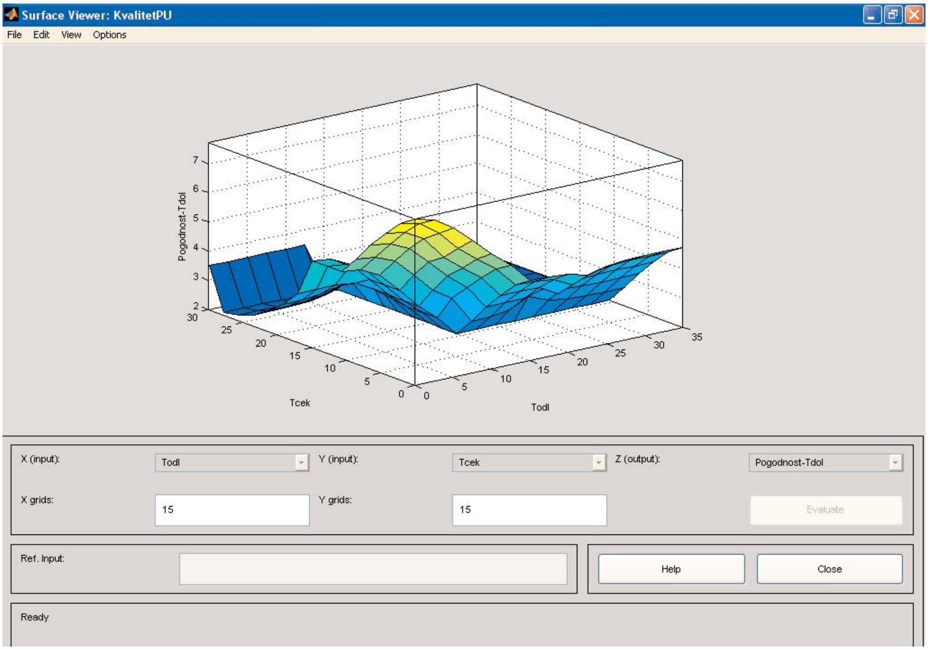

Figure 3. **The value of the outcome variable in FLT Surface Viewer**

The presented results indicate that commuter demands will be fulfilled if the timetable is recheduled. The presented results could be useful to planners in their further rescheduling activities on the observed line. The technical aspect of the system (the condition of the tracks, number of vehicles etc.) should be appreciated as well as commuters' demands. Among others, there is also the demand for the interval between departures of trains to be less than 25 min (during rush hours).

7. Conclusions. Railway timetable rescheduling is a part of a complex traffic planning problem where decisions require credible arguments. Thus, extensive research activities should be undertaken. Interviewing passengers and fuzzy modeling are important and crucial parts of them.

The research presented herein gives a clear picture of commuter behaviour, demands and attitudes towards the service on the observed line, and their reasons for the quality of travel service estimation. The commuter behaviour fuzzy modelling was shown to be an important activity in providing arguments relevant for sustainable urban-suburban railway service and traffic planning. The outputs from the fuzzy model clearly indicate what planners should take in consideration in order to achieve passenger satisfaction.

In addition to the sustainable urban-suburban traffic planning on the observed line, the presented results could also be used either for comprehensive transportation policy or sustainable development of public transportation urban-suburban system.

It is expected that further activities should lead to more complex fuzzy logic system development which will include new approaches and methods in this area.

8. Acknowledgements. *The authors are thankful to the Belgrade City Chamber and The Institute of transportation CIP for financial and technical support for the survey presented in this work.*

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Стаття надійшла до редакції 06.12.2012.