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MODEL OF FUZZY INFERENCE SYSTEM FOR FORECASTING DWELL TIME REQUIRED BY COMMUTER TRAINS AT STOPS

Hrvoje Haramina, Tomislav Josip Mlinarić, Branko Mihaljević

Original scientific paper

Every unexpected increase in the number of passengers may result in unplanned extension of the scheduled dwell times of commuter train at stop, i.e. its delay in departure regarding the planned timetable. This may cause consequent delays of other trains that, according to the planned timetable have headways or connections with the delayed train, thus disturbing the stability of the timetable. Therefore, it is important to start the procedure of adapting the timetable to the actual condition in traffic. As part of this procedure it is necessary to forecast the actually required dwell times for commuter trains and based on this to adapt their running times in order to compensate for the delays and to continue operating according to the planned timetable. In this paper, the model of fuzzy inference system has been defined and it serves to forecast the actually required dwell times of the commuter trains at the stops.

Keywords: *commuter railway traffic, fuzzy inference system, timetable rescheduling*

Model sustava neizrazitog zaključivanja za predviđanje potrebnog vremena zadržavanja prigradskih vlakova na stajalištima

Izvorni znanstveni članak

Svako neočekivano povećanje broja putnika može rezultirati neplaniranim produljenjem vremena zadržavanja vlaka na stajalištu odnosno njegovim kašnjenjem u polasku u odnosu na planirani vozni red. Tako nastalo primarno kašnjenje vlaka može izazvati posljedična kašnjenja drugih vlakova koji prema planiranom voznom redu imaju slijeđenje ili sastajanje s zakašnjelim vlakom, te na taj način narušiti stabilnost voznog reda. Iz tog je razloga u slučaju nastanka primarnog kašnjenja važno na vrijeme pokrenuti postupak prilagodbe voznog reda stvarnom stanju u prometu. U okviru tog postupka potrebno je čim preciznije predvidjeti potrebna vremena zadržavanja prigradskih vlakova na stajalištima i na temelju toga prilagoditi njihova vozna vremena kako bi se nadoknadila nastala kašnjenja i promet dalje mogao odvijati prema planiranom važećem voznom redu. U ovom radu definiran je model neizrazitog sustava zaključivanja koji služi za predviđanje stvarno potrebnog vremena zadržavanja prigradskih vlakova na stajalištima.

Ključne riječi: *neizraziti sustav zaključivanja, prilagodba voznog reda, željeznički prigradski promet*

1 Introduction

The rail operating plan has been defined by the published timetable which should guarantee the quality of the provided transportation services, which shows the great importance as well as complexity of its planning procedure. Here, one should keep in mind also the comfort and level of service onboard trains and at stations, i.e. adequate travel times in passenger transport, traffic operation strictly according to timetable, are the basic and necessary requirements of the present time in the commuter passenger service segment.

As part of timetable planning procedure it is extremely important to forecast as precisely as possible the times necessary for the trains to stay at certain stops, since this represents an extremely important element in planning the timetable on railway lines intended for the traffic of commuter trains. Namely, dwell times of commuter trains at stations are usually planned with an extra buffer time to improve the service operation concerning the ability to resist unexpected traffic disturbances which may cause instability of railway timetable. In the other hand, if this time is too much longer than required, it affects on line capacity reduction [1].

It is well known that the improvement of transportation service quality in commuter rail traffic mainly regarding the increase of its availability by introducing into traffic a larger number of trains, has positive impact on the increase in the number of its users [2]. At the same time, the increase in the number of users results in the problem of more difficult forecasting of the necessary dwell time of the commuter trains at the stops. Thus, in case when the number of passengers who want to alight or board a train at a stop is greater than planned, which may result in major extension of the dwell time at the stop, this can cause a delay in the realisation of the planned timetable. Therefore, scientific research is done with the aim of developing new models of the rail traffic management system which understand adjustment of the timetable to the actual condition in traffic [3, 4] There is higher probability for the deviation from the pre-planned timetable during its realisation at times of peak loads, i.e. at high level of usage of the railway line capacity. It is precisely for this reason important, in case of such deviations, to react on time and to start the procedure of timetable adjustment to the real condition in traffic. Such adjustment means the possibility of changing the driving method of the delayed, and if necessary, other trains whose driving depends directly or indirectly on the ride of the delayed train. It is necessary here to adjust their travel times and the times of stay at the stops in order to compensate the current delays and to continue to operate traffic in the way planned by the valid timetable [5]. Apart from data on the actual condition in the traffic process, this adjustment requires also data based on forecasts.

The aim of this research it to develop the fuzzy inference system model for forecasting of actually necessary dwell time of commuter trains at stops in order to realise maximum level of quality of service in commuter transport.

2 Impact of train dwell time at station forecasting on on-line timetable rescheduling

The dwell time of commuter trains at stops depends first of all on the number of passengers who board or leave the train. Thus, every unexpected increase in the number of passengers can result in unplanned extension of the train dwell time at the stop, i.e. its delay in departure regarding the planned timetable. This primary train delay can cause consequent delays of other trains that, according to the planned timetable have headway or meeting with the delayed train, and in this way it can disrupt the stability of the timetable. There is greater probability of consequent delay propagation at peak times during which the level of usage of the tracks capacity is greater. Therefore, in case of primary delay it is necessary to start on time the adjustment procedure of the timetable to the actual traffic condition. As part of this procedure it is necessary to forecast and determine the necessary dwell times of commuter trains at stops and consequently adjust their timetables in order to compensate for the resulting delays and to make it possible for the traffic to continue operating according to the planned valid timetable.

Therefore, in order to achieve greater robustness of the timetable, i.e. the possibility of its adjustment in order to annul the impacts of unexpected events that may cause deviations in its implementation, it is important to build into the timetable sufficient time additions in the form of regular time reserves to train travel times and their dwell times at stops as well as compensation time additions for their subsequent headways.

The timetable robustness is in direct correlation with the rail infrastructure capacity (both station and tracks infrastructure). All the possible reserves, namely, that could be built into the timetable at a certain moment, are not real if the usage capacity of the tracks is burdened by the introduction of a number of light rides. Also, the technological process of station operation, if it has not been optimally designed, additionally reduces the possibility of building-in certain reserves into the timetable. Building-in certain time reserves in the timetable is possible only on the infrastructure which is in good technical and technological condition.

It is important to emphasise that the aim of this adjustment is to avoid major modifications of the planned timetable, i.e. it is necessary to find such solutions that will maximally reduce the impact of the delay regarding its propagation to other train routes in the timetable. This can be achieved by adequate adjustment of timetables of trains included in the optimisation procedure with the change of their operation regime. It is, namely, necessary to select the most favourable train running regime which would realise the travel time necessary to adjust the timetable to the actual traffic condition. Thus, for example, by selecting the most favourable running regime which for instance means shorter running time in relation to the one planned by the timetable, the train may compensate its possible delay in departure from the station.

From the aspect of railway timetable stability, namely, it is important that commuter trains leave every stop regularly according to the planned timetable. Since the dwell time of a train at a stop may vary depending on the time necessary for boarding and alighting of a various number of passengers, it is important as part of the total time between two subsequent departures of the commuter train from the stop, to determine the share of time meant for its ride, i.e. stay at the stop. Therefore, as part of timetable adjustment to the actual traffic condition, prior to timetable determination procedure, i.e. most favourable train running regime, it is necessary to determine for each train the dwell time at the next stop. This dwell time may be determined on the basis of time forecasting that is necessary for the process of passengers boarding and disembarking at the stop, which can be realised by implementing the fuzzy expert system.

3 Fuzzy inference system model for forecasting necessary dwell times of commuter trains at stops

The fuzzy expert system represents a type of expert system which makes decisions based on fuzzy logics, starting from the fact that the human is often imprecise in describing the facts and in decision making. The development of computers, and especially by raising the significance to the study of artificial intelligence has resulted in the issue of transferring the form of human inference and management into formal mathematical description and software program.

Fuzzy logics ensures formal methodology to present the manipulation and implementation of the human (expert) knowledge on the problem of process regulation. This is one of the main reasons why the majority of works and implementation of fuzzy logics is related to the field of automatic regulation. The substitution of an experienced operator is the motto of all implementations of fuzzy logics in the process regulation for which, most often due to difficult-to-perform mathematical model, there have been not adequate conventional solutions [6]. The first major results in the field of studying fuzzy logics was provided by Lotfi Asker Zadeh whose basic idea was the introduction of fuzzy belonging of elements to a certain set. The advantage of the fuzzy expert system lies in the fact that inference is done by calculation, and not symbolic inference. Therefore, expert systems for real-time operation can also be developed [7]. Fuzzy logics represents in fact the expansion of classical Boolean logics, where unlike classical logics in which the rule is valid that everything can be expressed by means of binary values, fuzzy logics tries to substitute binary values by "level of truth". For example, in classical mathematical Boolean logics there is the notion of set and elements that can be determined by two values, i.e. whether they belong to the given set (whether they are its elements) or not. In fuzzy sets there is not clear border regarding belonging of a certain element to a set, but rather there is mention of a certain level of belonging. Therefore, in case of fuzzy sets, an element is not strictly within nor outside the set but rather it may also partly belong to a certain set. The level of this belonging of μ is defined by interval [0 1].

Fuzzy expert system with the set of belonging functions includes also the rules for inference. The set of such rules is called the knowledge base or base of rules. If the condition of rules has been satisfied, the inference value for that rule is calculated. The inference process in fuzzy expert system is performed in several steps:

- assignment of values of the function of belonging
- interference
- aggregation
- calculation of the belonging fix value.

In calculating the values of the function of belonging the input values are let through the functions of belonging in order to obtain the belonging values from them. The level of truth of the rule is called *alpha* rules truth, and in case the rule has truth greater than 0 then this rule acts. The rule action assigns to every conclusion one fuzzy subset.

According to the interference rules, the function of belonging of the fuzzy inference set for each acting rule is calculated. There are two basic interference procedures, and these are the minimum and the product. In this model the rule of minimum was used, with the output function of belonging calculated as the minimum function of belonging of the rule and its alpha value. The aggregation combines all the fuzzy sets which are assigned to one output variable by interference process. There are two basic procedures of aggregation, and these are the maximum and the sum. This model uses the procedure of the maximum in which the maximum for all the functions of belonging is calculated. Fuzzy set which is the result of the composition procedure has to be transformed into a numerical value, which is done by means of the defuzzification procedure.

Fuzzy set which is the result of the composition procedure has to be transformed into a numerical value, and this is done by the defuzzification procedure. There are several ways of carrying out the defuzzification procedure, the most common of which are the methods of centroid and the maximum. This model uses the centroid method which calculates the centroid of shape which describes the finally obtained fuzzy set, and it yields the coordinate of the centroid value as a fix output value which represents the solution of the fuzzy expert system inference procedure [7].

In order to forecast the train dwell time at the next stop, as part of this model, the fuzzy inference system of type Mamdani was defined, with two inputs and one output, Fig. 1. The data on the necessary train dwell time at the next stop obtained at the output of this system serves as the input parameter in defining the new solution of the adjustment of the timetable to the actual condition in traffic which is realised by the implementation of the genetic algorithm.

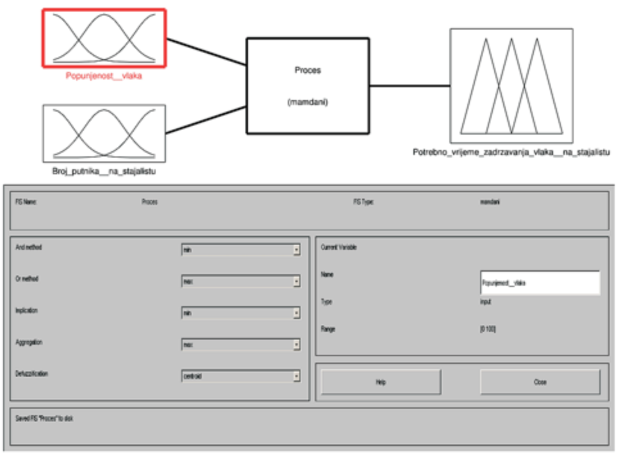

Figure 1 Defining of general parameters of the fuzzy inference system

The input values of the system represent the passenger occupancy of the train and the expected number of passengers who intend to get on the train at the next stop whereas the output value of the system is the minimally necessary dwell time of the train at the stop. Such choice of input values best enables forecasting of time which is necessary for the passengers to board and get off the train at the stop regarding the available methods of data collection on the number of passengers onboard train and at the stop [2].

The train occupancy level with passengers is determined on the basis of the ration of the actual number of passengers onboard train in relation to the maximally forecast one, Fig. 2. The actual number of passengers is determined by the automatic system for counting passengers which collects data on the number of passengers who got on and off the train and based on the difference the actual number of passengers onboard the train is determined [2].

Forecasting of the number of passengers who plan to board the train at the next stop can be carried out on the basis

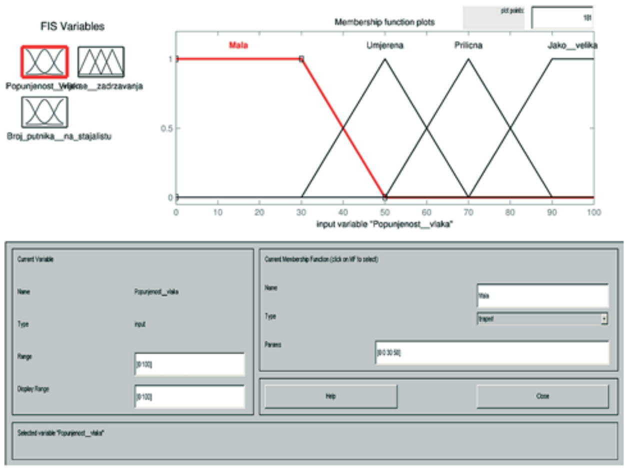

Figure 2 Defining of parameters for the input "Train occupancy"

of analysis of data collected within a certain past period, Fig. 3. It is based on observing the factors that affect the expected number of passengers, such as e.g. month in a year, day in a week, time of day, weather conditions, data on rail traffic delay, cancelled trains, etc. This data can be collected automatically by means of special passenger counting system [2].

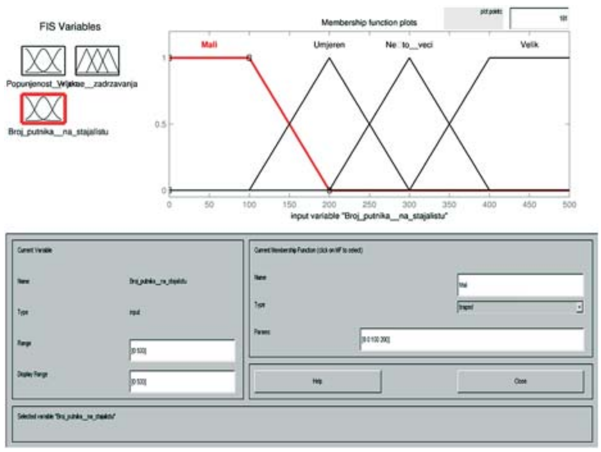

Figure 3 Defining of parameters for the input "Expected number of passengers at the next stop"

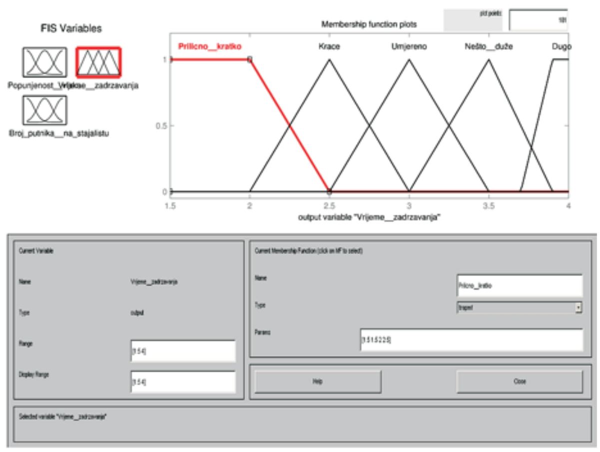

Figure 4 Defining of parameters for fuzzy inference system output

The output value of the system represents the necessary dwell time of the train at the stop. This time is defined in the range from 1,5 to 4 minutes. The bottom limit of the dwell time value of the trains at stations and stops has been defined by the interval of non-simultaneous arrival of trains, whose

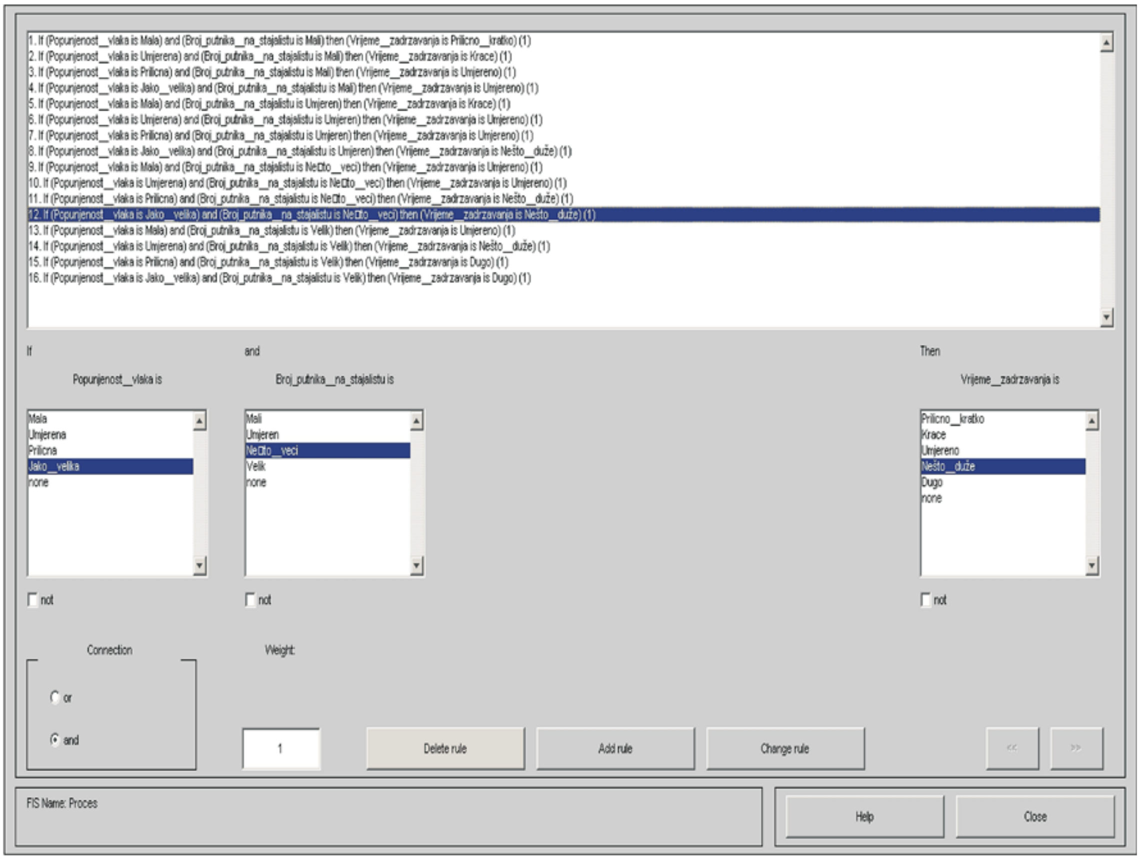

Figure 5 Defining of fuzzy inference rules

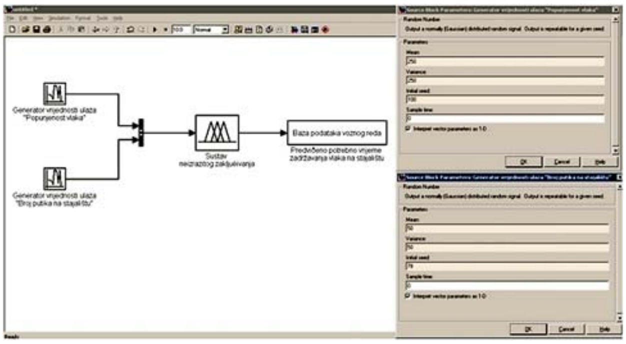

Figure 6 Model of fuzzy inference system for forecasting dwell time of commuter trains at stops

value as part of this model in all train crossings amounts to 1,5 minutes, and the upper limit is determined empirically, Fig. 4.

The inference system is carried out based on the set rules. They are defined based on the knowledge about the dwell time of the commuter trains at stops and their influence on the stability of the timetable, Fig. 5.

The defuzzification process is performed by the method of the centroid of shape resulting from the process of aggregation of the obtained solution of fuzzy inference process.

The operation simulation of the system model has been performed by the Simulink tool of the MATLAB software system, Fig. 6.

For the validation needs of this model, the input values are determined by the random number generators based on the normal distribution.

Fig. 7 shows the influence of 16 rules placed in the knowledge base and the defuzzification process in case when the occupancy level of the train is 38,3 %, and the number of passengers at the next stop amounts to 169. In this case the expert system plans the value of necessary dwell time of the train at the next stop in the amount of 2,5 minutes. By subtracting this amount from the total time, which was planned by the timetable between the train departure from the current stop and the first next one, you get the remaining highest amount of time which can be used for train ride on this inter-station distance.

Examination of the output surface is made by the output surface viewer which is for presented two-input and one-output system generate three-dimensional view on the system data, Fig. 8.

4 Discussion

The increase of demand for transport service in rail commuter traffic stipulates higher ratio of consumed infrastructure capacity. In this method of traffic flow even minor deviations from the planned timetable can have negative influence on its stability, and this can result in major reduction of the quality of transport service. The commuter rail traffic management with the application of real-time timetable rescheduling understands the application of the decision support system during the procedure of adjusting the timetable to the real condition in traffic. The minimal necessary dwell times of trains at stops obtained in this way may represent the input values in the procedure of adjusting the timetable to the actual condition in traffic, in which the dispatcher during rail traffic regulation uses computer systems to assist in decision making [8, 9, 10]. The data obtained in this method of forecasting have significant role in the rail traffic optimisation procedure regarding energy efficient train driving, since possible reduction of the share of dwell time of the commuter train at the stop in relation to the total time

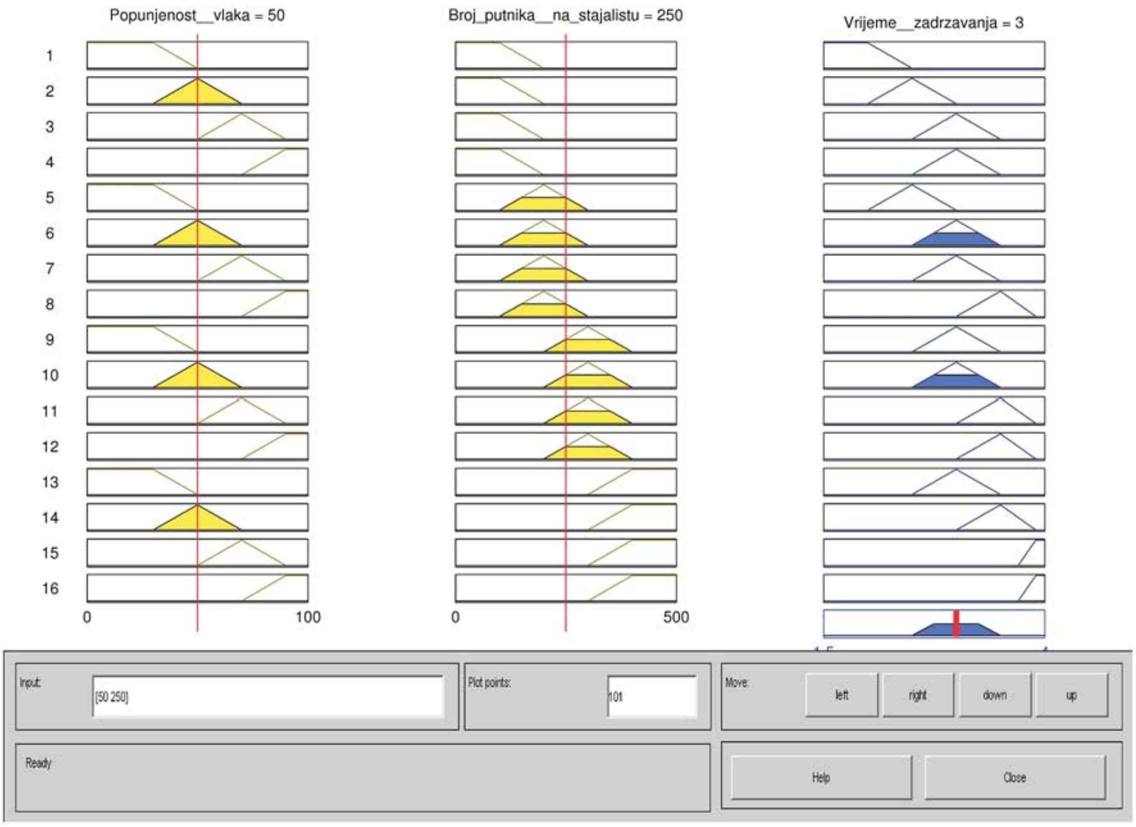

Figure 7 Overview of rules and defuzzification process for the case when the train occupancy is 38,3 % and the number of passengers at the next stop 169

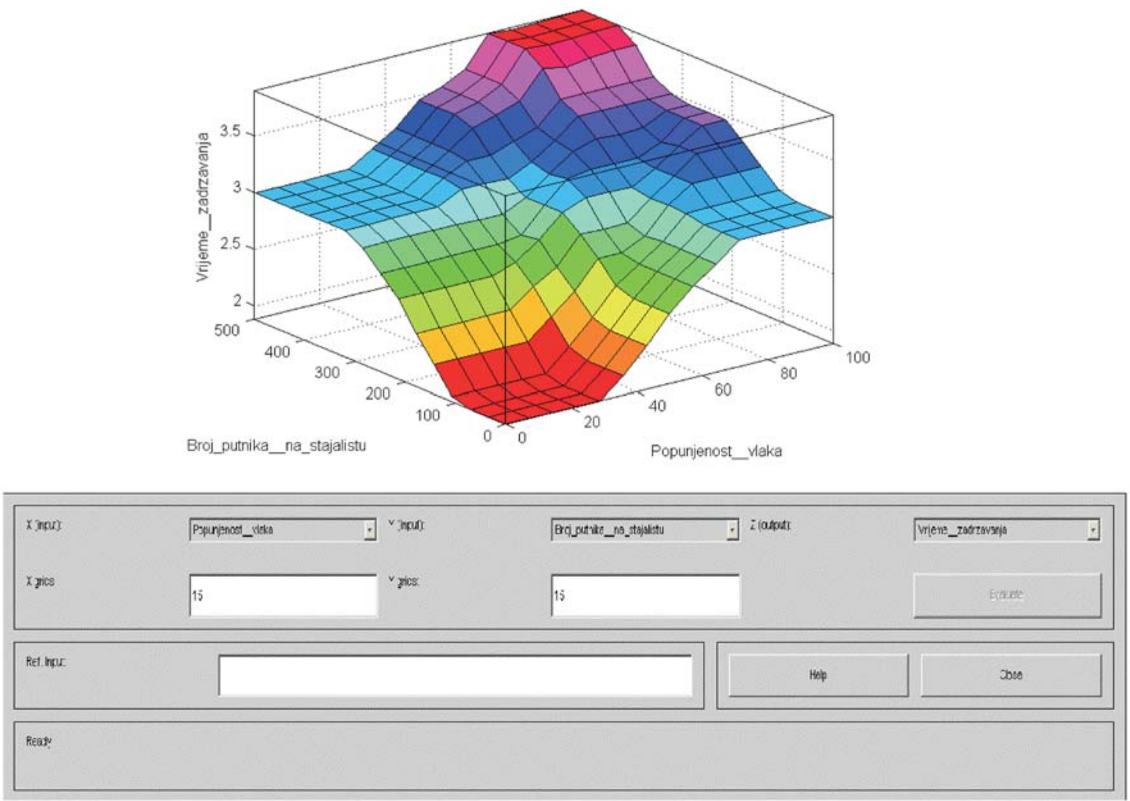

Figure 8 Output surface viewer of the system data

between its departure from this and the previous stop can increase the share of time spent in driving. The possibility of implementing longer running time enables the implementation of the running regime with the saving of propelling energy of the commuter train [11].

5 Conclusion

The development of new management methods of rail commuter traffic means implementation of computers regarding the development of different systems for the optimisation of the rail traffic. This paper presents the new fuzzy inference system which serves to forecast the necessary dwell time of the commuter trains at the stops as part of the adjustment procedure of the timetable to the actual condition in traffic. The model of this system can be implemented as part of the system for support to the decision-making of the dispatcher which centrally manages the commuter rail traffic. By its implementation, the adjustment procedure of the timetable to the actual condition in traffic, apart from solving the issue of preventing the propagation and eliminating the consequential train delay, can contribute to the efficiency of rail traffic, also regarding the energy saving in powering commuter trains.

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Authors' addresses

Hrvoje Haramina, Ph.D.
University of Zagreb
Faculty of Transport and Traffic Sciences
Department of Railway Transport and Traffic
Vukelićeva 4, Zagreb
E-mail: haramina@fpz.hr
Cell: 091/571-6660

Tomislav Josip Mlinarić, Ph.D.
University of Zagreb
Faculty of Transport and Traffic Sciences
Department of Railway Transport and Traffic
Vukelićeva 4, Zagreb
E-mail: mlinarić@fpz.hr

Branko Mihaljević, Ph.D.
University of Zagreb
Faculty of Electrical Engineering and Computing
Department of Control and Computer Engineering
E-mail: branko.mihaljevic@fer.hr