THE APPLICATION OF FUZZY LOGIC TO A SIMULATION OF RAILWAY STATION

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This article is a contribution to investigation concerning development of a simulation model of a passenger railway-station. Concretely to a part of this research, which is related to a problem, how to simulate a choice of a platform line to a delayed train. Potentiality of different methods of a computational intelligence to this task handling was reviewed. Although another method – an evaluation of options – was used for construction of simulation model [3], an applicable result was obtained also using fuzzy controller. An idea of fuzzy inference and of fuzzy system structure is described in this paper at some length. Following part is especially focused on a way how to create a fuzzy rules base. Last part of paper shows some results obtained in the process of creation of a Mamdani fuzzy logic controller and in the course of verification of its ability to choose a line to a delayed train correctly.

Key words: simulation, fuzzy controller, rules base, railway

1 Introduction

A development of a simulation models of transport process has certain tradition in our condition. Together with systems, serving to planning of transport and to analyse these plans, appears also a systems whose ambition is to be used to dispatch control of transport in real operation conditions presently. Czech Railways are employing an information system GTN – graphical-technological tool of electronic protecting device few years ago. This system enables a monitoring of train movement, an acquisition of data about real traffic situation and automatic and exact registration of documentation about transport process. More detailed advice about these applications is reporting for example in [1].

In context of this fact we can ask to what degree is possible to automatize solving of transport situations and which methods we need to achieve results. A human brain knows how to work with a vague terms intuitively and also it can to take often highly qualified decision on base of uncertain information, which aren't quantified exactly. Classical mathematical methods in principle don't enable us to do anything appropriate presently. There always exists dilemma flowing from a fact, that when a complexity of any system and a quantum of information about it increase, our ability to process this information and to describe, eventually to predict by means of this information system behaviour decrease.

However, a solutions resembling an intuitive decision making offers methods based on fuzzy set theory. Already well-proven is their use in the controls and regulation in systems that use feedback. Step by step, the theory of fuzzy set is increasingly applied also in the optimization of decisions based on the

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evaluation of vague data sets. It offers therefore a question whether this approach could be useful even at simulation of traffic situations. In this article the possibility of using fuzzy approach is demonstrated on the example of solving a task to allocate a line for a delayed train, which was formulated in the course of developing of the simulation model of passenger railway station.

2 Fuzzy system

Tool that enable to emulate an expert decision-making is fuzzy system. This system we construct on the assumption that the variables with which we work take the values that we can define in words through a linguistic variables.

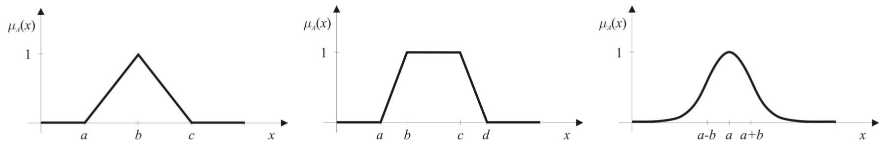
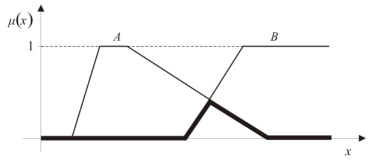
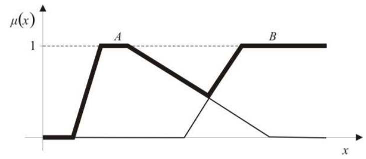
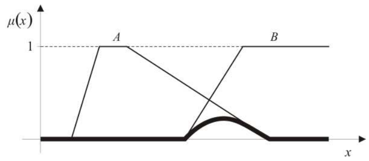
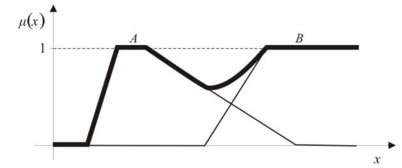
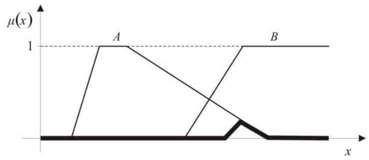
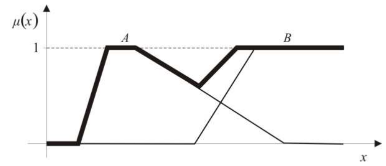


Fig. 1: Possible shapes of membership functions of linguistic variables

Linguistic variable is a variable whose values are words or phrases of natural or artificial language, so no numerical values. It's for example "travelling time" if its value are words such as "short", "medium", "long", etc. Denomination of values of linguistic variable may depend on the physical value. But often we use a universal denomination, e.g. "very small", "small", "medium", "large", "very large".

intersection of fuzzy sets	union of fuzzy sets
$\mu_{A\cap B}(x)=\min(\mu_A(x),\mu_B(x))$ 	$\mu_{A\cup B}(x)=\max(\mu_A(x),\mu_B(x))$ 
$\mu_{A\cap B}(x)=\mu_A(x)\cdot\mu_B(x)$ 	$\mu_{A\cup B}(x)=\mu_A(x)+\mu_B(x)-\mu_A(x)\cdot\mu_B(x)$ 
$\mu_{A\cap B}(x)=\max(0;\mu_A(x)+\mu_B(x)-1)$ 	$\mu_{A\cup B}(x)=\min(\mu_A(x)+\mu_B(x);1)$ 
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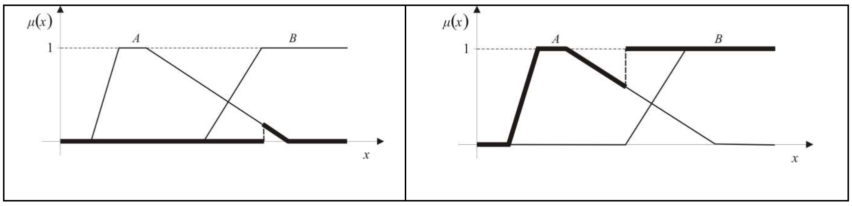


Fig. 2: Some possible definitions of intersection and union of fuzzy sets, gradually standard, product, Łukasiewicz, weak

The values of linguistic variables are fuzzy sets. To each numerical value x we can attribute a degree $\mu(x)$ expressing the persuasion that the value x belongs to a certain value of linguistic variables through the so-called membership function - see Fig. 1.

Algorithm enabling to model an expert decision-making through linguistic variables is based on the application of if- then rules, which describe the system outputs corresponding to certain values of inputs. Fuzzy rule represents a fuzzy implication of a fuzzy proposition. In applications, fuzzy proposition before particle then - antecedent - represents the input variable of system or set of inputs variables if antecedent is a complex proposition. Fuzzy proposition after the particle then - consequent - represents an output variable of system. Fuzzy proposition is composed of linguistic variable and of value of this variable, for example: "delay is small". Individual fuzzy proposition may be atomic or complex. Atomic proposition corresponds to a certain fuzzy set. Complex propositions are created by combining of atomic proposition by means of connectives and, or, not. If the atomic propositions defined on a one universe are composed, their conjunction (and) is determined by intersection of fuzzy sets, which correspond to considered proposition. Similarly, an alternative (or) corresponds to the union of fuzzy sets. Negation (not) is given by a complement of fuzzy set. Examples of some possible definitions of union and intersection of fuzzy sets are shown in Fig. 2. More detailed information you can obtain for example in [5], [6].

If the linguistic variables included in the complex proposition are defined on the different universes, it is impossible to work with fuzzy sets directly. It is necessary to create at first theirs cylindrical extension. Conjunction is then represented by an intersection of cylindrical extensions of fuzzy sets accordant with considered propositions; an alternative is represented by union of cylindrical extension of the fuzzy sets. Fig. 3 and 4 illustrate the shapes of membership functions of conjunctions, which we obtain, considering the triangular-shaped membership functions of fuzzy sets representing the atomic proposition.

There is no an established axiomatic definition for fuzzy implication. Constructions used in practical applications are most commonly based on the relation $a \Rightarrow b = a \wedge b$. One of the most frequently used implications of this kind is Mamdani implication. It is based on the assumption that consequent can have up to the same degree of membership of a fuzzy set as antecedent, so

$$\mu(x, y) = \min\left(\mu_A(x); \mu_B(y)\right).$$

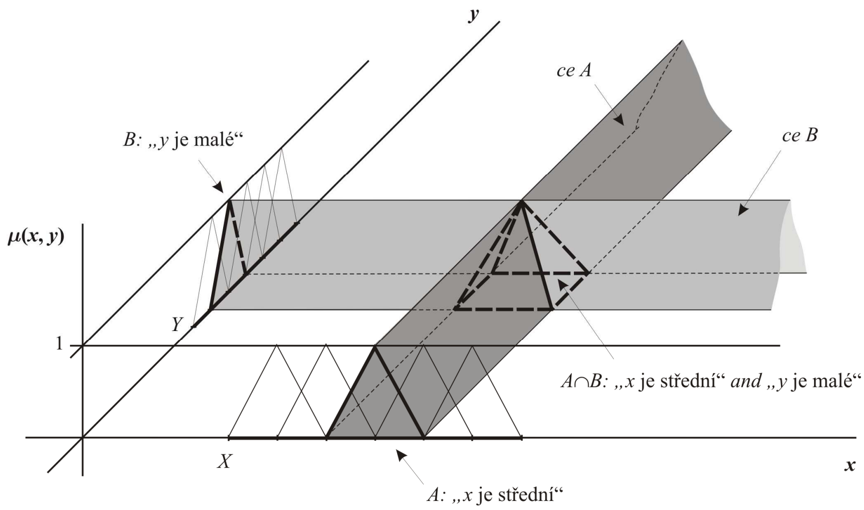
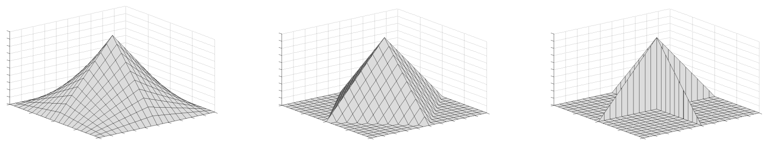


Fig. 3: Standard conjunction of fuzzy sets



a) b) c)

Fig. 4: Other possible shapes of membership functions of conjunctions

A result of fuzzy inference by means of Mamdani implication is shown in Fig. 5. A degree of membership of the measured values of antecedent x_0 determines the way in which we cut output fuzzy set *B*. We can use this way even if the antecedent of implication is the complex proposition. If we are working with a larger number of decision rules, their outputs should be aggregated. Some of the operation of the union of fuzzy sets is typically used to that.

If we need an output in the form of a concrete value, the last step is defuzzification - selection of one value from all possible values belonging to the resulting fuzzy set. Here again, we can choose from a variety of approaches. For example a coordinate of the centre of gravity of shape illustrating the output of membership function of fuzzy set is often used. More detailed information can be drawn from [4].

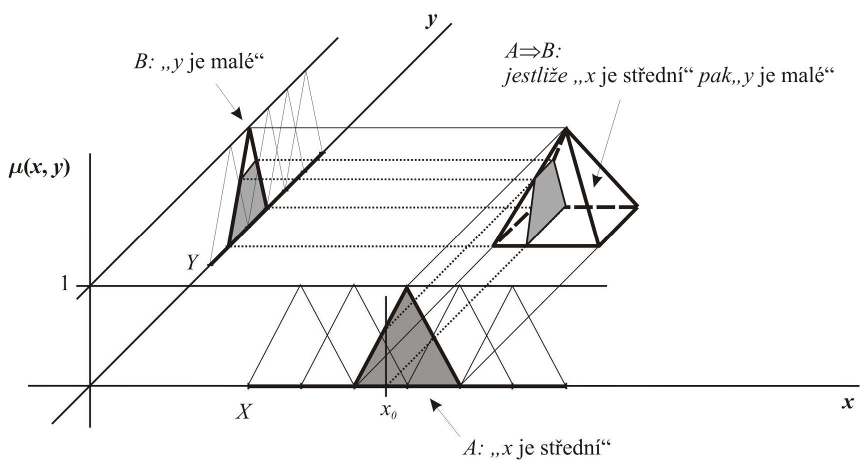


Fig. 5: – Implication Mamdani

3 Contruction of a fuzzy system to solving a task to allocate a platform line to a delayed train

The first step in creating a fuzzy system is the formulation of a problem and a ensuing determination of input and output variables. In determining of platform line for an arriving delayed train it is important to derive above all from a knowledge about a current occupation of the track in the station, a planned occupation of the track in the next period and about location of a connecting trains. We can choose one of the following strategies:

- determination of line with the priority of compliance with the original "track occupation diagram",
- determination of line with the priority of minimisation of the changing time between delayed and connecting train,
- determination of line with the priority of minimisation of a delay of other trains that may arise as a direct result of a tracks occupation change [2].

In practice, the choice of strategy may vary from case to case. Cogitation presented thereinafter prefers strategy of minimization of the changing time between delayed and connecting trains.
On the basis of operational data it was found that the most common are situations when the arrival of the train is directly followed by departures at most two connections. Input variables therefore were established as follows:

x_1 - the time at which the track will be free from the moment of announcement of the delayed train from the neighbouring station,
x_2 - the time during which the track will be free from the moment of announcement of the delayed train from the neighbouring station,
x_3, x_4- distance from the track, on which stands the connecting train,
x_5, x_6- time since the announcement of a delayed train from the neighbouring station to the regular departure of connection,
x_7 - distance of the substitutive track from the track on which train usually arrive (as usual is considered track intended to train by the "track occupation diagram"), this variable reflects the demands on orientation of a passenger in the course of a change of trains.

The output variable is a number representing the valuation of the track. Platform line which receives the highest valuation we regard as optimal for the arriving delayed train.

It is also necessary to determine what kind of rules will be used for fuzzy inference. Together with the above-described method, which is known as system Mamdani is often used system Suggeno. He works with the rules whose antecedent is, as well as in the system Mamdani, fuzzy proposition, but consequent has a shape of a function of input variables (typically linear or constant).

In general we can say that the Sugeno-type systems work well with inputs that have their basis in mathematical analysis (differential equations describing the system). They are well applied mainly in adaptive control, because it is possible to ensure continuity of theirs output. Mamdani system provides output in the shape of an area, which can be seen as a certain disadvantage. However, it is intuitive and it work well with information which have their basis in empiricism. To solving the problem under consideration was chosen Mamdani system.

A tool, which is probably the most frequently used for building fuzzy systems, is fuzzy toolbox Matlab. The central part of the fuzzy system is the rules base. Set of rules that constitute it, must have the following characteristics:

- completeness - output fuzzy set must have a positive height for any input values, e.g. for each input there must exist an output,
- consistency - there are no rules that would have the same antecedent but different consequent,

- continuity - if two rules, relating to the same input variable, have theirs antecedents created by neighbouring fuzzy sets, then theirs output fuzzy sets mustn't have an empty intersection.

Basic literature on fuzzy logic usually mentions that the rules base allow to model an expert experience expressed by linguistic terms. But the idea that you can sit at the table and on the basis of empiricism create an effective rules base is in majority of practical cases very naive. However, a source of rules base could be in many cases datasets containing crisp values of input and the corresponding output variables. Generating of rules base on the basis of these data proceeds in the following steps:

- fuzzification of input and output variables,
- generating of *if – then* rules on the basis of data,
- reduction of the number of rules by discard of repeating rules,
- reduction of the number of rules by discard of less universal rules.

Data about real occupation of tracks and about placement of connecting trains in a concrete station was in our case gained from GTN. Information included here it was necessary to complete with knowledge in placement of track and platforms in station and in "track occupation diagram" and with information on regular departures and waiting time of connecting train in station. Everything it is possible to find in respective documents and publics notices of Czech Railways.

4 Conclusion

The aim of this research was above all to assess a potential of fuzzy methods for solving the above-described task. But obtained findings may be also used as a frame for reflection on the usability of fuzzy approach for the simulation of the railway station or automatization of solving of real traffic situations.

Gradually it was created several variants of rules bases with different numbers of considered variables and with different number of rules. The largest rules base considers all seven variables x_1 to x_7 listed in Chapter 3 and was consisted of 117 rules. The most concise rules base on the contrary took into account only four of these variables - x_2, x_3, x_4, x_6 - and it was comprised of 15 rules. The influence of number of variables, of number of rules forming the rules base, impact of number of membership functions assigned to individual variables and their shape and influence of a defuzzification method on quality of decisions was studied withal. Marginal attention was paid also to the possibility of using Sugeno type fuzzy system. However, it was found that this system does not produce significantly better results in the considered case. In particular, it is not clear, which concrete shape would have a functions constituting a consequent of fuzzy rules.

On the basis of gained experience we can advise to create the rules base on the basis of artificial, generated data. Completeness of obtained rules bases is then more easily guaranteed. The operating data needn't offer all possible combinations of considered variables. But it can't be excluded that some of these combinations doesn't occur in operation in the future. Conversely, the functioning of the fuzzy system is better to check on the basis of operational data. It isn't possible to simulate operational data corresponding to the real situation without difficulty, without preceding statistical analysis. Actual operational data can be obtained easily. Unfortunately, a vision of easy acquisition of electronic operational data has not been fulfilled yet, because GTN protocol contains irregularities, which make impossible easy filtering of data. However, it is possible to expect that this problem can be solved.

As already mentioned, the function of fuzzy controller is to evaluate the matrix of input values. Each line of input matrix contains information about the monitored parameters of individual platform line in the station at the moment of announcement of the delayed train from the neighbouring station. The output is a column vector, in which each value corresponds to the evaluation of one platform line. The line with a maximum evaluation is considered the most appropriate.

As quality criteria of fuzzy controller was chosen advisability and uniqueness of determining a convenient line. As regards the first of the criteria - advisability - it can be said that all lines with a high evaluation are really suitable for the allocation to the delayed train. The controller doesn't offer quite inappropriate solutions.

In the meaning of the second criterion, the results of the comparison of fuzzy controllers are more complicated. We can say that the fuzzy controller based on more complicated rules base is able to decide uniquely in a larger number of cases. But when it isn't able to decide uniquely, the result is vaguer than when the simpler rules base is used. In general, we can accept thesis that more satisfactory results provides simpler rules base, see Fig. 6.

Contrary to initial expectations, we can also say that the number of membership functions assigned to individual variables and their shape doesn't fundamental affect the quality of the output. The shape of membership functions influences the output minimally. Greater number of membership functions has resulted in the origination of more complex and mare extensive rules base, but it doesn't bear significantly higher decision quality.

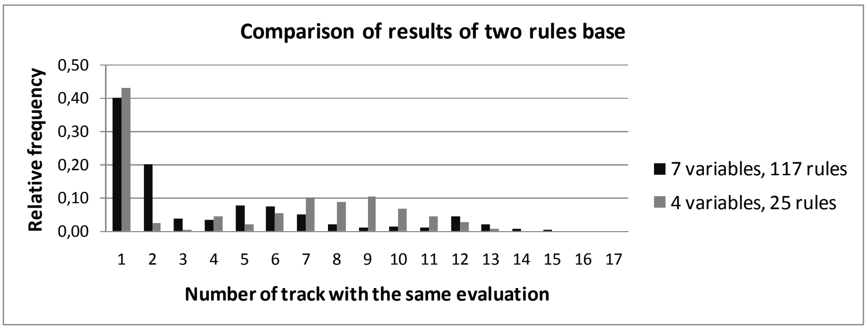


Fig. 6: Ability of different rules base to choice the platform line to delayed train

Furthermore, we can state that it isn't possible to construct a regulator, which would be able to decide unambiguously in 100% of cases. This fact already follows from the nature of the problem because they aren't rare situations where a more number of tracks objectively have in the same moment the same parameters. This implies that if this system should be used in the simulation, it is necessary at the first step to determine a set of suitable tracks by means of the fuzzy controller and after, at the next step, to choose one of the offered tracks by means of some other, preferably crisp, discrimination condition.

A compliance with the dispatcher decision also offers itself as an evaluation criterion. It was in all examined cases approximately 33%. On closer examination of the results it was found, that it causes from fact that the input variables used for the construction of fuzzy systems aren't quite conform with a way of thinking of dispatchers. Dispatcher deciding is from big parts based on information which track is free at the time of arrival of the delayed train. It takes into account, of course, also an aspects arising from local and possibly personal habits. It can be assumed that these aspects may vary from station to station. In the case of system design for the practice would be necessary to supplement the knowledge of them and determine which ones are essential.

From the comparison of results of the choice of track by fuzzy controller and by dispatcher is quite clear that the dispatcher decision-making doesn't take into account the distribution of connections and departure time of connecting trains. The human brain may not be able to obtain fast enough all the information that it would be necessary and to evaluate it. This fact may explain why the agreement of the fuzzy controller and dispatcher decision increases, if the fuzzy controller is based on simpler rules base, which isn't considering a departure time of connecting train.

We can imagine an existence of an application that would offer a solution in the form of choosing one or more tracks and thus facilitate decision of dispatcher. Such applications might be able to work with more information than a man and to contribute, as seen, for example to increase comfort of passengers during movement in the station, especially during the change of trains.

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