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APPLICATION OF FUZZY LOGIC FOR TRAIN BRAKING DISTANCE DETERMINATION

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Abstract

Determination train braking distance or where should train stop in station represent delicate task which consist of many factors. This factors can be human and technical. In this paper we focused on external factors that mostly affect braking distance and can cause changes in its length. This factors are often imprecisely, crisp data like speed, grade, braking force and braking equipment response time, and for that purpose we use fuzzy logic.

A fuzzy logic system that uses rules based on the experience and expert knowledge of a locomotive drivers and railway operators is proposed and applied to achieve train braking distance.

The aim of this paper is to determine train braking distance and difference between calculated braking distance and data from the field. In this paper an attempt has been made to create model that can represent real state. This model was created and simulated using Matlab fuzzy logic toolbox.

Special attention in this paper is paid on sensitivity analysis, which shown the stability of the obtained results. Sensitivity analysis was done through two phases which shown the stability of the results to a change in the types and values of membership functions and change in the defined fuzzy rules. FLS is tested for ten variants for different train categories and different conditions on the field.

Key words: fuzzy, train braking distance, sensitivity analysis, Matlab

INTRODUCTION

Fuzzy logic is a proven methodology for solving the problems with crisp data, like calculation of braking distance or analyzing the braking performance which can lead to improvement of the rail lines and promote technical parameters of trains [1]. This alternative way allows the modeling of a complex system, using knowledge and experience of the expert and thereby circumventing the needs for rigorous mathematical calculations.

The aim of the model is reflected in its practical application, i.e. according to this model it is possible to quickly make the calculation of the required train braking distance. These obtained values can be used both for newprojected lines and for checking the train braking distance on the existing lines.

Many papers which uses fuzzy logic for this type of problem, mostly use input variables for calculation the train braking force and automatic train control. Main advantage of this fuzzy model in relation to analytical and simulation models is its simple application in the case when a large number of input variables do not have a precisely defined value.

This paper does not refer to the calculation of the train braking distance and what degree of braking machine engineer should apply, it is primarily devoted to the design of the railway infrastructure, i.e. those elements whose layout depends on the length of the train braking distance, such as: signals, approach contacts, etc.

LITERATURE REVIEW

This section presents a brief description of the relevant literature. There are a lot of papers that using fuzzy logic for solving problems on railway. The authors of [2]developed fuzzy logic controller for automatic train control, using Matlab. Using four input values, they calculate braking system and torque. Fuzzy logic controller for an automatic train braking system is used in [3] to develop a braking system that will stop the subway train. Paper [4] gives the idea of automatic braking system in trains by using artificial intelligence technique. The intelligence is provided by a fuzzy logic controller, which is simulated using Matlab-Simulink toolbox. Authors proposed model which can help in reduction of manpower for train operation on Indian railways.

The authors of [5] presented predictive fuzzy control model for automatic train operation. In this control model, fuzzy control method and predictive control algorithm and also computer simulations are all mixed with each other to compose the predictive fuzzy control.

In paper [6] the general idea of automatic train operation based on MATLAB. This paper explains Automatic Train Stopand Automatic Warning System. It is based on the Data Oriented Control Method (DOME) to achieve train control. Implementation fuzzy logic in solving railway problems is presented in [7], where authors developed fuzzy model for braking wagon in marshalling yard.

FUZZY INFERENCE SYSTEM

Standard Fuzzy Inference System (FIS) consist of four elements: fuzzification, fuzzy rules, conclusion and defuzzification. [8, 9 and 10].

There are two basic FIS types: Mamdani and Takagi-Sugeno. Mamdani's approach is characterized by the fact that the final exit from all fuzzy rules is fuzzy set selected with a minimum strength of rules. Output from Mamdani type is fuzzy set, which requires aggregation process in the defuzzification process. Takagi-Sugeno is very similar to Mamdani, there is same approach in the fuzzification of input variable. The main difference is observed in the type of output function, which in case of the Sugeno model, only appears as a linear function or constant [11].

Typical fuzzy logic system is shown on Figure 1 [12]:

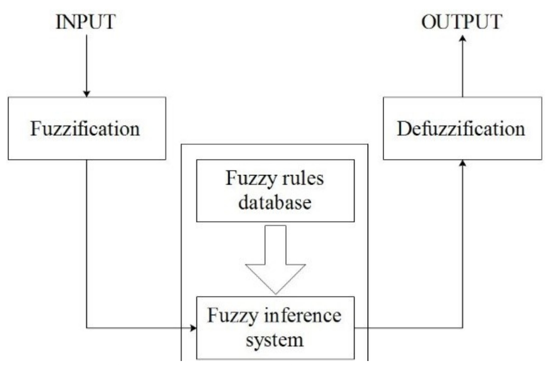

Figure 1. Fuzzy inference system

This rule can be represented as follow [9]:

$$\text{If } x_1 \text{ is A and } x_2 \text{ is B then } y = f(x) \tag{1}$$

where A and B are fuzzy sets in premise, *y=f(x)* is a faded function in the sequel. Usually *f(x)* is a polynomial of constant, but there can be any other function that adequately describes the system output in the fuzzy domain defined by the premise if the rule. Output of each rule y_i, is hampered by the strength of the rule w_i, which represents the degree of satisfaction of the premising part of the rule, also known as the degree of fulfilment.

For example, for one "*and rule"* the strength of the rule is:

$$w_i = \text{AndMethod}\left(\mu A\left(x_1\right), \mu B\left(x_2\right)\right) \tag{2}$$

where $\mu A(x_1)$ and $\mu B(x_2)$ are membership functions for x_1 and x_2, respectively. The final output of the system can be calculated as follow [9]:

$$KI = \frac{\sum_{i=1}^{N} w_i y_i}{\sum_{i=1}^{N} w_i} \quad (3)$$

MODEL FORMULATION

In proposed model, there are four input variables, and one output variable. Input variables are: speed, grade, braking force and braking equipment response time. This variables were chosen since they have largest impact on braking distance [13].

It is known how speed and grade affect the extension of braking distance, while braking equipment response time and achieved braking force are variables which depends on many other external parameters. It is not suitableto use too many input variables due to the large number of possible rules, so all the others factors which affect on train braking distance are included in these two variables.

For this kind of problem is developed Mamdani fuzzy model. The model was tested under normal conditions, i.e. unplanned events such as unbraked train or braking equipment response time was infinitely large are not considered.

Membership functions parameters for all variables are given in table 1.

Table 1. Parameters membership functions

Variable	Membership function	Parameters
x_1 - train speed	**(L)** Low	trampf (0,0,40,70)
	(M) Medium	trimf (40,70,100)
	(H) High	trampf (70,100,120,120)
x_2 - grade	**(LD)** Large downgrade	trampf (-15,-15,-14,-7)
	(SD) Small downgrade	trimf (-14,-7,0)
	(H) Horizontal	trimf (-7,0,7)
	(SU) Smallupgrade	trimf (0,7,14)
	(LU) Large upgrade	trampf (7,14,15,15)
x_3 - braking force	**(S)** Small	trampf (0,0,0.5,2)
	(M) Medium	trimf (0.5,2,3.5)
	(B) Big	trampf (2,3.5,5,5)
x_4 - braking equipment response time	**(SH)**Short	trampf (0,0,1,3)
	(N) Normal	trimf (1,3,5)
	(L) Long	trampf (3,5,6,6)
y_1 - train braking distance	300	trampf (0,0,300,500)
	500	trimf (300,500,700)
	700	trimf (500,700,1000)

	1000	trimf (700,1000,1100)
	1200	trampf (1000,1100,1200,1200)

Train speed

The speed of the train is the parameter of which most depends achievement certain train braking distance. Braking distance changes exponentially with a change in speed.On Serbian railway network, maximum speed for all trains is up to 120 km/h, but average speed is much lower. Division domain of the input variable „speed” and their membership functions are shown on figure2.

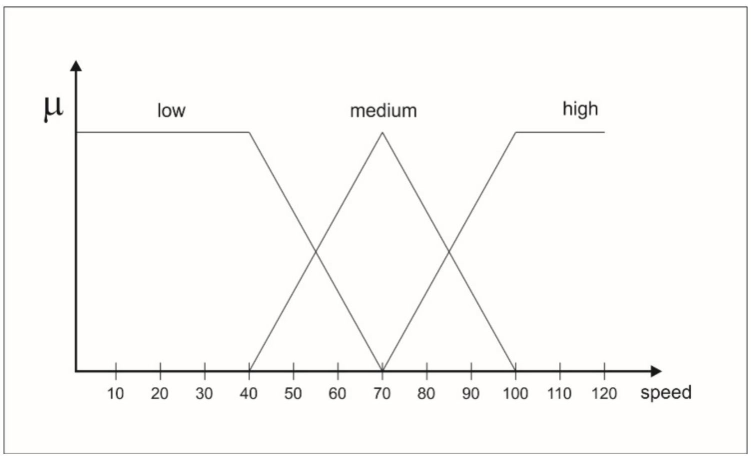

Figure2. Membership functions for input variable x_1 train speed

Membership functions of the triangular and trapezoidal fuzzy numbers „low“, „medium“ and „high“ are represented in the forms (4)-(6) [14]:

$$\mu_{low}(x)\begin{cases} 1, 0 \le x \le 40 \\ \dfrac{70-x}{30}, 40 \le x \le 70 \\ 0, x \ge 70 \end{cases} \tag{4}$$

$$\mu_{medium}(x)\begin{cases} 0, x \le 40 \\ \frac{x-40}{30}, 40 \le x \le 70 \\ 1, x = 70 \\ \frac{100-x}{30}, 70 \le x \le 100 \\ 0, x \ge 100 \end{cases} \tag{5}$$

$$\mu_{high}(x)\begin{cases} 0, x \le 70 \\ \frac{x-70}{30}, 70 \le x \le 100 \\ 1, x \ge 100 \end{cases} \tag{6}$$

Grade

Under normal conditions of exploitation, grade is the second most important parameter that affect the braking distance. The change in braking distance with the change of grade also has an exponential characteristics.Maximum grade on the observed network is up to 18‰, and grade values greater than 15‰ are present only on very small number of railway sections. For this reason, the maximum grade value is 15‰.

Membership functions of the triangular fuzzy numbers „low downgrade“, „small downgrade“, „horizontal “„small upgrade“ and „large upgrade“, are represented in figure 3.

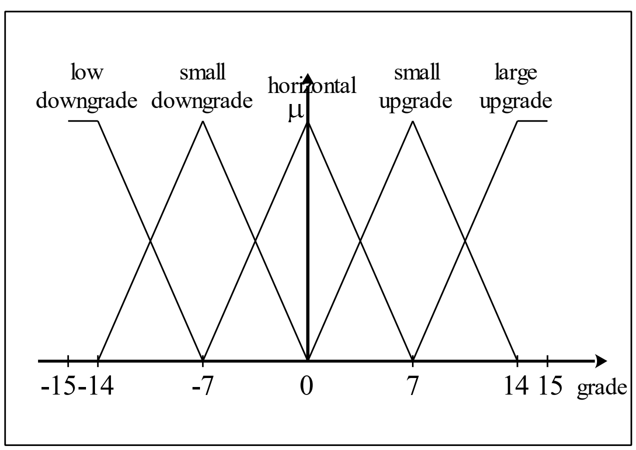

Figure 3. Membership functions for input variable x_2 grade

Braking force

Within the input variable braking force, we include all characteristics of braking system, adhesion characteristics and external conditions from the field that can affect on braking distance.When initial braking step is established, the pressure in the main brake pipe is reduced by 0,5 to 1 bar, and therefore braking force is small. When fully brake application is established the pressure in the main brake pipe is reduced by 1 to 3 bar in relations to its normal value with the release state and therefore braking force is medium. When a process of rapid or emergency braking occurs, main brake pipe is completely discharged from 5 to 0 bar and therefore braking force is the largest [15].

The value of the achieved braking force of certain wagons in the train composition depends on the value of the pressure drop in the main brakepipe, due to which the triple valve reacts and allows the achievement of a certain braking force that is proportional to the masses of these wagons.

For this reason, the mass of the train has not been taken into consideration as a separate input variable, it has already been implemented in braking force, regardlessof the train composition.

Membership functions of the triangular and trapezoidal fuzzy numbers „small", „medium" and „big" are represented in figure 4.

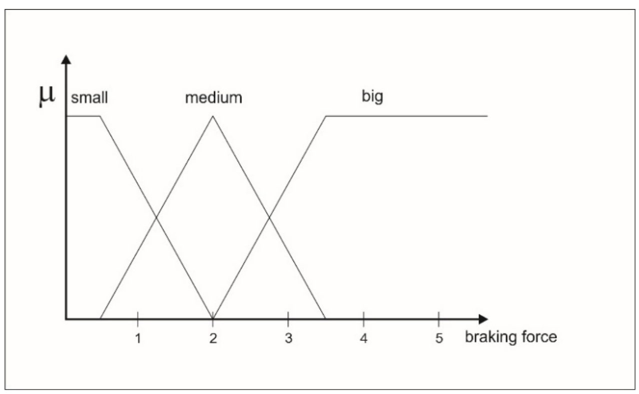

Figure 4. Membership functions for input variable x_3 braking force

Braking equipment response time

Braking equipment response time at higher speeds can have a significant impact on reaching a certain train braking distance. The assumption is that only P or R brakes are used. At the time of the response of braking equipment, the time taken to achieve the maximum value of the braking force under the observed conditions was taken into account. This time primarily depends on the length of the train. For the purposes of this paper, the following times of braking equipment response time were used:

- 0-2 s short braking equipment response time,
- 2-4 s normal braking equipment response time,
- 4-6 s longer braking equipment response time.

Short braking equipment response time is usually achieved with short trains, while slower response time is present with longer trains and different brake types in the same train composition.Membership functions are represented in figure 5.

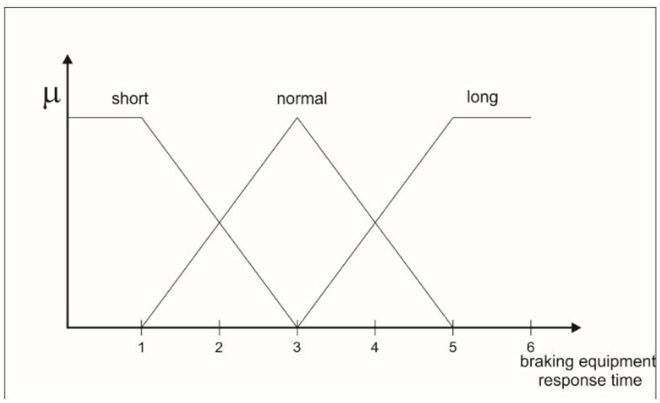

Figure 5. Membership functions for input variable x_4

Train braking distance

After defining all input variables, we define one output variable, train braking distance which membership functions of the triangular and trapezoidal fuzzy numbers „300“, „500“, „700“, „1000“ and „1200“ are represented in figure 6.

At the observed railway network, at a speed of 100 km/h and on the horizontal part of the train path, and under normal conditions of exploitation, the normal value of the braking distance is up to 700m.

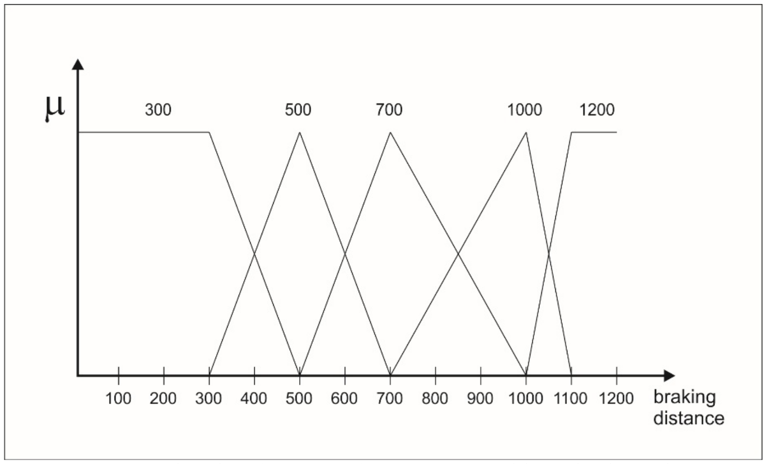

Figure 6. Membership functions for output variable y_1 braking distance

FUZZY RULES

After defining all input and output variables, the base of fuzzy rules was created. One of the most commonly used methods for generating the base of fuzzy rules is Wang Mendel method, which combines numerical data and linguistic information [14].

The database contains 135 fuzzy rules, including all combinations of input variables. All rules are the same weight, with a value of 1. One of the rules is:

If (*train speed* is **high**) and (*grade* is **largedowngrade**) and (*braking force* is **small**) and (*braking equipment response time* is **short**) then (train braking distance is**1200**).

RESULTS AND SENSITIVITY ANALYSIS

Model was tested for real data from the field, for different train categories and speed. Based on interviews with experts, the values of the input variables and real train braking distance were recorded and represent ten different variants. Model results are marked with y_1, and data from field with y_1*, and presented in table 2.

Table 2. Model results

	x_1	x_2	x_3	x_4	y_1	y_1*	y_2	y_3
V_1	100	-10	2	1	1200	1200	1200	979
V_2	100	-10	5	3	979	1000	1200	979

V_3	100	-4	1	2,5	998	1100	1200	924
V_4	80	0	1,5	3	660	700	662	664
V_5	80	8	1,5	3	446	600	479	600
V_6	60	-7	3	2	505	500	755	659
V_7	60	0	5	1	369	400	500	369
V_8	60	9	5	2,5	268	300	249	369
V_9	40	-10	1	3,5	427	500	677	625
V_{10}	40	0	2	3	201	150	302	213

Given results are very close to real data from the field in almost all situations. We can see that when train speed is very high and other variables are unsuitable braking distance is close to 1200 m. On the other hand if train speed is very low, about 40-50 km/h, regardless of the others variables braking distance is in the range of 200 to 450 m, which fully corresponds to the situation on the field.

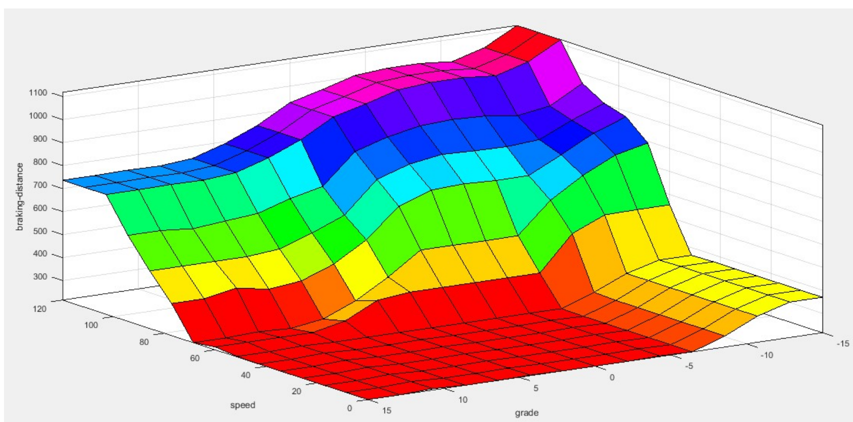

Figure 7. Surface viewer for input speed and grade and output braking distance

As we can see from figure 7 different colors represents a change in braking distance, which mostly depends of train speed and grade. For high speed and large downgrade train braking distance takes maximum values close to 1200m and vice versa.

A sensitivity analysis of fuzzy model, which can determine the stability of the obtained results, was carried out in two phases. The first phase was an analysis of the stability of the solution to a change in the types and values (parameters) of membership functions for all input variables (values y_2 in table 2). For that purpose some membership functions for variable train speed and grade are changed from triangular to trapezoidal fuzzy number. Also parameters for this two variables are changed and they are represented through new fuzzy numbers. Another two variables braking force and braking equipment response time are the same in this phase.

The second phase was a stability analysis of the results depending on change in the defined fuzzy rules (valuesy_3 in table 2). In this phase some of the rules in fuzzy rules database are modified, and used different output value. Total number of changed rules are 50.

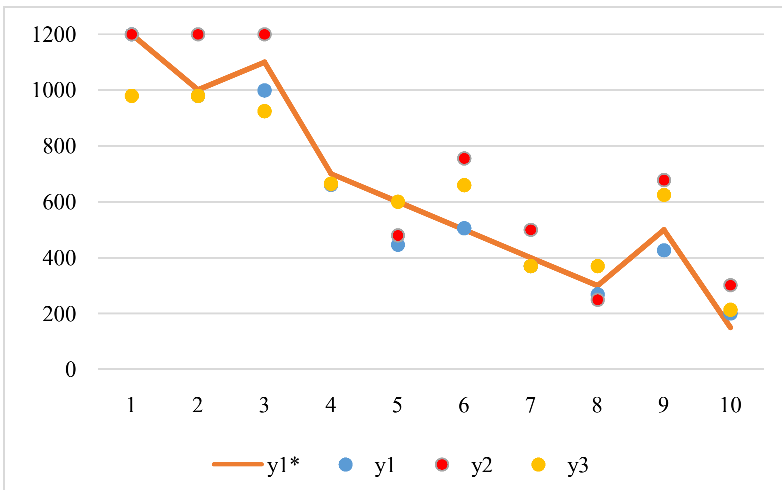

Figure 8. Model results distances from data from field

Figure 8 represent closeness of obtained results in all three cases: original model (y_1), model with modified membership functions and parameters (y_2), and modified model with changed fuzzy rules database (y_3), to data from the field. All models are tested for ten different situations from the field. Almost all variants shown that obtained results are close to data from the field, or braking distance is the same.

All values for y_3, are relatively close to the results of y_1 and at the same time from y_1^*. This sensitivity analysis can confirm us that given results have a stability on changing the existing fuzzy rules database. A less stability is shown on changing the parameters or types of membership functions. The largest discordance is noticeable for variants 6 and 9.

CONCLUSION AND FUTURE WORK

General conclusion is that model gives real data, and in next phase of our research it can be used for some simulation models. Also model can be upgraded by using more input parameters, and changing membership functions of existing variables to be more realistic. Input variable braking force can be decomposed on new input variables like adhesion characteristics or detailed external conditions.

In future research and development of this model, authors want to combine fuzzy logic with simulation modeling of real state, where in various conditions we can analyze where train stop in stations and in front of signals on open line.

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