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MODEL FOR PREDICTING THE FREQUENCY OF BROKEN RAILS

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Broken rails can cause train delays, trains cancelations and, unfortunately, they are common causes of accidents. This affects planning of a resources, budget and organization of railway track maintenance. Planning of railway track maintenance cannot be done without an estimation of number of rails that will be replaced due to the broken rail incidents. There are many factors that influence broken rails and the most common are: rail age, annual gross tonnage, degree of curve and temperature in the time of breakage. The fuzzy logic model uses acquired data as input variables to predict the frequency of broken rails for the certain rail types on some Sections.

Keywords: broken rails, track maintenance, fuzzy logic

Model za predikciju broja prsnuća tračnica. Prsnuća tračnica mogu prouzrokovati kašnjenje vlakova i jedan su od najčešćih uzroka izvanrednih događaja. Zbog toga utiču i na planiranje resursa, budžeta i održavanja željezničkih pruga. Planiranje održavanja pruga ne može se uraditi bez procjene broja tračnica koje će se zamijeniti zbog prsnuća. Postoji mnogo faktora koji utiču na prsnuće tračnica, a najčešći su: strarost tračnica, godišnje bruto tone, radijus krivine i temperatura u vrijeme prsnuća. Model fuzzy logike koristi prikupljene podatke kao ulazne promjenljive da bi proračunao broj prsnuća tračnica za određeni tip tračnice na nekim sekcijama pruga.

Ključne riječi: prsnuća tračnica, održavanje kolosijeka, fuzzy logika

INTRODUCTION

The main task of the railway track is to guide the vehicle and to take their vertical and horizontal loads and transmits them to the substructure. Rails carry railway vehicles and transfer their loads to sleepers and to ballast. Wear and deformation of rails is a negative side effect of exploitation [1]. This phenomenon has a significant impact on maintenance costs and determines the lifetime of the tracks on the lines. Any replacement or repair of damaged rails in addition to maintenance costs causes costs generated by train traffic disturbance (delays or blocked traffic) [2].

Deformations in tracks lead to premature damage to the wheels and the wagons, and thus affect the stability of the vehicle and the traffic safety. The costs of purchase and replacement of new tracks are very large. According to [3] some data, the share of costs for rails is about 40 % of the entire cost of rail construction.

According to the degree of rail defect there can be consequences on train traffic, from restriction of speed on a section to a track closure. If the broken rail is without a loss of material from the rail head, trains can pass over the broken rail with restricted speed of 5 km/h. If the broken rail is secured by temporary fish-plate, trains can pass with 20 km/h.

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Broken rails are threat to the regularity and reliability of the train traffic, leads to increased risk of accidents, and generates high costs of reconstruction of such sites and increased operating costs of transport.

To reduce the overall costs, good planning is necessary for rail maintenance. Efficient maintenance of the rail tracks demand a forecast on the number of broken rails that will occur in certain period. Analytical models [4] can give a good prediction, but they demand a detailed database. When there is no sufficient data to create and verify analytical model, fuzzy logic model can be used to predict the number of broken rails. Fuzzy logic has been shown to be a good mathematical tool for modelling processes that are distinguished by subjectivity, uncertainty, ambiguity and imprecision [5].

With normalized input variables and predefined database of rules, occurrence of broken rails can be calculated for any specific case. Predicted number of broken rails can be used for planning the rail inventory and maintenance plan.

RAILS CHARACTERISTICS

Movement of the vehicle on the railway tracks causes vertical and horizontal forces, which lead to large dynamic loads on the rails. The design of the rail (Figure 1) is such that it provides a longer service life.

The maximum stresses are occurring between the wheel and rail on a small elliptical surface of 1,5 ÷ 2,0

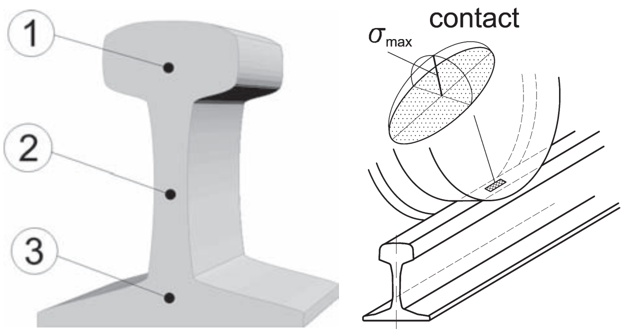

Figure 1 a) Rail: 1-head of rail, 2-web of the rail, 3 - base of rail and b) wheel-rail contact

cm^2, and for a common axle load the contact strains are within the range of 45 ÷ 80 kN/cm^2. Bending moments in the middle of the rail between the two threshold stresses causes bending of 5,5 ÷ 11,5 kN/cm^2. Movement of vehicles along the track rails causes oscillations, whose frequency can reach a value of 1 000 ÷ 3 000 Hz. The high concentration of stresses on a small area leads to fatigue which causes tearing and crushing of material on the surface of the rail head. Contact area between two curved elastic bodies (wheel and rail head) is form of an ellipse (Figure 1).

The choice of rail type depends on the rail axle load, highest train speeds and traffic volume. For example, for axle load of 225 MN, speeds up to 120 km/h and traffic volume of 10^6 gross tons (GRT) per annum, rail type S-49 shall be installed. At higher values of speed, axle load and traffic volume, rail type UIC-60 would be appropriate. According to the UIC (International Union of Railways) standards for rails in Europe are rails of quality R0700, R0900A, R0900B and R1100 by the minimal tensile strengths [6]. Rail steel is required to have strength, abrasion resistance, not to be brittle, nor flammable, good for welding and with a lower price.

RAIL DEFECTS

Rail defects are the result of growth of cracks due to fatigue [7]. Cracks appear in the production of steel or by stress concentration. Because of the possibility of detecting cracks before the creation of the defect it is usually to perform ultrasound control. At very low temperatures there can be a brittle fracture of rail, with no apparent cause. The origin of this fracture is transverse crack in the rail head, which is not detected. It is known that with the rail steel with greater hardness, fragility increases with temperature decrease. Invisible cracks in rails can lead to sudden fracture. Therefore, the condition of rails are monitored and controlled in regular periods [8].

A horizontal crack occurs at the ends of rails and has a tendency to separate the rail head from the rest of rail (Figure 2).

A progressive kidney shape crack is formed in the process of rail production and develops from the inside of the rail head center from internal horizontal crack or

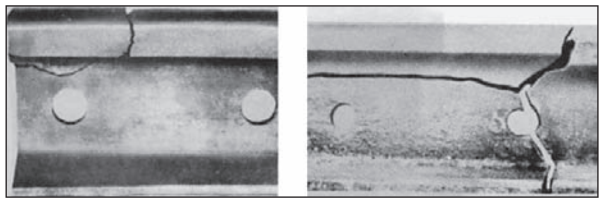

Figure 2 Horizontal cracks below the rail head

Figure 3 Progressive transverse cracking

from the flaking of the deep inner edge of the head (Figure 3).

A transverse crack in the rail head caused by weld material fatigue from weld base comes from the inclusions of oxides of local discontinuities due to the instability of cheating or flaking. Fracture is characterized by smooth, shiny spots on the weld (Figure 4).

Figure 4 Transverse cracks

Rails that are in use in Europe are by the recommendations of the UIC (International Union of Railways) standards that are of quality R0700, R0900A, R0900B and R1100 and with minimal tensile strength according to Table 1.

In terms of naturally hard rails quality, R0900A or R0900B, increased tensile strength of these tracks is obtained by increasing the content of C and Mn. The rails 90A quality the content of C was increased compared to Mn and they are easier for welding.

Table 1 **The prescribed properties of steel for rails**

The characteristics of rail steel		Steel quality			
		R0700	R0900A	R0900B	R1100
Chemical Composition /%	C	0,4-0,6	0,6-0,8	0,55-0,75	0,6-0,8
	Mn	0,8-1,25	0,8-1,3	1,3-1,7	0,8-1,3
	Si	0,05-0,35	0,1-0,5	0,1-0,5	≤ 0,9
	S	≤ 0,05	≤ 0,04	≤ 0,04	≤ 0,03
	P	≤ 0,05	≤ 0,04	≤ 0,04	≤ 0,03
	Cr				0,7-1,2
	V				≤ 0,2
Tensile strength / MPa		680 - 830	880 – 1 030	880 – 1 030	≥ 1 080
Elongation /%		≥ 14	≥ 10	≥ 10	≥ 9
Hardness /MB					≥ 321

ANALYSIS OF THE BROKEN RAIL DEFECTS CAUSE

The average age of rails in Serbian Railways is 39,67 years [9]. About 80 % of the rails are continuous welded rail (CWR) track, and about 20 % with classical ensembles. Most of the tracks are with the rail type 49, and only 10 % of all rails are rails type UIC 60. In terms of rails age, over 54 % of rails are over 20 years old, and only about 16 % are under 10 years old.

In year 2009, there were 240 broken rails on Serbian Railways network with the following types of the broken rails (Figure 5):

- 96 (40,18 %) defects was at the AT welds,
- 92 (38,55 %) defects at the rail joints and
- 52 (21,27 %) defects were in the continuous rail track.

Many studies have already shown that there are many factors that cause rail deformations, and broken rails [4]. The most significant factors on broken rails occurrence are: rail age, rail type (weight), degree of curve, annual gross tonnage, annual wheel passes, average dynamic load, rail steel type, rail surface roughness, temperature at the time of the break.

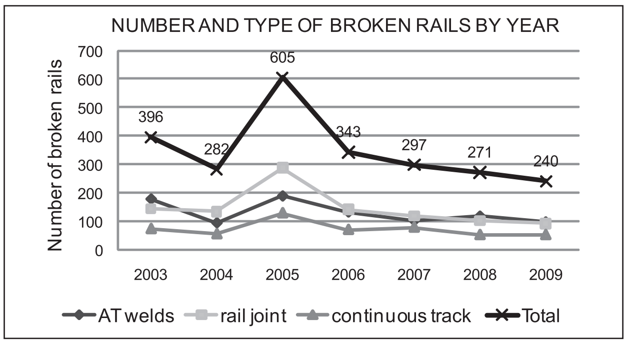

Figure 5 Number of broken rails by defect type and by year on Serbian Railways

Statistical analysis of data from Serbian Railways [9] for a period of 10 years shows that 78 % of broken rails occur in winter and autumn period (42 % and 36 % respectively). The most critical period is from November to February (Figure 6).

Analysis also showed that the occurrence of broken rails is higher on older railway tracks. Combination of

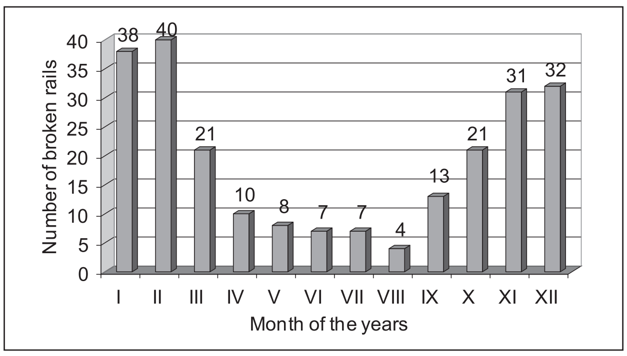

Figure 6 Average number of broken rails by month in 3 years (2008 – 2010)

several factors can often produce an increase in broken rails occurrence. For instance, on some lines with old rails there are trains with excess weight load.

Old rails, as well as the fatigue of carrying the excess weight per axle create a combination of these causes and their joint action. Statistical analysis of broken rails data from year 2008 to 2010, indicates on the difference in broken rails occurrence between different Sections of Serbian railway network (Figure 7).

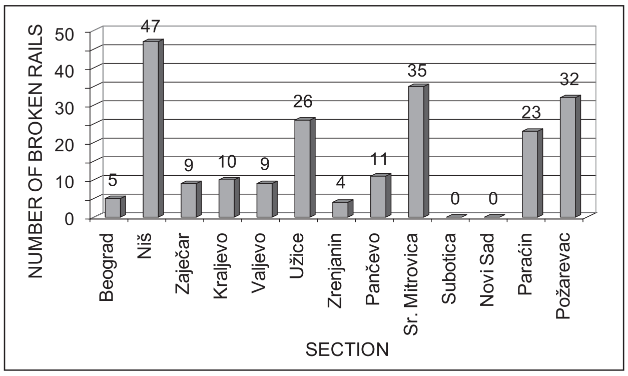

Figure 7 Average number of broken rails by network sections (2008 – 2010)

This can be explained by the fact that Sections have significant differences in railway lines characteristics (rail age, degree of curve), different monthly gross tonnage and wheels passes. Observing the data from year 2008 to year 2010 on Serbian Railways it can be concluded that the most important factors for predicting broken rails are temperature, the age of rail, the volume of traffic expressed in gross tonnage and degree of rail curve.

FUZZY MODEL FOR PREDICTING THE NUMBER OF BROKEN RAILS

Fuzzy logic is the base of the fuzzy model. It enables making decisions based on incomplete and imprecise information. Model based on fuzzy logic consists of the "if-then" rules which are interconnected with "else" or "and" logical operators. Fuzzy model is defined with four input variables: *temperature, rail age, gross tonnage* and *degree of rail curve*.

The membership function for output variable *number of broken rails is* defined with 3 fuzzy sets: *low, mid* and *high* (Figure 8).

Values and boundaries of input and output variables fuzzy sets are defined by normalized data for each data category and for each specific case. Fuzzy logic system comprises of 16 rules. These fuzzy rules translate 4 input fuzzy variables into 1 output fuzzy variable.

Logical AND operator is employed (the rule of minimum for AND relationships, the so-called Mamdani rule of minimum). In creating the consequent fuzzy set, MAX – MIN inference is used. Defuzzification of the output fuzzy variable is by center of gravity method (COG).

Figure 9 shows the relationship between number of broken rails and selected input variables: temperature and gross tonnage.

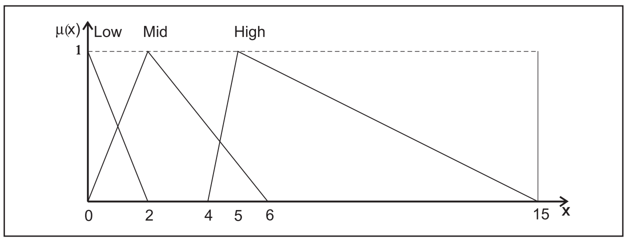

Figure 8 Membership function plots for output variable

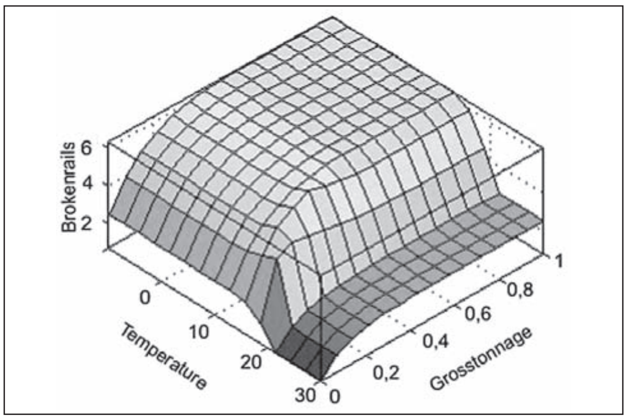

Figure 9 Fuzzy model input – output relationship

MODEL TEST RESULTS

Model is tested on several network sections and with various input values. Normalization of input and output variables allows easy and fast adaption of the model for specific cases. Input values are crisp and calculated by statistical analysis and then normalized to fit the range for each variable. The model is used to calculate the number of broken rails of certain type for each Section of railway network. Fuzzy inference system (FIS) (Figure 10) presents an example of MAX – MIN calculation of broken rails for Section Nis, for month of November.

Input data are collected from the Serbian Railways database for average rail age, average gross tonnage and for the numbers and radius of curves on railway tracks. Input data values are as follows:

- average temperature – 6,3;
- average rail age – 27 years;
- gross tonnage (*normalized value*) – 0,68 and
- degree of curve (*normalized value*) – 0,75.

Defuzzified and normalized output variable gives calculated number of broken rails for the Section for one month. The average number of broken rails calculated by the fuzzy model is 6,72 and real data for the same input parameters is 6 broken rails in 2010.

CONCLUSION

Analytical models for occurrence of broken rails gives the most precise data on broken rails, but they require detailed and large database. It is difficult and sometimes impossible to collect all necessary data needed for analysis of broken rails occurrence. Fuzzy model uses only basic data and data that are relatively easy to collect. Base of rules in the fuzzy model incorporates "if-then" logic and experience of experts to define the model. Results obtained from the model can be used as a decision support in process of railway track maintenance planning.

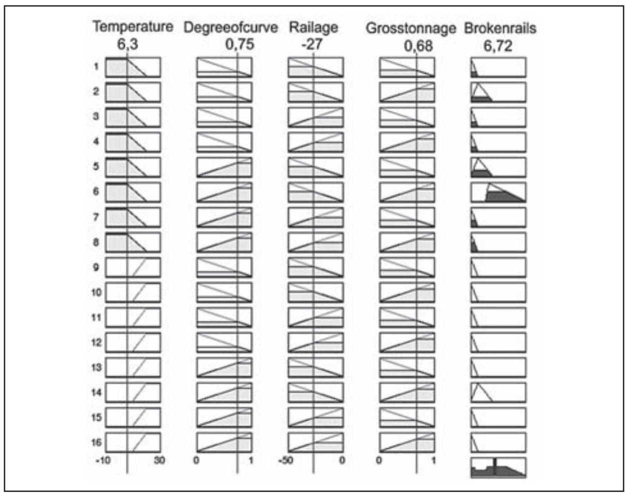

Figure 10 Fuzzy inference system

Quality maintenance demands a system of inventory that can quickly respond to rail defects and thus keep maintenance and operational costs at minimum.

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