Scientific Journal of Silesian University of Technology. Series Transport
Zeszyty Naukowe Politechniki Śląskiej. Seria Transport

Volume 101 **2018**

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: https://doi.org/10.20858/sjsutst.2018.101.7

Journal homepage: http://sjsutst.polsl.pl

Article citation information:
Gibała, Ł., Konieczny, J. Application of artificial neural networks to predict railway switch durability. *Scientific Journal of Silesian University of Technology. Series Transport*. 2018, **101**, 67-77. ISSN: 0209-3324. DOI: https://doi.org/10.20858/sjsutst.2018.101.7.

Łukasz GIBAŁA[1], **Jarosław KONIECZNY**[2]

APPLICATION OF ARTIFICIAL NEURAL NETWORKS TO PREDICT RAILWAY SWITCH DURABILITY

Summary. The article presents the possibility of applying artificial intelligence to forecast necessary repairs on ordinary railway switches. Railway switch data from Katowice and Katowice Szopienice Północne Stations were used to model neural structures. Using the prepared data set (changes in values of nominal dimensions in characteristic sections of 15 railway switches), we created three variants of railway switch classifications. Then, with the results, we determined the values of classifiers and the low mean absolute error, as well as compared charts of effectivity. It was calculated that the best solution by which to evaluate necessary repairs in railway switches was, in part, to repair the crossing nose. It was assessed that a structure with single output data was more effective for the accepted data.
Keywords: artificial neural networks; railway switch; maintenance; prediction

1. INTRODUCTION

In 2015, the Polish railway system used 39,988 railway switches including 17,894 built on main tracks and running lines and 22,094 built on tracks at stations [1]. The requirements for

[1] Department of Railway Transport, Faculty of Transport, Silesian University of Technology, Krasińskiego 8 Street, 40-019 Katowice, Poland. Email: l.gibala9494@gmail.com.
[2] Department of Railway Transport, Faculty of Transport, Silesian University of Technology, Krasińskiego 8 Street, 40-019 Katowice, Poland. Email: jaroslaw.konieczny@polsl.pl.

railway switches grow all the time. The operation of railway switches affects the availability of railway lines, so actions should be taken to improve reliability. The complexity of the railway switch system requires preferential improvements. The continuous improvement of manufacturing techniques, as well as the processing technology of steel and assembly construction, results in a useful life. Progress has been seen in the field of environmental protection with the substitution of wooden sleepers by concrete sleepers and in the scientific area, for example, in the implementation of bainitic steel, polymeric sleepers and new diagnostic techniques [6].

Conducting technical examinations is necessary to confirm correct work in “wheel-rail” junctions and reduce undesired processes, for example: jamming wheelsets between wing rails and steering rails, hitting wheel flanges at crossing noses or hitting wing rails before clear spaces. The greater the tolerance field, the greater the difference between the permitted differences, and the better adjustment of the tolerance field to measured values, such that the railway switch can be used for a longer period without the necessity of repair [9]. These undesired processes can be avoided by controlling and reacting to crossed permitted differences in characteristic sections of railway switches. Insignificant crossed permitted differences are not reasons for the classification process or reasons for derailment. Differences should be designed to ensuring the security of rail traffic and the stability of train gears.

Therefore, development diagnostic computer tools are intentional. Their operation affects infrastructure management. By using them, it is possible to plan necessary maintenance work in an easy way and reduce the implementation of speed limits, which impacts on financial loss. For example, in 1999, the speed limits on the UK railway system caused faults and damage to railway switches, which increased the travelling time by 900,000 min, or by about 10%, costing GBP 18 million [2].

In the article, we present possibility to use the program Statistica Neural Network PL 4.0 F, developed by StatSoft, to evaluate necessary repair railway switches. Work measures are also proposed to encourage infrastructure management, in order to deepen cooperation with research units.

2. CURRENT DIAGNOSTICS OF RAILWAY SWITCHES ON THE PKP POLSKIE LINIE KOLEJOWE (POLISH RAILWAY INFRASTRUCTURE MANAGEMENT)

Continuous monitoring of the technical state and reacting to faults in railway switches are some of the duties of track section employees, while the state carries out visual inspection. In this type of research, artificial intelligence methods can also be used. In the literature it is possible to find many examples of image analysis using modern computer methods [14-17]. Diagnosis provides information about actual states of elements: supporting, conjunctional, steel and sliding in railway switches. Evaluating the usability of railway switches is necessary for the smooth running of train routes. Moreover, work on switches should be checked in commutating process. These activities are the duties of employees involved in the technical regulation of operation points, where railway switches are built. The results of visual inspection are noted in special registers. Other kinds of diagnosis include the technical examination of railway switches. This activity is also employees’ responsibility. Additionally, technical examination should be carried out by commissions formed by employees and supervisors.

The range of technical examinations contains a process of visual inspection, which encompasses geometrical measures in the characteristic section of the respective object. The results of activity are noted in the same register for each object on technical examination sheets. The frequency of measuring railway switches depends on the maximum speed and load of the railway. The frequency of technical examinations in relation to local parameters is presented in Table 1 [8].

Table 1

Frequency of technical measurement in PKP Polskie Linie Kolejowe

No.	Parameter	Frequency of technical measurements as defined by parameters				
1	2	3	4	5	6	7
1	Speed [km/h]	$v \leq 40$	$40 < v \leq 120$		$120 < v \leq 160$	$160 < v \leq 200$
2	Load [Tg/year]	-	≤ 10	> 10	-	-
3	Basic frequency [months]	6	6	3	3	2
4	Protracted frequency [months]	Max. 12	Max. 9	Max. 6	Max. 6	Max. 3

Source: [8]

The parameter "load" refers to the cumulative transport load in all directions on railway switches expressed in the unit "teragram" in the period of one year (365 days).

The diagnosis of all kinds of railway switches requires the presence of a person in a dangerous area where rail traffic is conducted. It obligates an employee to show special care and an adequate reaction when a train is approaching. The endangering of an employee's life is sufficient reason to develop new methods of diagnosis without human reliability. Moreover, methods should not impede the conducting of rail traffic.

3. PRESENTATION OF PREPARING BACKGROUND ANALYSIS

3.1. Specification of used program

The program was developed through knowledge of the biological nervous system, which is realized by complicated chemo-electro processes. It uses two elementary building blocks, neurons and synapses, in order to solve complicated arithmetical and technical problems. Through learning and adapting to the evolving environment and creating a universal system of approximation, a data set is reflected, while the generalized collection of knowledge, via artificial neural networks, is able to solve practical problems [11,20,21]. These networks solve issues related to forecasting repairs of the track surface, diagnosing the track surface or researching the reasons for derailment, as described in [5]. Another example of using this tool is the improvement in materials in railway transport [7,18,19].

The functioning of the network is based on transmitting input signal x_i, via synapses or "conjunctions", to a neuron or "unit". Each input signal is multiplied by weight w_i. It can take positive values to work as stimulants, while negative values act as brakes of the neuron output signal y. The neuron executes two functions. After receiving all input signals $x_j w_{ij}$, a totalization block calculates the integer boost *net*. This is a sum of the values of input signals and weights. The next-step activation block calculates the output function *f*, which is the output signal *y*. The construction of the neuron block is presented in Figure 1.

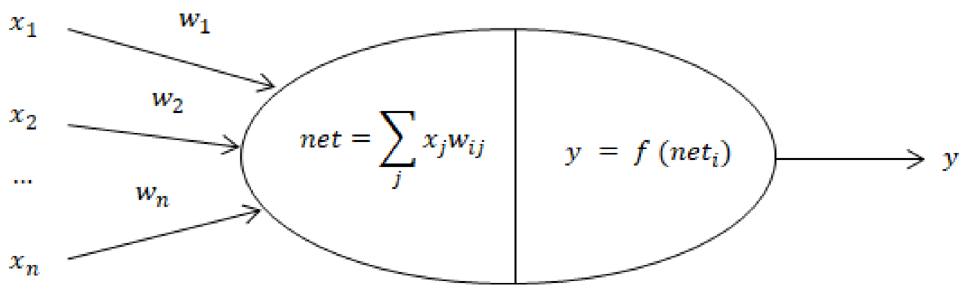

Fig. 1. Scheme of the McCulloch-Pitts neuron
Source: [10]

The learning process is based on the choice of recurring weights. The learning of the network is automatic, while the length of time depends on the size of the structure and can be interrupted at any time by the user. The choice of the time depends on user experience, with learning that is too low resulting in a big error. Lengthening learning means that the structure will generate a big error too, but the input data set must be changed [4].

The preparation of the neural network starts when the data set that is input and the output data are collected. This is the learning string. Data can be coded as:

a) Alternative trait: 0 - the trait does not exist; 1 - the trait exists (for example, a respective site is a railway switch with a diverging track radius R = 500 - 1) and -1 is when the trait does not concern an object.
b) Numerical trait.
c) The trait describes an increase or difference in the nominal dimension.
d) Factors - elements of the final formula [5].

Choosing the structure is not conditional on strict rules but depends on the experience of the user. A common structure is the multilayer perceptron (MLP), which is described as an easy training process. As mentioned before, the neural structure is created by neural units and conjunctions. The number of neural units in the input layer equals the amount of input data, while the number of neural units in the output layer equals the amount of output data.

3.2. Description of real objects

Technical examination sheets of railway switches were used for the analysis of data. There are nominal dimensions in characteristic sections: real values of these dimensions and the kinds of repairs made to reduce or remove exceeded permitted differences.

Technical examination sheets were shared by PKP Polskie Linie Kolejowe. In order to present the possibility of using the mentioned program, nine ordinary railway switches were chosen with a radius of 900 m and one with a radius of 190 m, located at the end of Katowice Station. The data set was enlarged four objects with a radius of 190 m and two with a radius of 500 m from Katowice Szopienice Północne Station. The railway switches work in train and manoeuvre routes.

The number of chosen objects is insufficient to perform an unequivocal analysis, nor does it make a valuable data set. The examination of diagnosis railway switches proved that even a group of 200 objects is insufficient to obtain encouraging results [3].

The task of diagnostics with longline artificial intelligence seems to be a duty of an infrastructure manager's engineering personnel, who have detailed knowledge about objects.

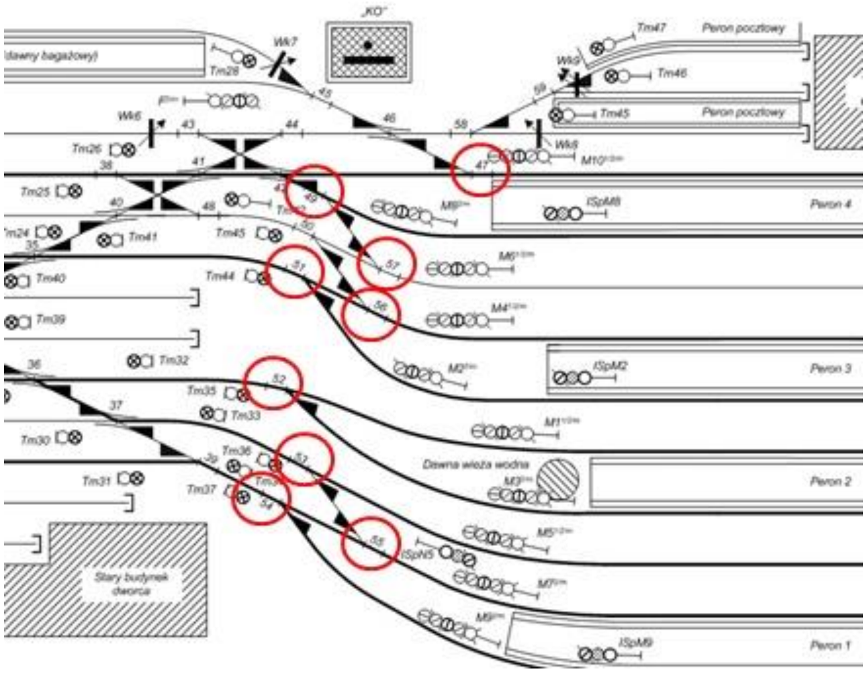

Fig. 2. Localization railway switches at Katowice Station
Source: [12]

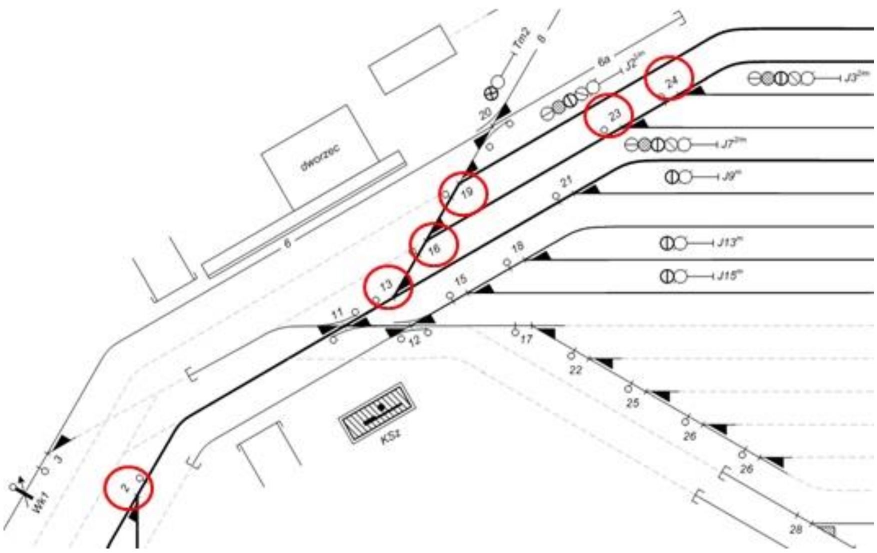

Fig. 3. Localization railway switches at Katowice Szopienice Północne Station
Source: [13]

The objective of analysis was the creation of a program, which would be able to evaluate the necessity to repair railway switches, as follows:

- A - exchanging half-switches and connecting railways lines, due to chipping needles or excessive side wear.
- B - tightening screws along railway switches due to excessive dynamic effects from trains and degradation of sleepers.
- C - automatic thickening of crushed stone
- D - regulating the width of basic trails by local tightening of screws, refilling fixation components or controlling the side wear of rails.
- E - regulating the width of turning trails by local tightening of screws, refilling fixation components or controlling the side wear of rails.
- F - exchanging sleepers due to excessive degradation levels.
- G - performing repairs at crossing noses by exchanging crossing noses, flame-plating or exchanging steering rails due to wear.

3.3. Preparation of the input and output data set

Input and output data sets, as learning strings, were collected in an MS Excel spreadsheet. The input data defined:

- service speed in basic trail $V_{\uparrow}$ [km/h]
- service speed in turning trail $V_{\uparrow}$ [km/h]
- a kind of fixation
- time from the first measure of dimensions to the last [days]
- bend of railway switch
- radius of turning trail R [m]

For every measure calculated, evaluation indicators were determined according to [2] as follows:

- indicator of synthesis maintains the accuracy of the railway switch J_r
- indicator of maximum relative over-dimension permitted differences Spm
- indicator of expanse differences E $[\%]$
- indicator of repeatability differences P $[\%]$

Additionally, there is a considered trend concerning the appearance of differences in each group of characteristic dimensions. The numerical amount of characteristic dimensions is added to the radius of the turning trail. Groups were created by divisional dimensions, as presented in Table 2. The location of the aforementioned dimensions for exemplary railway switches is presented in Figure 4.

Table 2

Apportionment of dimensions in characteristic places

Radius of turning trail	Basic trail	Turning trail	Joints	Width in part of the crossing nose
$R = 190\ [m]$	$b_1, c, d, e,$	$b_2, c_1, d_1, e_1,$	$a, b, k, k_1,$	$f, f_1, h, h_1, i, i_1,$

$R = 300\ [m]$	$b_1, c, d, d_2, e,$	$b_2, c_1, d_1, d_3, e_1,$	$a, b, k, k_1,$	$f, f_1, h, h_1, i, i_1,$
$R = 500\ [m]$	$b_1, b_3, c, d, d_2, d_4, e$	$b_2, b_4, c_1, d_1, d_3, d_5, e_1$	$a, b, k, k_1,$	$f, f_1, h, h_1, i, i_1,$

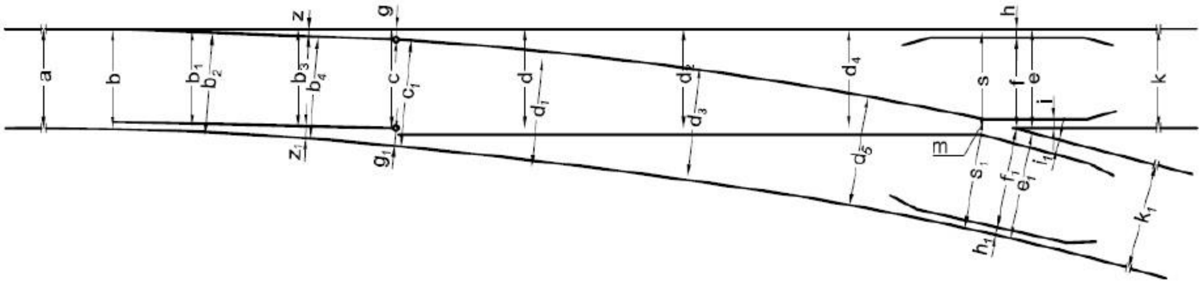

Fig. 4. Location characteristic dimensions in railway switches with
a turning trail radius of 500 m
Source: [8]

The next step was to add an output data set. In the spreadsheet, necessary repairs were coded as "1", while the absence of need was coded as "0". A fragment of the spreadsheet is presented in Figure 5.

INPUT																				OUTPUT						
Character of traffic			V↑	V→	R [m]	Fastening		Indicators				Occuring anomaly				Anomaly of witdh p,w,z	Days	Skew [m]		Need of repairing						
freight	passenger	maneuver				K	SKl-12	Jr	Spm	E [%]	P [%]	trail↑	trail→	Joints	Widths			1:9	1:12	A	B	C	D	E	F	G
1	0	0	50	40	190	0	1	3,06	0,71	0,00	0,00	1	1	1	1	0	0	1	0	1	0	0	0	0	0	0
1	0	0	50	40	190	0	1	3,78	0,79	5,56	0,00	1	1	1	1	0	25	1	0	0	0	0	0	0	0	0
1	0	0	50	40	190	0	1	4,83	0,93	16,67	5,56	1	1	1	1	0	216	1	0	0	0	0	0	0	0	0
1	0	0	50	40	190	0	1	4,22	0,86	5,56	5,56	1	1	1	1	0	231	1	0	0	1	0	0	1	0	0
1	0	0	50	40	190	0	1	5,17	2,14	16,67	5,56	1	1	1	1	0	383	1	0	0	0	0	0	0	0	0
1	0	0	50	40	190	0	1	4,11	0,79	5,56	5,56	1	1	1	1	0	560	1	0	0	1	0	0	1	0	0
1	0	0	50	40	190	0	1	5,54	1,14	22,22	5,56	1	1	1	1	0	574	1	0	0	0	0	0	0	0	0

Fig. 5. Fragment of spreadsheet program with a learning string

3.4. Triple variant analysis of the neural structure

On the grounds of a prepared learning string, three attempts were made to model optimal neural networks, which would point out necessary repairs to the railway switches.

Every time, from Set 424 and for the third variant of 426, the proposed structures program saved 10 with the best parameters. From the 10 structures, one was chosen as being guided by value classifiers, a low mean absolute error and the possibility of comparing the charts' *receiver operating characteristics* (ROC) in terms of calculation efficacy. All structures were MLP-learned using the backpropagation method. The received structures are presented in Figure. 6.

Prepared sensitivity analyses suggest that the indicators of evaluation are kinds of traffic (F-freight, P-passenger, M-manoeuvre) and time influences on results. The range of input data, which were prioritized, depended on neural structures. A common feature for all variants, in terms of importance, was the indicator of expanse differences $E\ [\%]$. Meanwhile, the lowest influential rate was an indicator of synthesis, which maintains the accuracy of the railway switch J_r, as presented in Table 3.

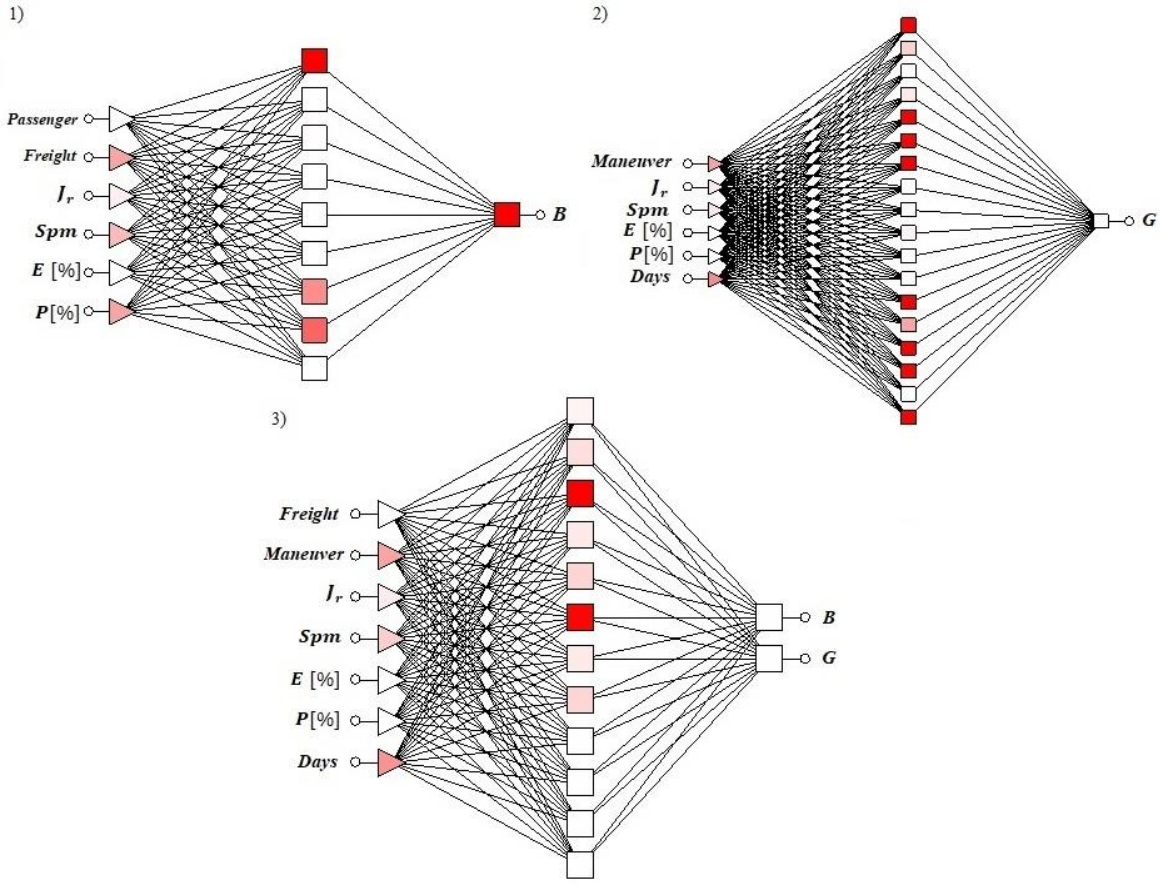

Fig. 6. Achieved neural networks: 1) MLP 6-9-1, 2) MLP 6-18-1, 3) MLP 7-12-2

Table 3

Presentation of input degrees according to variants

Degree	No. of variant	Character of traffic			Indicator				Days
		F.	P.	M.	J_r	Spm	$E[\%]$	$P[\%]$	
	I	6	3	-	5	4	2	1	-
	II	-	-	4	6	1	3	5	2
	III	2	1	7	6	5	3	-	4

The structure MLP 6-9-1 for Variant 1 describes a highly correct coefficient equal to 0.96 and a value area under the ROC curve equal to 0.69. This provides information about classification near to random classification. Sensitivity analysis highlights that there are braking input data comprising freight traffic. The mean absolute error equals 0.38, which is evaluated as a very good rate.

In Variant 2, we chose the structure MLP 6-18-1, which is evaluated with a great rate. The structure is described by the following:

- right classification of the current coefficient equals 1.00
- area under the ROC curve equals 0.99

These values determined the choice structure by which to evaluate the necessity to repair railway switches. The mean absolute error equals 0.24, while the value quotients of differences are positive about the correctness result.

The last proposed result is the structure MLP 7-12-2, as described by the correlation coefficient, which equals -0.04, and the regression coefficient, which equals 1.74. These values undermine MLP 7-12-2. Contrary to previous variants, Variant 3 has two output data. A negative assessment can be connected with reference to these two results.

The summary of results from three variants informs us that the non-zero classification error for Variant 3 equals 0.22. This means that it functions as risk classification data.

4. SUMMATION

As a result of scientific work, we have the neural network MLP 6-18-1 structure. The type of details and numerical amounts in this structure allow for an evaluation of the necessary repair element of railway switches - crossing the nose points of the neural network. The architecture of structures and solutions depends on a learning string.

The article was prepared on the basis of a limited amount of information about objects. It points to the possibility of creating a simple structure without taking into account complicated variables. The solution proposed is aimed at encouraging the creation of a universal network. It should be helpful for management work.

The presented works offer the possibility of utilizing artificial intelligence to diagnose and maintenance railway infrastructures. The results seem to be advantageous and allow for identifying the need to repair any component of infrastructure.

Research on neural networks requires ongoing work, in order to encourage anyone in the field to study the problem at the core of this paper. That said, progress will not be possible without cooperation from an infrastructure manager.

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Received 02.08.2018; accepted in revised form 08.11.2018

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