REDUCTION OF DELAYS IN THE SUPPLY CHAIN BY USING MAINTENANCE DECISION SUPPORTING SYSTEMS FOR RAIL VEHICLE PANTOGRAPH

[1]Małgorzata KUŹNAR, [1]Augustyn LORENC, [2]Natalia GÓRKA

[1]Cracow University of Technology, Institute of Rail Vehicle, Cracow, Poland, EU,
malgorzata.kuznar@mech.pk.edu.pl, alorenc@pk.edu.pl

[2]Cracow University of Economics, Cracow, Poland, EU,
natalia.gorka@poczta.onet.pl

Abstract

The aim of this study was to propose a system that increases the reliability of the supply chain using a rail mode of transport. Such system will reduce delays in a supply chain where a train is use as a mean of transport. In this paper, rail vehicles delays were identified as the problem in the break of the supply chain. Such situation can be caused, among others, by the immobilization of the locomotive on the route due to damage of locomotive pantograph.

The paper presents the scale of the problem related to damages of the pantograph - overhead contact line (OCL) system, and gives the overview of currently existing systems, which are used to diagnose the condition of a pantograph - OCL system. In the paper authors present the existing systems used by railway carriers. The target was to identify the benefits of implemented systems and find the gap and possibilities to improve the diagnostic system to reduce the rail delays and cost of the current collectors' services. For this purpose, there was conducted simulation using Artifitial Neural Network (ANN), which predict the technical condition of a pantograph.

The performed review shows that there is no system, which can support decisions about technical operations and service of a pantograph. Based on the developed method described in this paper, it is possible to create the system, which will support decisions about pantograph sliding strip replacement.

Simulation results shows that system will enable reduction of train delays, which will significantly affect the reliability of the supply chain.

Keywords: Rail delays, variant analysis, pantograph, current collector, rail transport, decision supporting system, delays simulation

1. INTRODUCTION

The reliability of the supply chain, in which the railway is used as a means of transport, depends on the delays along the route. According to reports [1], in the first quarter of 2018, punctual freight trains in Poland were around 38 %. Average delays in domestic traffic amounted to 575 minutes. As many as 46 % of delayed vehicles were above 120 minutes. One of the causes of such delays is pantograph and overhead contact line (OCL) damages. Therefore, it is so important to conduct an appropriate inspection of a pantographs' technical condition.

According to the standards, the measurements of a rail vehicle pantograph are carried out in about a month interval during technical reviews. The assessment of pantograph technical condition, and therefore the decision to replace the pantograph sliding strip, is made only on the basis of the values of measurements obtained during the technical review. During such inspections, the measured values, e.g. the thickness of the sliding strips, pantograph contact force, lifting and lowering time, are written to the measurement card [2,3].

The described method is a standard pantograph diagnostic procedure, where the measurements are usually made manually. In addition, the recording of the measured values is also made manually. However, currently exist more automatic diagnostic systems, which can be helpful in preventing damage to the pantograph.

2. SOLUTION OVERVIEW

Currently existing systems, the purpose of which is to improve the cooperation between pantograph and overhead contact line (OCL), can be divided into three groups: Automatic pantograph measuring stations (stationary), OCL monitoring systems (in real time), Pantograph monitoring systems (in real time).

Automatic pantograph measuring stations (stationary)

In Automatic pantograph measuring stations can distinguish the field measurement station. Such stations are mainly used to detect the contact force of current collectors or damage detection and constitute a control element for railway carriers [4][5]. Automatic measuring stations for current collectors can also be used in the production and maintenance process of rolling stock. They are used to measure parameters like lifting time of the collector to the nominal height, falling time of the collector, average static pressure, the difference between forces when lifting and lowering and holding force in the laid down position. In addition, manual thickness measurements of the sliding strip are made during the technical service [6-8].

Overhead catenary line monitoring systems (in real time)

Such systems are permanently mounted on the roof of a rail vehicle or on a power collector. That system is used to determine the geometry of the traction network [9]. In Europe is used overhead line diagnostic system. It consists of measuring wagons, in which the measurements are based on sensors placed near the insulators on the roof of the locomotive or impact sensors mounted on the current collector [10].

Real-time current collector monitoring systems

This type of systems requires additional tools mounted on the roof of the rail vehicle. They can be used only to monitor the parameters of the current collector, or to detect damages of the current collector - OCL system. It is possible due to additional software which enables such analysis. Such systems operate based on image analysis - it is necessary to use cameras on the roof of a rail vehicle [11,12].

There are also systems that, due to mounted sensors, enable defect detection (e.g. the Australian PCDS system - Pantograph Collision Detection System developed by ART company).

Mentioned systems are designed to the same target group. Their operation is based on the measurements of current collectors and catenary thanks to the additional tools or equipment. However, the decision to replace the sliding strips is made during technical service and the existing systems can only provide employees with information about the current parameters of the pantograph, but they do not support making the decision about strips replacement. The review of available on the market solutions shows that there is no system, which would support the decision about the recommended maintenance during the review.

Thanks to the information obtained from such systems, it will be possible to predict the wear of the sliding strips more accurately, so information about the recommended maintenance activity will be more precise. The mentioned systems may, provide measurement data to the authors' system, the concept of which is presented in the further part of the paper.

In Poland, the diagnostic of current collectors is based on the data obtained from automatic measuring stations or from measurements made manually by employees of the rolling stock maintenance and service company. Catenary diagnostics, on the other hand, is carried out thanks to measurements obtained from the overhead line diagnostic system. Due to costly damage to the pantograph - OCL system, carriers are increasingly installing HD cameras on the roofs of vehicles to record damage. There is, therefore, a need to identify the causes of damage and to develop methods that will help decision support during technical service [13-15]. **Table 1** summarises currently existing systems divided into mentioned types.

Table 1 List of companies offering products for current collector diagnostics

No	The name of the system group	Products available on the market	Tools
1	Stationary field measuring stations Figure 1a	SelectraVision PantoCheck; SelectraVision DIAGNOSTIC PORTAL; MER MEC S.p.A. Morph & Wear module; ART Pantograph Condition Monitoring System (PCMS); System MOP - a technical monitoring station for current collectors	- HD cameras, - vibration sensor, - shock sensor, - acceleration sensor, - laser distance sensors
	Stationary automatic pantograph measuring stations Figure 1b	ASCO Rail Sp. z o.o.;	- Pantograph pressure to the catenary sensor, - laser distance sensors
2	Real-time OCL monitoring systems Figure 2	System DST; System pomiarowy PanDiag; SelectraVision: CAT-V/VW, CAT-T, traCkAT, CAT-L, CAT-LW; MER MEC S.p.A.: Voltage and Drained Current, Geometry & Contact Wire Wear, Contact Wire Thermal Scanning, Longitudinal Defects Detection System	- HD cameras, - vibration sensor, - shock sensor, - acceleration sensor, - laser distance sensors
3	Real-time current collector monitoring systems Figure 3	ART Pantograph Collision Detection System; NewRail& Northern Power Transmission Research Laboratories; MER MEC S.p.A.: Pantograph / Catenary Interaction Measuring System, Electric Arcs Detection System (EADS)	- HD cameras, - vibration sensor, - shock sensor, - acceleration sensor, - laser distance sensors

3. CONCEPT OF THE DIAGNOSTIC SYSTEM FOR CURRENT COLLECTOR

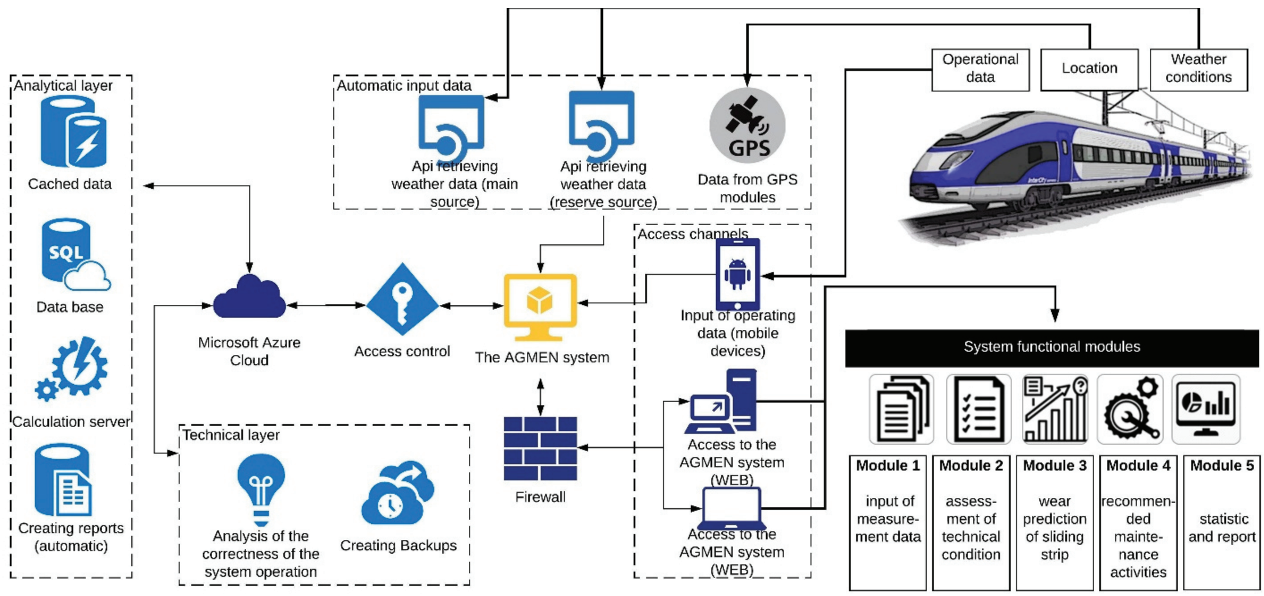

Figure 1 Functional scheme of the AGMEN system

As the review of the available solutions showed, the pantograph systems do not support the decision regarding replacement of the pantograph. Such a decision is significant not only because of the operational aspect but also because of ensuring a reliable supply chain. **Figure 1** shows the scheme of the system, which can support the diagnostic decision. Such a system should operate based on information available during the operation of the pantograph (during use, involving presented in the overview methods, and during maintenance where information about technical conditions are collected during technical review). It means that such a system is the combination of standard diagnostic procedure and automatic systems used to monitor the pantographs parameters. Based on such data, using the methods of artificial intelligence, a suggested operational decision will be generated.

By now, the system is based only on historical data provided during a standard diagnostic procedure. The conducted simulation showed, that an Artificial Neural Network (ANN) which gives the best results consist of 5 hidden layers (with the same number of neurons in each layer as a number of input data), and an output layer with 3 neurons. As an input data was used data such as: cycle number (one cycle from the nominal value of the sliding strip up to its replacement); inspection number in the cycle; days since the exchange; information whether the front or rear pantograph was examined; quarter of the year, pantograph type; the difference between the thickness of the sliding strips between inspections; previous technical condition; information about the cause of a previous replacement. As an output data was used the technical condition - the three-state assessment of the pantograph's ability to use. It means that there was not used a typical assessment of technical condition (able to use, and not able to use). There was used an additional technical condition - conditional ability to use - which gives the information if the frequency of technical review should be increased. Therefore, there was used 3 technical states all follow:

1) able to further use;
2) conditional able to use;
3) not able to further use.

Due to the application of three technical states, the output layer has 3 neurons. Such ANN structure was used to predict the technical condition of a pantograph.

4. RAILWAY TRANSPORT - SIMULATION ANALYSIS

In order to assess the benefits of the created system based on ANN, a simulation was conducted.

Based on historical data about the technical condition of pantograph about 830 cases were created. Each case concerned the monthly measurement of pantograph technical condition. The input data mainly contained data from the standard diagnostic procedure. Based on standard diagnostic data, algorithms to assess the technical condition of a pantograph were also prepared. Next, ANN structure was created and the simulation was conducted. The aim of the simulation was to determine the appropriate technical condition of a pantograph, which is necessary to avoid unwanted damages of OCL - pantograph system, which leads to delays in a supply chain.

The results from the learning process of ANN (training, validation and testing) are shown in **Figure 2**. The smallest squared error for the learning process was 0.0743, and was achieved at epoch 6. The regression function also applies to each stage of ANN learning process. It means that the regression function is created for the training, validation and testing process. On this basis, it can infer about the quality of the approximation of the objective function.

Results of the ANN simulation are presented in **Table 2** and **Table 3**. **Table 2** shows the results, which gives ANN during training process while **Table 3** shows the results from the simulation. During training, only 13.21 % of all cases were not predicted, while during simulation 23.27 % of all technical condition was not predicted. The first state was predicted correctly in about 87.5 % cases (in both, training and simulation), the second state was predicted correctly in 63.8 % during training, and as many as 97.6 % of the third state was predicted correctly.

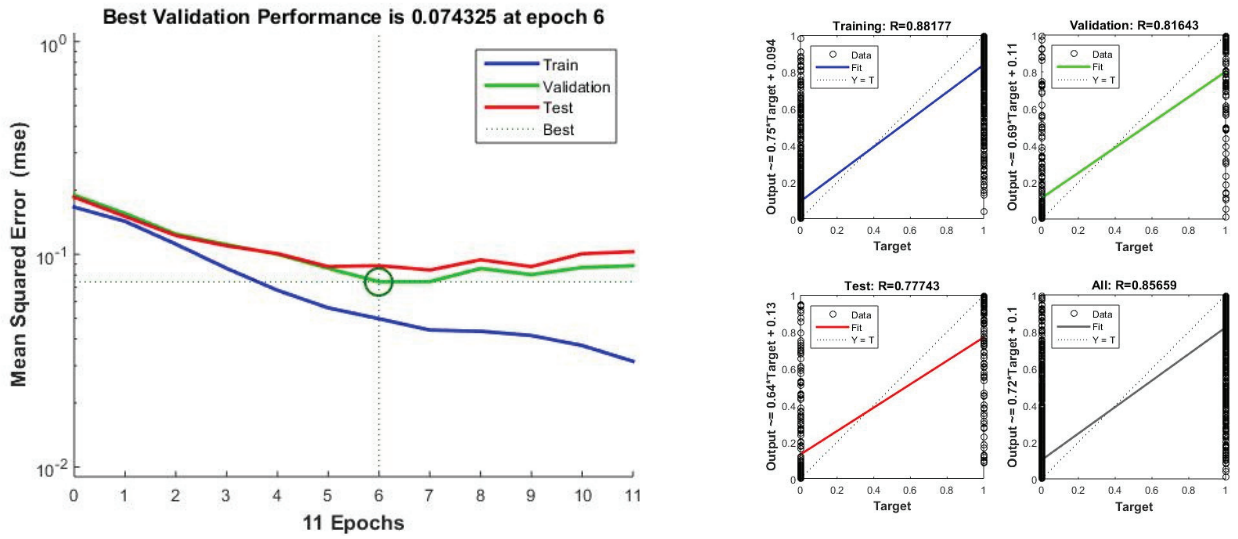

Figure 2 Best mean square error and the regrasion function of created ANN

When analyzing the test results, particular attention should be paid to the number of predicted states 2 during simulation. The result of 50 % predicted cases with the second technical condition means that it is possible to reduce unwanted damages of a sliding strip and OCL - pantograph system in 50 % cases. Such reduction can be possible because of an increased number of technical reviews after diagnosed the second technical condition. It means that the technical review, which was made once a month, will be made every 3 days. During more frequent revives, the sliding strip damage, leading to damages that are more expensive, could be noticed.

Table 2 Results of analysis during ANN training

The number of predicted technical condition	Technical condition			
	All	1	2	3
Correctly predicted technical conditions [%]	86.68	87.44	63.75	97.60
Incorrectly predicted technical conditions [%]	13.32	12.56	36.25	2.40
Predicted cases [%]	86.79	94.43	40.80	97.60
Unpredicted cases [%]	13.21	5.57	59.20	2.40

Table 3 Results of analysis during ANN simulation

The number of predicted technical condition	Technical condition			
	All	1	2	3
Correctly predicted technical conditions [%]	76.73	87.57	41.18	76.36
Incorrectly predicted technical conditions [%]	23.27	12.43	58.82	23.64
Predicted cases [%]	76.73	77.49	50.00	100.00
Unpredicted cases [%]	23.27	22.51	50.00	0.00

5. CONCLUSIONS

Cases of damage to the overhead contact line and pantograph on the route can cause significant financial consequences associated with: the exclusion the rail vehicles from movement, costs of expertise, and costs of repairing damage to vehicles and the traction network.

The development of the described system will reduce these costs and will positively affect the safety of rail vehicle traffic. The task of the proposed system is to support decision making related to the operation of the current collector and is an addition to the existing maintenance system. Analyses were made on the basis of data obtained during the standard technical review, so with the implementation of the system, there will be no significant change in the organization of technical inspections of the current collector. Such a system is also a pro-ecological solution due to the smaller number of waste (replaced sliding strips), and due to the reduced number of damage to the pantograph - OCL system. In addition, the number of downtimes and delays of electric rail vehicles will be reduced (which increases energy consumption for heating/ventilation, lighting, air conditioning). Thanks to the system, it will be possible to forecast damage of the sliding strip and detect their improper wear, which may cause damage to the collector and the catenary.

At this moment results show that it is possible to predict 50 % cases of the second technical condition, so 50 % of unwanted damages can be prevented. Because simulation was conducted only on data provided during the standard technical review, the system does not require mounting additional sensors on the roof of the vehicle, as in the case of real-time monitoring systems. In further research, it is planned to mount additional sensors and take into account the rout of the rail vehicle and the atmospheric conditions.

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