MODELING CARGO THEFT PROBABILITY IN RAIL TRANSPORT USING ARIFICIAL NEURAL NETWORK

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Abstract

The paper focuses on the safety of railway transport and the possibility of a risk appearance in a supply chain using rail vehicles as a mode of transport. The rail transport plays a significant role in the international market for goods forwarding and transportation. In this paper, authors present own model used to predict the probability of cargo theft. In the mining and metallurgical industry, adequate protection and securing the transported cargo is extremely important. In the Silesia - industrial region of Poland, every year there are over one thousand cases of theft. The cost of such incidents is higher than one million euro per year. The railway security guards use a low-cost method to make cargo harder to steal or use the newest technology like drone monitoring system to help find the theft cargo and catch the thieves.

In this paper, authors present the method which uses factors, such as the type of cargo, type of wagons, distance, delays, train speed and others, to predict the possibilities of theft during each transport case. This method can be used to develop a support system to plan the area of drone monitoring and security control of the rail line infrastructure. The presented method uses Artificial Neural Networks (ANN) as the core of the support system. The developed model can be also used to support decisions about additional cargo insurance for high risk of theft cases. This method is based on the latest data of disruptions in the supply chain, which allow appropriate response to supply chain disruptions in order to minimize losses and costs associated with losses.

Keywords: Rail transport securing, supply chain disruption, theft of the cargo, drone monitoring, security support system, artificial neural network

1. INTRODUCTION

Thefts from wagons expose the railway to huge losses. Therefore, appropriate cargo securing is of key importance for the entire transport chain [1], [2], [3]. The carrier is responsible for the load from the moment of acceptance to transport to the delivery of the recipient. He must pay for any damage; it is often compensated for as part of the transport fee [4]. Stolen loads cause losses exceeding even 1,4 million Euro annually [5].

The main product stolen in rail transport in Poland is coal and fuels. In the United Kingdom the one of the stolen cargo is metal. The government is increasing regulation of scrap-metal dealers to prevent metal theft to control urban areas, industry, other crime and road accessibility [6]. In the Unated States of the America the government is hardening the rail network against all forms of attack [7]. The regulations and possibility of securing cargo is describer inter alia by [8], [9], [10], but still there is lack of papers and systems to predict the theft in transport. The similar method to predict theft risk in road transport was described in [11]. Rail carriers not insure cargoes due to the gigantic costs of such insurance and the volume of transported cargoes per year.

2. IMPORTANCE OF THE PROBLEM

According to information provided by PKP Cargo, the largest number of thefts is stolen on the territory of Silesia - about 65 ÷ 70% of the theft of all cargoes in Poland. In 2014, PKP Cargo recorded 1637 incidents related to theft on the tracks. The value of the stolen goods was estimated at 1.5 million Euro. Silesia for rail transport in

Poland is of key importance because it is from here that 60 percent of domestic and 70 percent of export transportations are sent [12].

The main cities around which there is the theft of railway cargo in Poland: Rybnik, Jaworzno, Tarnowskie Góry, Kraków, Wrocław, Skarżyńsko-Kamienna, Poznań, and Gdynia.

Thieves steal loads from wagons not only during longer stops of trains, e.g. on railway sidings. Often a short stop before the semaphore is enough, and even a slower ride. They try to open the wagon then, and they collect the stolen cargo after the departure of the train. Protection of loads is carried out by the Railway Protection Guard (SOK).

To make it more difficult to steal, it's used painting the load with lime, wiring of wagons, and monitoring of wagons using drone.

As a result of the surveillance infrastructure using drones number of theft cases decreased by 55%. After 10 months of using drones, thefts in 2015 fell to 1044 incidents, and the losses were estimated at 0.75 million Euro[12]. PKP Cargo has approximately 44% share in the rail freight market in Poland [13]. According to the rail transport safety report of the Supreme Audit Office carried out in 2018, the number of crimes and incidents decreased by approximately 33% [14].

Attacks on the train due to the desire to steal a load are planned attacks - thieves know when and what train will pass with valuable cargo. Therefore, the action is usually well planned. There are frequent thefts as a result of vehicle stoppage (setting the blockade on the track and during planned stopovers). In addition, thefts occur also while the train is running - in this case, the load is squeezed from the wagons onto the track. For example, in 2014, PKP Cargo S.A. recorded the theft of over 8000 tons of cargo [15] which in relation to the transported 109.59 million tons of cargo [16] accounted for 0.75% of all transported loads.

In the Poland the theft occurs most often for: hard coal, lignite, oil and natural gas; briquettes, refined petroleum products; and metals, ready made metal products. Analyzing quarterly fluctuations for particular product groups on an annual basis, it was noted that they do not exceed 2.95%, therefore in the case of rail transport, the seasonality phenomenon can be considered as marginal.

Delays in deliveries are important for the efficient operation of the transport chain. Unfortunately, rail freight transport can not boast a high punctuality rate. According to Railway Transport Office (UTK) data, in 2018 the punctuality rate for freight deliveries was only 38% in domestic traffic and 28% in international traffic, which with an average delay time of 586 minutes in domestic traffic and 438 minutes in international traffic is a major rail problem. In addition, due to the low speed of trains and numerous stops, there is an increased risk of cargo theft.

3. METHODOLOGY

To be able to predict when and where the theft of loads in rail transport may occur, an analytical model using artificial neural networks was proposed. The main factors affecting the occurrence of thefts were also identified. The input data has been prepared on the basis of statistical data presented in the UTK and PKP Cargo S.A. reports. A developed model allowed to generate 10,000 transport cases. The generated data showed 0.73% cases of the theft, which in comparison to 0.75% of real cases of theft is a confirmation of the model's good representation of reality. The input data for the developed model was prepared in the following way:

P1 - Type of cargo. According to data [3], the thefts of coal concerned 65 ÷ 70% of all cases, therefore for generating data, the normal distribution was used with the interval 1 ÷ 5:
Aggregates - marked as 1; Metals - marked as 2; Coal - marked as 3; Fuels - marked as 4; Other goods - marked as 5

P2 - Type of wagons (P2), based on data with the largest market share in 2017 [11], [17]:
Wagons of the normal type E - marked as 1; wagons of the special type F - marked as 2; number of used wagons type E and F: 58657 pcs

tank cars type Z - marked as 3; number of wagons operated: 7142 pieces
wagons with sliding roof type T - marked as 4, wagons with sliding walls S - marked as 5; number of used wagons type T and S, approx .: 3253 pcs

P3 - Train speed. According to UTK data, the average speed of freight trains in 2017 was 25.1 km / h [18], so for generating data, the normal distribution was used with the interval 20 ÷ 30 km / h

Method of securing the wagons (P4):
No protection - marked as 0; Indication of the load with lime - marked as 1; Wagon wiring - marked as 2; Increased SOK control - marked as 3; Drones monitoring - marked as 4.

Travel time at night (P5), assumed as a percentage of the total route

Region (P6), was established in accordance with the administrative division of Poland

Distance (P7), base on the UTK data [17] the average distance of freight transport was 228.5 km in 2017, therefore a normal distribution in the interval was used to generate data. 100÷600 km

Number of stops - planned (P8), the generated data was assumed in the range 1÷10,

Number of stops and delays (P9), train delays were based on UTK report [18], the following delay intervals have been assumed:

up to 4 min. 59 sec - marked as 1; about 5 minutes - 59 min 59 sec - marked as 2; about 60 minutes - 119 minutes 59 sec - marked as 3; over 120 minutes - marked as 4; arrival in accordance with the plan - marked as 5.

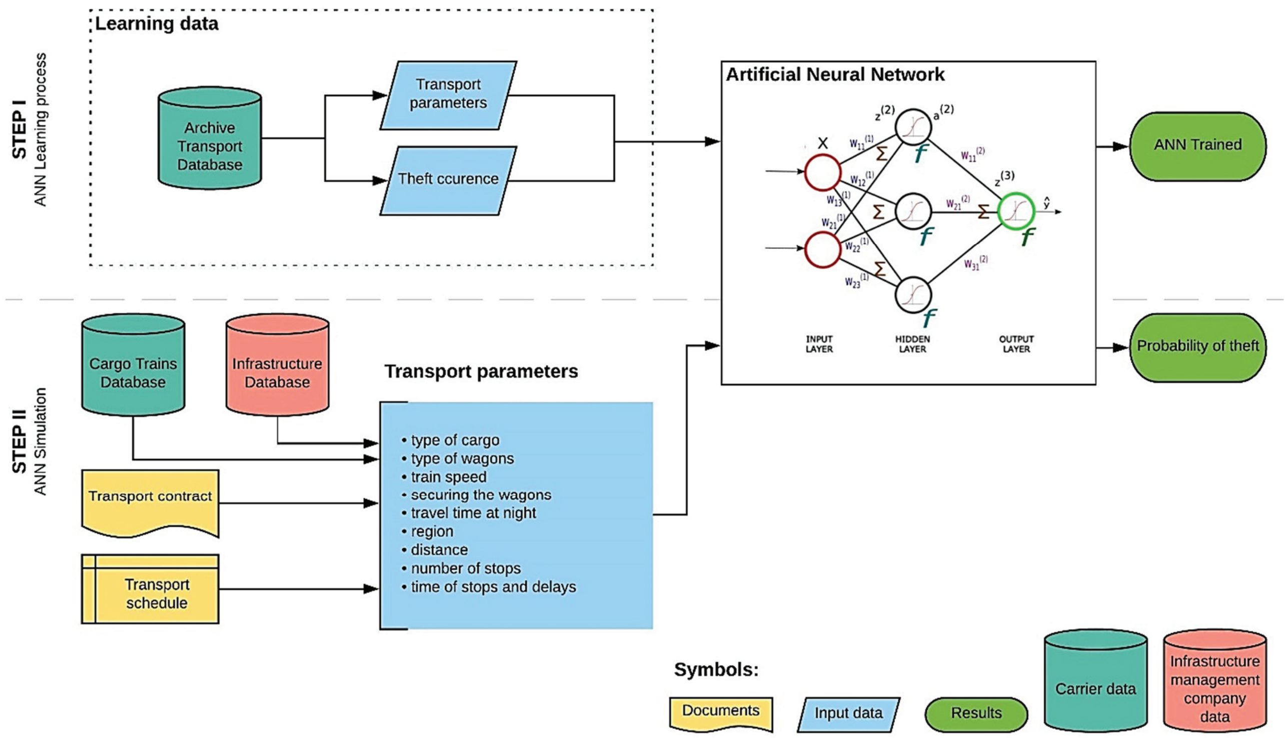

Figure 1 The method of theft probability prediction

Authors decide to develop a new method to predict theft cases in rail transport as part of supply chain. One of the good tools which can be used for this cases is Artificial Neural Network (ANN). In this chapter, authors show their method to predict disruption in road transport by using Matlab ANN Toolbox. This method consists of two steps: ANN learning, Simulation the probability of theft. **Figure 1** shows developed method for estimating the probability of theft risk appearance and its potential bases.

In the first step it was necessary to create a database containing such data as transport parameters and cases of theft occurrence. Transport parameters may include, inter alia, type of cargo, type of wagons, train speed, method of securing the wagons, travel time at night, region distance, number of planned stops and the time of stops and delays. On the basis of this information the probability of theft of transported cargo was determined. Every case of transport was represented as the vector. The example data used in the training is presented in the **Table 1**. The value in each column was described in the beginning of the Methodology chapter.

Table 1 Example of data set used for training ANN

case	input									target
	type of cargo	type of wagons	train speed	method of securing the wagon	travel time at night [%]	region	distance	number of stops	time of stops and delays	
	P1	P2	P3	P4	P5	P6	P7	P8	P9	
1.	3	1	28	1	14	4	205	2	3	0
2.	3	1	18	3	58	1	100	10	4	1

In a simulation a feed forward network was used. The selection of artificial neural network structure was based on the method of subsequent approximations. Created artificial neural network consist of one hidden layer containing 9 neurons, and one output layer. The Levenberg-Marquardt backpropagation method was used as the learning algorithm. As an activation function the tangensoidal function was used. The biggest neural network examined in the research gives the worse results. The network structure selection was made on the basis of the mean square error (mse) which was about 0,00204 (**Figure 2**). The chosen ANN architecture enable to finish teaching at third epoch. For prepared teaching data he theft cases were marked by target „1“, for other cases the „0“ target value was assumed. Because of that, the teaching chart for validation and test show poor correlation. That could suggest that the model is not working very well. But the simulation shows that ANN predicts all risky cases.

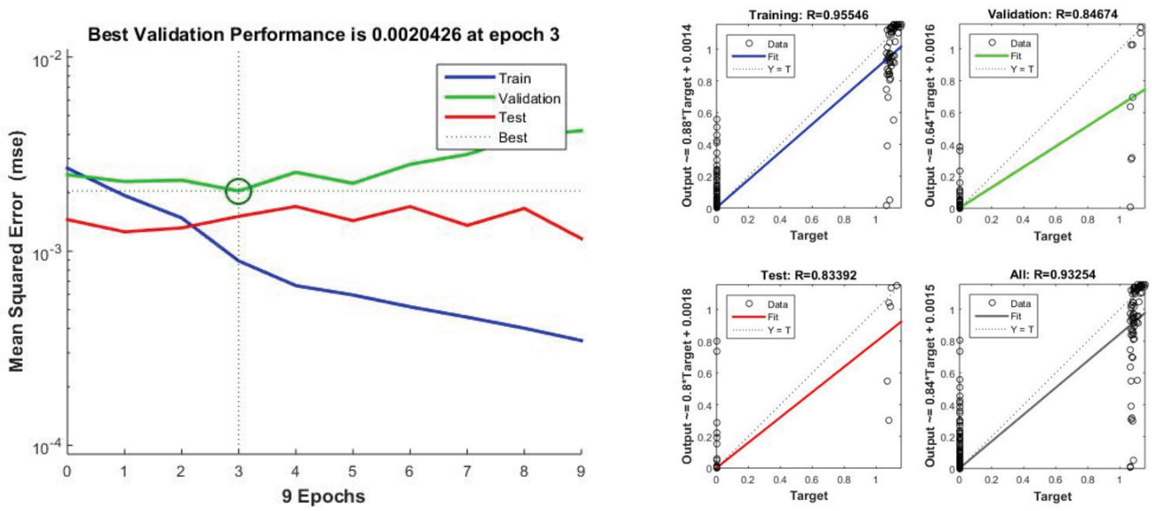

Figure 2 The MSE error during training artificial neural network and the regression plot for training, validation and testing of ANN

4. RESULTS

The methodology presented in the previous chapter was used to predict the theft probability for each rail transport of the cargo. The simulation uses 10 000 sample transport characterized by described parameters

(P1÷P9). In that sample the 75 cases of theft occurred (**Figure 3**). The ANN used for predict the probability detect all cases of theft. The used architecture of the ANN, and the teaching data set results the higher than expected theft probability factor. In analyzed cases, the probability for steel cargo was between 1,06 and 1,23. The network during simulation type that cases as extremely risky, but for that cases, the real data confirm that theft for the occurred. The ANN does not identify wrong cases. In the analyzed cases the transported cargo always was coal steal from the standard wagon type E. To predict the theft of other cargo type, the input data set must be bigger and represent more cases of theft other cargos. Lack of that information published in the reports cause no possibility of simulate that cases.

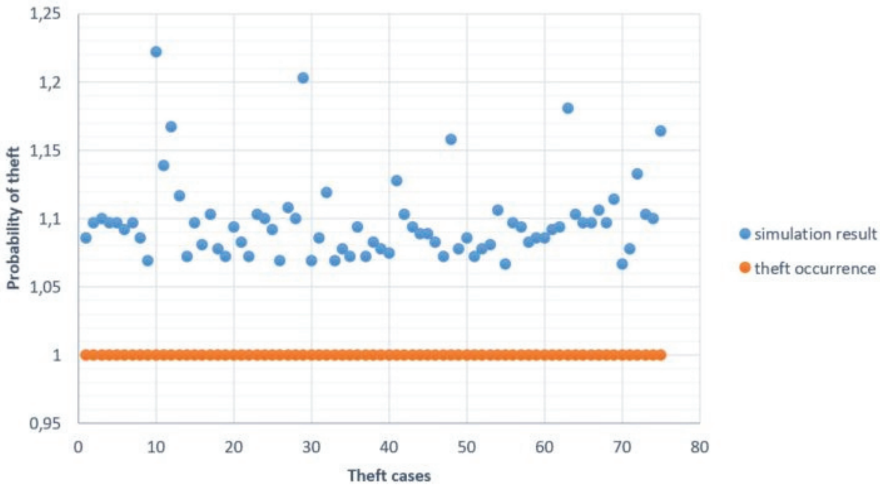

Figure 3 Probability of theft predicted by ANN regards to the cases of theft occurrence

The theft cargo cases were detected for six region (P6), in that region the biggest number of that incidents occurres in real data (1 - Silesian, 2 - Lower Silesian, 3 - Lesser Poland, 4 - Greater Poland, 5 - Pomeranian, 6 - Opole). The cases detected for each region is presented in the **Figure 4**.

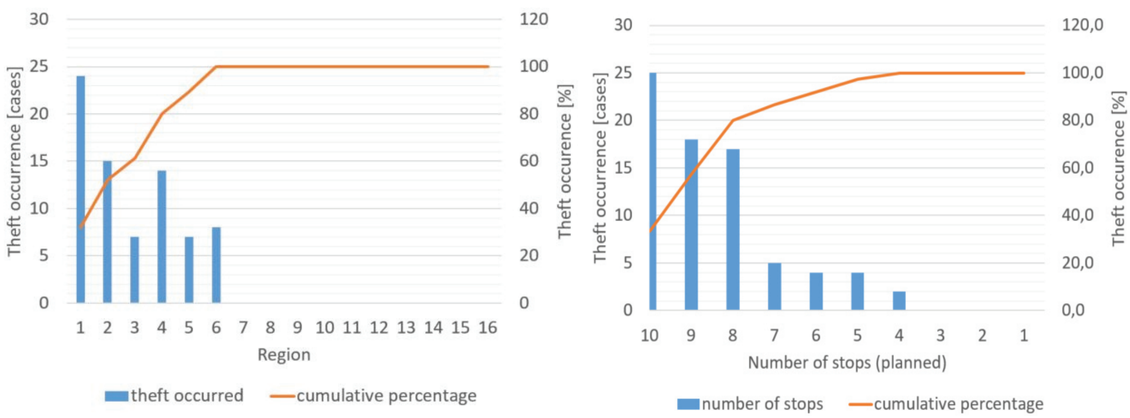

Figure 4 Predicted theft cases by the regions, and by the number of planned stops

The average transport speed was about 21 km/h, while the minimum was 15 km/h and maximum 29 km/h. The most cases were accurred in the night - about 76% part of the route was during the night. The average distance of the transport was 276.4 km. The 25 theft were done in the planned stops, and the 80% theft cases occourrs for eight or more stops. The 45 theft cases were done in the unplanned stops longer than 120 minutes, 27 cases for stops between 60÷120 minutes, and 3 cases for stops between 5÷60 minutes.

5. CONCLUSION

Stealing the cargo never is accidental. The thieves are planned the theft of a cargo from the rail wagons. There are many factors considered before the theft of the cargo. Inter alia thieves are stealing the coal and similar cargo because it is easy to sell it on the black market. Also it is easy to drop that cargo down from stopped wagons and take it directly to the pickup cars, or dump it from moving wagon on the trackway and later load it to the car. The thieves planned their action in the nights and in the unsecured area to reduce detection by railway security guard. There is no chance to monitor all wagons and infrastructure during transport, so the railway security guard do it randomly. Presented method can be used to develop system for predicting the high risk place, transport and the time when the theft could occur. Implementation of such system will be useful to schedule the patrols of the infrastructure.

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