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The application of neural networks for the life-cycle analysis of road and rail rolling stock during the operational phase

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Abstract

The aim of this article is to assess the possibility of using neural networks to analyse the life cycle of rolling stock in the operational phase by selecting the number of rolling stock sets and rail using the example of public transport in the Szczecin agglomeration. The research was conducted in September 2019 and June 2020. It included the number of tram and bus rolling stock sets on individual public transport lines based on data from the Central Public Transport Management System in the Szczecin agglomeration. The research, which was based on comparative analyses of individual types of rolling stock and their technical and economic data, took into account the life-cycle assessment criteria associated with the operation of vehicles in relation to the number of rolling stock sets. The use of neural networks on the example of the city of Szczecin for the purpose of life-cycle analysis, can make a significant contribution to creating a decision model for the improvement of public transport in cities with various types of public transport vehicles.

Keywords: neural networks, life cycle, road rolling stock, rail rolling stock, operation

1. Introduction

The aim of the article is to assess the possibility of using neural networks to analyse the life cycle of rolling stock with regard to its period of operation by selecting the number of rolling stock and rail on the example of public transport in the Szczecin agglomeration. The correct selection of the number of rolling stock sets has an impact on the improvement of road traffic flow in a specific place and time. The selection of the optimal number of rolling stock sets affects a number of operational factors. The rational use of the rolling stock increases its durability and reliability and reduces both energy consumption and the emission of harmful substances. Greater durability and reliability reduce operating costs. Lower energy consumption and reduced emission of harmful substances has a positive effect on the environment. Neural networks can be used wherever there are tasks related to prediction, classification or control. As a result of the use of neural networks for the optimal use of rolling stock in public transport, the time and cost of research can be reduced. In the presented analysis, rolling stock consists of cars (buses), and the rail rolling stock (trams). Life-cycle assessment (LCA) concerns the assessment of potential environmental hazards. This model consists of three areas:

1. production of the vehicle,
2. operation of the vehicle,
3. scrapping of the vehicle.

The area of vehicle operation will be analysed.

The following **evaluation criteria** were used:

Material and energy criterion – including durability, reliability, energy consumption and efficiency of vehicles.

Economic criterion – concerning investment costs related to durability and purchase price of vehicles.

Environmental criterion – relating to the emission of harmful substances during the operation of vehicles.

The oldest running trams in Szczecin were produced in the 1980s. One of the oldest style of buses operating in Szczecin are vehicles produced in 2002–2004. There are also electric trams in Szczecin. Most of the buses operating in Szczecin are combustion vehicles. In 2014, trams of type 120 NaS consisting of five sections and were purchased for Szczecin for PLN 458.4 million and were manufactured in Pesa Bydgoszcz establishments. The tramway is characterized by a compressive strength of 400 kN and crash resistance in accordance with the EN-15227 standard. The front of the vehicle is equipped with absorbers for absorbing the energy of collisions with obstacles and other vehicles, which ensures the safety of passengers and the driver whilst at the same time significantly reducing the costs and time of possible repairs. Wagon bogies are a proven and appreciated solution with a classic wheelset in which the wheels are connected with an axle. The design of these elements is universal and enables the replacement of drive, which prolongs the lifetime of the rims and the time between their reprofiling. The bogie operation is simple, intuitive and cheap. A modern drive system provides the possibility of energy recovery. The tram can be additionally equipped with energy storage, which contributes to lower operating costs. Thanks to the applied drive, it is possible to move the vehicle in conditions of a lack of power supply. The use of energy stored in batteries allows the tram to cover a short section of the route without a power supply from the catenary. The cost of purchasing one new 12-meter diesel-powered bus is approximately PLN 850 thousand, and an articulated bus is PLN 1.4 million. In 2010, the operation of the Solaris Urbino 18 articulated buses commenced in Szczecin. The buses are equipped with engines with a power of 251 kW. They have a suspension with the function of levelling and kneeling. The skeleton structure is made of corrosion-resistant steel. Newer buses with conventional drives are equipped with engines that meet the restrictive Euro 6 emission standard. Table 1 presents the criteria for evaluating the bus fleet in comparison to the tram fleet.

Table 1. Evaluation criteria of the bus fleet

Bus fleet	
durability, energy consumption and efficiency of vehicles	smaller compared to the tram rolling stock
investment expenditures related to the durability and purchase price of the vehicles	smaller compared to the tram rolling stock
emissions of harmful substances related to the operation of vehicles	larger compared to the tram rolling stock

Table 2 presents the criteria for evaluating the tram rolling stock in comparison to the bus rolling stock.

Table 2. Evaluation criteria of the tram rolling stock

Tram fleet	
durability, energy consumption and efficiency of vehicles	larger compared to the bus fleet
investment expenditures related to the durability and purchase price of the vehicles	larger compared to the bus fleet
emissions of harmful substances related to the operation of vehicles	smaller compared to the bus fleet

The use of the LCA cycle for vehicles is presented in several publications (Arena, Azzone, & Conte, 2013; Danilecki, Mrozik, & Smurawski 2017; Del Pero, Delogu, & Pierini, 2017; Mrozik, Eliasz, & Terelak-Tymczyna, 2013; Raugei, & Winfield, 2019). Public transport problems have also been described (Buehler, & Pucher, 2011; Holmgren, 2007; Paulley et al., 2006; Pucher, & Buehler, 2009; Thompson, & Schofield, 2007; Kiciński, & Solecka, 2018; Dudek, Richter, & Solecka, 2018; Birr, 2018). The use of the genetic algorithm in public transport is covered in other work (Basu, Raja, Gracious, & Vanajakshi, 2020).

Issues related to the buses have been published (Niewczas, Rymarz, & Debicka, 2019). The possibilities of using composite materials in the construction of bus frames are described in another publication (Pravilonis, & Sokolovskij, 2020). Operating measures of vehicle quality applied to the evaluation of transport services using artificial neural networks have also been reported (Świderski, Jóźwiak, & Jachimowski, 2018). The issues related to rail vehicles are described in other publications (Konowrocki, & Chojnacki, 2020; Selech, & Andrzejczak, 2020). The choice of the number of rolling stock affects many factors concerning the life cycle in the operational phase.

2. Methodology and analysis of research

The research was conducted in September 2019 and June 2020. This included the number of tram and bus rolling stock sets on individual public transport lines based on the data of the Central Public Transport Management System in the Szczecin agglomeration. In September 2019, the Szczecin agglomeration had twelve tram lines, fifty-three regular bus lines, sixteen night bus lines and seven express bus lines. Public bus transport connects Szczecin with the neighbouring communes of Police, Dobra and Kołbaskowo. In 2020, the number of fast bus lines was reduced. Moreover, numerous repairs and modernisations of streets and intersections were performed. Some tram and bus lines were suspended or had their route altered. Table 3 shows the selected values of the number of sets, the first and second coefficients of the rolling stock selection and the remaining value of each coefficient in September 2019.

Table 3. Selected values of individual coefficients in 2019

No.	Type of rolling stock	Line	Number of sets	The first coefficient of rolling stock selection	Material and energy criterion coefficient	Economic criterion coefficient	Environmental criterion coefficient	The second coefficient of rolling stock selection
1	tram	1	7	2	2	3	1	0
2		2	7	2	2	3	1	0
3		3	7	2	2	3	1	0
4		4	3	1	2	3	1	0
5		5	7	2	2	3	1	0
6		6	8	2	2	3	1	0
12		12	12	3	2	3	1	1
13	bus	51	5	1	1	1	2	0
21		60	6	2	1	1	2	0
22		61	10	2	1	1	2	1
36		75	12	3	1	1	2	1
42		81	5	1	1	1	2	0
55		101	3	1	1	1	2	0
60		107	15	3	1	1	2	1
67		123	1	1	1	1	2	0
69		A	5	1	1	1	2	0
70		B	7	2	1	1	2	0
71		C	2	1	1	1	2	0
72		F	3	1	1	1	2	0
73		G	2	1	1	1	2	0
74		H	2	1	1	1	2	0
75		521	1	1	1	1	2	0
76		522	2	1	1	1	2	0
90		536	1	1	1	1	2	0

3. Cluster analysis model

The following types of coefficients were determined: the rolling stock selection coefficient; the material and energy criterion coefficient; the economic criterion coefficient; the environmental criterion coefficient. The lowest value of the coefficients is marked with 1, and the highest with 5. Table 4 presents the value of the rolling stock coefficient for each numerical range.

Table 4. Value of the rolling stock selection coefficient

The range of the number of trains	Coefficient
1–5	1
6–10	2
11–15	3
16–20	4
21–25	5

In order to optimise the rolling stock selection coefficient as well as the material and energy, economic and environmental criteria, and neural networks with the use of the cluster analysis model (Kohonen networks) in the Statistica program have been applied. The following signals were identified:

- quantitative input variables: number of sets;
- qualitative input variables: rolling stock selection coefficient; material and energy criterion coefficient; economic criterion coefficient; environmental criterion coefficient.

Table 5 shows selected values of the prediction sheet.

Table 5. Selected values of the prediction sheet

No. – case	Activations
1	0.253531
2	0.253531
3	0.253531
4	1.245107
8	0.253531
12	1.243732
16	0.077296
26	0.065561
40	0.032440
60	0.017574
80	0.038988
90	0.038988

Figure 1 presents the activation histogram.

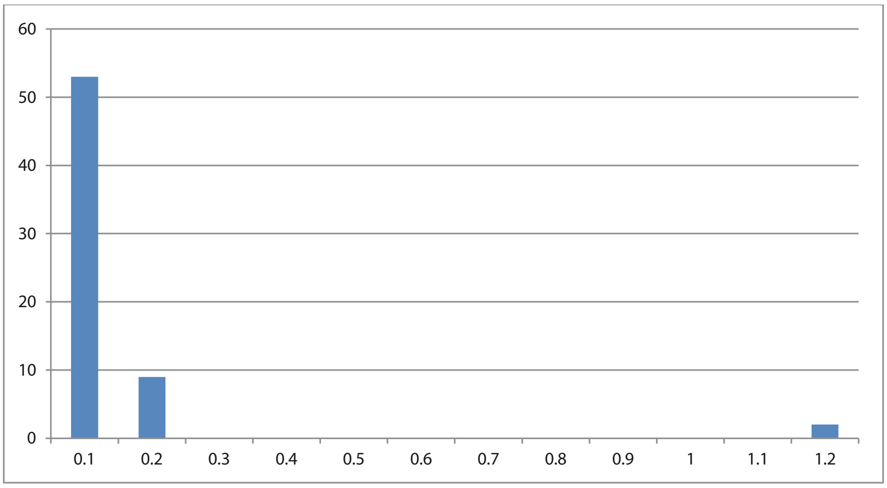

Fig. 1. Activation histogram (own studies)

Table 6 shows the list of errors in the cluster analysis model.

Table 6. List of errors in the cluster analysis model

Error (training)	Error (testing)	Error (validation)
0.060717	0.002260	0.014786

The cluster analysis model that uses Kohonen networks applied in neural networks was used for the studies conducted in 2019 and 2020; this included the described criteria that affect the life cycle. The Kohonen network is taught without a teacher and appears entirely in cases involving only input variables. As a result of the analysis with neural networks, the optimal activation value is close to number 1, which means the probability of this event is close to certain. In studies conducted in September 2019, the optimal activation value was 3 and twelve rolling stock sets. In other cases, the activation value is not optimal because it is close to 0. In studies conducted in June 2020, the optimal activation value was twelve rolling stock sets. In other cases, the activation value is not optimal because it is close to 0. In the studies in 2019 and 2020, due to a slight variation in the number of bus rolling stock sets, the activation value was not optimal.

4. Regression model

The following types of coefficients have been defined: material and energy criterion coefficient; economic criterion coefficient; environmental criterion coefficient and two coefficients of the rolling stock selection. The lowest value of the coefficients is marked by the number 1, and the highest is 5. The value of the rolling stock coefficient is presented in Table 4. Table 7 presents the value of the second rolling stock selection coefficient for each numerical range.

Table 7. Value of the second rolling stock selection coefficient

The range of the number of trains	Coefficient
up to 9	0
over 10	1

In order to optimise the first and second coefficients of rolling stock selection and the coefficients of material and energy, and economic and environmental criteria, neural networks with the regression model in Statistica were applied. The following signals were identified:

- quantitative input variables: number of sets
- qualitative input variables: the first coefficient of the rolling stock selection, coefficient of material and energy criterion, coefficient of economic criterion, coefficient of environmental criterion
- quantitative output variables: the second coefficient of the rolling stock selection

Table 8 presents selected values of the prediction sheet.

Table 8. Selected values of the prediction sheet

No. – case	Output
1	0
3	0
6	0
8	0
12	1
16	0
22	1
28	0.000004
35	0
43	0
51	0
60	1
68	0
76	0
83	0
90	0

Figure 2 shows the activation histogram.

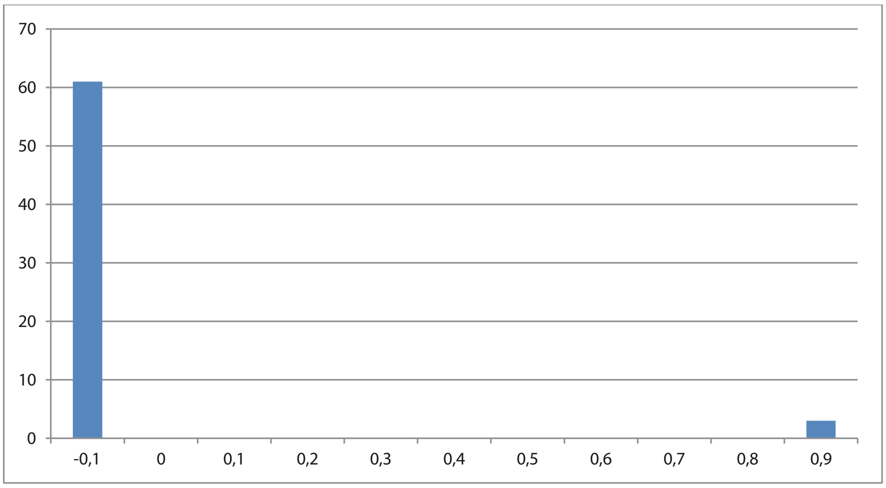

Fig. 2. histogram (own studies)

Table 9 shows the list of the qualities and errors in the regression model.

Table 9. List of qualities and errors of the regression model

Quality (training)	Quality (testing)	Quality (validation)	Error (training)	Error (testing)	Error (validation)
1	0	1	0	0	0

The regression model applied in neural networks was used for the studies conducted in 2019 and 2020, taking into account the described criteria that affect the life cycle. There are input and output variables in the regression model. As a result of the analysis with neural networks, the optimal value of the output variables is 1, which means that the probability of this event is certain. In the research conducted in September 2019, the optimal value of the input variables was 12 rolling stock sets, and 10 and 15 bus stocks. In other cases, the value of the output variables is not optimal because it is 0 or it is close to 0. In the research conducted in June 2020, the optimal value of the input variables was 12 rolling stock sets, 10, 12 and 15 bus stocks. In other cases, the value of the output variables is not optimal because it is 0.

5. Conclusions

The research was conducted with the use of neural networks. The research, based on comparative analyses of individual types of rolling stock, their technical and economic data, took into account durability, energy consumption, efficiency and emissions of harmful substances related to the operation of vehicles in connection with the number of rolling stock sets.

The use of neural networks with the use of the cluster analysis model made it possible to determine the optimal number of rolling stock sets.

The use of neural networks with the use of the regression model made it possible to determine the optimal number of the rail and bus rolling stock sets.

The research carried out on the existing tram and bus lines in Szczecin has shown that it is possible to determine the optimal number of rolling stock sets and bus rolling stock sets with the use of neural networks.

The use of neural networks on the example of the city of Szczecin, taking into account the life cycle, can make a significant contribution to creating a decision model for the improvement of public transport in cities with various types of public transport vehicles.

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