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The material and economic assessment of the life cycle of city buses in the operational phase

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The aim of the article is the material and economic assessment of the life cycle of city buses with combustion engines. As part of the analysis, the analyzed parameters were optimized using neural networks with the use of a regression model. As part of the life cycle assessment criteria, three types of Solaris Urbino buses were analyzed. As a result of the research carried out for buses, the results were obtained regarding the optimal duration of operation, the number and cost of oil, air and fuel filter changes, and the replacement period of buses. The presented research and analyzes have a significant impact on the processes of purchasing and operating city buses.

Key words: *life cycle assessment, city buses, operation, neural networks, combustion engines*

1. Introduction

Life Cycle Assessment (LCA) concerns the assessment of potential environmental hazards. This model consists of three areas [12]:

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

The area (phase) of vehicle operation will be analyzed.

The aim of the article is the material and economic assessment of the life cycle of city buses with combustion engines. The following parameters were analyzed: duration of operation, mileage, number and cost of filter changes: oil, air, fuel, and the period of replacement of buses. City buses often form the basis of the functioning of public transport. Solaris buses are operated in many Polish and European cities and meet the currently applicable emission standards. Low exhaust emissions from buses are of great importance for the protection of the environment.

2. Literature review

The use of the LCA cycle for vehicles has been presented in many publications. The publication [1] presents a set of key sustainable development indicators for various stages of the car's life cycle. The publication [2] uses the life cycle assessment methodology to determine whether the material composition strategy of the popular Volkswagen Golf model has reduced its environmental burden over the last 30 years. The publication [3] presents the supporting LCA method, within which fuel consumption was calculated. The application of the LCA cycle for internal combustion engines is presented in publications [4, 5]. The aim of the publication [4] was to present, using LCA analysis, the impact of changes in the material composition of engines on the environment under selected internal combustion conditions used in passenger cars. The simplified LCA model presented in the article presents energy consumption and total CO_2 emissions on the basis of the mass of materials from which the engine is made. The aim of the publication [5] was to demonstrate the environmental impact of changes in the material composition of Volkswagen Golf passenger cars in the last 30 years using the LCA methodology. The presented simplified LCA model of an engine shows the energy consumption and total CO_2 emissions based on the weight of the engine materials. The publication [6] presents the material and energy life cycle of a car. Changes in energy consumption and emission levels are presented. The publication [7] presents the application of the life cycle assessment to the analysis of ecological properties of a passenger car during its operation. The issues related to the operational efficiency of city buses are described in the publication [8]. The publication [9] presents research on the use of batteries in electric cars. The publications [10, 11] present a fleet management strategy that does not take into account the number and cost of replacing oil, air and fuel filters.

3. Research methodology

As part of the life cycle assessment criteria, three types of Solaris Urbino buses were analyzed. Figure 1 presents the Solaris Urbino 10.5 bus [17].

Figure 1. Solaris Urbino 10.5 bus [17]

Table. 1 presents the technical data of the Solaris Urbino 10.5 bus.

Table. 1 Technical data of the Solaris Urbino 10.5 bus [20]

Type of Solaris Bus	Urbino 10.5
Years of production	Since 2017
Doors layout	2-2-0 2-2-2 1-2-0 1-2-2
Number of doors	2-3
The height of the floor	320 mm
Engines	Cummins ISB6.7E6C DAF MX-11
The power of the engines	Cummins: 187 kW (254 HP), 209 kW (277 HP), 224 kW (305 HP), DAF: 210 kW (286 HP), 240 kW (326 HP), 271 kW (368 HP)
Transmission	Automatic: ZF-EcoLife Voith DIWA.6
Length	10550 mm
Width	2550 mm
Height	3040 mm
Wheelbase	4450 mm
Number of seats	Up to 29
ABS	Yes
ASR	Yes
EBS	Yes
ESP	Yes
Air conditioning	Optional

Figure 2 presents the Solaris Urbino 12 bus. Figure 3 presents the Solaris Urbino 18 bus.

Table 2 presents the technical data of the Solaris Urbino 12 bus. Table 3 presents the technical data of the Solaris Urbino 18 bus.

Table. 2 Technical data of the Solaris Urbino 12 bus [20]

Type of Solaris Bus	Urbino 12
Years of production	Since 1999
Doors layout	2-2-2 2-2-0 1-2-2 1-2-0
Number of doors	2-3
The height of the floor	320 mm
Engines	1) Cummins ISB6.7E6C 250B 2) Cummins ISB6.7E6C 280B 3) Cummins ISB6.7E6C 300B 4) DAF MX-11 210 5) DAF MX-11 240 6) DAF MX-11 271
The power of the engines	1) 189 kW (257 HP) 2) 209 kW (284 HP) 3) 224 kW (304 HP) 4) 210 kW (286 HP) 5) 240 kW (326 HP) 6) 271 kW (368 HP)
Transmission	1) ZF-EcoLife 2) Voith DIWA.6
Length	12000 mm
Width	2550 mm
Height	3040 mm
Wheelbase	5900 mm
Number of seats	Up to 43
ABS	Yes
ASR	Yes
EBS	Yes
ESP	Optional
Air conditioning	Optional

Fig. 2. Solaris Urbino 12 bus

Fig. 3. Solaris Urbino 18 bus

Table. 3 Technical data of the Solaris Urbino 18 bus [20]

Type of Solaris Bus	Urbino 18
Years of production	Since 1999
Doors layout	2-2-2-0 2-2-2-2 1-2-2-0 1-2-2-2
Number of doors	3-4
The height of the floor	320 mm
Engines	1) DAF MX-11 240 2) DAF MX-11 271
The power of the engines	1) 240 kW (326 HP) 2) 271 kW (368 HP)
Transmission	1) ZF-EcoLife 2) Voith DIWA 6
Length	18000 mm
Width	2550 mm
Height	3090–3200 mm
Wheelbase	5130 mm 6770 mm
Number of seats	Up to 53
ABS	Yes
ASR	Yes
EBS	Yes
ESP	No
Air conditioning	Optional

For this purpose, neural networks were used to determine the optimal values of the operation duration, mileage, number and costs of replacement of selected consumables and the replacement period of buses. Neural networks can be used wherever there are tasks related to prediction, classification or control. In the conducted analysis, tasks related to prediction were used.

The analyzed parameters were determined on the basis of source data. The duration of operation was determined on the basis of the publication [20]. The mileage in one year was 100,000 km [18]. The engine oil filter was changed every 30,000 km [21], the air filter every 20,000 km, and the fuel filter every 100,000 km [19]. The cost of purchasing one engine oil filter was PLN 17 [14], one air filter PLN 220 [15], and one fuel filter PLN 32 [13]. The analyzed engine oil, air and fuel filters are used in all analyzed types of buses. As part of the costs of replacing individual filters, the costs of their purchases were taken into account. The bus replacement period was every 9 years [16]. Table 4 presents the values of the analyzed parameters of selected types of buses.

Table 4. Values of the analyzed parameters of selected types of buses

Type of Solaris Bus	Urbino 10,5				
Duration of operation[years]	4	3	2	1	
Mileage [1000·km]	400	300	200	100	
Number of filter changes [–]:					
the engine oil filter	13	10	7	3	
the air filter	20	15	10	5	
the fuel filter	4	3	2	1	
The cost of replacing [PLN*]:					
the engine oil filter	221	170	119	51	
the air filter	4400	3300	2200	1100	
the fuel filter	128	96	64	32	
Bus replacement period	0	0	0	0	
Type of Solaris Bus	Urbino 12				
Duration of operation [years]	9	8	7	6	
Mileage [1000·km]	900	800	700	600	
Number of filter changes [–]:					
the engine oil filter	30	27	23	20	
the air filter	45	40	35	30	
the fuel filter	9	8	7	6	
The cost of replacing [PLN*]:					
the engine oil filter	510	459	391	340	
the air filter	9900	8800	7700	6600	
the fuel filter	288	256	224	192	
Bus replacement period	1	0	0	0	
Type of Solaris Bus	Urbino 18				
Duration of operation[years]	9	6	5	4	3
Mileage [1000·km]	900	600	500	400	300
Number of filter changes [–]:					
the engine oil filter	30	20	17	13	10
the air filter	45	30	25	20	15
the fuel filter	9	6	5	4	3
The cost of replacing [PLN*]:					
the engine oil filter	510	340	289	221	170
the air filter	9900	6600	5500	4400	3300
the fuel filter	288	192	160	128	96
Bus replacement period	1	0	0	0	0
(*) 1 PLN = 0.2 EUR					

As part of the analysis, the analyzed parameters were optimized with the use of neural networks with the use of a regression model in the Statistica program.

The following signals are identified:

- quantitative input variables: operation time, mileage, number of engine oil filter replacements, number of air filter replacements, number of fuel filter replacements, cost of engine oil filter replacements, cost of air filter replacements

Table 5. Prediction sheet

No. – case	Output
1	0
2	0
3	0
4	0
5	1
6	0
7	0
8	0
9	1
11	0
12	0

- qualitative input variables: cost of fuel filter replacement,
- quantitative output variables: bus replacement period.

Table 5 presents the prediction sheet. Figure 4 presents the activation histogram. Table 6 shows the list of the qualities and errors in the regression model.

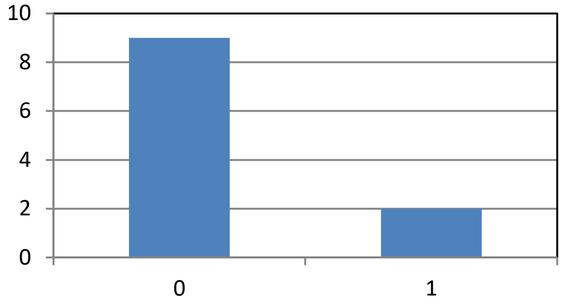

Fig. 4. Histogram of activation

Table 3. List of qualities and errors of the regression model

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

4. Research analysis

The conducted research shows that for optimization equal to 1 for Solaris Urbino 12 and 18 buses with combustion drive, with a mileage of 900,000 km, the number of engine oil filter changes 30, the number of air filter changes 45 and the number of fuel filter changes 9 and the cost of engine oil filter replacements PLN 510, the cost of replacing the air filter PLN 9,900 and the cost of replacing the fuel filter PLN 288 and the replacement period for buses equal to 1, the optimal duration of operation is 9 years.

For Solaris Urbino 10.5 buses, the optimization results were below 1 and it was not possible to determine the optimal values of the analyzed parameters due to the shorter duration of operation compared to Solaris Urbino 12 and 18 buses.

5. Conclusions

On the basis of the conducted research and analyzes for the assessment of the life cycle of city buses in the operation phase, it has been shown that the optimal duration of operation is 9 years and is related to their mileage, the bus replacement period as well as the cost and number of filter replacements. The use of neural networks to determine the optimization of the analyzed parameters is an important source of information for the processes of planning the operating costs of bus companies. The presented research and analyzes have a significant impact on the processes of purchasing and operating city buses. Further research should be verified on the example of buses in operation in a specific company.

Nomenclature

ABS	anti-lock braking system
ASR	acceleration slip regulation
CO_2	carbon dioxide
EBS	electronic braking system
ESP	electronic stability program
LCA	Life Cycle Assessment

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