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STAGES OF OPERATING VEHICLES WITH RESPECT TO OPERATIONAL EFFICIENCY USING CITY BUSES AS AN EXAMPLE

ETAPY UŻYTKOWANIA POJAZDÓW ZE WZGLĘDU NA EFEKTYWNOŚĆ EKSPLOATACYJNĄ NA PRZYKŁADZIE AUTOBUSÓW MIEJSKICH*

The aim of the article is to compare the operational efficiency of the city buses in various stages of their operational life. Technical readiness tests, repair costs and revenues during the six years of operation were conducted using two popular bus makes as an example (domestic and imported). Based on these tests, the characteristics of the operational efficiency of buses was determined. It has been shown that the service life has a significant effect on the operational efficiency. The division of the total operational period of the vehicle into the warranty and post-warranty period was considered and a new division was introduced, of the „period of full operational usefulness" and "period of limited operational usefulness". This new division of service life into stages makes it possible to determine the most reasonable limit of the vehicle usage until it is taken out of service. It can also be used when choosing a vehicle make as part of a fleet renewal or extension program.

Keywords: *public transport city buses, costs of repairs of wear defects, operational efficiency, usage stages.*

Celem artykułu jest porównanie efektywności eksploatacyjnej autobusów miejskich w różnych etapach okresu użytkowania. Przeprowadzono badania gotowości technicznej, kosztów napraw i przychodów w czasie sześciu lat eksploatacji na przykładzie dwóch popularnych marek autobusów (krajowych i importowanych). Na podstawie tych badań wyznaczono charakterystykę efektywności eksploatacyjnej autobusów. Wykazano, że czas użytkowania wpływa znacząco na efektywność eksploatacji. Rozpatrzono podział całkowitego okresu użytkowania pojazdów na okres gwarancyjny i pogwarancyjny oraz wprowadzono nowy podział na „okres pełnej przydatności eksploatacyjnej" i „okres ograniczonej przydatności eksploatacyjnej". Ten nowy podział czasu użytkowania na etapy umożliwia wyznaczenie najbardziej racjonalnej granicy użytkowania pojazdu do chwili wycofania go z eksploatacji. Może być także wykorzystany przy wyborze marki pojazdu w ramach programu odnowy lub rozbudowy floty.

Słowa kluczowe: *autobusy komunikacji miejskiej, koszty napraw uszkodzeń zużyciowych, efektywność eksploatacyjna, etapy użytkowania,*

1. Introduction

In large urban agglomerations, public transport faces a new challenge, which is the progressive increase in the number of vehicles used and the resulting restrictions on traffic flow and driving safety as well as noise and environmental pollution. Research conducted in many countries has proved that public transport should absolutely dominate in passenger urban traffic due to environmental and transport efficiency [6, 10, 18].

An important problem of the public collective transport is the reliability of transport means. Low level of reliability of buses worsens the punctuality of the system and decreases passenger confidence, as well as increases transport costs and reduces the effective use of the fleet. Therefore, many transport companies pay a lot of attention to the selection of high-quality transport means [15]. It means striving to balance two requirements: ensuring maximum reliability at an acceptable level of investment and operating costs [3, 5, 7, 8, 16]. For this reason, transport enterprises use systems for monitoring the risk of wear defect and diagnosing the change in the residual value of the vehicles used [17]. This is an important problem from the point of view of ensuring the continuity of the transport system in the city. Another important problem in the process of vehicle operation is the issue of time limit (end) of use, after which the vehicle should be taken out of service (replaced or disposed of) [1, 14].

The paper [12] presents results of technical readiness tests of the city buses as a function of time of use. It has been demonstrated that technical readiness during the warranty and post-warranty periods may vary significantly depending on the bus make. A more comprehensive picture of the vehicle's operational characteristics can be obtained after considering the costs of repairs related to the physical wear of components and parts [11, 17]. It is then possible to assess the operational efficiency of the vehicle depending on the time of use or the mileage. Operational efficiency is one of the most important characteristics of the operational quality of the vehicle and may be a criterion for assessing its operational usefulness [2, 13, 14].

This article presents the author's model for the assessment of operational efficiency and its use to determine the rational time of use (service life) of the buses. This model takes into account the indicators of technical readiness and reliability of vehicles as well as related costs of repairs and downtime. The model is the basis for the new division of time of use for a period of full operational usefulness and limited operational usefulness of buses. The model has been verified based on the bus tests during the 6 years of operation using the city of Lublin as an example.

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl***

2. Model of the operation efficiency evaluation

This paper uses the concept of revenue from the implementation of planned quasi-continuous transport tasks. The potential revenue P_P and forecast revenue P_R were distinguished. The average revenue P_{Pi} in the i-th month of the month for the sample of buses was calculated as:

$$P_{P_i} = \lambda_i \times s \, . \tag{1}$$

where:
- λi – intensity of use, average monthly number of kilometres for one bus in the i-th month of operation [km];
- s – 1 km transport rate applied in the examined enterprise [PLN/km];
- i = 1,2,3, ... 72

Predicted revenue P_{Ri} in the i-th month of operating the bus was calculated according to the following formula:

$$P_{R_i} = K_{gi} \times P_{Pi} \tag{2}$$

where:
- Kgi – average technical readiness indicator in the i-th month of operation [-].

$$K_{G_i} = \frac{N_{zi} - N_{ni}}{N_{zi}} \, . \tag{3}$$

where: N_{zi} – the number of inventory vehicle-days in the i-th month of operation; N_{ni} – number of downtime vehicle-days due to repair in the i-th month of operation.

There are no downtimes shorter than one day.

The operational efficiency index of the bus in the i-th month of operation $E_{e,i}$ was calculated from the formula:

$$E_{e,i} = \frac{P_{Ri}}{C_{Ni}} \, . \tag{4}$$

where: C_{Ni} – the cost of bus repairs in the i-th month [PLN]

The average operational efficiency index E_e [-] of the bus in the period under consideration was calculated according to the following formula:

$$E_e = \frac{1}{n} \sum_{i=n_p}^{n_k} \frac{P_{Ri}}{C_{Ni}} \, . \tag{5}$$

where: n – number of months in the considered period of operation; n_p – the initial month in the considered period of operation; n_k – the final month in the considered period of operation.

3. The course of tests

Two popular makes of buses were selected for the tests - the domestic brand (designated in the article as D) and the imported make (marked as I). In the problem considered here, of vehicle makes being compared, and while taking into account the similarity of technical and economic characteristics; the planned operating costs (fuel costs, service fluids costs, personnel costs) and programmed technical maintenance costs and depreciation write-offs, have been omitted [11, 13].

The essential technical and operational data of buses is presented in Table 1. The tests were conducted using the continuous test method. Buses were operated in comparable road and climatic conditions. The selection of vehicles from one production lot and the fact of their simultaneous introduction into service were the basis for recognizing the sample as homogeneous.

Table 1. Technical and operational indicators of the examined buses

	D	I
Engine power [kW]	188	210
Max. torque [Nm]	1 050	1 100
Length [mm]	12 000	11 950
Curb weight [kg]	10 900	10 860
Total weight max. [kg]	18 000	18 000
Seating places	29	27
Standing places	74	78

Table 2. Indicators of the operating intensity of the buses tested

No.	Name of the indicator		Unit of measure	Mark of the indicator	
				D	I
1	Number of samples		items	20	22
2	The average mileage of the vehicle during the testing period		km	438 303	438 942
3	Average mileage of the vehicle per month	min	km	77	130
		Average	km	6088	6464
		max	km	8859	8948
5	Total research time		months	72	72

The sample size was 20 vehicles of the D make and 22 vehicles of the I make. Operational data were registered over a period of 72 months. This corresponded to the total operational mileage equal to 8.766 million km for all buses from sample D and 9.656 million km of all buses from sample I. The average observed road mileage of the operational period amounted to 438.3 thousand kilometres for buses of the D make and 448.9 thousand kilometres for buses I make (Table 2). Average daily mileage was about 250 km. The average monthly mileage was 6 088 km for buses D and 6 464 km for buses I.

4. Test results

4.1. Operational availability of the buses

The operational availability indicators for the buses as a function of time of operation on a monthly basis are shown in Figure 1. In the initial period (up to 27 months), the availability of D vehicles amounted to an average of 0.890, and then decreased, reaching a minimum value of 0.700 at 62 month. The average availability of the I-make buses amounted to approx. 0.900 in the initial period of operation. In the later (post-warranty) period it decreased to approx. 0.650, which was caused by a long waiting for spare parts.

4.2. Predicted revenue

The estimated revenue P_{Ri} indicators were calculated based on the formula (2) assuming a transport rate s = PLN 6.5/km, applied at MPK Lublin. It is worth noting that the size of the rate s may in gen-

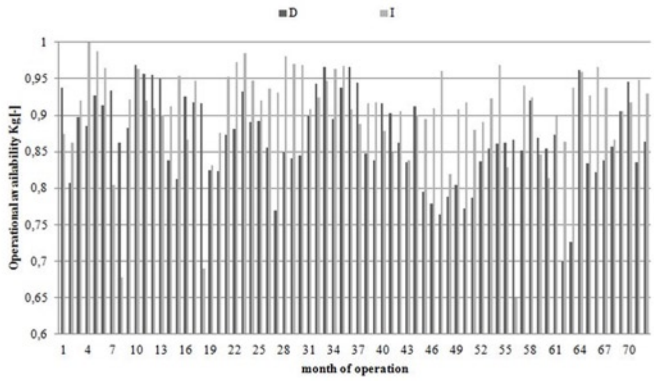

Fig. 1. Operational availability of buses as a function of time of operation on a monthly basis [12]

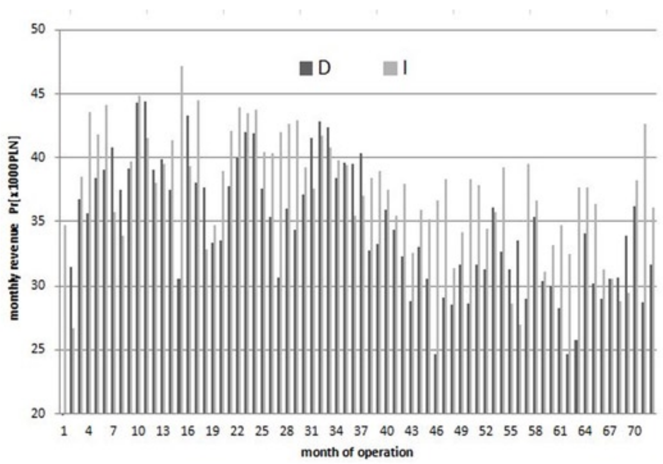

Fig. 2. Average forecast monthly revenue as a function of time of operation [9]

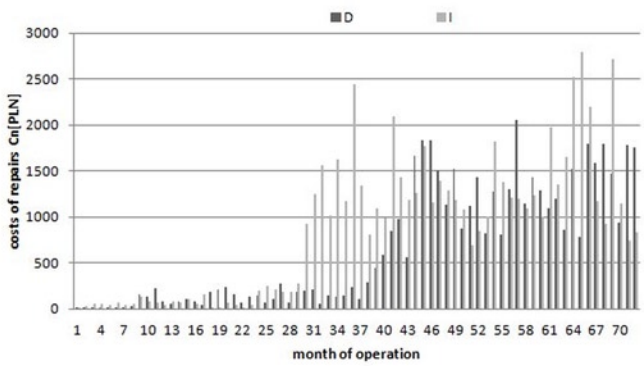

Fig. 3. Monthly costs of repairs per 1 bus [9]

eral assume very diverse values [4]. The results of revenue tests for buses of the D and I makes are presented in the function of time of operation in Figure 2 on a monthly basis. In the warranty period of operation (0 - 24 months), the average forecast revenue for D-make buses amounted to an average of PLN 37.5 thousand (for 1 bus), while for I buses - PLN 39.8 thousand. Relatively high revenue in the initial period of operation was largely due to low user costs and low number of defects. As the time of operation increased, revenue decreased. In the post-warranty period, a level of approximately PLN 33.0 thousand (D make) and approx. PLN 36.5 thousand (I make) was recorded.

4.3. Characteristics of bus repairs costs

The repair costs C_{Ni} included repair of parts caused by operational wear, including but not limited to: brake pads, wipers, bulbs, fuses, coolers, etc. However, parts whose damage was not directly related to the age (mileage) of the vehicle (e.g. mirrors, windows, parts replaced for reasons of accidental mechanical damage or theft) and parts regarded as an additional equipment of the bus (e.g. LCD monitors, ticket vending machines), were not included. Figure 3 presents a graph of monthly repair costs over the entire period of vehicle usage observed.

Considering the dynamics of costs presented in Fig. 3, it can be noticed that in the initial period of using vehicles of the I make (1- 29 months) an average monthly cost of repair amounted to approx. PLN 90. In the next period, the cost of repairs increased sharply, reaching an average level of about PLN 1380. A similar, gradual increase in the cost of repairs occurs in the case of vehicles of the D make, however, only after approx. 40 months of operation. The average cost of D bus repairs in the first period (1-40 months) was 110 PLN, while in the second period (41-72 months) - 1200 PLN.

When analyzing the bus reliability structure, it has been demonstrated that the reliability associated with the operational wear of individual construction systems varies depending on the bus make (Table 3). In both vehicles tested, the largest number of defects is associated with the electrical system. The probability of correct operation of this system is the lowest, and the mileages between defects are the shortest of all analyzed systems.

In the case of both brands, the most distinctive sources of wear damage were the electrical system, and lighting. However, the highest reliability was found in the case of suspension systems, heating and air conditioning and tires. Analyzing the defects of individual systems on D-make buses, it was found that the most common were electrical, engine, door and lighting systems. While, the highest mileages between defects occurred in heating and air conditioning systems as well as in the suspension system. In the I make buses, it has been observed that the following four systems get most often damaged: electrical, pneumatic, doors and lighting and power transmission.

Based on the research conducted, it was shown that the I make buses are characterized by a greater mileage between defects than the

*Table 3. List of results of reliability assessment for R * (t) = 0.5*

No.	Structural system	The mileage between defects [km]	
		Mark D	Mark I
1.	engine (US)	15 068	39 580
2.	cooling (UCH)	27 364	76 200
3.	fuel supply (UZ)	46 969	58 090
4.	brake (UH)	46 693	40 040
5.	power transmission (UN)	44 647	29 616
6.	suspension (UZW)	80 076	94 444
7.	electrical (UE)	7 360	11 361
8.	pneumatic (UP)	17 355	29 233
9.	heating and air conditioning (UOK)	87 424	81 946
10.	doors (UD)	15 215	24 779
11.	tires (UOG)	54 545	94 444
12.	lighting (UOW)	9 867	7 325

D-class buses. The average mileage figure between defects is 2786 km for buses I and 1787 km for buses D.

4.4. Buses operational efficiency

The operational efficiency E_{ek} was calculated according to the formula 4. Figure 4 shows the chart of operational efficiency on a monthly basis. The operational efficiency of the D-make buses, averaged over the entire period of use n = 72 months considered, was E_{ek}^D (n = 72) = 306. This means that PLN 306 of the revenue was obtained after spending PLN 1 for repair. Accordingly, the efficiency of the I-make buses was E_{ek}^I (n = 72) = 263. The operational efficiency course of the examined buses is characterized by a rapid change in value and dynamics after a specified period of operation.

Based on the analysis of the efficiency course presented in Fig. 4 and the analysis of defects and repair costs (Fig. 3), a new division of the total period of operation was introduced, i.e. for the period of full operational usefulness (PPE) and the following period of limited operational usefulness (OPE).

In the case of the D make, the border between PPE and OPE was found to be n_x^D = 40 months, whereas for I make n_x^I = 30 months.

As a criterion for choosing the best division border between the PPE and OPE stages, the minimum value of the relative mean square error in the set of E_{ek} values characterizing the stage of limited operational usefulness of the vehicle, was adopted.

The optimization criterion (objective function) is described by the formula:

$$\nu(n_x) = \frac{S(n_x)}{\frac{1}{n_k - n_x}\sum_{i=n_x}^{n_k} E_{e,i}} \rightarrow min$$

$$S(n_x) = \sqrt{\frac{1}{n}\sum_{i=n_x}^{n_k}\left(E_{e,i} - \frac{1}{n_k - n_x}\sum_{i=n_x}^{n_k} E_{e,i}\right)^2}$$

where:

$\nu(n_x)$ – relative mean square error of the vehicle operational efficiency in the stage of limited operational usefulness,

$S(n_x)$ – mean square error of the operational efficiency of the vehicle in the stage of limited operational usefulness,

E_{ei} – vehicle efficiency in the i-th month of operation,

i = 1,2,3 ... n, n- the number of months in the period considered,

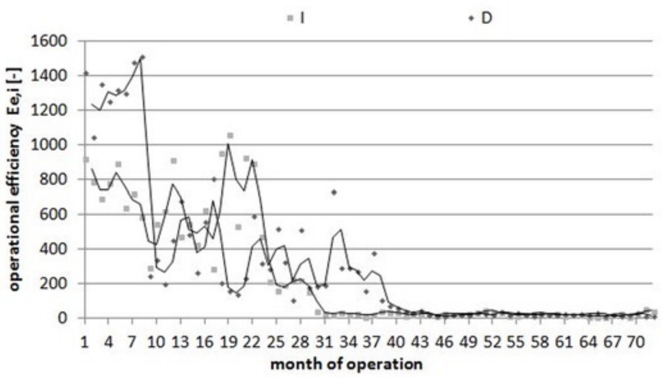

Fig. 4. The course of operational efficiency of buses as a function of time of operation on a monthly basis

Table 4. Descriptive statistics of the operational efficiency of buses in the period of full operational usefulness (PPE) and limited operational usefulness (OPE)

Period of operation	make of the bus	Operational efficiency				
		mean value E_e	standard error S	relative error ν	Ee_{min}	Ee_{max}
PPE	D	530	445	0,841	61	383
OPE		26	9	0,358	14	51
PPE	I	566	285	0,504	42	1066
OPE		29	10	0,358	11	58

Table. 5. Descriptive statistics of the operational efficiency of buses during the warranty period (G) and post-warranty (P)

Period of operation	make of the bus	Operational efficiency				
		mean value E_e	standard error S	relative error ν	Ee_{min}	Ee_{max}
G	D	698	488	0,699	143	1517
P		110	158	1,439	14	737
G	I	665	227	0,341	219	1066
P		46	52	1,128	11	231

n_x – the number of months sought is the limit between the period of full and the period of limited operational usefulness of the vehicle,

n_k – final, tested month of the operation (total number of months in the period of operation under scrutiny).

Table 4 gives the results of calculations of operational efficiency using the above-described principle of optimal division of operating period into phases - formula 6. Operational efficiency of buses in the period of full usefulness (PPE) was E_{ep}^D = 530 – D make; E_{ep}^I = 566 - the I make, while in the period of limited usefulness (OPE), the E_{eO}^D = 26 - the D make; E_{eO}^I = 29 – I make.

For the purpose of comparison, similar calculations were made assuming the division of the period of operation into the warranty period (G) and post-warranty (P) (Table 5) and assuming a "standardized" division covering equally for both vehicle makes: first unified stage - first 36 months of operation and second unified stage - the remaining 36 months of operation (Table 6).

When analyzing the results of the statistical assessment given in Tables 4,5,6, it should be noted that with the optimal division of the useful life into stages according to the stable level of operational efficiency, the coefficient of variation (OPE) was $\nu_D(n_x)$=0,358 for the D make and $\nu_I(n_x)$= 0,358 for the I make, while in the case of a warranty and post-warranty period, ν_D =1,439 and ν_I =1,128 respectively, and in the case of the "standardized" division ν_D = 1.498 and ν_I = 0.369.

4.5. Statistical evaluation of the significance of differences in average values of operational efficiency

A one-way analysis of variance with division into the warranty and post-warranty period and division into a period of full operational usefulness (PPE) and limited operational usefulness (OPE) was carried out. The classification factor was the "vehicle's make", while the dependent variable (being explained) was the operational efficiency.

It was considered that the analyzed variables are measurable and independent. In the analyzed sets, the compliance of the data with the normal distribution was checked. The normality charts for each group (bus makes) were determined. The results of the W. Shapiro - Wilk compliance test are shown in Figure 5. The test found that the level of significance met the condition of conformity $p>\alpha = 0.05$ only for

Table 6. Descriptive statistics of the operational efficiency of buses in the first and second unified period of operation

Period of operation	make of the bus	Operational efficiency				
		mean value E_e	standard error S	relative error ν	Ee_{min}	Ee_{max}
unified first	D	571	449	0,786	110	1517
unified second		41	61	1,498	14	383
unified first	I	476	329	0,690	15	1066
unified second		29	11	0,369	11	58

was the "vehicle make", while the dependent variable was the operational efficiency.

It was found that the assumptions of the independence of variables and measurability had been met. The normality of the distribution of variables was checked by creating categorized normality charts for each of the vehicle makes (Figure 6). Comparing the average values of effectiveness in the Shapiro-Wilk test, it was found that the level of significance in three cases is lower than assumed, p <α = 0.05 (except for I buses in the OPE period). Therefore, the null hypothesis about homogeneity of variance was rejected. But the non-parametric Kruskal-Wallis test was used. The results of the test for the PPE period are presented in Table 9, and for the OPE period in Table 10. For both vehicle makes, in the period of full operational usefulness, the significance level p was equal to p> α = 0.05. It was therefore concluded that there were no grounds to reject the hypothesis of equality of mean values. Therefore, it can be concluded that in the period of full operational usefulness (PPE), the average efficiency of bus operation of both makes is not significantly different.

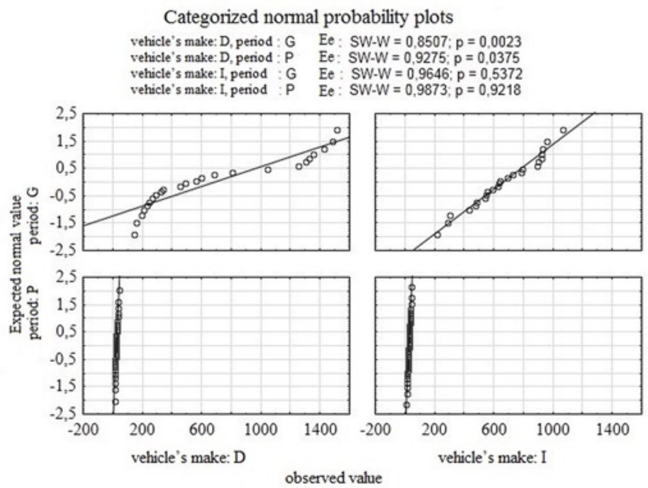

Fig. 5. Categorized diagrams of the normality of a dependent variable - operational efficiency of D and I buses during the warranty period (G) and post-warranty (P)

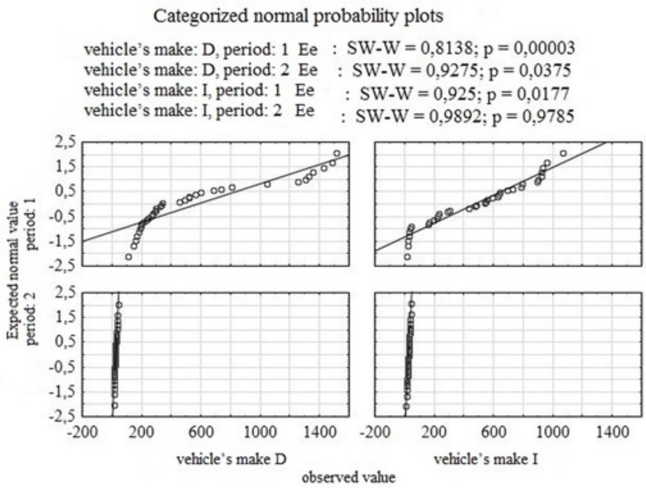

Fig. 6. Categorized diagrams of the dependent variable normality - operational efficiency for the D and I makes buses in the period of full operational usefulness (1) and limited operational usefulness (2)

buses I. In the case of buses D, the hypothesis of normality of distributions was rejected.

The Kruskal-Wallis test in a warranty (G) and post-warranty (P) intervals was used to check the comparability of mean values. During the warranty period in the Kruskal-Wallis test (Table 7), the significance level is 0.5777 and is greater than 0.05, so there is no reason to reject the null hypothesis.

Then an analysis of variance for the „vehicle make" factor was carried out in the post-warranty period. The results of Kruskal-Wallis tests are presented in Table 8. The level of significance here was 0.1233 and was greater than 0.05. It was therefore concluded that there were no grounds for rejecting the null hypothesis on the equality of the mean values.

Next, a one-way analysis of variance was carried out, divided into a period of full operational usefulness (PPE) and a period of limited operational usefulness (OPE). The classifying factor

Table 8. Results of the ANOVA rank Kruskal-Wallis test of a dependent variable - operating efficiency for the "vehicle make" factor in the post-warranty period

dependent variable: item	ANOVA Kruskal-Wallis ranks; operational efficiency Independent variable (grouping): vehicle make Kruskal-Wallis Test: H (1, N=72)=2,3746; p=0,1233			
	Code	N of the important ones	total of the ranks	mean rank
D	101	31	996,0	32,129
I	102	41	1632,0	39,805

N - number of all important observations, 1 - number of degrees of freedom of the asymptotic distribution χ^2 of the statistics H, H - value of the Kruskal-Wallis test statistics, p - probability level

Table 7. Results of ANOVA Kruskal-Wallis ranks test for the "vehicle make" factor during the warranty period

dependent variable: item	ANOVA Kruskal-Wallis ranks; operational efficiency Independent variable (grouping): vehicle make Kruskal-Wallis Test: H (1, N= 48)=0,3099490; p=0,5777			
	Code	N of the important ones	total of the ranks	mean rank
D	101	24	561,0	23,375
I	102	24	615,0	25,625

N - number of all important observations, 1 - number of degrees of freedom of the asymptotic distribution χ^2 of the statistics H, H - value of the Kruskal-Wallis test statistics, p - probability level

The results of Kruskal-Wallis tests in the OPE period presented in Table 10 indicate that the significance level is 0.2074 and is greater than 0.05. Therefore, there is no reason to reject the null hypothesis about the equality of mean values and it can be stated that the vehicle make does not significantly affect the average efficiency of operation during the period of limited operational usefulness.

Table 9. ANOVA Kruskal-Wallis ranks test results dependent variable - operating efficiency for the "vehicle make" factor in the period of full operational usefulness (PPE)

dependent variable: item	ANOVA Kruskal-Wallis ranks; operational efficiency Independent variable (grouping): vehicle make Kruskal-Wallis Test: H (1,N=72)=0,3171; p=0,5734			
	Code	N of the important ones	total of the ranks	mean rank
D	102	36	1264,000	35,11111
I	101	36	1364,000	37,88889

N - number of all important observations, 1 - number of degrees of freedom of the asymptotic distribution χ^2 of the statistics H, H - value of the Kruskal-Wallis test statistics, p - probability level

Table 10. ANOVA Kruskal-Wallis ranks test results dependent variable - operating efficiency for the "vehicle make" factor in the period of limited operational usefulness (OPE)

dependent variable: item	ANOVA Kruskal-Wallis ranks; operational efficiency Independent variable (grouping): vehicle make Kruskal-Wallis Test: H (1,N=65)=1,589; p=0,2074			
	Code	N of the important ones	total of the ranks	mean rank
D	102	34	1218,0	35,824
I	101	31	927,0	29,903

N - number of all important observations, 1 - number of degrees of freedom of the asymptotic distribution χ^2 of the statistics H, H - value of the Kruskal-Wallis test statistics, p - probability level

Table 11. Results of ANOVA Kruskal-Wallis rank test of a dependent variable – operational effectiveness for the factor – period of full operational usefulness (PPE) and limited operational suitability (OPE) of buses D

dependent variable: item	ANOVA Kruskal-Wallis ranks; operational efficiency Independent variable (grouping): PPE i OPE Kruskal-Wallis Test: H (1,N=67)=49,235; p=0,000			
	Code	N of the important ones	total of the ranks	mean rank
PPE	1	36	1782,000	49,50000
OPE	2	31	496,000	16,00000

N - number of all important observations, 1 - number of degrees of freedom of the asymptotic distribution χ^2 of the statistics H, H - value of the Kruskal-Wallis test statistics, p - probability level

Table 12. Results of ANOVA Kruskal-Wallis rank test of a dependent variable – operational effectiveness for the factor – period of full operational usefulness (PPE) and limited operational suitability (OPE) of buses I

dependent variable: item	ANOVA Kruskal-Wallis ranks; operational efficiency Independent variable (grouping): PPE i OPE Kruskal-Wallis Test: H(1,N=70)=36,766; p=0,000			
	Code	N of the important ones	total of the ranks	mean rank
PPE	1	36	1794,000	49,83333
OPE	2	34	691,000	20,32353

N - number of all important observations, 1 - number of degrees of freedom of the asymptotic distribution χ^2 of the statistics H, H - value of the Kruskal-Wallis test statistics, p - probability level

The next stage of the variance analysis was carried out for the „period of operation" factor - PPE and OPE. The operational effectiveness for the two analyzed bus makes was a dependent variable.

In the Kruskal-Wallis test, the significance level for buses D is 0.000 and is less than 0.05 (Table 11). Thus, the null hypothesis about equality of mean values was rejected. The operating periods differ in terms of average operational effectiveness.

In the Kruskal-Wallis test, the significance level for buses I is 0.000 and is less than 0.05 (Table 12). Thus, the null hypothesis about equality of mean values was rejected. The statistical analysis carried out shows that in each of the considered periods of use: PPE and OPE, as well as warranty (G) and post-warranty (P), the average value of effectiveness of both tested bus makes do not differ significantly. However, each of the makes has significantly different effectiveness in the period of limited operational usefulness (OPE) in comparison to the period of full operational usefulness (PPE).

5. Conclusions

Based on the experimental studies on the operational efficiency of city buses, the following conclusions were made:

1. If the criterion of bus assessment is to be assumed their operational efficiency, then in the total period of operation of the examined buses, two different stages of their operational usefulness may be distinguished: the full usefulness stage and the stage of limited operational usefulness.
2. The criterion for dividing the time of operation into stages results from the step change in the average operational efficiency of the vehicle, defined as the ratio of projected revenues (resulting from technical readiness and freight rate) to the costs of repairs related to the wear of a vehicle parts. The stage of full operational usefulness is characterized by high technical readiness, low repair costs and relatively high operational efficiency of the vehicle. The stage of limited operational usefulness is characterized by increased repair costs and reduced, but stable operational efficiency of the vehicle.
3. It has been shown that the regularity of the division of time of operation into periods of different operational usefulness is repeated in both cases of the bus makes tested, whereas there are differences between the makes regarding the length of these stages.
4. It has been shown that in the statistical sense, the operational efficiency of both makes under consideration does not differ significantly both in the period of full operational usefulness and in the period of limited operational usefulness. Likewise, there is no difference of values of the average efficiencies between makes during the warranty and post-warranty periods.
5. The vehicle effectiveness indicator presented in the article may be used as a criterion for the selection of a reasonable period of bus operation.
6. The effectiveness indicator presented in the article may be applied to other commercial vehicles as well as for passenger cars.

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