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Research Article

THE ENGINE SET DAMAGE ASSESSMENT IN THE PUBLIC TRANSPORT VEHICLES

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ABSTRACT

The article presents the analysis of the combustion engine damage assessment in the public transport vehicles. The analyses concerned checking the interrelation between the initial and annual kilometrage of vehicles and the number of the registered orders at the maintenance and conservation system. The examinations were performed on the four brands of buses that were exploited by Municipal Transport Company Lublin. The information about repairs relates to year 2015.

Keywords: engine, transport, buses, kilometrage, service.

INTRODUCTION

While assessing the cost-efficiency of a bus, numerous factors must be taken into consideration. They are: the use intensity, the value of the established transportation tariff, personal expenses, consumables etc [12]. The use intensity may be, in theory, increased in two ways: by increasing the speed on the itinerary or by decreasing the duration of stoppages. In practice, the average speed of buses depends mostly on: the condition of the road infrastructure and the road traffic regulations. During the usage of a vehicle, regulations and legal norms that regulate its allowance to participate in the road traffic may be subject to variations [2, 3]. Thus, buses that perform transport operations on repetitive itineraries drive with a fixed average speed. Taking this fact into consideration, the use intensity mostly reflects the degree of exploitation of a vehicle, which mostly depends on the established usage strategy [7]. The two most important factors of the exploitation process are: the vehicle kilometrage in a given period of time (a day, a month or a year) and maintenance and service costs. The service costs are the sum of the material costs due to exploitation factors and the service station's workers labour costs.

In literature there exists many research works devoted to issues concerning the maintenance of the reliability of means of transport. Michalski and Wierzbicki [14] concducted the analysis of degradation of different systems in vehicles being already in service. Skrúcaný and others [16, 17] investigated dangers to traffic related to heavy goods vehicle traffic under different loads and in varying conditions of operating. Marczuk et all [10] presented the problem of degradation of means of transport and use of components from end-of-life vehicles. Execution of the transport service depends on the bus's whole drive system's efficiency, in particular on the combustion engine. A change in the technical condition of mechanical components of internal combustion engines may not be detected by on-board diagnostic systems installed in vehicles [6]. In similar cases, measurements and analyses of vibroacoustic signals being recorded prove useful. For these reasons, there are numerous research works that use vibroacoustic methods in the combustion engines' diagnosis [5, 6, 8, 9, 18].

That is why statistical analiyses concerning the engine set damage are relevant and often performed [9, 15]. On the basis of the available information, the authors performed data analysis related to the service of the combustion engine set in the buses utilised by Municipal Transport Company Lublin (MTC Lublin) during one calendar year.

STATISTICAL ANALYSIS OF THE RESULTS

Reliability of the means of public transport is a vital criterion for their operational usability [13]. Reliability is defined as the ability to perform the operational tasks without stoppages due to damage in the established period of time and conditions [4]. The statistical analysis of the engine set damage that occurred in 2015 was performed for 4 brands of vehicles utilized by MTC Lublin. The vehicles subject to analysis were: Mercedes-Benz 628 O 530 G Citaro, Solaris Urbino 12, Autosan M12LF and Jelcz M121. The available data allowed to indicate both initial and annual kilometrage of vehicles and the number of registered orders at the maintenance and service system. Statistical analysis was performed with the use of STATISTICA PL software [1]. Technical data of the analyzed vehicles is presented in Table 1 below.

The analysis comprised the following units of a combustion engine:

1) cooling system
2) power supply system
3) inlet-outlet system [11].

At the first stage of the analysis, the descriptive statistics characterizing the analyzed variables were counted. The results are presented in Tables 2, 3 and 4.

Table 1. Selected technical data of the analyzed vehicles [11]

Bus manufacturer	Engine type	Engine power [kW (KW)]	Length [mm]	Width [mm]	Height [mm]	Laden mass [kg]
Autosan	IVECO F2BE3682 B	243 (330)	12000	2500	2890	18000
Jelcz	MAN D0826 LUH 12	162 (220)	12000	2500	3021	17500
Mercedes	OM 457 LA	220 (300)	12000	2500	2994	28000
Solaris	DAF PR 183 SI	220 (300)	12000	2550	2850	18000

Table 2. Location and dispersion parameters of the initial kilometrage parameters for particular buses

Bus manufacturer	Average value	Standard deviation	Median	Skewness	Kurtosis	Minimum value	Maximal value
Autosan	191710.3	48302.7	199619	-0.8176	-0.5519	99996	252069
Jelcz	1183134	74056.7	1186400	-0.6450	0.7795	993675	1310836
Mercedes	199031.7	11910.9	194764	0.8197	-0.1253	181900	226024
Solaris	471430.7	20277.8	471390	-0.3707	-0.6078	432978	500283

Table 3. Location and dispersion parameters of the annual kilometrage parameters for particular buses

Bus manufacturer	Average value	Standard deviation	Median	Skewness	Kurtosis	Minimum value	Maximal value
Autosan	75570	6756.5	77446	-0.8938	-0.4578	55879	85698
Jelcz	57867	14131.9	62229	-1.2787	0.9448	24903	75621
Mercedes	61577.7	6616.3	61743	-0.2276	-1.3388	50384	70363
Solaris	67654.1	6849.0	67388	-0.1479	-1.3928	56593	77184

Table 4. Location and dispersion parameters of the number of the registered orders at the maintenance and service system of the examined units for particular buses

Bus manufacturer	Average value	Standard deviation	Median	Skewness	Kurtosis	Minimum value	Maximal value
Autosan	57.6	15.19	55	0.4263	-0.2729	28	90
Jelcz	60.2	12.78	62	-0.3950	-0.7773	37	82
Mercedes	39.1	7.91	36	1.1397	1.3215	28	62
Solaris	77.9	19,12	76	0.2776	-0.8253	48	113

While analyzing results from Tables 2–4, it should be noted that there is a difference in the average value of the initial kilometrage. The highest values are in case of Jelcz M121, while the lowest in case of Autosan M12LF. While analyzing the annual kilometrage for particular buses, the average values are similar. It is worth pointing out, that for Jelcz M121 the value of standard deviation is the highest. In case of the parameter of the number of the registered orders at the maintenance and service system of the examined units, Solaris Urbino 12 showed the highest failure rate, which was expressed by the average value.

The next step of the statistical analysis was to check adjustment of the empirical research results to normal distribution by means of Shapiro-Wilk test and Kolmogorov–Smirnov test. Statistical analysis (with significance level $\alpha = 0.05$) of the compatibility test of the empirical distribution with normal distribution showed that the initial kilometrage distribution for the examined buses Jelcz M121 and Solaris Urbino 12 may be adjusted with normal distribution. When it comes to Autosan M12LF buses, though, their kilometrage distribution cannot be adjusted with normal distribution. Calculations showed that the Weibull distribution adjusts best to empirical data. In case of the Mercedes-Benz 628 O 530 G Citaro bus, the initial kilometrage distribution cannot by adjusted by means of normal distribution. The obtained results were presented in Table 5.

The analysis of the empirical distribution compatibility with normal distribution showed that the kilometer distribution of the annual kilometrage for the examined Solaris Urbino 12 buses may be adjusted with normal distribution. Shapiro-Wilk statistic is $W = 0.9596$ and $p = 0.5362$, which was presented in Table 6. For the other examined buses, the analysis of the empirical distribution compatibility with normal distribution showed that the kilometer distribution of the annual kilometrage cannot approximate with normal distribution. Calculations proved that distributions best adjusted to empirical data are the following: for Autosan M12LF - lognormal distribution, for Jelcz M121 Weibull distribution, for Mercedes-Benz 628 O 530 G Citaro - extreme value distribution.

The analysis of the empirical distribution compatibility with normal distribution showed that the kilometer distribution of the annual kilometrage for the number of orders at the maintenance and service system of Autosan M12LF, Jelcz M121 and Solaris Urbino 12 buses may be adjusted with normal distribution. Shapiro-Wilk statistic amounted to the following values: $W = 0.9659$ and $p = 0.1349$, $W = 0.9454$ and $p = 0.2157$ and $W = 0.9309$ and $p = 0.1611$. In case of Mercedes-Benz 628 O 530 G Citaro, the anal-

Table 5. Types of the kilometer distribution of the initial kilometrage for particular buses

Bus manufacturer	Shapiro - Wilk statistic W	P - value p	Normal	Kologorow -Smirnow statistic K-S	P - value p	Distribution
Autosan	0.8553	0.0001	No	0.1960	p>0.05	Weibull Treshold = 0.0000 scale = 209504.6 shape = 5.16
Jelcz	0.9640	0.524	Yes			
Mercedes	0.9235	0.048	No	0.1331	p>0.20	Extreme value Location = 193685.8 scale = 8885.5
Solaris	0.9540	0.4326	Yes			

Table 6. Types of the kilometer distribution of the annual kilometrage for particular buses

Bus manufacturer	Shapir -Wilk statistic W	P - value p	Normal	Kologorow -Smirnow statistic K - S	Significane level / P - value p	Distribution (parameters)
Autosan	0.9368	0.0075	No	0.1242	p>0.20	Lognormal treshold=0.000 scale=11.23 shape=0.094
Jelcz	0.8561	0.0028	No	0.1708	p>0.20	Weibull treshold=62842.79 scale=5.66 shape=0.1708
Mercedes	0.9207	0.041	No	0.1383	p>0.20	Extreme value location=58282.09 scale=6105.89
Solaris	0.9596	0.5362	Yes			

ysis of the empirical distribution compatibility with normal distribution showed that the kilometer distribution of the annual kilometrage for the number of orders at the maintenance and service system cannot be adjusted with normal distribution. Calculations showed that the extreme value distribution adjusts best to empirical data, which was presented in Table 7.

In order to check whether there are any relations between initial and annual kilometrage of the examined buses and the annual number of orders at the maintenance and service system, the correlation analysis was conducted. Its results were presented in Table 8 and Figure 1. In case the assumptions about the normality of the analyzed distributions were fulfilled, the Pearson correlation coefficient r were calculated. Otherwise, non-parametric correlation analysis with use of the Spearman's correlation coefficient R was used.

Because of the fact, that for variables the initial kilometrage and the annual number of orders at the maintenance and service system of the examined units for Jelcz M121, the assumption about the normality of distribution is fulfilled, the Pearson correlation coefficient was r=0.081 and p=0.707. The results showed that there are not any relations between the initial kilometrage and the annual number of orders at the maintenance and service system of the examined units in 2015. Figure 1 presents the chart of dispersion between the analyzed variables. For Solaris Urbino 12, the results indicated an average relation (statistically insignificant), whereas for Merceedes-Benz 628 O 530 G Citaro, an average correlation was indicated (statistically insignificant). For Autosan M12LF buses, the Spearman correlation coefficient R=0.3171 and p=0.0206 indicate an average correlation (statistically significant) between the initial kilometrage and the annual number of orders.

For the relation of the annual kilometrage of the buses to the annual number of orders at the maintenance and service system of the examined units, the obtained values of non-parametric correlation coefficients indicate unequivocally that there is no relation of the examined units for Autosan M12LF buses (Table 9). In case of relations between these variables for Mercedes-

Table 7. Types of the kilometer distribution of the annual kilometrage for the number of orders at the maintenance and service system of the examined units for particular buses

Bus manufacturer	Shapir -Wilk statistic W	Significance level / P - value p	Normal	Kologorow -Smirnow statistic K - S	Significane level / P - value p	Distribution (parameters)
Autosan	0.9659	0.1349	Yes			
Jelcz	0.9454	0.2157	Yes			
Mercedes	0.9050	0.0175	No	0.1561	p>0.20	Extreme value location=36.6568 scale=5.6708
Solaris	0.9309	0.1611	Yes			

Table 8. Correlation coefficients' values between the initial kilometrage and the annual number of orders at the maintenance and service system of the examined units for particular buses

Bus manufacturer	Correlation coefficients	P - value p	Statistical significance	Type of correlation
Autosan	R=0.3171	0.0206	Yes	Average correlation
Jelcz	r=0.081	0.707	No	No relation
Mercedes	R=0.3122	0.1127	No	Average correlation
Solaris	r=0.3838	0.095	No	Average correlation

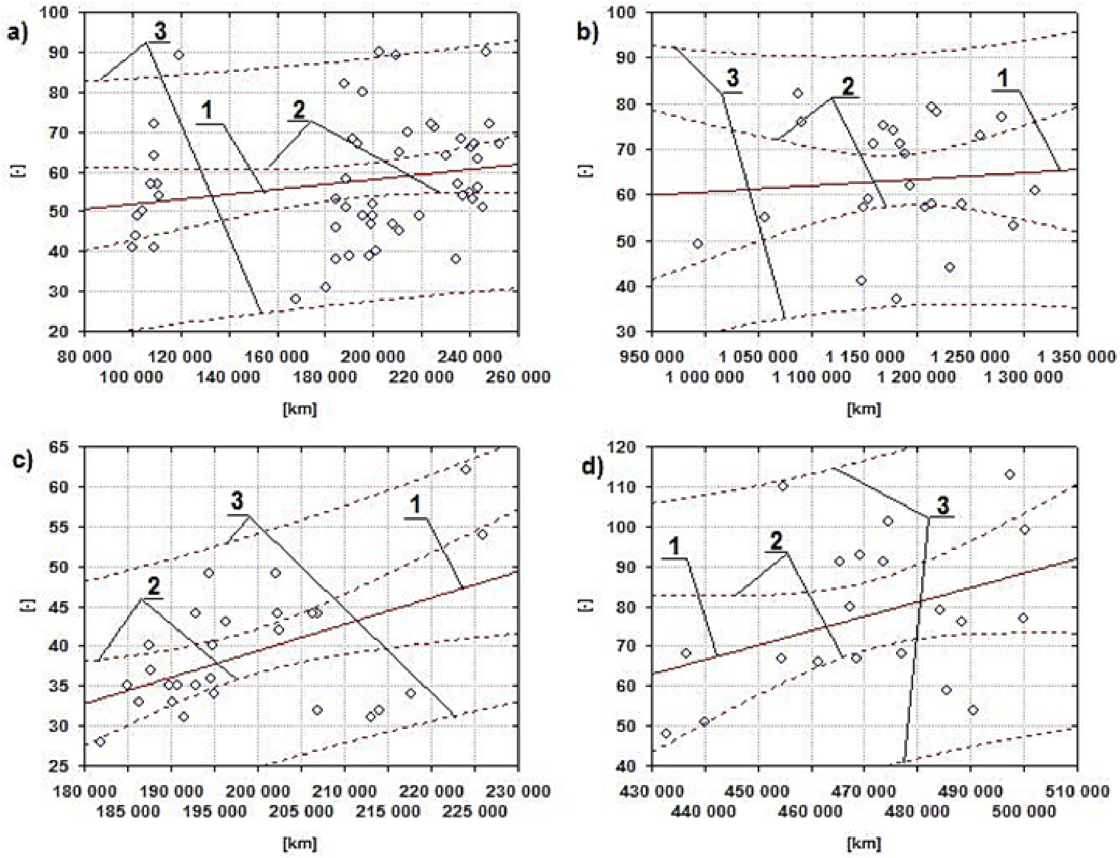

Fig. 1. The chart of dispersion and the regression line between the initial kilometrage and the annual number of orders at the maintenance and service system of the examined units for buses; a) Autosan, b) Jelcz, c) Mercedes, d) Solaris, 1 - regression line, 2 - confidence interval for the forecasted average observation, 3 - confidence interval for the forecasted observation

Benz 628 O 530 G Citaro and Solaris Urbino 12, the results of correlation coefficients give a clear indication of a weak correlation (statistically insignificant). When it comes to Jelcz M121 buses, the obtained correlation coefficients' values give a clear indication of an average correlation (statistically significant) between the annual kilometrage of the buses and the number of orders at the maintenance and service system of the examined units. The obtained results were depicted in Figure 2.

Non-parametric correlation coefficients' values give a clear indication of a weak correlation (statistically insignificant) between the annual and initial kilometrage of Autosan M12LF and Solaris Urbino 12 buses. When it comes to the correlation coefficients' values for the two other buses, they give indication of an average correlation. For Jelcz M121 it is statistically significant. The results of the analysis were presented in Table 10.

The chart of dispersion between the initial and the annual kilometrage of the vehicles' units was

Table 9. Correlation coefficients' values between the annual kilometrage and the number of orders at the maintenance and service system of the examined units for particular buses

Bus manufacturer	Correlation coefficients	P - value p	Statistical significance	Type of correlation
Autosan	R=-0.0325	0.2036	No	No relation
Jelcz	R=0.4533	0.026	Yes	Average correlation
Mercedes	R=-0 2175	0.9142	No	Weak correlation
Solaris	r=0.2913	0.213	No	Weak correlation

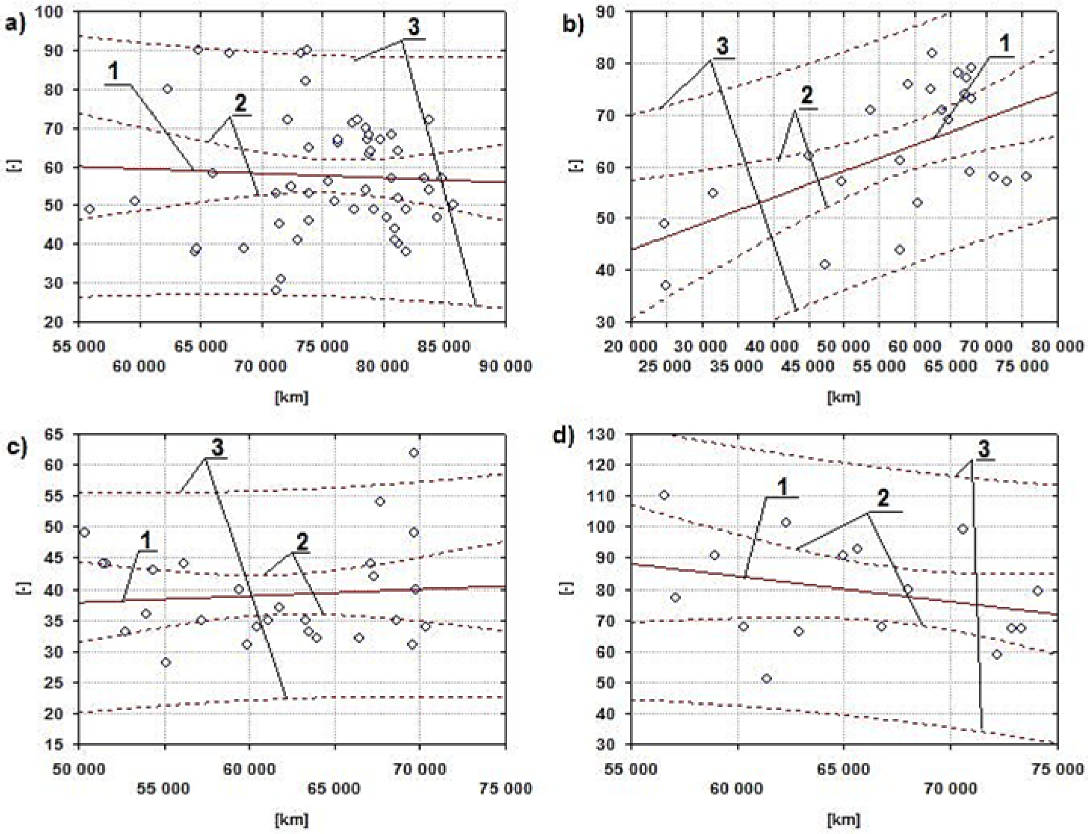

Fig. 2. The chart of dispersion and the regression line between the annual kilometrage and the annual number of orders at the maintenance and service system of the examined units for buses; a) Autosan, b) Jelcz, c) Mercedes, d) Solaris, 1 - regression line, 2 - confidence interval for the forecasted average observation, 3 - confidence interval for the forecasted observation

presented in the Figure 3. The regression line and the confidence interval for the forecasted average observation were also indicated on the charts.

The analysis of variance was conducted in order to check whether the variations in average values of the initial and annual kilometrage and of the annual number of orders at the maintenance and service system of the examined units, depending on the bus type, are statistically significant.

Based on results relating to a type of distribution, it may be stated that the assumption about the normality of the distributions of the analyzed variations for particular types of buses is not fulfilled. Because of that, non-parametric analysis of variance with use of Kruskal-Wallis test K-W was used. Results of the aforementioned analysis for the manipulative factors, which are types of the examined buses, were presented in Table 11.

Calculations presented in Table 11 show, on an applied level of significance $\alpha = 0.05$, that observed differences in average values of the initial and annual kilometrage and the annual number of orders at the maintenance and service system are statistically significant for the examined buses. The results of multiple comparisons (post - hoc) of K-W test for the analyzed variables were presented in Table 12.

Table 10. Correlation coefficients' values between the annual and the initial kilometrage for particular buses

Bus manufacturer	Correlation coefficient	P - value p	Statistical significance	Type of correlation
Autosan	R=0.1774	0.2036	No	Weak correlation
Jelcz	R=0.4605	0.0235	Yes	Average correlation
Mercedes	R=0.3791	0.0511	No	Average correlation
Solaris	r=0.2575	0.273	No	Weak correlation

Table 11. The results of Kruskal-Wallis K-W test of the equality of means of the initial and annual kilometrage and the annual number of orders at the maintenance and service system of the examined units for particular buses (manipulative variable- a type of bus)

Variable	K-W Statistic's value	P - value p	Are there differences decision
Initial kilometrage	88.6784	0.00001	Yes
Annual kilometrage	55.0636	0.00001	Yes
Number of orders	59.4581	0.00001	Yes

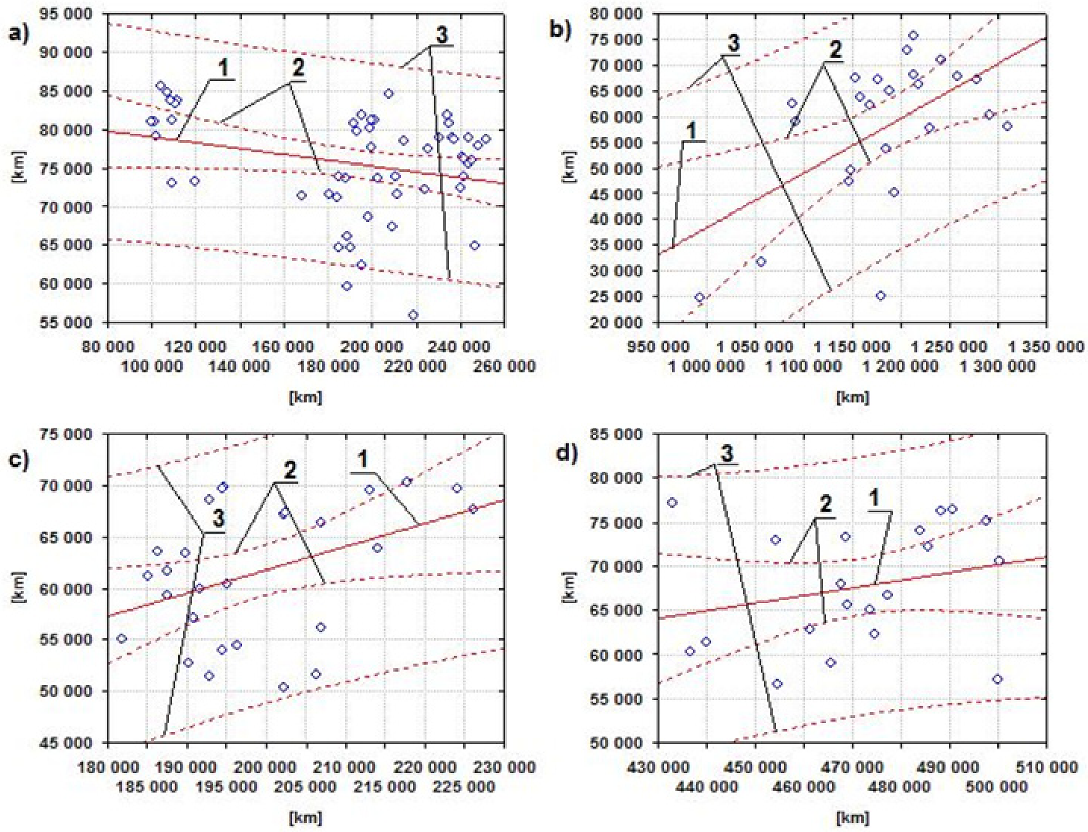

Fig. 3. The chart of dispersion and the regression line between the annual and the initial kilometrage for buses: a) Autosan, b) Jelcz, c) Mercedes, d) Solaris, 1 - regression line, 2 - confidence interval for the forecasted average observation, 3 - confidence interval for the forecasted observation

The results presented in Table 12 point out unequivocally that the observed differences for the initial kilometrage of the buses are between Autosan and Jelcz, Autosan and Solaris, Jelcz and Mercedes and Solaris and Mercedes. Figure 4 represents a categorized box plot for the initial kilometrage for the examined types of buses. The post-hoc tests results presented in Table 13 point

Table 12. The results of multiple comparisons for the means of the initial kilometrage for the examined buses

Type of bus	Autosan	Jelcz	Mercedes	Solaris
Autosan	------	0.000001	1.0000	0.000001
Jelcz	0.000001	------	0.000001	0.2591
Mercedes	1.0000	0.000001	------	0.000006
Solaris	0.000001	0.2591	0.000006	------

Table 13. The results of multiple comparisons for the means of the annual kilometrage for the examined buses

Type of bus	Autosan	Jelcz	Mercedes	Solaris
Autosan	------	0.000001	0.000001	0.0046
Jelcz	0.000001	------	1.0000	0.2096
Mercedes	0.000001	1.0000	------	0.2233
Solaris	0.0046	0.2096	0.2233	------

Table 14. The results of multiple comparisons for the annual number of orders at the maintenance and service system of the examined units for the examined buses

Type of bus	Autosan	Jelcz	Mercedes	Solaris
Autosan	------	0.6727	0.000001	0.0026
Jelcz	0.6727	------	0.000001	0.4740
Mercedes	0.000001	0.000001	------	0.000001
Solaris	0.0026	0.4740	0.000001	------

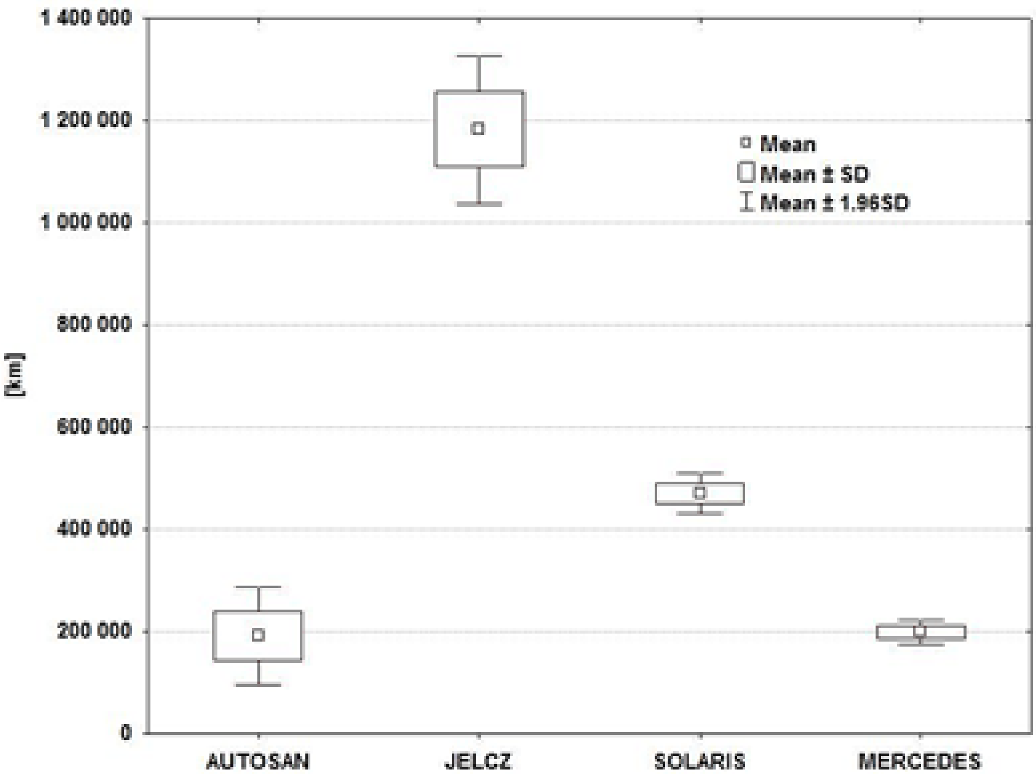

Fig. 4. Categorized box plot for an independent factor - a type of bus, and a dependent variable - the initial kilometrage

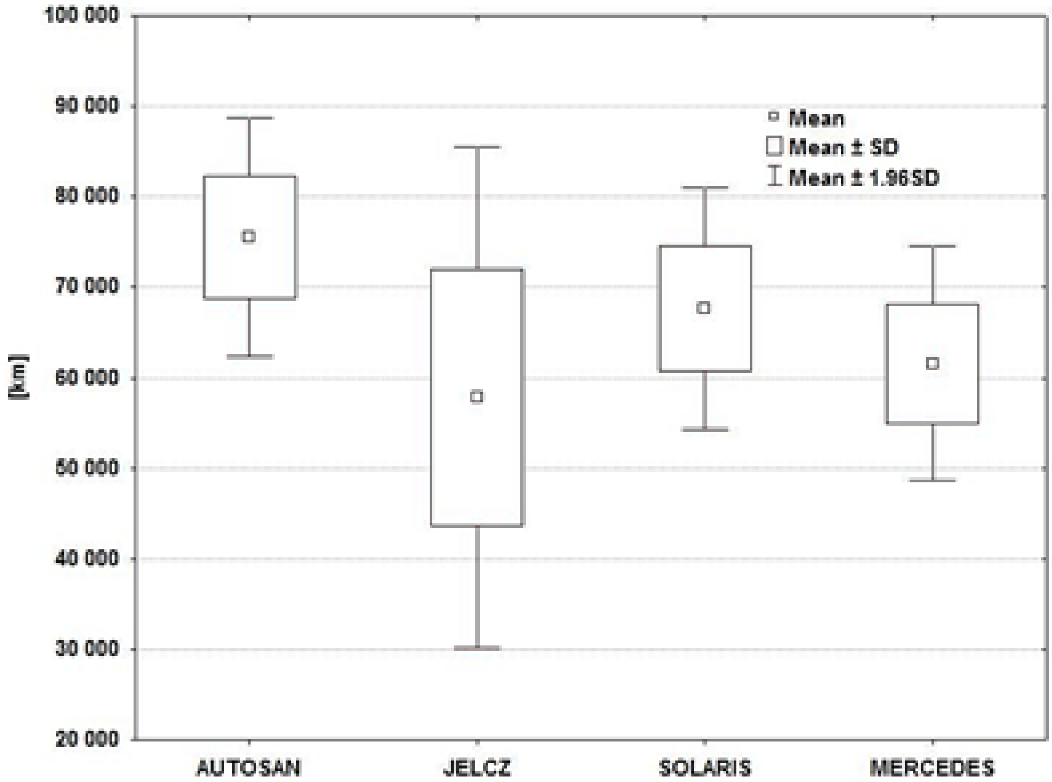

Fig. 5. Categorized box plot for an independent factor - a type of bus, and a dependent variable - the annual kilometrage

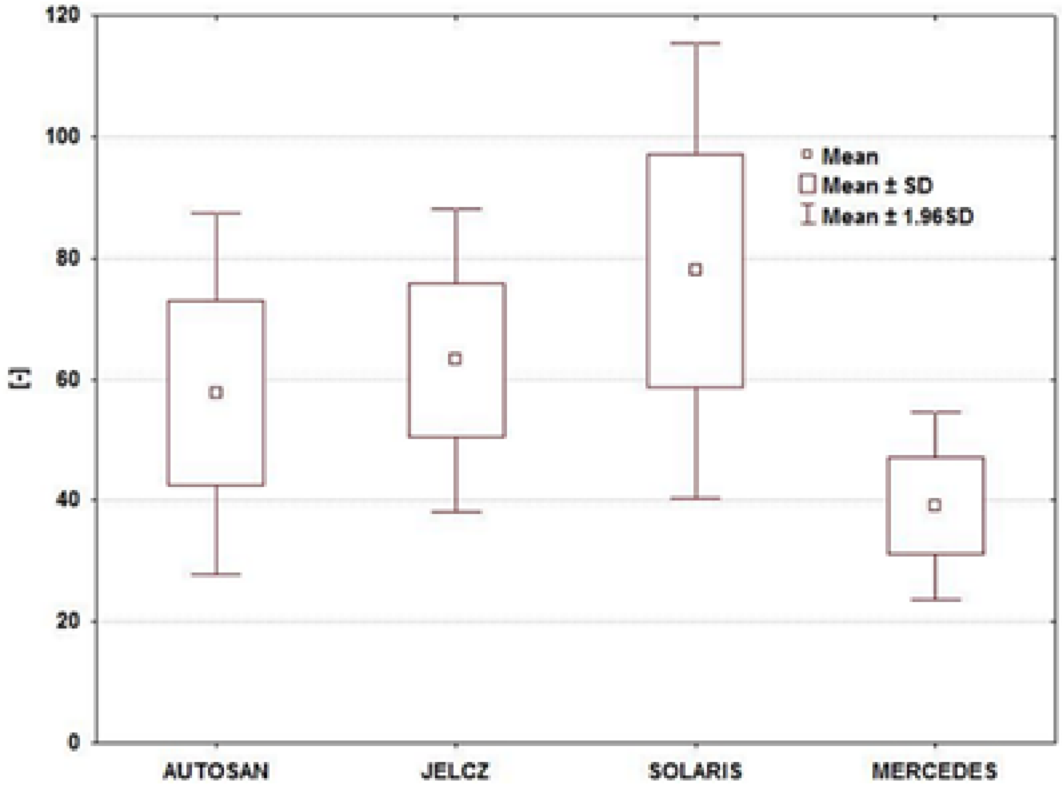

Fig. 6. Categorized box plot for an independent factor - a type of bus, and a dependent variable - the annual number of orders at the maintenance and service system of the examined units

out unequivocally that the observed differences for the annual kilometrage of buses exist between Autosan and Jelcz, Autosan and Mercedes, Autosan and Solaris. Figure 5 depicts a categorized box plot for the annual kilometrage for the examined buses.

The results of multiple comparisons for the annual number of orders at the maintenance and service system of the examined units for the examined buses indicate clearly that the observed differences of the annual number of orders at the maintenance and service system of the examined units exist between Autosan and Mercedes, Autosan and Solaris, Jelcz and Mercedes, Mercedes and Solaris.

Figure 6 depicts a categorized box plot for the annual number of orders at the maintenance and service system of the examined units for the examined buses.

CONCLUSIONS

Based on the analysis of obtained results of the combustion engines' sets and elements used in four brands that were exploited by Municipal Transport Company Lublin in 2015, the following conclusions were drawn:

1. A small relation between the number of registered orders at the maintenance and service system of combustion engines and the initial kilometrage for particular buses may be observed. It implies that buses with higher kilometrage are more prone to sustain the combustion engine damage.
2. A similar observation relates to correlation between the annual kilometrage and the number of registered orders at the maintenance and service system of combustion engines.
3. The occurring differences in the annual kilometrage of the buses exploited by Municipal Transport Company Lublin in 2015 indicate a non-uniform exploitation of different vehicles by this carrier. Unfortunately, based on the analysis of the available data, it is impossible to state what factors caused this situation.
4. The highest number of maintenance and service of combustion engine orders was registered for the Solaris buses. Taking into consideration the fact that their initial kilometrage was similar to the buses of other manufacturers, it must be stated, that the engines in the Solaris buses are the most unreliable.

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