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Original article

Fault analysis of the combustion engine used in public transport vehicles

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INFORMATIONS

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ABSTRACT

The goal of this article is the fault analysis of combustion engines on the basis of the assessment of dependent variables: initial mileage, annual mileage and the annual number of orders made in the service and repair system compared with the independent factor, i.e. bus make. In the research four vehicle makes were tested: Jelcz M121, Mercedes-Benz Citaro, Solaris Urbino 12 and Autosan Sancity 12LF. The research encompassed the number of faults of a vehicle and its systems, the initial and annual mileage. It was conducted on the basis of 2015 data broken into particular months.

KEYWORDS

engine, mileage, service

Introduction

Reliability plays a significant role at each stage of an industrial process from manufacturing to exploitation. In the analysis of engine reliability it is necessary to know the construction and operation of the engine as well as the specificity of the faults of its elements and subassemblies [Rymarz 2015]. A better reliability of an engine means a possibility to cover longer distances while maintaining a small number of faults and low exploitation costs. Among others, it is related to the number of kilometres, the number of service and repair orders as well as exploitation intensity [Wierzbicki and Smieja 2014].

Transport services depend on the performance of the whole bus transmission system and particularly the combustion engine. These are the reasons why it is possible to find numerous research works referring to vibro-acoustic methods used in the diagnostics of combustion engines [Juscinski and Piekarski 2010; Internal materials… n.d.; Rymarz and Niewczas 2012; Woropay et al. 2014].

Due to this, the static analyses of engine element faults are of paramount importance and are frequently conducted [Drozdziel et al. 2014; Myslowski and Myslowski 2006].

The analysis of the available data related to the repairs of the combustion engine system of buses used by the Municipal Transport Company in Lublin.

1. Results analysis

Reliability is defined as the ability to conduct operating tasks without engine outage caused by a fault in a defined period of time and in assumed conditions [Woropay et al. 2014]. The exploitation of vehicles is inseparably connected with the possibility of fault occurrence. The investigation of random fault occurrence documentation is time consuming. The information on the vehicle use process is obtained on the basis of a basic document, namely a waybill. It is completed every day and submitted to the vehicle exploitation department, among others, to obtain the information on the mileage of a given vehicle and possible faults [Rymarz 2015]. The subject of the research were the bus engines of the following makes: Jelcz M121, Mercedes-Benz Citaro, Solaris Urbino 12 and Autosan Sancity 12LF. The investigated engines were not produced at the same time. The oldest model was the Jelcz M121 engine and the newest were the Mercedes-Benz Citaro and Autosan Sancity 12LF engines. The data allowed to determine the initial and the annual mileage of the vehicles as well as the number of registered service and repair orders. The technical data of the tested vehicles are presented in Table 1.

Table 1. Selected technical data of analysed vehicles

Bus make	**Engine type**	**Engine power [kW (KW)]**	**Length [mm]**	**Width [mm]**	**Height [mm]**	**Total mass [kg]**
Autosan Sancity 12LF	IVECO F2BE3682 B	243 (330)	12 000	2500	2890	18 000
Jelcz M121	MAN D0826 LUH 12	162 (220)	12 000	2500	3021	17 500
Mercedes-Benz Citaro	OM 457 LA	220 (300)	12 000	2500	2994	28 000
Solaris Urbino 12	DAF PR 183 SI	220 (300)	12 000	2550	2850	18 000

Source: [Internal materials… n.d.].

The sample size was 24 Jelcz M121 vehicles, 20 Solaris Urbino 12 vehicles, 27 Mercedes-Benz Citaro ones and 53 Autosan Sancity 12LF ones. During the fault rate test all events takin place in the period of the previous 12 months were taken into account. The following engine systems and elements were taken into consideration:

– cooling system,
– feed system,
– intake and exhaust system,
– camshaft,
– engine accessories,
– engine compartment extinguishing system,
– engine [Michalski and Wierzbicki 2006].

The obtained empirical data were introduced to the Statistica software. Statistical analyses were conducted using the Shapiro-Wilk and Kolmogorov-Smirnov normality tests, the conformity of the obtained results of empirical research for the analysed variables with the normal distribution was checked.

1.1. Statistical analysis of the obtained initial mileages of the analysed bus makes

Table 2 presents the statistical calculations of the probability level and corresponding distributions selected to match materiality level α=0.05.

Table 2. Types of initial mileage distribution for particular buses

Bus make	Shapiro--Wilk statistics W	Probability level *p*	Normal	Kologorov--Smirnov statistics K-S	Probability level *p*	Distribution
Autosan Sancity 12LF	0.8553	0.0001	No	0.1960	p>0.05	Weibull threshold = 0.0000 scale=209504.6 shape=5.16
Jelcz M121	0.9640	0.524	Yes			
Mercedes-Benz Citaro	0.9235	0.048	No	0.1331	p>0.20	Extreme value position = 193685.8 scale=8885.5
Solaris Urbino 12	0.9540	0.4326	Yes			

Source: [Own elaboration].

Table 2 shows that Jelcz M121 and Solaris Urbino 12 buses were characterised by normal distribution while Autosan Sancity 12LF had the Weibull distribution and Mercedes-Benz Citaro had extreme values. Figure 1 presents the histogram of the initial mileage for the investigated bus population representing various bus makes with the density function of normal distribution matching empirical data.

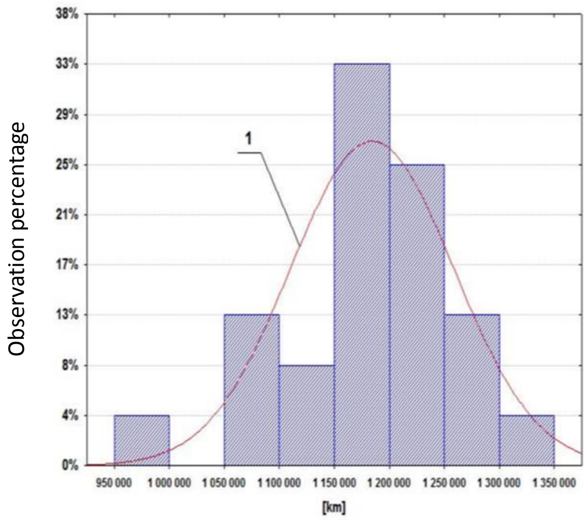

Fig. 1. Histogram of the initial mileage of tested vehicles Jelcz M121,
1 – density function matches empirical data
Source: [Own elaboration].

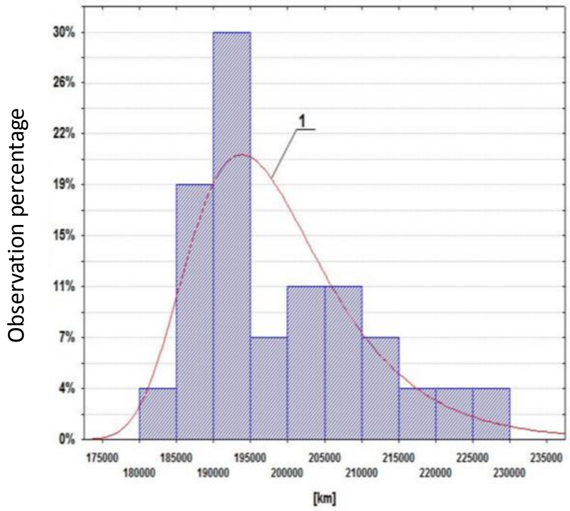

Fig. 2. Histogram of the initial mileage of tested vehicles Mercedes-Benz Citaro,
1 – density function matches empirical data
Source: [Own elaboration].

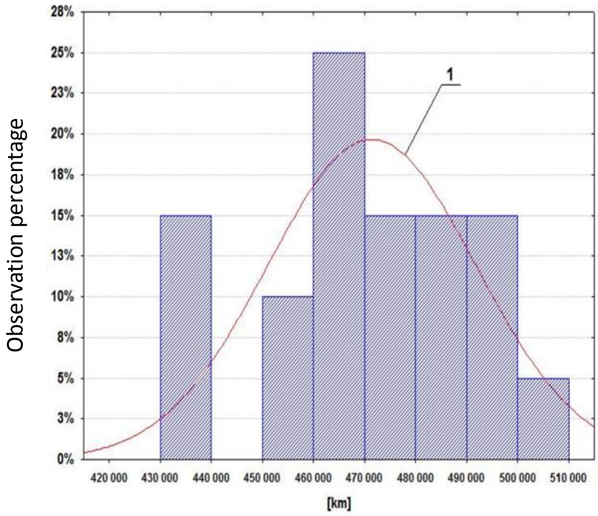

Fig. 3. Histogram of the initial mileage of tested vehicles Solaris Urbino 12,
1 – density function matches empirical data
Source: [Own elaboration].

The initial mileage distribution of Jelcz buses can be matched with the normal distribution presented in the histogram in Fig. 1,it shows that the mileage of 33% of buses was in the range of 1 150 000-1 200 000 km. The mileage of 25% of buses was in the range of 1 200 000-1 250 000 km. None of the buses had the initial mileage value in the range of 1 000 000-1 050 000 km. The initial mileage of 66% of the tested bus population was 150 000 km. The investigation on the conformity of the empirical distribution with the normal distribution showed that the initial mileage distribution cannot be matched with the normal distribution presented in the histogram in Figure 2, which shows that 30% of the buses had the initial mileage in the range of 190 000-195 000 km, 19% in the range of 185 000-190 000 km. The initial mileage value of 67% of the investigated Mercedes-Benz Citaro bus population was 20 000 km. The investigation on the conformity of the empirical distribution with the normal distribution showed that the initial mileage distribution of Solaris Urbino 12 buses can be matched with the normal distribution presented in the histogram in Figure 3, which shows that 25% of buses had the initial mileage in the range of 460 000-470 000 km, 15% in the range of 430 000-440 000 km and more than 470 000-500 000 km, none of the buses had the initial mileage in the range of 440 000-450 000 km. The analysis of the conformity of the empirical distribution with the normal distribution that the initial mileage distribution of Autosan Sancity 12LF buses (Fig. 4) cannot be matched to the normal distribution, which shows that about 21% had the initial mileage in the range of 236 861.7-252 069.0 km, 19% in the range of 99 996.0-115 203.3 km and 191 239.8-206 447.0 km, none of the buses had the initial mileage in the range of 130 410.6-160 825.2 km. The initial mileage of 47% of the investigated Autosan Sancity 12LF bus population had the initial mileage of 60 800 km.

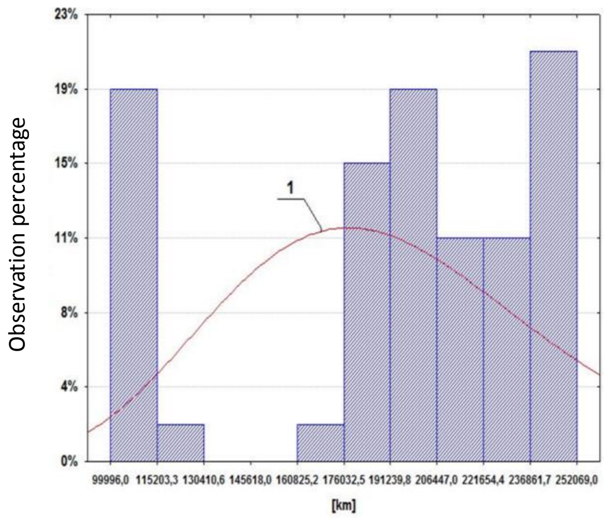

Fig. 4. Histogram of the initial mileage of tested vehicles Autosan Sancity 12 LF,
1 – density function matches empirical data
Source: [Own elaboration].

Table 3 below presents the position and dispersion parameters describing the distributions of the above histograms. It shows Mercedes-Benz Citaro buses had the smallest initial mileage obtained before the end of 2014 and Jelcz M121 buses had the biggest mileage.

Table 3. Position and dispersion parameters of the initial mileage for particular bus makes

Bus make	Average value	Standard deviation	Median	Minimum value	Maximum value
Autosan Sancity 12LF	191710.3	48302.7	199 619	99 996	252 069
Jelcz M121	1183134	74056.7	1 186 400	993 675	1 310 836
Mercedes-Benz Citaro	199031.7	11910.9	194 764	181 900	226 024
Solaris Urbino 12	471430.7	20277.8	471 390	432 978	500 283

Source: [Own elaboration].

1.2. Statistical analysis of the obtained annual mileages of the analysed bus makes

The conformity analysis of empirical distribution with normal distribution showed that the annual mileage distribution of the investigated Solaris Urbino 12 buses can be matched with normal distribution. The Shapiro-Wilk statistics is W=0.9596 and *p*=0.5362, which is presented in Table 4. In the case of the other analysed bus makes the statistical analysis of the conformity of empirical distribution with normal distribution showed that the annual mileage cannot be approximated with the normal distribution. The calculations showed that the make which had the best match to empirical data in terms of the log-normal distribution was Autosan Sancity 12LF, in terms of Weibull distribution – Jelcz M121 and for extreme values – Mercedes-Benz Citaro.

Table 4. Types of annual mileage distribution for particular bus makes

Bus make	Shapiro--Wilk statistics W	Probability level *p*	Normal	Kologorov--Smirnov statistics K-S	Probability level *p*	Distribution
Autosan Sancity 12LF	0.9368	0.0075	No	0.1242	*p*>0.20	Log-normal thresh-old =0.000, scale=11.23, shape=0.094
Jelcz M121	0.8561	0.0028	No	0.1708	*p*>0.20	Weibull thresh-old=62842.79, scale=5.66, shape=0.1708
Mercedes-Benz Citaro	0.9207	0.041	No	0.1383	*p*>0.20	Extreme values position =58282.09, scale=6105.89
Solaris Urbino 12	0.9596	0.5362	Yes			

Source: [Own elaboration].

Figure 2 presents the histogram obtained for the annual mileage of the investigated bus population with the density function of the Weibull distribution matched to empirical data.

The investigation of the conformity between empirical distribution and normal distribution showed that the annual mileage distribution for the tested Jelcz M121 buses could not be matched to the normal distribution presented in the histogram (Fig. 5), which shows that 25% had the annual mileage in the range of 65 000-70 000 km, 21% in the range of 60 000-65 000 km. None of the buses had the annual mileage in the range of 35 000-45 000. The annual mileage of 84% of the investigated Jelcz M121 bus population was 30 000 km. The investigation of conformity of empirical distribution with normal distribution showed that the annual mileage distribution of Mercedes-Benz Citaro buses could not be matched with the normal distribution presented in the histogram (Fig. 6). The annual mileage of 19% of buses was in the range 68 000-70 000 km, 15% in the range of 66 000-68 000 km, 11% in the range of 50 000-52 000, 54 000-56 000 and 60 000-64 000 km. None of the buses had the annual mileage distribution in the range of 64 000-66 000 km. The distance covered by 62% of the tested Mercedes-Benz Citaro bus population was 14 000 km per year. The analysis of the conformity between empirical distribution with normal distribution showed that the distribution of Solaris Urbino 12 buses can be matched to normal distribution. The histogram (Fig. 7) shows that 15% of the buses had the annual mileage in the range of 72 000-74 000 km and 76 000-78 000 km. The annual mileage of 10% of the buses was in the range of 56 000-58 000 km, 60 000-66 000 and 74 000-76 000 km. In the case the Solaris Urbino 12 buses, 50% of the tested population covered the distance of 12 000 km per year. In terms of the conformity between empirical distribution and normal distribution, the annual mileage distribution for the Autosan Sancity 12LF buses could not be matched with the normal distribution presented in the histogram (Fig. 8). About 21% of buses had the annual mileage distribution in the range of 76 752.3-79 734.2 km, 19% in the range of 70 788.5-73770.4 km and 79 734.2-82 716.1 km. The distance covered by 74% of the tested Autosan Sancity 12LF bus population was 14 900 km per year.

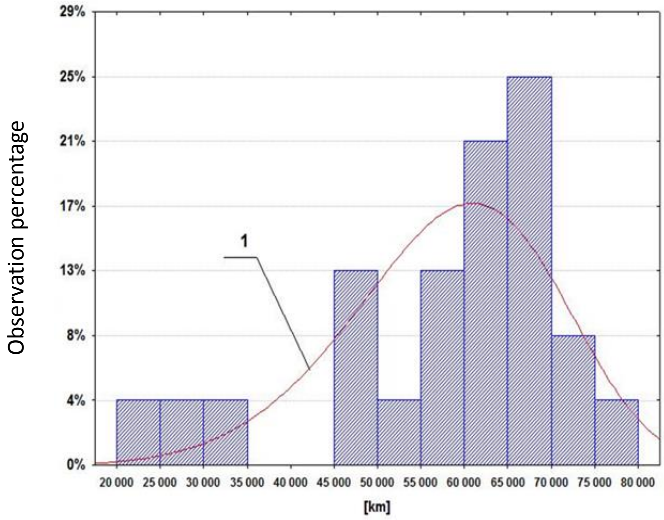

Fig. 5. Histogram of the annual mileage of tested vehicles Jelcz M121,
1 – density function matches empirical data
Source: [Own elaboration].

Table 5. Position and dispersion parameters of the annual mileage for particular bus makes

Bus make	**Average value**	**Standard deviation**	**Median**	**Minimum value**	**Maximum value**
Autosan Sancity 12LF	75570	6756.5	77446	55879	85698
Jelcz M121	57867	14131.9	62229	24903	75621
Mercedes-Benz Citaro	61577.7	6616.3	61743	50384	70363
Solaris Urbino 12	67654.1	6849.0	67388	56593	77184

Source: [Own elaboration].

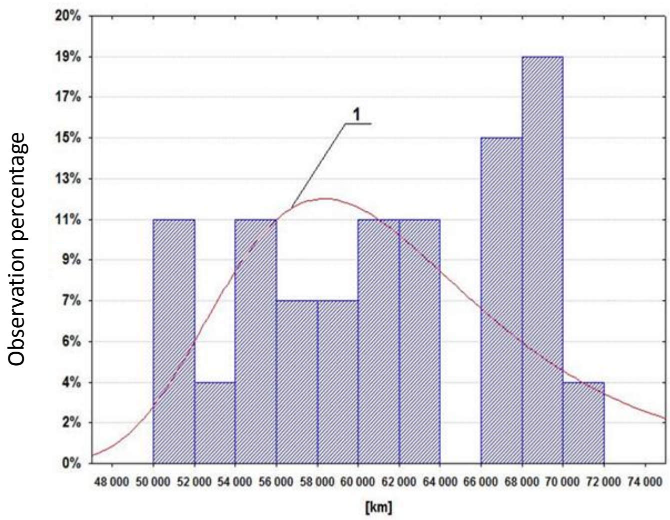

Fig. 6. Histogram of the annual mileage of tested vehicles Mercedes-Benz Citaro,
1 – density function matches empirical data
Source: [Own elaboration].

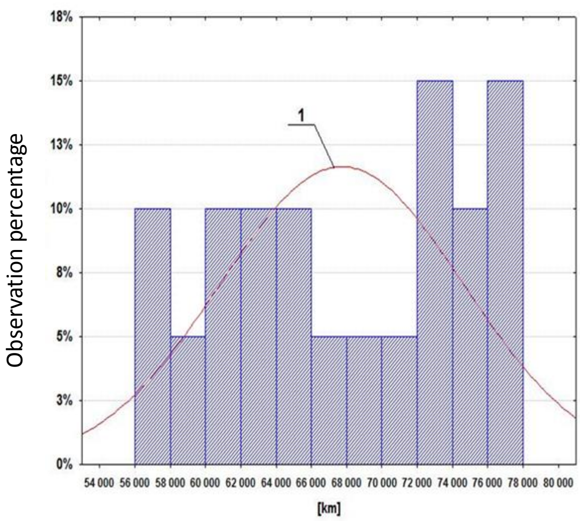

Fig. 7. Histogram of the annual mileage of tested vehicles Solaris Urbino 12,
1 – density function matches empirical data
Source: [Own elaboration].

The analysis of the annual mileage of particular buses (Table 5) shows that the longest annual distances were covered by the Autosan Sancity 12LF buses, while the shortest ones by the Jelcz M121 buses with the biggest difference between the minimum and maximum number of covered kilometres.

1.3. Statistical analysis of the annual number of service and repair orders for the systems of the investigated bus makes

In the case of the statistical analysis the conformity tests of empirical and normal distribution showed that the annual mileage distribution for the number of service and repair orders of the investigated systems of the following buses: Autosan Sancity 12LF, Jelcz M121 and Solaris Urbino 12 can be matched using normal distribution. The Shapiro-Wilk statistics for them was W=0.9659 and p=0.1349, W=0.9454 and p=0.2157, W=0.9309 and p=0.1611, respectively. The investigation of the conformity between the empirical and normal distribution for Merceedes-Benz Citaro showed that the distribution of the annual number of service and repair orders related to the tested systems can be matched using normal distribution. The calculations showed that the distribution of the extreme values presented in Table 6 were best matched with the empirical values.

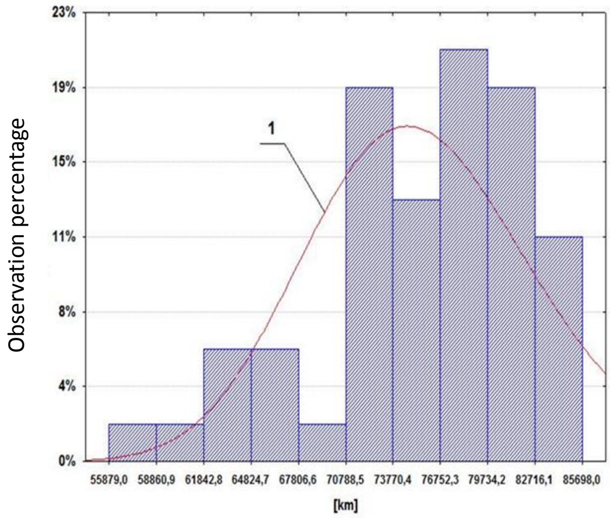

Fig. 8. Histogram of the annual mileage of tested vehicles Autosan Sancity 12LF, 1 – density function matches empirical data
Source: [Own elaboration].

Table 6. Types of annual mileage distribution for the number of registered service and repair orders related to the tested systems of particular bus types

Bus make	**Shapiro- -Wilk statistics W**	**Probability level *p***	**Normal**	**Kologorov- -Smirnov statistics K-S**	**Probability level *p***	**Distribution**
Autosan Sancity 12LF	0.9659	0.1349	Yes			
Jelcz M121	0.9454	0.2157	Yes			
Mercedes-Benz Citaro	0.9050	0.0175	No	0.1561	*p*>0.20	Extreme values Position =36.6568, scale=5.6708
Solaris Urbino 12	0.9309	0.1611	Yes			

Source: [Own elaboration].

Figure 3 presents the histogram of the annual number of service and repair orders for the tested systems of the investigated vehicles with the density function of normal distribution matched to empirical data.

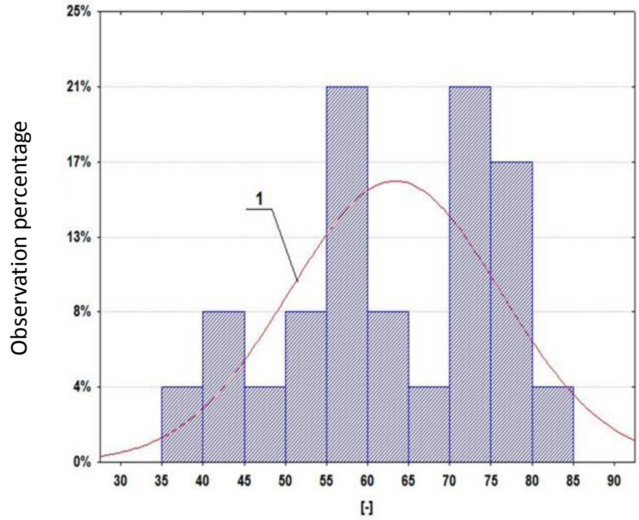

Fig. 9. Histogram of the annual number of service and repair orders for the tested systems of Jelcz M121, 1 vehicles – density function matches empirical data
Source: [Own elaboration].

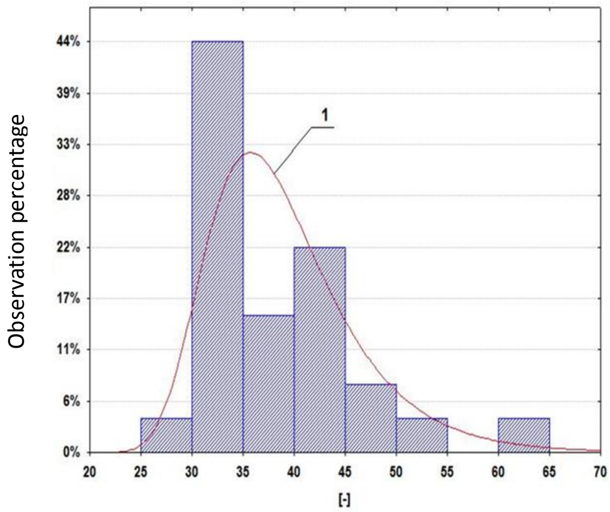

Fig. 10. Histogram of the annual number of service and repair orders for the tested systems of Mercedes-Benz Citaro, 1 vehicles – density function matches empirical data
Source: [Own elaboration].

The tests of the conformity between empirical distribution and normal distribution showed that the distribution of the annual number of service and repair orders for the Jelcz M121 buses can match the normal distribution presented in the histogram (Fig. 9), which means that for 21% of buses the annual number of orders was in the range of 55-60 and 70-75, 17% in the range of 75-80. The number of service and repair orders for 62% of the investigated population of Jelcz buses was 25. The conformity between empirical and normal distribution showed that the distribution of the annual number of service and repair orders in the case of the Mercedes-Benz Citaro buses can be matched using the normal distribution presented in the histogram (Fig. 10), which shows that for 44% of the buses the annual number of orders was in the range of 30-35% and for 22% in the range of 40-45%. In the case of 81% of the analysed buses the number of service and repair orders was 15. The analysis of the conformity between empirical distribution and normal distribution showed that the distribution of the annual number of service and repair orders for the Solaris Urbino 12 buses can be matched to the normal distribution presented in the histogram (Fig. 11), which shows that for 25% of the buses the number of orders was in the range of 60-70 and for 20% of them the number was in the range of 70-80 and 90-100. The number of service and repair orders for 65% of the tested population of buses was 40 per year. The investigation of the conformity between empirical and normal distribution showed that the distribution of the number of service and repair orders for the Autosan Sancity 12LF buses can be matched to the normal distribution presented in the histogram (Fig. 12), which means that for 19% of the buses the number of orders per year was in the range of 46.6-59.0 and for 15% in the range of 65.2-71.4. The number of service and repair orders was 25 for 61% of the investigated population of buses.

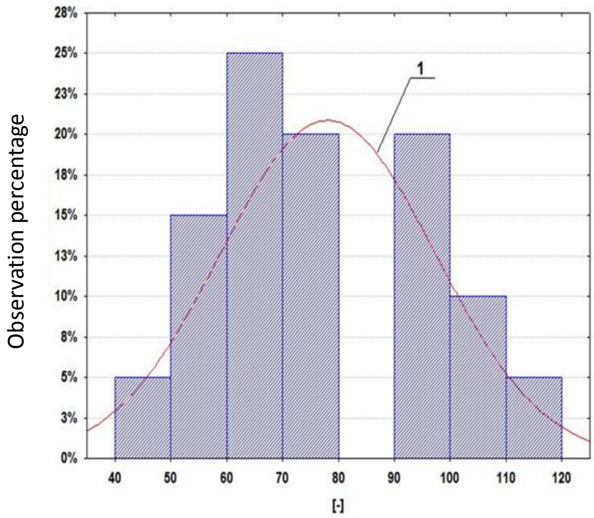

Fig. 11. Histogram of the annual number of service and repair orders for the tested systems of Solaris Urbino 12,1 vehicles – density function matches empirical data
Source: [Own elaboration].

Table 7. Position and dispersion parameters of the number of registered service and repair orders for the tested systems of particular bus types

Bus make	Average value	Standard deviation	Median	Minimum value	Maximum value
Autosan Sancity 12LF	57.6	15.19	55	28	90
Jelcz M121	60.2	12.78	62	37	82
Mercedes-Benz Citaro	39.1	7.91	36	28	62
Solaris Urbino 12	77.9	19.12	76	48	113

Source: [Own elaboration].

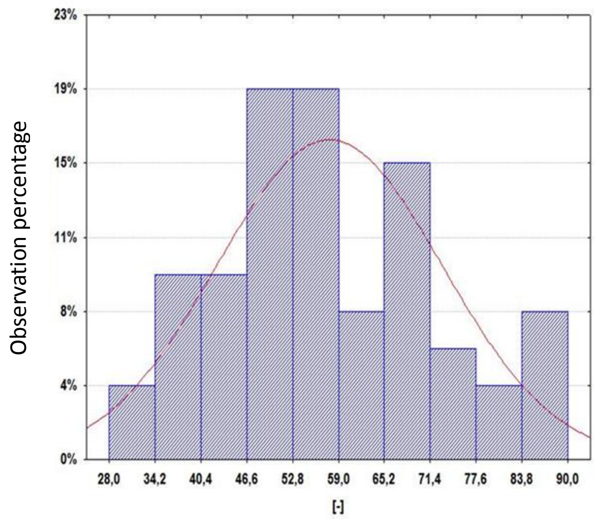

Fig. 12. Histogram of the annual number of service and repair orders for the tested systems of Autosan Sancity 12LF, 1 vehicles – density function matches empirical data
Source: [Own elaboration].

The parameters of the number of registered service and repair orders of the tested systems show that in the period of one year the Mercedes-Benz Citaro buses had the smallest number of orders and Solaris Urbino 12 the biggest (Table 7).

Conclusions

The analysis of the tested combustion engines took into consideration the following variables: initial mileage, annual mileage and the annual number of registered service and repair orders for the tested systems of the investigated group of buses: Jelcz M121 – 24 vehicles, Mercedes-Benz Citaro – 27 vehicles, Solaris Urbino 12 – 20 vehicles and Autosan Sancity 12LF – 53 vehicles. The above mentioned vehicles are used by the Municipal Transport Company in Lublin. They were manufactured at different times. The oldest vehicles were the Jelcz M121 buses made in the years 1996-1999, next Solaris Urbino 12 made in 2008, and then Mercedes-Benz Citaro and Autosan Sancity 12LF made in 2011.

The Mercedes-Benz Citaro buses were characterised by the smallest values of the initial and annual mileage as well as the number of service and repair orders for the tested systems of the combustion engine. This small mileage influences the small number of faults. In the case of Solaris Urbino 12, which had the largest number of service and repair orders of the tested systems, the initial mileage was not much bigger than that of Mercedes-Benz Citaro and Autosan Sancity 12LF. Its annual mileages was also comparable with all the other makes. Solaris Urbino 12 is also characterised by the frequent occurrence of the tested systems faults. The Autosan Sancity 12LF buses covered the largest number of kilometres per year with an average number of faults. No dependence was observed between the annual mileage and the annual number of service and repair orders for the tested systems. This may be due to the relatively small initial mileage comparable with that of Mercedes-Benz Citaro. The comparison of the annual mileage and the annual service and repair orders shows that the Autosan Sancity 12LF and Mercedes-Benz engines are characterised by a small number of faults, while the Solaris engines show the least positive results. Although the average number of Jelcz repairs was only slightly higher than the number of repairs for Autosan Sancity 12LF, taking into consideration the initial mileage which was five-fold bigger than that of Autosan Sancity 12LF and Mercedes-Benz Citaro, the Jelcz M121 engines seem to extremely reliable.

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Conflict of interests

The author declared no conflict of interests.

Author contributions

All authors contributed to the interpretation of results and writing of the paper. All authors read and approved the final manuscript.

Ethical statement

The research complies with all national and international ethical requirements.

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