EFFECTIVENESS OF THE FAILURE RATE ON MAINTENANCE COSTS OF THE CITY BUSES

WPLYW CZĘSTOŚCI USZKODZEŃ NA KOSZTY UTRZYMANIA AUTOBUSÓW KOMUNIKACJI MIEJSKIEJ

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Abstract: The purpose of this paper was to present a failure rate and maintenance cost comparison for two types of city transport buses. The paper presents in detail a case study of well known bus brands used at Municipal Transport Company in Lublin. A failure index of all functional and constructional systems of the vehicles and their technical availability with regards to calendar time was determined. The paper also presents analysis of the factors related to maintenance costs of buses, including costs of fluids, repair costs and maintenance service. It has been demonstrated, that both analyzed buses generate similar maintenance costs, while their failures and technical availability differ significantly in operational practice. These differences are particularly evident in relation to the cumulative costs of repairs.

Keywords: city transport buses, failure index, technical availability, maintenance costs

Streszczenie: Celem pracy było porównanie wpływu częstości uszkodzeń dwóch marek autobusów miejskich na koszty ich utrzymania. Przedstawiono szczegółowo studium przypadku na przykładzie znanych marek autobusów, użytkowanych w Miejskim Przedsiębiorstwie Komunikacyjnym w Lublinie. Wyznaczono wskaźniki uszkodzeń wszystkich układów funkcjonalno - konstrukcyjnych autobusów oraz ich gotowość techniczną w funkcji czasu kalendarzowego. W artykule zaprezentowano również analizę czynników związanych z kosztami eksploatacji autobusów, w tym m.in. koszty płynów eksploatacyjnych, koszty napraw i obsług. Wykazano, że w praktyce eksploatacyjnej w analizowanym okresie czasu pojazdy obu marek generują podobne koszty użytkowania, natomiast ich uszkodzenia oraz gotowość techniczna różnią się znacząco. Wymienione różnice są szczególnie widoczne w zakresie skumulowanych kosztów napraw.

Słowa kluczowe: autobusy komunikacji miejskiej, wskaźniki uszkodzeń, gotowość techniczna, koszty utrzymania

1. Introduction

An effective vehicle maintenance is a main issue for each user. It is especially significant in case of utility vehicles. Each carrier selecting vehicle brand takes into account factors related to forecasted operating costs of the vehicle. Manufacturers and sellers advertising their products usually emphasize such aspects as fuel consumption and technical maintenance frequency. Since these both factors generate most of the operating costs.

In this article analysis of the factors related to operating costs of the public buses are presented. Special focus is made to factors differentiating these costs. In order to do that costs directly related to vehicle use, such as fuel costs, engine oil, and AdBlue liquid were analysed. Analysis of maintenance costs was divided into two parts: costs related to scheduled maintenance works and costs related to failures. Due to the fact that failure vehicle does not generate any income, difference in revenues obtained during the use of buses of both brands was estimated. Thus, availability ratio was analysed. The ratio was applied as a ratio of possibility of vehicle use for profit-making.

2. Studies process

The study included Mercedes-Benz Conecto LF 628 and Solaris Urbino 12 buses at Municipal Transport Company in Lublin [14]. The study included 22 buses of Mercedes-Benz 628 Conecto LF and 20 buses of Solaris Urbino 12. All buses were observed from the first day of the operation (January 2009 for Mercedes-Benz and June 2008 for Solaris) to the 57 months of operation and had similar vehicle mileage. The studies were conducted under natural conditions at Municipal Transport Company in Lublin.

3. Use of operating liquids

In the conducted analyses the costs related directly to vehicle usage included the following costs: fuel, diesel, AdBlue liquid, windshield washer fluid, air conditioning filling factor (gas and oil) and engine oil. Characteristics of fuel, AdBlue fluid, oil and number of kilometres done by the vehicles are listed in table 1. Presented data were obtained based on the analysis of the operating documentation within the period of 57 months. It can be seen that for both brands a monthly mileage was similar and was approximately 6 thousand km per one bus within a month.

Table 1. Characteristics of operating fluids consumption during 57 months of operation

	Mercedes Benz	Solaris Urbino
Average mileage /1 bus x 1 month [km]	5811	6081
Average fuel consumption/ 100 km x 1 bus[l]	39,47	39,78
Average fuel consumption /100km acc. to standard x 1bus [l]	40,99	39,99
Average fuel consumption with central heating /100 km x 1bus [l]	40,87	41,17
Average AdBlue fluid consumption /1 bus x 1 m-c [l]	86,9	10,3
Average AdBlue fluid consumption specified by the manufacturer [dm ³ /100 km]	1,3	0,21
Average engine oil consumption/1 bus x 1 m-c [l]	2,92	4,16

Average fuel consumption per month of operation of 1 vehicle for both brands is comparable and is above 39 l/100 km. Fuel consumption for central heating in winter season increases for approximately 1.5 l/100 km. A significant part in costs of operating fuels is AdBlue fluid costs. A monthly consumption of AdBlue is approx. 86.9 l for Mercedes buses and 10.3 l for Solaris.

4. Failure characteristics

Analysis included failures of all systems and structural units of the studied buses. Figure 1 presents average failure number per 1 vehicle within 1 month of operation. Investigated frequency of failure occurrence in the whole studied period of 57 months was about 3.16 for Solaris Urbino 12 and 2.23 for Mercedes Benz. Whereas during first 24 months (thus during warranty period) it was approx. 3.27 for Solaris and 2.85 for Mercedes buses. Considering period from 25 to 57 month of operation the value was 3.0 for Solaris bus and 1.7 for Mercedes vehicles. As it can be seen in the whole studied operating period less failures of Mercedes buses than Solaris buses were observed. While a significant decrease in the frequency of Mercedes buses failure occurred between 24 to 57 month of operation.

Fig. 1 Frequency of vehicle failures versus operating time

5. Technical availability characteristics

From the user point of view besides the failure number, time for troubleshooting is also of high importance. For troubleshooting time the analysis of availability factor was used. It was assumed that the time of incapacity equalled the time needed for troubleshooting. In the conducted studies the availability was defined based on the following formulas [16]:

$$K_g(t) = \frac{E(T)}{E(T) + E(\Theta)} \quad (1)$$

where:

$E(T)$ – expected value of random variable of technical object of technical object usability time,

$E(\Theta)$ – expected value of random variable of unavailability time of technical object (renewal and time to renewal),

Directly for calculations a simplified formula was used:

$$K_g = \frac{T_z}{T_z + T_n} \quad (2)$$

where:

T_z – average time of being available,

T_n – average time of being unavailable.

Technical availability factors of Solaris and Mercedes buses versus calendar time are presented in figure 2. The average availability of buses of both brands in the whole analysed operating period remained at the similar level and for the whole period of 57 months was 0.875 for Solaris buses and 0.909 for Mercedes Benz. It is worth mentioning that in the first and especially third quarter of each year the technical availability of both analysed types of vehicles decreased even to approx. 0.7.

Fig. 2 Technical availability K_g versus operating time

In the first operating period i.e. till to approx. 14 month the technical availability for Solaris buses was about 0.91. Afterwards their availability was decreasing reaching a minimum value of 0.764 in 47 month of operation. It can be noticed that in 8 and 43 month of operation the technical availability of Mercedes buses was reaching the lowest values, 0.712 and 0.649, respectively, which resulted from a prolonged waiting time for spare parts.

6. Characteristics of the operating time

Repair costs

From the previous considerations it can be concluded that Mercedes buses more rarely fail. Usually they are fixed in a shorter time (except the situations where it is necessary to wait for the spare parts). Repair time is a period when the vehicle does not make the money, while the owner is bearing the additional costs. In such context the analysis of the repair costs was conducted. The average monthly cumulated repair costs of the studied vehicles within the whole considered period were analysed.

Fig. 3 Monthly repair costs per 1 bus [PLN]

Average monthly repair costs in the first two years of operation (including warranty period), thus till 24 month differ significantly and are 372 zloty and 73 zloty for Solaris and Mercedes, respectively (Figure 3). In after warranty period, thus between month 24 and 57 of the operation the difference between repair costs is lower and is 252 zloty (749 zloty for Solaris and 1000 zloty for Mercedes).

Effectiveness of the failure rate on maintenance costs of the city buses
Wpływ częstości uszkodzeń na koszty utrzymania autobusów komunikacji miejskiej

It is worth stressing that between 33 and 57 month of operation the repair costs of Mercedes buses are approx. 1200 zloty per 1 vehicle per 1 month, thus exceeding repair costs of Solaris buses.

Fig. 4 Cumulated repair costs per 1 bus [PLN]

Figure 4 presents cumulated repair costs per 1 bus. After 57 months of operation the total costs of repair service per 1 vehicle is 33 111 zloty for Solaris buses and 34 755 zloty for Mercedes buses. From the user point of view a shape of the curve showing the cumulative repair costs is important. As it can be seen from the figure in case of Mercedes buses after 33 month of operation the costs start growing rapidly exceeding value of the cumulated repair costs of Solaris buses after about 53 months of operation.

Conducted analyses of the repairs excluded parts which failures were not related to the age (mileage) of the vehicle (e.g. mirrors, windows, safety hammers, license plate frames, replaced due to mechanical failures or theft), as well as the one being supplements installed per request of MPK Lublin (e.g. LCD screens, naturals).

Service costs

Analysis of the service costs is a significant component of the analysis of the full operating costs of the buses. The average service costs in the first two years of operation, thus until 24 month of operation are comparable and are 135 zloty and 143 zloty for Solaris and Mercedes buses (fig.5). In after warranty period, thus between 24 and 57 month of operation the difference between service costs is higher and is 52 zloty (378 zloty for Solaris and 325 zloty for Mercedes buses).

It could be stressed that in 36 month of operation the service costs for Mercedes buses increased to 1091 zloty, and for the next two months remained at level of 724 and 606 zloty.

Fig. 5 Monthly maintenance costs per 1 bus [PLN]

Fig. 6 Cumulated maintenance costs per 1 bus [thousand PLN]

Figure 6 presents cumulated costs of technical service per 1 bus at a certain month of operation. After 57 months of operation total service costs per 1 vehicle is 16 068 zloty for Solaris buses and 13 858 zloty for Mercedes buses. Growth rate of the service costs is similar for both brands.

7. Conclusion

Failures related to operation of Solaris buses occurred more often than failures of Mercedes buses. It was proofed by the difference in monthly number of failures.

Technical availability of both brands was comparable, although there was a lower number of failures of Mercedes buses. However in this case, there was a longer waiting time for spare parts.

Frequency of failures as a function of time for Solaris buses indicates that failure frequency remain stable in the whole studied operating time, while for Mercedes buses failure frequency decreases after 48 months of operations.

Repair cost distribution analysis as a function of time indicates in case of Solaris buses, that the costs increase proportionally to operating time. In case of Mercedes buses a rapid growth of costs after 34 months operating time was observed.

The cumulated repair costs per 1 bus after 57 months of observation are higher in case of Mercedes buses, although total lower number of failures.

In the studied operating period Mercedes Benz 628 and Solaris Urbino 12 generated similar operating costs related to fuel and operating liquids consumption, as well as cost related with necessity of performing scheduled maintenance works.

8. Bibliography

- [1] Aksezer C. S.: Failure analysis and warranty modelling of used cars. *Engineering Failure Analysis*, 18/2011, s. 1520–1526.
- [2] Chukova S, Arnold R, Wang DQ.: Warranty analysis: an approach to modelling imperfect repairs. *Int J Prod Econ*, 89(1)/2004, s. 57–68.
- [3] Gołębek A.: *Niezawodność autobusów*. Wydawnictwo Politechniki Wrocławskiej, Wrocław 1993.
- [4] Grabski F., Jaźwiński J.: *Funkcje o losowych argumentach w zagadnieniach niezawodności, bezpieczeństwa i logistyki*. WKiŁ, Warszawa 2009.
- [5] Grądzki R., Lindstedt P.: Metoda oceny stanu zdatności obiektu technicznego w otoczeniu warunków użytkowania i obsługi. *Eksplatacja i Niezawodność – Maintenance and Reliability*, 1/2015, 54-63.
- [6] Kleynera A., Sandborn P.: A warranty forecasting model based on piecewise statistical distributions and stochastic simulation. *Reliability Engineering and System Safety*, 88/2005, s. 207–214.
- [7] Majeske K. D.: A non-homogeneous Poisson process predictive model for automobile warranty claims. *Reliability Engineering and System Safety*, 92/2007, s. 243–251.
- [8] Matuszak Z.: Problemy badania niezawodności siłowni transportowych obiektów oceanotechnicznych, *Autobusy* 6/2010.
- [9] Michalski R., Wierzbicki S.: Badania porównawcze niezawodności autobusów komunikacji miejskiej. *Eksplatacja i Niezawodność – Maintenance and Reliability*, 4/2006, s. 22-26.
- [10] Murthy D.N.P., Djamaudin I.: New product warranty: A literature review. *Int. J. Production Economics*, 79/2002, s. 231–260.

- [11] Naikan VNA, Kapur S.: Reliability modelling and analysis of automobile engine oil. Proc IMechE Part D: J Automob Eng 220(2)/2006, s. 187–94.
- [12] Pecht M.: Establishing a relationship between warranty and reliability. IEEE Trans Electron Packag Manuf, 29(3)/2006, s. 184–90.
- [13] Rymarz J., Niewczas A.: Ocena niezawodności eksploatacyjnej autobusów komunikacji miejskiej. Problemy Eksploatacji – Zeszyty Naukowe Instytutu Technologii Eksploatacji - PIB, Radom 1/2012.
- [14] Rymarz J., Niewczas A., Pieniak D.: Reliability analysis of the selected brands of city buses at municipal transport company, Journal of KONBiN 2(26)2013, s. 111-122
- [15] Shafiee M., Chukova S.: Maintenance models in warranty: A literature review. European Journal of Operational Research, 229/2013, s. 561–572
- [16] Woropay M., Szubartowski M., Migawa K., Model oceny i kształtowania gotowości operacyjnej podsystemu wykonawczego w systemie transportowym. Wydawnictwo i Zakład Poligrafii Instytutu Technologii Eksploatacji, Radom 2003

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Effectivness of the failure rate on maintenance costs of the city buses
Wpływ częstości uszkodzeń na koszty utrzymania autobusów komunikacji miejskiej