RELIABILITY ANALYSIS OF THE SELECTED BRANDS OF CITY BUSES AT MUNICIPAL TRANSPORT COMPANY

PORÓWNAWCZA ANALIZA NIEZAWODNOŚCI AUTOBUSÓW KOMUNIKACJI MIEJSKIEJ

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Abstract: *The purpose of this paper was to present a reliability comparison of city transport buses on the example of Solaris Urbino 12 and Mercedes-Benz 628 Conecto LF at Municipal Transport Company in Lublin. A reliability index for the most failure parts and complex systems for the period of time up to first damage was determined. It has been demonstrated, that during the operation significant reliability differences occur between the buses produced nowadays.*

Keywords: *reliability, city bus*

Streszczenie: *Celem pracy było porównanie niezawodności autobusów miejskich na przykładzie marki Solaris Urbino 12 i Mercedes-Benz 628 Conecto LF w Miejskim Przedsiębiorstwie Komunikacyjnym w Lublinie. Wyznaczono wskaźniki niezawodności najbardziej awaryjnych układów i zespołów w zakresie czasu do pierwszego uszkodzenia. Wykazano, że w praktyce eksploatacyjnej występują znaczące różnice niezawodności pomiędzy współcześnie produkowanymi autobusami znanych firm.*

Słowa kluczowe: *niezawodność, autobus miejski*

1. Introduction

In recent years, in municipal transport companies an increased demand for current operational information regarding vehicles in use was observed. This is crucial from the point of view of ensuring readiness of the whole municipal transport system in the city, as well as the use of technical risk analysis methods for maintenance process management. Therefore, the company should assure a continuous monitoring of vehicles failure and damage.

Monitoring of operational suitability of vehicles and their main components, especially with separation of "weak points" [3] are also a basis for rationalization of the technical services range, according to criterion of not exceeding acceptable levels of the risk of damage risk.

Selection of the reliability analysis method depends on the type of the analyzed technical object and the required accuracy of the estimate. In general, the method should take into account all of the possible factors affecting the reliability of the analyzed system, and at the same time the simplest procedure for registration and calculation as possible [6]. In practice, the method is selected individually for each study case, taking into account simplifying assumptions, independent observation limitations and the work-intensity expectancy.

2. Studies process

The study included 22 buses of Mercedes-Benz Conecto LF 628 and 20 buses of Solaris Urbino 12. All buses were observed from the first day of the operation and had similar vehicle mileage. The studies were conducted under natural conditions of the operation of public transport in Lublin. The analysis covered damages of the following systems and structural complexes: engine (US) supply system (UZ), cooling system (UCH), brake system (UH) and driving system (UN). Damages were recorded in the range of vehicle mileage (generalized working time) up to the first failure occurrence. Reliability was analyzed based on Weibull model.

3. Study results

Figures 1 and 2 frame Charts of the failure-free operation of the selected structural systems, for Mercedes and Solaris buses, respectively. Average mileage to the first damage for Mercedes buses for the driving and cooling system is about 50 thousand km, for brake system and engine is about 80 thousand km, and for the supply system - 120 thousand km. In case of Solaris buses average mileage to the first damage is higher than for the Mercedes buses, and amounts respectively 52 thousand km for the driving system, 90 thousand km for the cooling system, 110 thousand km for the brake system, and 55 thousand km for the engine.

Fig.1 Box plots presenting time to the first damage of the selected Mercedes Benz buses systems: engine (US) supply system (UZ), cooling system (UCH), brake system (UH) and driving system (UN)

Fig.2 Box plots presenting time to the first damage of the selected Solaris Urbino 12 buses systems: engine (US) supply system (UZ), cooling system (UCH), brake system (UH) and driving system (UN)

4. Analysis of Kaplan – Meier survival function

The survival function of Kaplan – Meier describes the relation between the number of the observed objects remaining in the state of usability in time “t” to the initial number of objects [5]. This function is sometimes readily used by some researchers, among the others in analysis of the reliability of internal-combustion engines [2], as well as in maintenance models and automotive reliability analysis [9-13]. The Kaplan - Meier function has a discrete character. This function approximates the time distribution of suitability as an estimator of the reliability function. From the reliability theory it is known, that the reliability distribution is a continuous distribution [4].

Fig.3 The Kaplan - Meier survival functions of the selected Mercedes Benz buses systems: engine (US) supply system (UZ), cooling system (UCH), brake system (UH) and driving system (UN)

Table 1. Percentiles of the Survival Function of the Mercedes Benz buses

Percentile	Survival [km]
25'th percentile (lower quartile)	23672,50
50'th percentile (median)	54512,95
75'th percentile (upper quartile)	93368,58

The Kaplan - Meier functions of the selected bus systems are shown in the figures 3 and 4. It has been found in Mercedes buses, that in the case of the engine and cooling system, Kaplan – Meier’s curve shows a much faster decrease than the other systems in the initial stage of operation. However, the survival function of the supply system of Solaris buses shows slower initial decline compared with other systems. The curves also demonstrate that the greatest chance of proper operation is for brake, supply and cooling system.

Fig.4 The Kaplan - Meier survival functions of the selected Solaris Urbino 12 buses systems: engine (US) supply system (UZ), cooling system (UCH), brake system (UH) and driving system (UN)

Table 2. Percentiles of the Survival Function of the Solaris Urbino12 buses

Percentile	Survival [km]
25'th percentile (lower quartile)	10654,8
50'th percentile (median)	39515,0
75'th percentile (upper quartile)	145174,8

In tables 1 and 2 survival function percentiles are given. A median mileage of the Mercedes-Benz buses is over 54 thousand km, while for Solaris buses is 15 thousand lower.

5. Reliability function analysis

In reliability evaluation a Weibull model was used. A parameter estimation of a two-parameter Weibull distribution was performed by a maximum likelihood method (Table 3) [4,7]. A shape parameter is equal to slope coefficient of the fitted regression line, whereas the scale parameter can be calculated as the quotient (intercept/slope). Nonparametric methods of this type are used a.m. in assessment of the expected warranty time of vehicles.

Table 3. Scale and shape parameters of a two-parameter Weibull distribution according to types of buses and their systems

Bus type	Structural systems	Shape parameter [c]	Scale parameter [b]
Mercedes Benz	all systems	0,95470	87 935
Solaris Urbino 12		0,81877	80 511
Mercedes Benz	engine	0,66355	64 545
Solaris Urbino 12		0,89030	57 516
Mercedes Benz	brake system	0,93131	101 600
Solaris Urbino 12		0,65572	96 445
Mercedes Benz	driving system	1,7738	50 601
Solaris Urbino 12		0,80079	47 462
Mercedes Benz	cooling system	0,84551	66 897
Solaris Urbino 12		0,78806	91 081
Mercedes Benz	supply system	1,1859	138 900
Solaris Urbino 12		0,77658	115 900

The scale parameter (characteristic ability) indicates how long (mileage) 63.2% of the observed buses break down. For the brake and power supply system in both types of buses, 63.2% of buses have failed at mileage above 100 thousand km. For the driving system and engine this is half of the value - 50 thousand km.

Different shape parameter values indicate a diversity of reliability distribution. In case of the shape parameter value below one (here - especially in case of engine, brake system and cooling system for both vehicle types), there is a rapid decrease in reliability function in the initial period of the operation. It corresponds to the objects characterized by a high failure rate in the running-in period.

In case the value of the shape parameter is close to unity, there is a kind of random failure, independent of time (in this case - supply system). However, if c is greater than 1, ($c = 1.7738$ here for the driving system of Mercedes buses) dominates operational wear. Significant wear effects were observed at about 290 thousand km mileage.

Figure 5 presents the results of analysis of the time to first failure of all studied systems of Solaris and Mercedes buses. A significant decrease in reliability of Solaris buses began to appear after 13 thousand km ($R(t) = 0.8$) and after 50 thousand km reliability is ≈ 0.5 . Mercedes buses showed a similar reduction in the level of reliability after long period of operation, respectively, $R(t) = 0.8$ at 19 thousand km and $R(t) = 0.5$ at 60 thousand km. The graphs also present the line fitted to the data points. The boundary lines of the confidence interval of 95% are indicated.

Fig. 5 Reliability function diagram of all studied systems of Solaris Urbino and Mercedes Benz buses

Fig. 6 Reliability function diagram of the supply systems of Solaris Urbino and Mercedes Benz buses

Fig.7. Reliability function diagram of the driving systems of Solaris Urbino and Mercedes Benz buses

Figures 6 and 7 present the results of reliability analysis of power and driving systems of Solaris and Mercedes buses. In case of the supply system of Solaris The buses the decrease in reliability occurs after the mileage of 18 thousand km

Fig.8 Reliability function diagram of the engine of Solaris Urbino and Mercedes Benz buses

Fig.9 Reliability function diagram of the cooling system of Solaris Urbino and Mercedes Benz buses

Fig.10 Reliability function diagram of the brake system of Solaris Urbino and Mercedes Benz buses

($R(t) = 0.8$). The level of $R(t) = 0.5$ is reached after 73 thousand km mileage. The level of $R(t) = 0.8$ states at the mileage of 38 thousand km for Mercedes buses. In case of Mercedes buses in the first 50 thousand km mileage the reliability decreases from a value of 1.0 to about 0.7. Similar tendency is observed in case of the driving system, where reliability $R(t) = 0.8$ occurs at the mileage of 28 thousand km and 5 thousand km, respectively, for Mercedes and Solaris buses, and $R(t) = 0.5$ after the mileage of 42 and 28 thousand km.

Figures 8-10 presents the results of reliability analysis of the cooling and brake system, and engine. In case of brake system analysis of Mercedes buses the reliability decrease occurs later than for Solaris buses. The level of $R(t) = 0.8$ was demonstrated after 28 thousand km for Mercedes buses and 12 thousand km for Solaris buses. However, in case of the engine and cooling system, Solaris buses reach a much higher level of reliability. The level of reliability $R(t) = 0.8$ for the engine was observed at 11 thousand km mileage for Solaris buses, and 7 thousand km mileage for Mercedes buses. A similar situation appears in case of the cooling

system, where reliability decreases to the value of $R(t) = 0.8$ at 17 thousand km and 14 thousand km for Solaris and Mercedes buses, respectively, and to the level of $R(t) = 0.5$, after 60 thousand km and after 43 thousand km.

6. Conclusions

Time to the first failure and reliability of the following systems: brake, driving and cooling system, power system and engine, of the Solaris Urbino 12 and the Mercedes-Benz 628 Conecto LF buses were compared.

It has been shown, that the reliability of the various structural systems differs and depends on the brand of the bus. Mercedes buses stands out lower mileage to the first failure comparing to the Solaris buses. In case of the two analyzed brands the most unreliable systems were cooling system and engine. However, the lowest risk of failure was found in the case of supply system and brake system.

The obtained results can be practically used for improving functioning of public transport companies.

7. Bibliography

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