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Frequency of failures in selected urban vehicle systems

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Abstract

The aim of this study was to examine the relationship between the occurrence of selected types of failures and the time and season of their occurrence in public transport buses in the city of Lublin. The analysis was carried out for buses operated in the Municipal Transport Company within the past 3 years. The chi-squared analysis showed that during operation, there are significant differences between the failures and the annual season, but there are no differences between the frequency of failures and the time of day.

Introduction

In municipal transport companies, there is a greater demand for current operational information concerning vehicles in use. This is crucial from the point of view of ensuring the readiness of the whole municipal transport system in a city, as well as the use of technical risk analysis methods for maintenance process management (Gołąbek, 1993; Matuszak, 2010; Aksezer, 2011).

In the field of public transport, failure is a key criterion for the operational reliability of vehicles; therefore, a transport company should constantly monitor the failures and deficiencies of its active fleet. This is very important from the point of view of ensuring the current availability of the whole public transport system in a city. Registering these failures is necessary not only to assess the suitability of particular types of vehicles or to determine their operating costs, but also to determine what spare parts or maintenance staff are necessary (Municipal Transport Authority, 2018).

Monitoring the operational suitability of vehicles and their main components, especially with the separation of "weak points", is the basis for rationalizing the technical services range while not exceeding acceptable levels of damage risk (Niewczas et al., 2019).

Niewczas et al. (Niewczas et al., 2019) presented the incapacity risk of commercial vehicles performing transport tasks under market conditions. The results of the research confirmed the suitability of the incapacity risk model for predicting potential expenses to guarantee a vehicle's continuous operation in a company and to verify the selection of the vehicle brand and the period of use.

Ensuring the reliability of a vehicle and planning its maintenance during a period of operation is a very difficult task (Niewczas, Rymarz & Debicka, 2019). Therefore, every urban transport system should take into account business continuity safeguards related to the risk of its vehicle fleet being unfit (Gong, 2006; Andrzejczak, 2013). Much research has been devoted to the issue of bus reliability, including (Bedewy, 1989; Kaplan & Cooper, 1992; Gołąbek, 1993; Niziński, 2002; Michalski & Wierzbicki, 2006; Naikan & Kapur, 2006; Skrobacki, 2006; Rymarz, Niewczas & Stokłosa, 2015).

The 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 possible procedure for registration and calculation. In practice, the method is selected individually for each study case, taking into account simplifying assumptions, independent observation limitations, and the work-intensity expectancy (Shafiee & Chukova, 2013).

This article discusses the research sample of busses under actual conditions and the course of research. In the next part, a chi-squared analysis is performed to examine the relationship between the occurrence of individual defects and the annual season and peak/off-peak times.

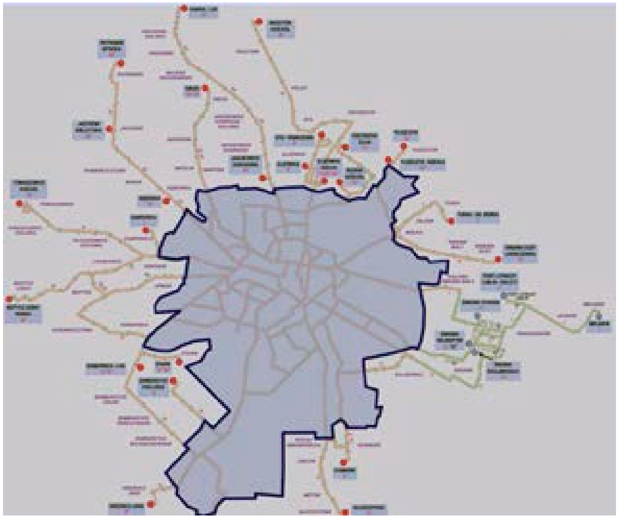

Figure 1. Scheme of urban and suburban lines (Municipal Transport Authority, 2018)

Study object and research

At the order of the Municipal Transport Authority (MTA), four operators provide transport services in the city of Lublin (Figure 1). One of them is the Municipal Transport Company, which is an internal operator of the Lublin Municipality. In the Municipal Transport Company in Lublin, managed by MTA, 214 buses powered by diesel engines are used. These are vehicles of various capacities and lengths, the majority of which are vehicles with a standard length of 12 m and a capacity of about 90 passengers. The remaining vehicles are 93 mega-class buses (15–18 m long with a capacity of more than 135 people) and 20 midi-class buses (8.5 m long with a capacity of 60 people). All vehicles in operation are low-floor (Table 1).

The transport distance of the entire transport network is 20,329,860 km per year. Buses travel on average over 15 million km a year just in the city of Lublin (Table 2). The maximum number of buses in operation is 252, which occurs around 5 p.m. on a weekday. The peak hours are 7:00–9:00 and

Table 1. List of buses powered by compression-ignition engines used in Lublin's public transport (Municipal Transport Authority, 2018)

Make	Type	Number	EURO norm	Type of vehicle	Carrier
Autosan	Sancity 12LF	53	EEV / EURO 5	single-unit	MPK Lublin
Autosan	Sancity 9LE	20	EEV / EURO 5	single-unit	MPK Lublin
Jelcz	M121M	15	EURO 2	single-unit	MPK Lublin
Mercedes Benz	O530 Citaro	27	EEV / EURO 5	articulated	MPK Lublin
Mercedes Benz	628 Conecto LF	22	EURO 4	single-unit	MPK Lublin
Mercedes Benz	628 Conecto G	10	EURO 4	articulated	MPK Lublin
Mercedes Benz	O 405 N	10	EURO 2	single-unit	MPK Lublin
Neoplan	N4020	3	EURO 2	single-unit	MPK Lublin
Solaris	Urbino 12	20	EURO 4	single-unit	MPK Lublin
Solaris	Urbino 15	1	EURO 3	single-unit	MPK Lublin
Solaris	Urbino 18	30	EURO 6	articulated	MPK Lublin
Solaris	Urbino 18	18	EURO 6	articulated	Irex-1
Solbus	SM12	3	EURO 5	single-unit	LLA
MAZ	103	4	EURO 5	single-unit	LLA
MAZ	203	3	EURO 5	single-unit	LLA
Ursus	CS12LFD	8	EURO 6	single-unit	MPK Lublin
Mercedes Benz	628 Conecto LF	11	EURO 6	single-unit	Warbus
Mercedes Benz	628 Conecto G	22	EURO 6	articulated	Warbus
Total		280			

Table 2. The number of operational buses in Lublin's public transport operating on behalf of MTA in Lublin (Municipal Transport Authority, 2018)

Total operational buses:	Year		
	2017	2018	2019
On the entire communication network (together with other cities /communes) [km/year]	19 410 255 (including buses 15 107 294)	20 507 414 (including buses 15 383 417)	21 071 913 (including buses 16 085 565)
Only in the city [km/year]	18 760 136 (including buses 14 457 175)	20 507 414 (including buses 15 383 417)	20 175 933 (including buses 15 189 585)

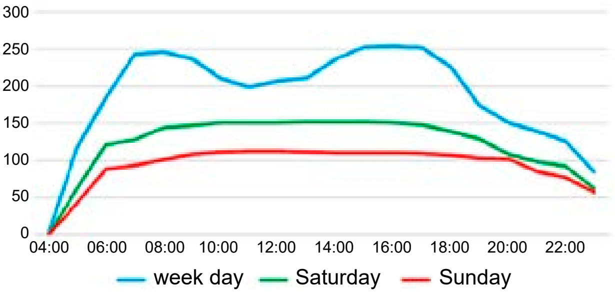

Figure 2. Number of buses in operation on particular days of the week (Municipal Transport Authority, 2018)

15:00–17:30 (Figure 2). The year was divided into 2 seasons of vehicle operation – the summer season, which included the months of April–September and the winter season, which included the months of October–March.

The aim of this study was to examine whether there is a relationship between the occurrence of failures and the time and season of occurrence. The analysis considered failures in the cooling and power supply systems, driving systems, and the engine, separated as a whole during 3 years of operation in all analyzed buses.

Study results

Statistical analyses were carried out using IBM SPSS Statistics 25 package, which was used to perform chi-squared analysis. The significance level in this chapter was considered $\alpha = 0.05$.

In order to test the hypotheses that there is a relationship between the occurrence of individual failures and the annual season and peak/off-peak hours (separately for the summer and winter seasons), a chi-squared analysis was performed. The detailed results of the analysis are presented in Tables 3 and 4.

The analysis showed a statistically significant relationship between the frequency of failure and the annual season, but the dependence of failure

Table 3. Relationship between the occurrence of an individual failure and the annual season

	Winter season		Summer season		Total		$\chi^2(3)$	p	V_c
	N	%	N	%	N	%			
Engine	508	38.1	678	37.1	1186	37.5	27.10	< 0.001	0.093
Cooling system	171	12.8	337	18.4	508	16.1			
Driving system	336	25.2	357	19.5	693	21.9			
Power supply system	317	23.8	457	25.0	774	24.5			

Table 4. Relationship between the occurrence of individual failures and peak hours depending on the season

		Outside of peak hours		Peak hours		Total		$\chi^2(3)$	p	V_c
		N	%	N	%	N	%			
Winter season	Engine	325	39.9	183	35.3	508	38.1	3.35	0.341	0.050
	Cooling system	100	12.3	71	13.7	171	12.8			
	Driving system	196	24.1	140	27.0	336	25.2			
	Power supply system	193	23.7	124	23.9	317	23.8			
Summer season	Engine	412	36.4	266	38.2	678	37.1	3.44	0.329	0.043
	Cooling system	218	19.2	119	17.1	337	18.4			
	Driving system	211	18.6	146	21.0	357	19.5			
	Power supply system	292	25.8	165	23.7	457	25.0			

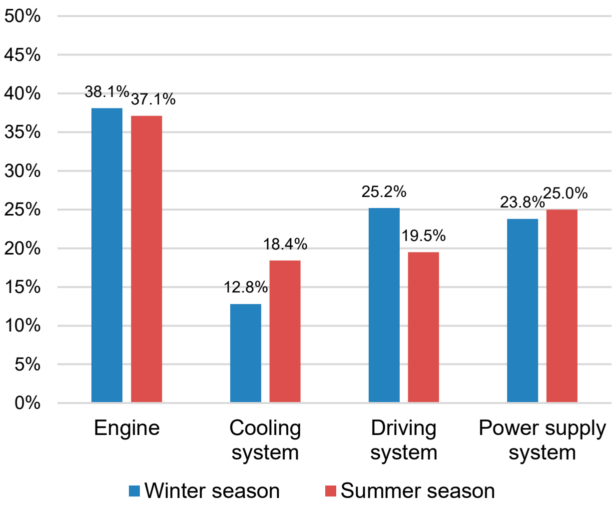

Figure 3. Percentage of the occurrence of individual system failures depending on the annual season

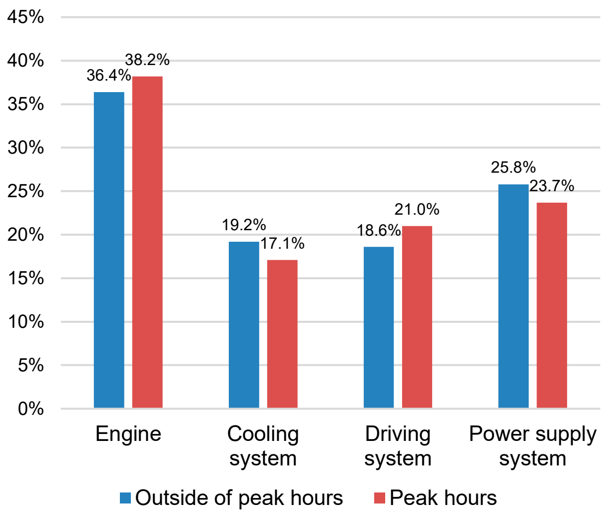

Figure 4. Percentage of the occurrence of individual system failures depending on the peak hours in the summer season

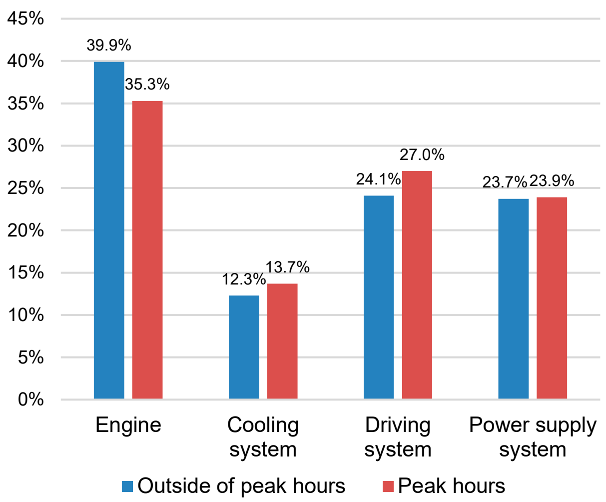

Figure 5. Percentage of the occurrence of individual system failures depending on the peak hours in the winter season

occurrence on the time of day (peak hours vs. off-peak hours) was not statistically significant.

To determine the relationship between a failure's occurrence and the season, a post-hoc analysis was carried out that took into account the values of corrected residuals. It showed that significant differences were related to the cooling system and the driving system. The failures occurring in the cooling system were 5.6 percent higher in the summer, while in the case of the power supply system, failures were 5.7 percent higher in the winter (Figure 3). It turns out that in the summer season, failure of the cooling system is a significantly more frequent cause of vehicle downtime, and less often the power supply system. The results of the conducted analyses are presented in Figures 3–5.

A large difference in the results between the tested vehicle systems related to individual structural systems is noticeable. Based on the conducted tests, the bus construction systems have a relationship between the frequency of failure and the season of vehicle operation. Failure of engine components was the most frequent, and accounted for almost 40% of all failures in the analyzed vehicle system; however, the greatest reliability was found in the case of cooling systems. Analyzing the damage to this system showed that in the winter season these damages were the lowest, i.e. 12.8%, and in peak hours 12.3%. It has been shown that the failures of the various structural systems are different and depend on the maintenance time and the annual season.

The results of this research can be used to improve the functioning of public transport companies.

Conclusions

In order to assess whether there is a relationship between the occurrence of a failure in the tested systems in urban vehicles and the time of their operation and the seasonality of their occurrence, a chi-squared analysis was performed. It was shown that there is a statistically significant relationship between the frequency of failure and the annual season. There was no statistically significant correlation between the frequency of failure and the time of day. Significant differences in the annual season involved the cooling system and driving system.

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