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Assessment of the Braking System Damage in the Public Transport Vehicles of a Selected Transport Company

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Abstract

This paper analyzes damage to safety systems over a five-year period for a group of vehicles. In the first step of analysis, descriptive statistics characterizing the analyzed variables were calculated and analyses related to the assessment of damage to the braking system. The analyses were carried out in order to examine the relationship between the mileage of vehicles and the number of defects quarterly and monthly and the fit of the obtained empirical results of the analysed variables to a normal or other theoretical distribution was checked. In order to check whether the observed differences in the mean values of the number of failures of the safety systems are statistically significant, a non-parametric analysis of variance was performed. The Kolmogorov-Smirnov test was applied, the distribution of the monthly sum of the braking system faults, distribution of the sum of the braking system faults from individual quarters, distribution of the monthly kilometrage of all vehicles and distribution of the quarterly kilometrage of all vehicles were presented. After describing previous correlation analyses, a linear regression analysis was conducted in which a model was built to predict the number of braking system faults based on monthly vehicle mileage and month of measurement. The last part of the analysis was to verify whether the number of the braking systems faults depends on the season of the year and it was checked whether the season makes any difference to the vehicle's quarterly kilometrage. One-way analysis of variance (ANOVA) was carried out to this end.

Keywords

public transport, buses, kilometrage, analysis, braking system

1 Introduction

Road safety has an extremely important role in existing transportation systems. Drivers on the road are influenced by various factors (light and temperature conditions, visual smog, surrounding environment, etc.) (Madleňák et al., 2016). When undertaking an economic efficiency assessment of a means of transport, such as a bus, numerous factors should be taken into consideration. They include, among others: the intensity of use, the value of the transportation fee, the value of the personnel costs, or the costs of the consumables (Mendyk, 2009; Šarkan and Stopka, 2018). Theoretically, the intensity of use may be increased in two ways: by increasing the speed on the transport routes or by reducing downtime. In practice, though, the average speed of buses mainly depends on the condition of the road infrastructure and the road traffic regulations. While the vehicle is in operation, legal provisions and norms that regulate its roadworthiness may be changed (see Caban et al., 2012; Droździel et al., 2012; Droździel and Rybicka, 2016). This means that the buses that operate on repetitive routes over a longer period of time ride at a fixed average speed. Due to this fact the intensity of use mainly reflects the degree of the vehicle's exploitation, which depends primarily on the adopted exploitation strategy. Thus, determining the appropriate vehicle to operate in a particular territory in the context of city logistics undoubtedly represents an essential aspect for individual enterprises (see Figlus et al., 2014; Stopka et al., 2017). Two most important factors of the exploitation process include: the vehicle's kilometrage during the specified period of time (a day, a month or a year) and the costs related to maintenance and repairs of that means of transport. Repair costs are the sum of the costs of tangible exploitation factors and the labour costs of the maintenance station personnel (Droździel et al., 2017; Poliak et al., 2016; 2017). The statistical analyses of the braking system damages are of high

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importance and are often conducted (Juściński et al., 2010; Rymarz and Niewczas, 2012). For many years, research has been conducted into the causes of damage to the bus safety systems during real traffic conditions. The initial stage of such assessments are the statistical analyses that describe the frequency of these systems' faults (Wrzesiński, 1973). In this article, the authors present the results of such analysis for a selected group of buses operated by the Municipal Transport Company [MPK] in Lublin, Poland.

2 What is a braking system?

The established provisions (Dz.U. 2016 poz. 2022 dział-3-rozdział-4, 2022) regulate braking performance and define braking distance standards from a certain speed. They also define requirements and methods of testing and specify that each test must be carried out on cold brakes (Wrzesiński, 1973).

The aim of the braking system is to stop or reduce the speed of a vehicle by creating an operating force with a sense opposite to the direction of movement of the vehicle. Due to different tasks and ways of operation, the brakes are divided into:

- service brakes (enable safe stopping and manoeuvring of the vehicle regardless of weight and terrain);
- emergency brakes (activated independently of the service brake);
- parking brakes (used to immobilise the vehicle when parked);
- retarders (decelerate the vehicle when going downhill) (Jedliński, 2007; Reński, 1997).

Each braking system contains two basic mechanisms that create a system:

- braking mechanism;
- brake actuating mechanism (Gabrylewicz, 2014).

Pneumatically controlled systems, which have a different way of operating the actuating mechanism, are used in trucks and buses. This is in order to reduce the force exerted by the driver on the pedal in relation to the increased braking force. The brake pedal only controls the pneumatic valve controllers. The air delivered from the compressor activates the braking mechanisms. Due to safety reasons, the braking systems in trucks and buses are divided into single circuit, dual-circuit and multi-circuit ones. Thanks to such solutions, in case of failure of one of the circuits, the others can still operate without issues and the vehicle can be stopped. Two types of braking systems are usually used in trucks and buses:

- Air-overpressure system – such system consists of: a piston compressor driven by the engine, pressure regulator, air tank, main brake valve; – brake cylinders; - brake lines. Brakes are activated by the driver by pressing the brake pedal, causing the exhaust valve to open and supply compressed air to the brake cylinders. The dual-circuit systems are most commonly used (Wrzesiński, 1973).
- Hydraulic-air system – the advantage of such system is that it the ability to create higher pressures, which is associated with the lack of the need to install large expanders. Smaller expanders will work in the same way at higher pressure. Another advantage of such system is the reduced dimensions of components and assemblies due to the removal of mechanical brake activation. Such brakes include two subgroups: a system supported by compressed air and an air system actuating the hydraulically controlled brakes (Hebda, 2005).

Retarders are installed in buses in order to maintain smooth running and relieve the service brake, which is exposed to overheating. Retarders work by maintaining a constant speed when driving downhill for a long time. They act on the drive system, thus avoiding prolonged use of the service brake. Additionally, retarders have positive impact on the economic operation. Also, the use of the vehicle's brakes is reduced, which prolongs the lifespan of, among others, lining (Wrzesiński, 1973). This, in turn, translates into reduced repair costs.

The brake force regulator performs a very important function in heavy vehicles. The centre of gravity shifts, which is why the braking force distribution is practically impossible. Therefore, very high braking performance is required for such vehicles. The brake force regulator is used to this end. It changes the distribution of braking forces, taking into account the position of the centre of mass. It is used both in hydraulic and pneumatic systems (Droździel et al., 2014).

Braking systems need to meet several requirements (Hebda, 2005), such as:

- vehicle motion stability during braking, i.e. the vehicle's ability to maintain the track set with use of the steering wheel during braking (also in case of wheel locking);
- proportional and smooth increase of braking force in relation to the increasing force actuating the system;
- full brake release, i.e. the disappearance of the braking effect after subtracting the braking force;
- high durability and ease of use;

- high reliability;
- high efficiency in various road conditions;
- short set working time (from the moment the braking force is applied until the system is activated);
- appropriate distribution of the braking forces on individual wheels;
- low noise level.

3 Own research on the selected group of vehicles

In public transport, the reliability of the safety systems is an important criterion for the operational usefulness of buses (Poliak et al., 2016). Reliability is defined as the ability to complete the operational tasks without downtime caused by damage in the specified period of time and assumed conditions (see Michalski and Wierzbicki, 2006). Therefore, every public transport company should ensure constant monitoring of damage and inefficiency of the fleet of vehicles in use. This is of high importance from the perspective of ensuring the ongoing readiness of the entire public transport system in the city, but also from the point of view of planning the purchases of new buses. The introduction of new types of vehicles implies the need of getting to know their operational properties. This is necessary not only to assess the suitability of the individual types of vehicles or determine their operating costs, but also to determine their spare parts or maintenance staff (Poliak et al., 2016).

4 Statistical analysis of the obtained result

Statistical analysis of the braking system damages that had occurred over a five-year period was carried out for a group of 60 vehicles (20 vehicles in each analysed year) of one brand operated by the Municipal Transport Company in Lublin (MPK Lublin) (see Internal documentation of the Municipal Transport Company in Lublin, 2022). Data for the calculations was obtained based on the analysis of the monthly road cards and a list of repairs of the braking systems in buses during the analysed period of time. This let determine the sum of the monthly number of faults, the sum of the braking system faults from individual quarters, the monthly kilometrage and the distribution of the quarterly kilometrage for all vehicles.

In order to respond to the research questions, the statistical analyses were conducted with use of the statistical software. It was used to carry out the basic descriptive statistics along with the Kolmogorov-Smirnov tests, Pearson's correlation coefficient, Spearman's rho test and the linear regression analysis. The significance level in this distribution was set at $\alpha = 0.05$.

The first step included testing the distributions of variables introduced to the analysis. The basic descriptive statistics along with the Kolmogorov-Smirnov test, examining the distribution's normality, were carried out to this end. In the case of the monthly number of faults and the monthly kilometrage, the Kolmogorov-Smirnov test's result was statistically significant, which means that their distributions were abnormal. Due to this fact the analyses conducted with parametric tests were confirmed with the non-parametric tests when possible. In the case of the results for the kilometrage and the number of quarterly faults, the variable distributions turned out to have a normal distribution, therefore parametric tests were carried out for them. The results described hereinabove are presented in Tables 1 and 2. Figs. 1 to 4, in turn, show their distributions.

The relationship between the number of braking system faults, the monthly kilometrage of the vehicle and the month of measurement was analysed. It was verified whether the number of the braking system faults depends on the vehicle's monthly kilometrage. In addition, it was checked if both these variables depend on the overall

Table 1 The basic descriptive statistics of the analysed variables with the Kolmogorov-Smirnov test (own work – part 1)

	Mean	Median	Standard deviation	Skewness
The number of the braking system faults (monthly)	22.80	21.00	10.70	1.17
The number of the braking system faults (quarterly)	68.40	73.50	22.44	0.22
Monthly kilometrage	100412.08	101327.50	14431.43	0.44
Quarterly kilometrage	301236.25	296591.50	35741.92	0.23

Table 2 The basic descriptive statistics of the analysed variables with the Kolmogorov-Smirnov test (own work – part 2)

	Kurtosis	Value min.	Value max.	K-S	*p*
The number of the braking system faults (monthly)	1.82	8.00	60.00	0.12	0.041
The number of the braking system faults (quarterly)	−0.02	34.00	120.00	0.12	0.200
Monthly kilometrage	0.95	71197.00	145454.00	0.12	0.025
Quarterly kilometrage	−0.73	241917.00	371831.00	0.13	0.200

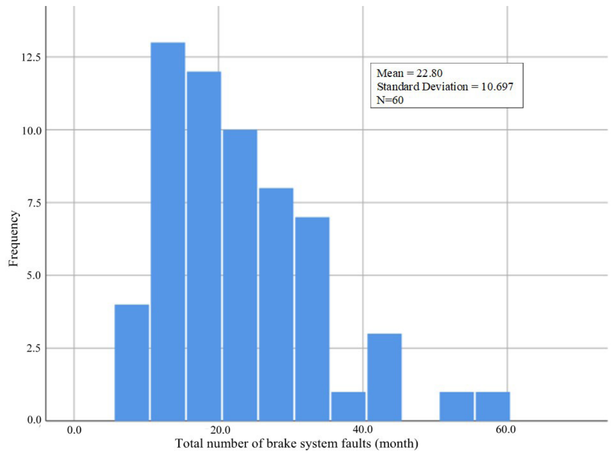

Fig. 1 Distribution of the monthly sum of the braking system faults (own work)

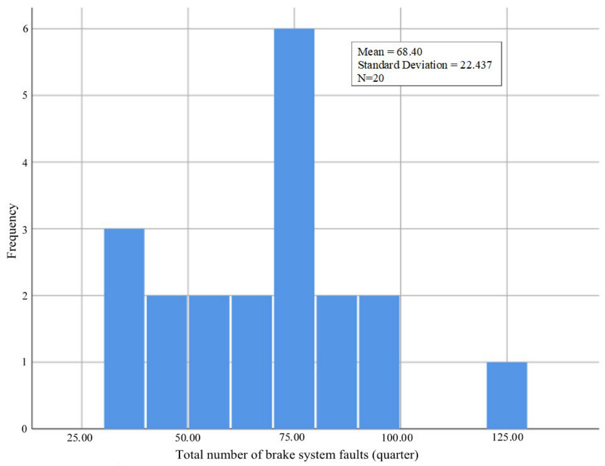

Fig. 2 Distribution of the sum of the braking system faults from individual quarters (own work)

age of the vehicle, which was measured as the month of measurement (from 1 to 60, between 2011 and 2015).

First, the relationship between the number of braking system faults and the monthly kilometrage of the vehicle was tested. In order to eliminate the impact of outliers and covariates, the results of the Pearson's parametric analysis were confirmed using the Spearman's correlation analysis and the partial correlation analysis, to which the month of measurement was entered as a covariate.

The analysis showed that the number of the braking system faults does not depend on the vehicle's monthly kilometrage. In the partial correlation analysis, the value of the correlation coefficient increased, compared to the Pearson's and Spearman's coefficients. However, it was still statistically insignificant. Detailed results of the analysis are presented in Table 3 and in Fig. 5.

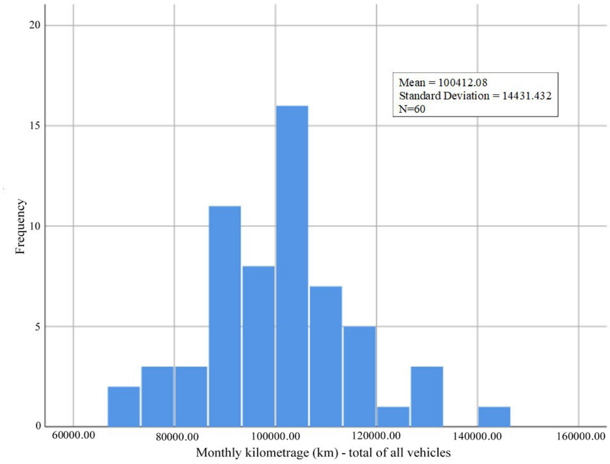

Fig. 3 Distribution of the monthly kilometrage of all vehicles (own work)

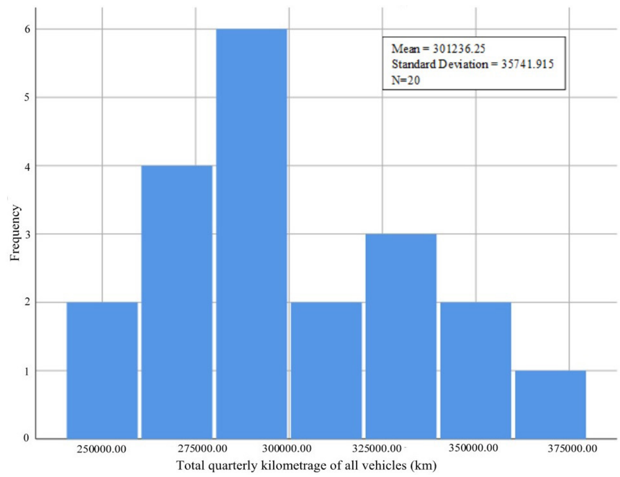

Fig. 4 Distribution of the quarterly kilometrage of all vehicles (own work)

Next, it was checked whether the number of the vehicle's braking system faults and its monthly kilometrage changed with the overall age of the vehicle, measured as the month of measurement. Then the Pearson's, partial and Spearman's correlation coefficients were calculated again.

The analysis showed that both the number of the braking system faults and the monthly kilometrage depend on the month of measurement. All tested relationships

Table 3 Correlation of the number of the braking system faults and the vehicle's monthly kilometrage (own work)

		The number of the braking system faults (monthly)		
		Pearson's correlation	Partial correlation*	Spearman's correlation
Monthly kilometrage	Correlation coefficient	0.001	−0.19	−0.01
	p value	0.945	0.146	0.911

* a month of measurement as a covariate

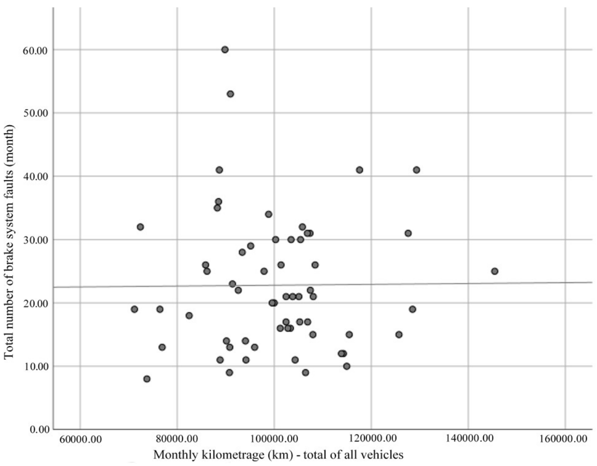

Fig. 5 Scatter diagram showing the relationship between the monthly kilometrage and the number of the braking system faults (own work)

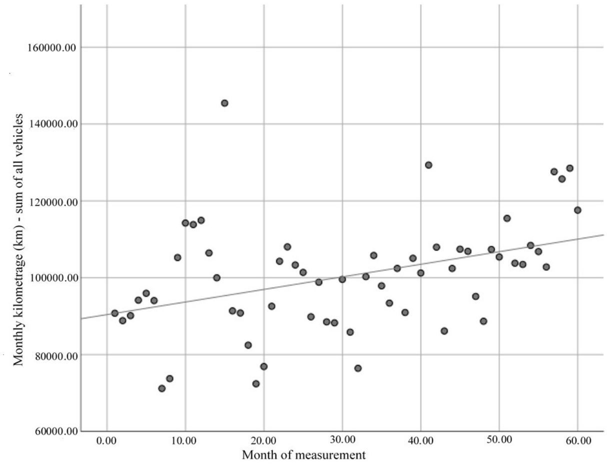

Fig. 6 Scatter diagram showing the relationship between the month of measurement and the monthly kilometrage (own work)

turned out to be statistically significant, positive and strong (in case of the Spearman's correlation between the month of measurement and the number of the braking system faults) or moderate (in case of all other relationships). The results of the analyses show that the vehicle's kilometrage increased along with the consecutive months of measurement. At the same time, the number of the braking system faults increases along with the vehicle's age and does not depend on the vehicle's monthly kilometrage. Detailed results of the analysis are presented in Table 4 and in Figs. 6 and 7.

To summarise the previous correlation analyses' results, a linear regression analysis was carried out, in which a model predicting the number of braking system faults based on the monthly kilometrage of the vehicle and the month of measurement was built.

The regression analysis results show a good adjustment of model to data. It predicts 21.1% of the dependent variable variance in total (R^2 = 0.211). The coefficients

Table 4 Correlation of the number of the braking system faults and the vehicle's monthly kilometrage with the month of measurement (own work)

		Month of measurement		
		Pearson's correl.	Partial correl.	Spearman's correl.
The number of the braking system faults (monthly)	Correl. coefficient	0.43	0.46*	0.52
	p value	<0.001	<0.001	<0.001
Monthly kilometrage	Correl. coefficient	0.40	0.43**	0.43
	p value	0.002	0.001	<0.001

* month of measurement as a covariate
** the number of the braking system faults as a covariate

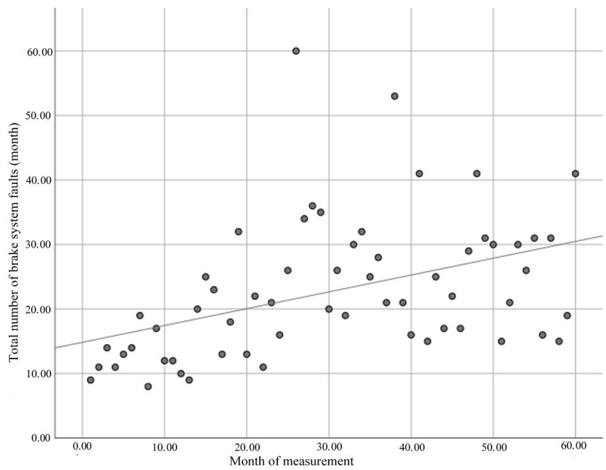

Fig. 7 Scatter diagram showing the relationship between the month of measurement and the number of the braking system faults (own work)

for the individual predictors, similarly to the correlation analyses conducted previously, indicate that the number of the braking system faults increases with the month of measurement. At the same time, it is independent of the monthly kilometrage of the vehicle. Detailed results of the analysis are presented in Table 5.

The influence of the season of the year on the number of the braking system faults was studied as well. The last part of the analysis was to verify whether the number of the braking systems faults depends on the season of the year. In addition, it was checked whether the season makes any difference to the vehicle's quarterly kilometrage. One-way analysis of variance (ANOVA) was carried out to this end.

The analysis showed that both the number of the braking system faults, as well as the quarterly kilometrage are independent of the season of the year. Detailed results of the analysis are presented in Table 6 and in Figs. 8 and 9.

Table 5 The linear regression analysis' coefficients predicting the number of the braking system faults based on the monthly kilometrage of the vehicle and the month of measurement (own work)

	(Constant)	Month of measurement	Monthly kilometrage
B	27.52	0.31	0.00
SE	8.95	0.08	0.00
Beta		0.50	−0.19
T	3.07	3.91	−1.48
p significance level	**0.003**	**<0.001**	0.146
R^2		0.211	
F		7.63	
p significance level		**0.001**	

5 Conclusions

Based on the results of the statistical analyses of the braking system damage for a selected group of vehicles owned and operated by the Municipal Transport Company in Lublin, the following conclusions may be drawn:

1. The observed damages of the analysed vehicles' braking systems do not depend on the length of their routes. It is of high probability that the greatest impact on the frequency of damage is exerted by the weather conditions occurring during the bus rides.
2. The study showed no relationship between the season of the year (quarterly course) and the number of faults in the analysed system.
3. The statistical analysis showed the number of the braking system faults does not depend on the vehicle's monthly kilometrage.
4. Both the number of the braking system faults, and the monthly kilometrage depend on the month of measurement. The number of the braking system faults increases along with the vehicle's age and does not depend on the vehicle's monthly kilometrage.
5. According to the analysis results, that number of faults increases with the month of measurement and, at the same time, is independent of the vehicle's monthly kilometrage.

Table 6 The influence of the season of the year on the number of the braking system faults (own work)

		n	Median	Standard deviation	F	*p* significance level	η^2
The number of the braking system faults (quarterly)	Q1	5	75.80	33.71	0.21	0.886	0.04
	Q2	5	66.40	20.67			
	Q3	5	65.60	13.35			
	Q4	5	65.80	23.62			
Quarterly kilometrage	Q1	5	307720.40	32445.23	1.62	0.223	0.23
	Q2	5	295920.60	30423.97			
	Q3	5	277610.40	39201.12			
	Q4	5	323693.60	33719.36			

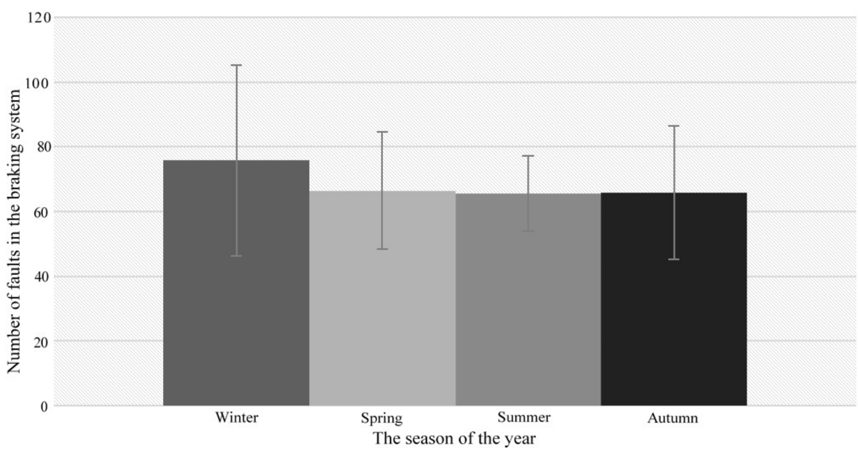

Fig. 8 Mean values together with confidence intervals of 95% of the total number of the braking system faults in the individual quarters (own work)

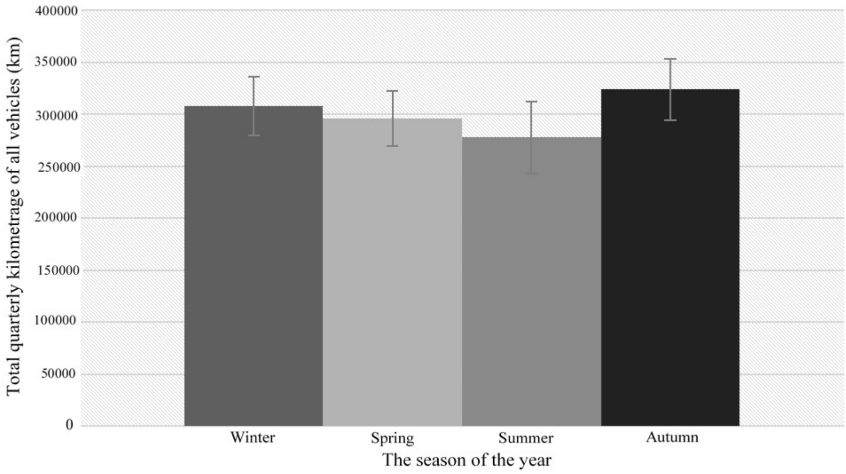

Fig. 9 Mean values together with confidence intervals of 95% of the total kilometrage of all vehicles in the individual quarters (own work)

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