applied sciences

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Analysis of Technical Condition of Cars in Western Poland: A Study Based on Selected Indicators

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Abstract: (1) *Background*: Ensuring road user safety relies on the optimal technical condition of cars, addressing both active and passive safety measures. In Poland, vehicle regulations, articulated in the Minister of Infrastructure's decree of 31 December 2002, establish technical prerequisites and necessary equipment. For this purpose, the main question was: What is the current technical condition of cars on the road in Western Poland? (2) *Methods*: A total of 1067 vehicles were tested, reflecting a maximum error of 3% in a population of 20 million cars. Tests were conducted at the diagnostic station from 1 October 2022 to 30 September 2023. Statistical analysis was conducted using STATISTICA software. (3) *Results*: Periodic technical tests yield insights into passenger car safety standards in western Poland. The application of formulated characteristics allows a comprehensive evaluation, providing valuable information on the overall safety condition of inspected vehicles. The vehicles in Poland have an average age exceeding 14 years, and their average mileage is 168,000 km. (4) *Conclusions*: The examination uncovered various technical defects and provided statistical interpretations, unequivocally demonstrating that these identified issues have the potential to impact traffic safety. Such studies act as a reference point for other researchers addressing the broader issue of road traffic.

Keywords: vehicle safety; personal vehicles technical state; car safety; technical condition of cars in Poland

Citation: Obst, M.; Glowinski, S.; Kurpisz, D. Analysis of Technical Condition of Cars in Western Poland: A Study Based on Selected Indicators. *Appl. Sci.* **2024**, *14*, 645. https://doi.org/10.3390/app14020645

Academic Editor: Suchao Xie

Received: 12 December 2023
Revised: 27 December 2023
Accepted: 10 January 2024
Published: 12 January 2024

1. Introduction

Periodic vehicle inspections are essential for ensuring that a vehicle's technical condition complies with legal requirements [1]. The extent and quality of these inspections play a crucial role in safeguarding the safety of road users. It is important to emphasize that a well-maintained vehicle meeting specific technical standards forms the cornerstone of considerations for road safety, pedestrian safety, and environmental well-being. During a periodic technical inspection, a vehicle undergoes a swift evaluation of selected systems. The diagnostician's expertise, coupled with diagnostic equipment, is paramount in this process. As in any specialized field, diagnostic methods and equipment evolve over time. Present-day equipment is distinguished by its speed, precision, and integration with electronics featuring intuitive controls. A comprehensive review of literature sheds light on various aspects of motor vehicle diagnostics, operation, and safety [2–4]. In a notable study [5], the authors introduced an algorithm designed to predict the service life of both passenger and heavy goods vehicles. This algorithm relied on vehicle condition data accumulated over their operational lifespan. Equipped with a measuring system, the vehicles provided data that allowed for inferences about their ongoing functionality, including predictions about potential breakdowns. The study proposed the integration of this algorithm with the electronic systems of vehicles.

Accurately predicting failures enhances the safety of car usage and enables efficient planning for periodic servicing, thereby facilitating the work of diagnosticians at vehicle inspection stations. Through the analysis of data collected from various diagnostic stations in nine European Union countries, a comparison of vehicle condition ratings was conducted [6]. Utilizing the average vehicle age for each country, an effort was made to identify correlations between the technical condition of vehicles in the analyzed countries. Notably, in Poland, the lowest average value (2.00%) was estimated for temporary and inoperative vehicles, with the average age of passenger cars being 13.9 years. This suggests that vehicles in circulation in Poland exhibit exemplary technical conditions. Drawing on studies conducted in Slovakia, Finland, and Germany, it was observed that the highest number of serious and dangerous defects occur in vehicles aged between 4 and 16 years. This leads to the conclusion that a well-functioning, uniform vehicle technical inspection system constitutes one of the fundamental elements for enhancing road safety. The authors of [7] have summarized the operating conditions of vehicle inspection stations in Poland, providing insights into the requirements and diagnostic procedures.

The procedure to be followed during the technical examination of a vehicle by an authorized diagnostician is outlined, encompassing the following checkpoints: identification of the vehicle, quasi-static or dynamic testing of the braking system, inspection of the chassis, suspension and steering, lighting, and environmental protection (emissions, leakage of operating fluids). It is important to note that the current procedure enables an accurate assessment of the vehicle's technical condition, provided that all diagnostic operations ensure an objective result. The examination of the technical condition of vehicles in the eastern region of Poland was undertaken by the authors of [4], including a comparison with analogous results of tests conducted by vehicle inspection stations in Germany. In addition to activities related to obligatory technical inspections, attention was devoted to whether the vehicle was accident-free, the place of first registration (Poland/EU), the number of previous vehicle owners, the number of vehicle users, vehicle servicing (authorized stations/repairs in independent workshops), the type of roads on which the vehicle was used (asphalt/gravel), the periods of vehicle use (year-round/summer/winter), and the place where the vehicle was parked. It is noteworthy that vehicles operated in Germany exhibit twice as many disabling faults compared to the results of studies in Poland. The authors of [8] indicate that the most significant differences between Polish and German tests assessing the technical condition of cars were observed in the efficiency of the steering and suspension systems of vehicles. The findings of studies on the failure states of steering components are outlined in [9], emphasizing that the effectiveness of the steering system is a critical aspect in terms of road safety. During bench tests, the ball pin of a vehicle with a Gross Vehicle Weight (GVW) exceeding 3500 kg was examined. Based on the results obtained, the maximum number of cycles for the pin connection, defining a failure condition when the required level of safety is not met, was estimated. Importantly, it was highlighted that there are no clear indicators defining a failure condition for a ball stud. Therefore, research should be conducted to establish diagnostic procedures that unambiguously assess the technical condition of the ball stud, ensuring that the result is independent of the individual conducting the periodic vehicle inspection. It is noteworthy that the concept of technical condition is not only applicable to modern vehicles. One paper [10] highlights the deficiencies in periodic inspection procedures for historic cars at vehicle inspection stations in Poland. The responsibility for assessing the technical condition of a historic car and deciding on its admission to traffic lies with the diagnostician, who lacks appropriate guidelines. Attention is also drawn to the safety issue arising from collisions between modern and historic cars. It appears that the procedures for the periodic diagnosis of braking systems need to be revised. In their study, the authors of [11] conducted brake efficiency tests at various vehicle inspection stations in Poland to compare the obtained results. These findings were utilized to formulate a methodology for the technical testing of vintage vehicles. Notably, significant differences were observed in the brake test results across different vehicle inspection stations. The identified reason for this variance was the performance of measurements by different diagnosticians. The study also highlighted disparities in equipment, the technical condition of measuring tools, and variations in the competence levels of diagnosticians at different vehicle inspection stations.

Researchers have proposed a method for diagnosing clutch friction linings, utilizing the work of frictional forces as an indicator for assessing the technical condition [12]. They have also developed a methodology to estimate the service life of friction linings and the expected replacement time for these components. An intriguing observation is the potential correlation between the technical condition of vehicles and the level of exhaust emissions. As presented by the authors of [13], CO and HC emissions increase in the exhaust of cars older than 10 years. It was further noted that in cars surpassing the 10-year mark, the average exhaust emissions exceed permissible limits. The authors hypothesize that, given the average age of cars in Poland exceeding 10 years, a significant proportion of vehicles in the country may be in poor technical condition concerning exhaust emission standards. The results of tests conducted on electronic diagnostic systems fitted in modern cars are detailed in [14]. The objective of the analysis was to assess the suitability of on-board diagnostic systems for evaluating the technical condition of vehicles and efficiently diagnosing faults. It was emphasized that, particularly concerning safety systems, the on-board diagnostic system did not consistently detect faults. In [15], a proposal was made to utilize a dual extended Kalman filter for analyzing current vehicle condition information. Given that active safety systems necessitate the provision and processing of real-time information, which may introduce errors, the authors of [16] underscored the limitations of current solutions. These considerations were validated through simulation on a vehicle model with three degrees of freedom. The accurate and unambiguous assessment of the technical condition of a vehicle is crucial in the work of expert witnesses. In [17], it was presented that the data acquired by expert witnesses examining vehicles is sourced from the vehicle control unit, measurements, calculations, etc. A procedure is proposed for the evaluation of the technical condition of vehicles, aiming to streamline the work of expert witnesses and enhance the objectivity of the technical opinions they provide. Despite existing legal regulations and advancements in diagnostic equipment, issues pertaining to the assessment of the technical condition of cars persist and necessitate ongoing research and modification. Given that numerous researchers have highlighted these problems, it is essential to systematically and attentively monitor the current state of affairs.

In this study, an attempt was made to statistically assess the technical condition of vehicles using data obtained from a vehicle inspection station in western Poland. The authors did not find any studies of this nature conducted in the specific Polish region under investigation. The input data included both quantitative and qualitative indicators, such as braking forces of individual wheels, tire pressure, vehicle mileage, age, lighting faults, make, occurrences of operating fluid leakage, and instances of advanced corrosion. The work, along with the results of research by other authors, can serve as a valuable compendium of knowledge regarding the current technical condition of passenger cars in operation in Poland. This study sets the stage for further research focused on evaluating the active and passive safety of vehicles with varying operating histories.

2. Materials and Methods

Using data gathered at the district vehicle inspection station in a district town in western Wielkopolska, statistical characteristics were developed to serve as a foundation for inferring the technical condition of cars in this region of Poland. The research group comprised 1067 passenger cars whose presence at the diagnostic station was necessitated by the requirement for periodic tests. The test results were documented between 1 October 2022, and 30 September 2023, utilizing the measuring equipment available at the service station.

Tire pressure measurements were conducted using a dedicated A.N.I. 25/GR 80 pressure gauge with an accuracy class of 1.6, specifically designed for use in vehicle inspection stations. Braking force measurements were performed on the diagnostic path of the HEKA TE Bolid A4 device, equipped with an overrun plate device designed for assessing the operation of brakes in vehicles with a Gross Vehicle Weight (GVW) of 3.5 t. The device is versatile, allowing for the diagnosis of motorbikes and agricultural tractors with trailers. At the time of recording braking forces, the brake testing device held a valid certificate issued by the Transport Technical Supervision [17].

All statistical calculations were conducted using the statistical package from StatSoft. Inc. (Tulsa, OK, USA, 2020), specifically STATISTICA version 13.3. Quantitative variables were characterized by their arithmetic mean and (standard deviation), median, minimum and maximum values (range), and 95% confidence interval (95% CI). A 95% confidence interval means that if we were to take 100 different samples and compute a 95% confidence interval for each sample, then approximately 95 of the 100 confidence intervals will contain the true mean value. Tests were employed to assess whether a quantitative variable originated from a population with a normal distribution, including the Shapiro–Wilk, Lilliefors, Kolmogorov–Smirnov, and Jarque-Bera tests. Conversely, the Levene (Brown–Forsythe) test was utilized to examine the hypothesis of equal variances. The significance of differences between two groups (unrelated variables model) was tested using Student's *t* test (when variances were not homogeneous) or the Mann–Whitney U test (when the applicability conditions of Student's *t* test were not met). To assess differences in the same variable among different structures in the absence of a normal distribution, the Kruskal–Wallis test was employed, and in the case of a statistically significant result, a post hoc test was additionally conducted.

Correlation analysis was used to ascertain the association of strength and direction between the variables by calculating Pearson correlation coefficients (*). Before examining the correlation between the variables, graphs were drawn to illustrate the strength and direction of the relationships between the variables. This made it possible to determine whether there were outlier points. A detailed methodology is presented in [18]. In all calculations, $p = 0.05$ was taken as the significance level. Statistically significant values are denoted in bold text in the tables.

3. Results

Table 1 displays the characteristics of the cars, including their age, mileage, and engine displacement (pure electric cars were not included in the survey). The largest number of cars participating in the survey belonged to the VW make (158 units—14.8%). This was followed by Opel (115—10.8%), Ford (88—8.2%), Renault (68—6.4%), Fiat (53—5.0%), Skoda (46—4.3%), and Audi (38—3.6%). The average age of the cars examined at the vehicle inspection station during the considered period was over 14 years. According to the TUV 2023 fault report published by the German Technical Inspection Association (TUV), the average age of a car in Germany is 10 years [19]. The average mileage of the cars inspected in western Greater Poland was 168,325 km.

Table 1. Baseline characteristics of the study population ($N = 1067$); mean (SD), range, median, [95% CI].

Age (years)	14.4 (6.17) 0.0–55.0 14.0 [14.04; 14.78]	Diesel ($n = 428$)	13.6 (5.5) 1.0–55.0 13.0 [13.04; 14.09]
		Fuel ($n = 580$)	14.9 (6.5) 1.0–38.0 15.0 [14.39; 17.59]
		Fuel + Gas ($n = 56$)	15.8 (6.6) 0.0–35.0 16.5 [14.05; 17.59]
		Hybrid ($n = 3$)	9.0 (2.0) 7.0–11.0 9.0 [4.03; 13.97]
		p-value	**0.0004** [1]

Table 1. *Cont.*

Mileage (km)	168,325 (85,307) 5128–565,101 160,594 [163,200; 173,449]	Diesel (*n* = 428)	209,631 (86,200) 7312–565,101 208,058 [201,441; 217,820]
		Fuel (*n* = 580)	134,567 (69,046) 5128–413,292 129,819 [128,936; 140,198]
		Fuel + Gas (*n* = 56)	201,200 (81,654) 30,905–406,234 199,738 [179,333; 223,067]
		Hybrid (*n* = 3)	188,442 (49,264) 132,022–222,942 210,362 [66,063; 310,821]
		p-value	**0.0000** [1]
Capacity (cm^3)	1610.0 (451.2) 652.0–6208.0 1590.0 [1582.9; 1637.1]	Diesel (*n* = 428)	1836.2 (337.3) 1199.0–3222.0 1896.0 [1804.2; 1868.3]
		Fuel (*n* = 580)	1441.0 (450.0) 652.0–6208.0 1390.0 [1404.3; 1478.7]
		Fuel + Gas (*n* = 56)	1596.5 (411.8) 963.0–2976.0 1593.0 [1486.3; 1706.8]
		Hybrid (*n* = 3)	2250.3 (1054.9) 1497.0–3456.0 1798 [0.0; 4870.9]
		p-value	**0.0000** [1]

[1] Kruskal–Wallis test.

The highest mileage, around 200,000 km, was recorded for diesel and gas-powered vehicles, while petrol-powered vehicles had the lowest mileage at 135,000 km (Figure 1). The highest engine capacity was observed in hybrid vehicles; however, due to the limited number of only three such vehicles in the study group, a high standard deviation value was recorded. A significant correlation coefficient was observed between the mileage (km) variable and the age (years) variable (0.3768) (Figure 2).

Table 2 provides descriptive statistics concerning the typical brands of cars undergoing periodic inspection. Cars (*n* < 50) were grouped under "Other" (*n* = 454). Fiat and VW vehicles, being the most numerous, were observed to be, on average, the oldest compared to other brands (Figure 3). This is likely associated with the import of vehicles from Germany and the popularity of these brands in Europe. A similar pattern was observed for Opel and Renault. The brand with the youngest average vehicle age was Dacia (*n* = 12) at 8 (5.3) years old. It can be seen that the average lowest capacity was observed for Fiat.

Table 2. Baseline characteristics of car brand: mean (SD), range, median, [95% CI].

Brand	Age [Years]	Mileage [km]	Capacity [cm^3]
VW (*n* = 158)	16.8 (6.8) 3–55 16.5 [15.7; 17.8]	217,256 (95,501) 10,809–565,101 219,074 [202,250; 232,263]	1692 (319) 999–2967 1714 [1642; 1742]

Table 2. *Cont.*

Brand	Age [Years]	Mileage [km]	Capacity [cm^3]
Opel (n = 115)	15.2 (6.5) 3–31 15 [14.2; 16.3]	166,360 (81,828) 19,886–391,640 176,979 [151,243; 181,476]	1557 (314) 973–2231 1598 [1498; 1615]
Ford (n = 88)	12.2 (5.1) 3–24 12 [11.2; 13.3]	175,121 (80,281) 8367–470,520 172,594 [158,111; 192,131]	1650 (472) 998–4951 1560 [1550; 1750]
Toyota (n = 72)	14.1 (6.7) 3–25 15 [12.8; 15.5]	142,028 (72,691) 23,293–382,998 135,270 [124,947; 159,110]	1429 (347) 998–2231 1329 [1347; 1510]
Renault (n = 68)	16.0 (6.1) 0–24 17 [14.8; 17.2]	177,632 (73,728) 24,285–351,044 179,956 [159,786; 195,478]	1434 (256) 898–1998 1461 [1372; 1496]
Peugeot (n = 59)	14.2 (6.5) 3–27 15 [12.8; 15.6]	185,302 (91,935) 11,506–441,427 178,678 [161,344; 209,261]	1567 (299) 998–1997 1560 [1468; 1624]
Fiat (n = 53) (F = 40; D = 10, F + G = 3)	17.3 (8.3) 2–29 19 [15.4; 19.2]	127,448 (64,778) 8584–287,623 121,360 [109,593; 145,303]	1205 (282) 652–1997 1108 [1127; 1283]
Other (n = 454)	13.3 (6.1) 1–38 13 [12.7; 13.9]	155,819 (80,544) 5128–409,635 146,017 [148,391; 163,248]	1698 (535) 652–6208 1595 [1649; 1747]
p-value	**0.0000** [1]	**0.0000** [1]	**0.0000** [1]

[1] Kruskal–Wallis test.

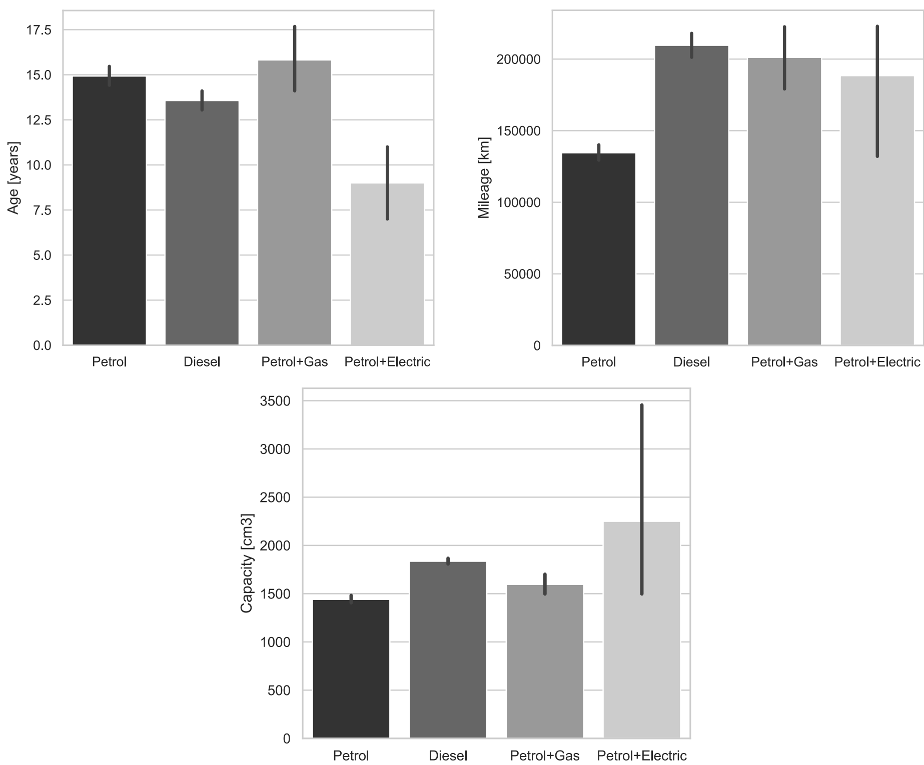

Figure 1. Age, mileage, and capacity of the 1067 cars.

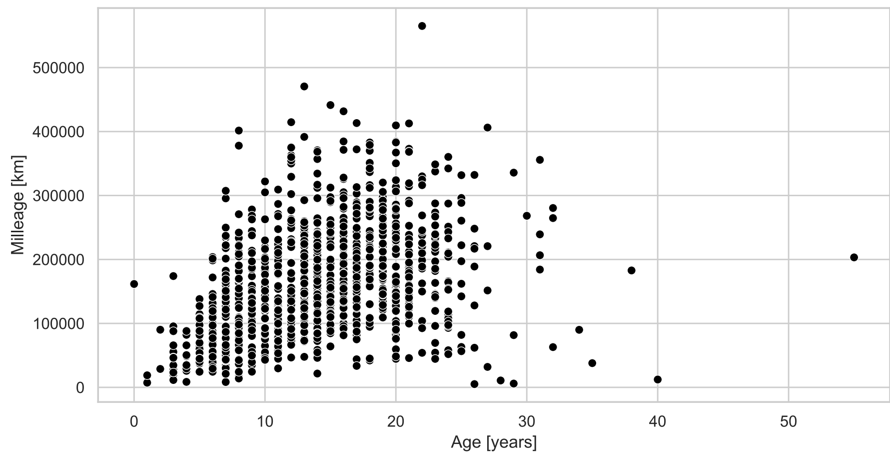

Figure 2. Mileage vs. age of the 1067 personal cars.

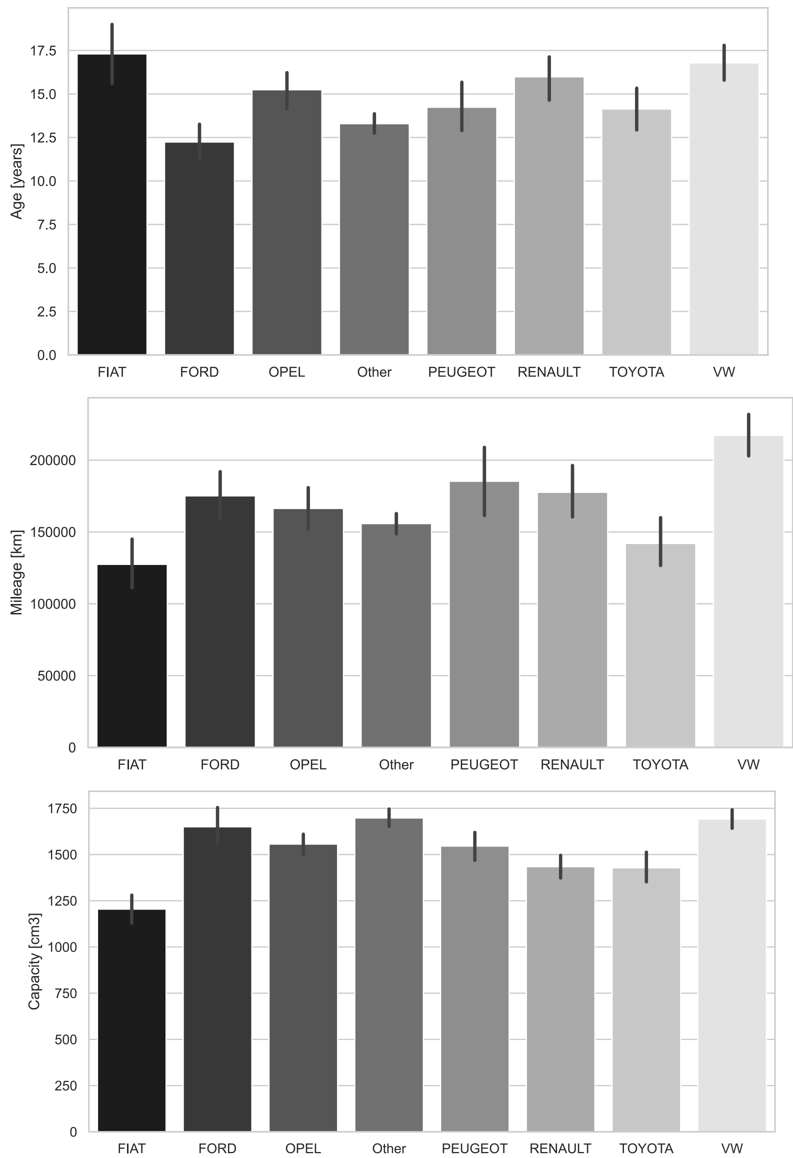

Figure 3. Age, mileage, and capacity vs. brand of cars.

Table 3 presents the results of the multivariate analysis in the form of a dependency matrix. The dependent variables were age, mileage (km), and capacity (cm^3), while the independent variable was the make of the car in question. Significant differences are highlighted in bold text.

Table 3. *p*-values for multiple (two-sided) comparisons; age, mileage, capacity.

Dependent: Age (Years)	**Independent Variable (Grouping): Brand Kruskal–Wallis Test: H (7, N = 1067) = 73.64346, p = 0.0000**							
	Peugeot R: 534.21	**VW R: 641.71**	**Toyota R: 532.22**	**Other R: 472.10**	**Fiat R: 692.42**	**Ford R: 423.02**	**Renault R: 636.74**	**Opel R: 582.56**
Peugeot		0.6224	1.0000	1.0000	0.1869	0.8959	1.0000	1.0000
VW	0.6224		0.3488	**p < 0.0001**	1.0000	**p < 0.0001**	1.0000	1.0000
Toyota	1.0000	0.3488		1.0000	0.1141	0.7211	1.0000	1.0000
Other	1.0000	**p < 0.0001**	1.0000		**p < 0.0001**	1.0000	**0.0011**	**0.0167**
Fiat	0.1869	1.0000	0.1141	**p < 0.0001**		**p < 0.0001**	1.0000	0.8898
Ford	0.8959	**p < 0.0001**	0.7211	1.0000	**p < 0.0001**		**0.0005**	**0.0072**
Renault	1.0000	1.0000	1.0000	**0.0011**	1.0000	**0.0005**		1.0000
Opel	1.0000	1.0000	1.0000	**0.0167**	0.8998	**0.0072**	1.0000	

Dependent: Milleage (km)	**Independent Variable(Grouping): Brand Kruskal–Wallis Test: H (7, N = 1067) = 77.82803, p = 0.0000**							
	Fiat R: 381.15	**Ford R: 567.00**	**Opel R: 540.26**	**Other R: 488.20**	**Peugeot R: 585.63**	**Renault R: 582.10**	**Toyota R: 441.04**	**VW R: 696.32**
Fiat		0.0146	0.0524	0.4678	**0.0127**	**0.0104**	1.0000	**p < 0.0001**
Ford	0.0146		1.0000	0.7877	1.0000	1.0000	0.2830	0.0449
Opel	0.0524	1.0000		1.0000	1.0000	1.0000	0.9006	0.0010
Other	0.4678	0.7877	1.0000		0.6255	0.5350	1.0000	p < 0.0001
Peugeot	**0.0127**	1.0000	1.0000	0.6255		1.0000	0.2112	0.5195
Renault	**0.0104**	1.0000	1.0000	0.5350	1.0000		0.1901	0.2968
Toyota	1.0000	0.2830	0.9006	1.0000	0.2112	0.1901		p < 0.0001
VW	**p < 0.0001**	**0.0449**	**0.0010**	**p < 0.0001**	0.5195	0.2968	**p < 0.0001**	

Dependent: Capacity (cm^3)	**Independent Variable (Grouping): Brand Kruskal–Wallis Test: H (7, N = 1067) = 102.8552, p = 0.000**							
	Fiat R: 212.29	**Ford R: 571.44**	**Opel R: 523.33**	**Other R: 581.33**	**Peugeot R: 502.59**	**Renault R: 419.65**	**Toyota R: 405.17**	**VW R: 612.46**
Fiat		**p < 0.0001**	**p < 0.0001**	**p < 0.0001**	**p < 0.0001**	**0.0067**	**0.0152**	**p < 0.0001**
Ford	**p < 0.0001**		1.0000	1.0000	1.0000	0.0640	**0.0192**	1.0000
Opel	**p < 0.0001**	1.0000		1.0000	1.0000	0.7799	0.3002	0.5123
Other	**p < 0.0001**	1.0000	1.0000		1.0000	**0.0015**	**0.0002**	1.0000
Peugeot	**p < 0.0001**	1.0000	1.0000	1.0000		1.0000	1.0000	0.5446
Renault	**0.0067**	0.0640	0.7799	**0.0015**	1.0000		1.0000	**0.0004**
Toyota	**0.0152**	**0.0192**	0.3002	**0.0002**	1.0000	1.0000		**0.0001**
VW	**p < 0.0001**	1.0000	0.5123	1.0000	0.5446	0.0004	0.0001	

Table 4 displays the braking force of individual wheels and the braking force of the parking brake. No statistically significant difference was observed among the individual wheels.

Table 4. Breaking force; LF—left front, RF—right front, LR—left rear, RR—right rear, parking brake.

Brand	Breaking Force LF (kN)	Breaking Force RF (kN)	p-Value	Breaking Force LR (kN)	Breaking Force RR (kN)	p-Value	Breaking Force Parking (kN)
VW (n = 158)	6.2 (1.4) 2.5–11.4 6.0 [6.0; 6.4]	6.2 (1.4) 2.5–10.0 6.1 [6.0; 6.4]	0.4812 [3]	2.0 (0.6) 0.5–4.0 2.0 [1.9; 2.1]	1.9 (0.6) 0.4–4.0 1.9 [1.8; 2.0]	0.7681 [3]	5.1 (1.3) 2.0–10.0 5.0 [4.9; 5.4]
Opel (n = 115)	6.3 (1.6) 3.1–11.4 6.1 [6.0; 6.6]	6.3 (1.5) 3.3–11.4 6.2 [6.0; 6.6]	0.2696 [3]	1.9 (0.6) 0.6–4.0 1.9 [1.8; 2.0]	1.9 (0.5) 0.6–3.3 1.8 [1.8; 2.0]	0.7708 [3]	4.4 (1.3) 0.0–7.9 4.5 [4.1; 4.6]
Ford (n = 88)	6.8 (1.8) 2.7–11.4 6.7 [6.4; 7.1]	6.8 (1.8) 2.6–11.4 6.8 [6.4; 7.2]	0.9634 [3]	2.2 (0.7) 0.6–5.6 2.3 [2.1; 2.4]	2.1 (0.7) 0.5–5.6 2.2 [2.0; 2.3]	0.9611 [3]	5.5 (1.9) 1.4–11.0 5.3 [5.1; 5.9]
Toyota (n = 72)	5.7 (1.6) 3.0–10.0 5.0 [5.3; 6.0]	5.7 (1.6) 3.0–10.0 5.4 [5.4; 6.1]	0.8105 [3]	1.7 (0.5) 0.5–3.3 1.7 [1.6; 1.8]	1.6 (0.5) 0.5–3.3 1.6 [1.5; 1.8]	0.9331 [3]	4.7 (1.4) 2.7–8.7 6.0 [4.4; 5.1]
Renault (n = 68)	5.7 (1.5) 3.4–9.8 5.4 [5.3; 6.0]	5.7 (1.4) 3.3–9.4 5.4 [5.3; 6.0]	0.9601 [3]	1.7 (0.4) 0.9–2.8 1.7 [1.6; 1.8]	1.7 (0.4) 0.8–2.9 1.6 [1.6; 1.8]	0.9445 [3]	4.5 (1.3) 1.2–8.7 4.5 [4.2; 4.8]
Peugeot (n = 59)	6.3 (1.5) 3.7–10.0 6.0 [5.9; 6.7]	6.2 (1.5) 3.3–10.0 5.9 [5.8; 6.6]	0.4658 [2]	1.8 (0.5) 0.4–3.0 1.8 [1.7; 2.0]	1.7 (0.4) 0.7–3.2 1.8 [1.6; 1.9]	0.9774 [3]	4.6 (1.3) 1.2–8.8 4.6 [4.2; 4.9]
Fiat (n = 53)	5.2 (1.9) 1.9–10.7 4.6 [4.7; 5.7]	5.1 (2.0) 1.5–10.3 4.6 [4.5; 5.6]	0.8041 [2]	1.3 (0.8) 0.3–3.2 1.0 [1.0; 1.5]	1.3 (0.9) 0.1–3.8 1.0 [1.0; 1.5]	0.9195 [3]	3.6 (1.7) 0.7–8.0 3.3 [3.1; 4.1]
Other (n = 454)	6.6 (1.7) 1.8–11.4 6.5 [6.4; 6.7]	6.6 (1.7) 2.1–11.4 6.4 [6.4; 6.8]	0.2894 [3]	2.1 (0.8) 0.3–6.4 1.9 [2.0; 2.1]	2.0 (0.8) 0.4–6.4 1.8 [1.9; 2.0]	0.6742 [3]	5.1 (1.8) 1.0–10.0 4.8 [4.9; 5.3]
p-value	0.2294 [1]	0.5450 [1]	---	**0.0000 [1]**	**0.0000 [1]**		**0.0000 [1]**

[1] Kruskal–Wallis test. [2] Student's t test. [3] Mann–Whitney U test.

The highest average front brake force was noted for Ford cars at 6.8 kN (1.8), while the lowest was recorded for Fiat cars at 5.2 kN (1.9) (Figure 4). Similarly, the rear brake force (Figure 5) was highest for Ford cars at 2.0 kN (0.7) and lowest, mirroring the front brakes, for Fiat cars at 1.3 kN (0.8). The situation was analogous for the parking brake. Statistically significant differences were observed between brands. Table 5 summarizes the variance in braking between the wheels on the front axle and the rear axle. The allowable difference in braking force for wheels on one axle is a maximum of 30% (Figure 6). It can be observed that, in the case of the front axle brakes, significant differences in braking power occur in isolated cases. On the rear axle, such instances are more numerous. Differences across car brands are depicted in Table 6. The highest values for the front axle were recorded for Peugeots (9.27%), while the lowest were for Toyota (6.4%) (Figures 7 and 8). For the rear axle wheels, the highest values were recorded for Fiat (26.02%), and the lowest were for Ford (9.80%). Statistically significant differences were recorded for all brands except the front axle.

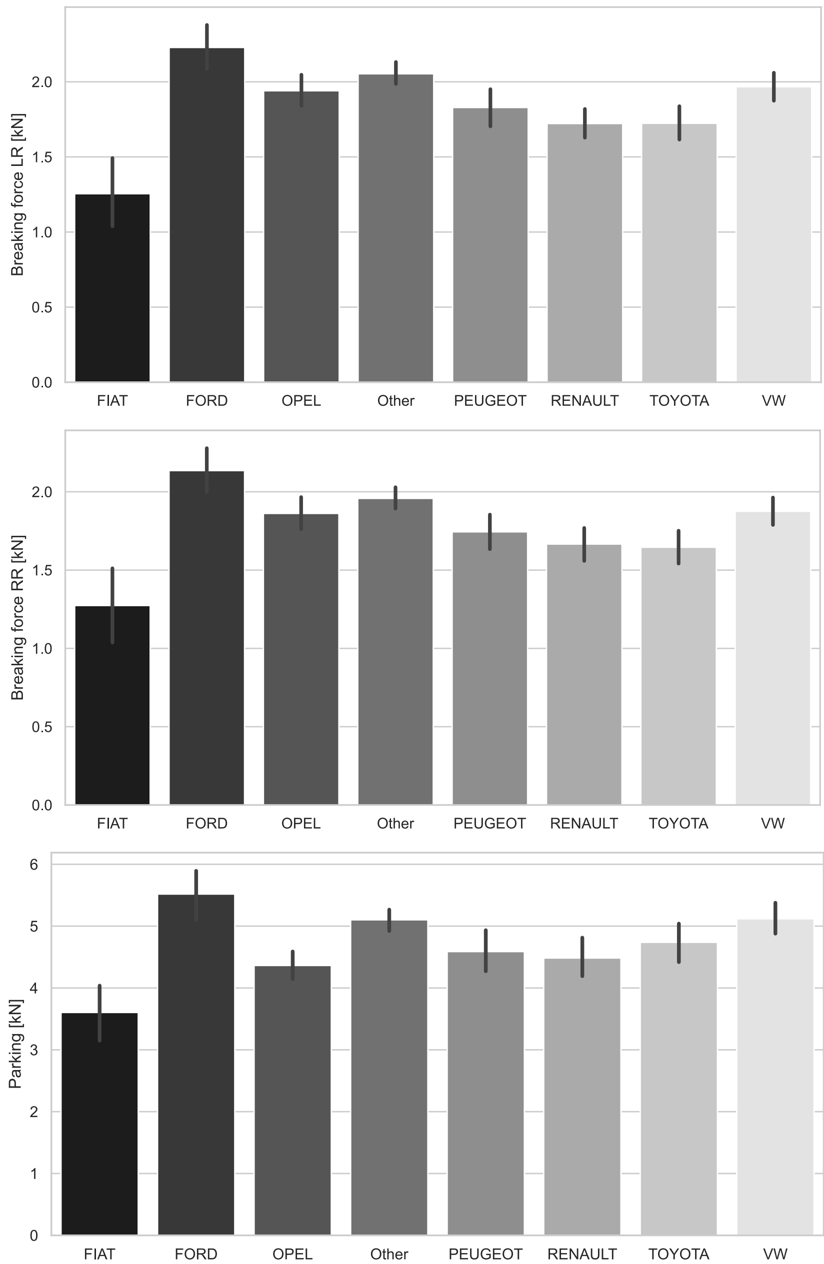

Figure 4. Breaking force of rear left, rear right, and parking brake (mean (SD)).

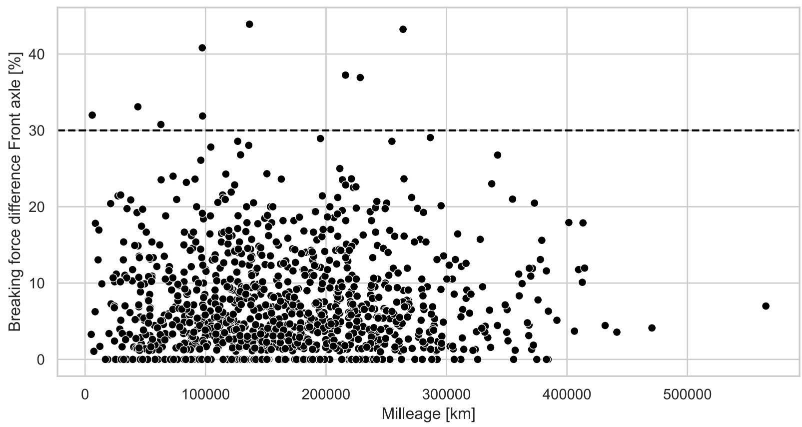

Figure 5. Breaking force difference in % for front axle of 1067 cars.

Table 5. Breaking difference, pressure difference, mileage per year.

Brand	Front Breaking Difference (%)	Rear Breaking Difference (%)	Front Pressure Difference (%)	Rear Pressure Difference (%)	Milleage per Year (km)
VW (*n* = 158)	8.32 (6.76) 0.0–43.24 6.90 [7.27; 9.39]	12.99 (10.88) 0.0–58.82 10.26 [11.29; 14.70]	7.56 (11.51) 0.00–85.71 4.65 [5.76; 9.37]	8.99 (13.94) 0.00–100.00 4.49 [6.80; 11.18]	13,883 (6422) 308–38,420 12,593 [12,874; 14,892]
Opel (*n* = 115)	7.00 (6.03) 0.0–29.06 5.71 [5.88; 8.11]	13.40 (11.84) 0.0–56.41 10.53 [11.21; 15.58]	8.76 (13.22) 0.00–104.76 4.88 [6.32; 11.20]	6.96 (8.97) 0.00–50.00 4.44 [5.30; 8.62]	10,862 (4688) 2420–30,126 9832 [9996; 11,728]
Ford (*n* = 88)	7.16 (7.51) 0.00–40.82 4.82 [5.57; 8.75]	9.80 (8.38) 0.0–34.48 7.70 [8.03; 11.57]	9.74 (20.74) 0.00–175.33 4.65 [5.34; 14.13]	8.31 (10.78) 0.00–50.00 4.88 [6.03; 10.60]	15,237 (7391) 1195–43,506 14,368 [13,671; 16,803]
Toyota (*n* = 72)	6.40 (6.34) 0.00–28.04 4.20 [4.91; 7.89]	11.71 (12.02) 0.00–57.14 9.11 [8.89; 14.54]	5.44 (10.58) 0.00–72.73 4.09 [2.96; 7.93]	5.29 (7.30) 0.00–32.26 4.26 [3.58; 7.01]	10,394 (4608) 2165–26,071 9557 [9312; 11,477]
Renault (*n* = 68)	7.87 (6.63) 0.00–28.57 5.77 [6.26; 9.47]	12.00 (9.88) 0.00–40.00 10.53 [8.89; 14.54]	10.43 (13.68) 0.00–70.59 5.13 [7.11; 13.74]	10.26 (14.89) 0.00–66.67 5.13 [6.66; 13.87]	10,934 (4991) 101–36,940 10,557 [9312; 11,477]
Peugeot (*n* = 59)	9.27 (9.01) 0.00–37.24 7.14 [6.92; 11.62]	12.62 (14.59) 0.00–93.33 8.00 [8.81; 16.42]	7.62 (11.22) 0.00–62.86 4.88 [4.69; 10.54]	9.28 (13.41) 0.00–81.48 4.88 [5.79; 12.78]	13,512 (7041) 1977–44,618 12,622 [11,678; 15,348]
Fiat (*n* = 53)	8.13 (6.92) 0.00–26.09 5.00 [6.23; 10.04]	26.02 (34.89) 0.00–100.00 16.22 [16.41; 35.64]	11.80 (19.35) 0.00–103.03 5.13 [6.47; 17.14]	7.99 (9.81) 0.00–42.86 5.41 [5.28; 10.69]	8710 (6448) 1185–31,096 6731 [6932; 10,487]
Other (*n* = 454)	7.03 (6.30) 0.00–43.90 5.71 [6.45; 7.61]	12.85 (14.17) 0.00–100.00 10.72 [11.54; 14.16]	7.02 (13.24) 0.00–165.22 4.44 [5.80; 8.24]	6.66 (9.93) 0.00–63.41 4.44 [5.75; 7.58]	12,650 (6565) 197–41,993 11,651 [12,045; 13,256]
p-value	0.1536 [1]	**0.0372 [1]**	**0.0069 [1]**	0.0578 [1]	**0.0000 [1]**

[1] Kruskal–Wallis test.

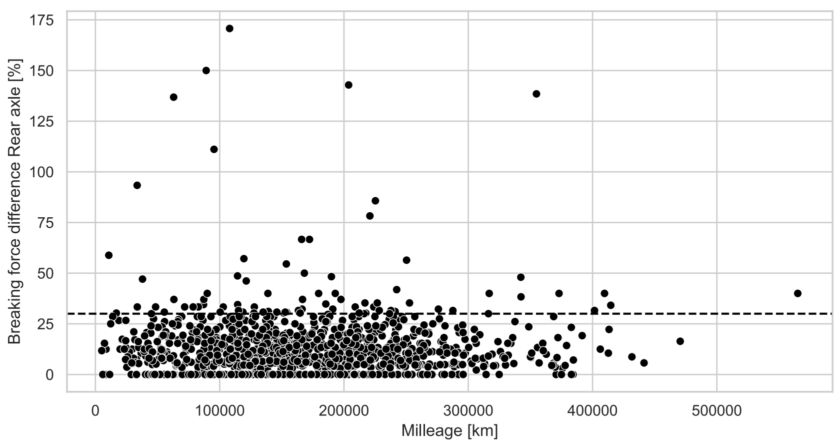

Figure 6. Breaking force difference in % for rear axle of 1067 cars.

Table 6. Front axle (mm), rear axle (mm).

Brand	Front Axle (mm)	Rear Axle (mm)	Light Setting: Yes/No Correction	Front Suspension Play: Yes/No	Chassis Corrosion: No/Foci/Holes	Oil Leaks: None/ Sweating/Drops	Lighting Fault Yes/No
VW (n = 158)	0.6 (2.7) −7.5–8.5 0.6 [0.2; 1.0]	2.7 (2.0) −3.4–8.6 2.9 [2.4; 3.0]	Y—84 (53.2%) N—74 (46.8%)	Y—12 (8.6%) N—146 (92.4%)	F—10 (6.3%) N—147 (93.0%) H—1 (0.6%)	S—25 (15.8%) N—128 (81.0%) D—5 (3.2%)	Y—4 (2.5%) N—154 (97.5%)
Opel (n = 115)	0.1 (2.5) −9.0–5.7 0.3 [−0.4; 0.5]	2.7 (1.3) −0.7–6.5 2.6 [2.5; 3.0]	Y—48 (41.7%) N—67 (58.3%)	Y—12 (10.4%) N—103 (89.6%)	F—3 (2.6%) N—112 (97.4%)	S—32 (13.9%) N—93 (80.9%) D—4 (3.5%)	Y—6 (5.2%) N—109 (94.8%)
Ford (n = 88)	0.7 (2.3) −8.5–6.7 1.0 [0.2–1.2]	3.1 (2.5) −7.6–6.6 3.7 [2.6; 3.7]	Y—40 (45.5%) N—48 (54.5%)	Y—9 (10.2%) N—79 (89.8%)	N—88 (100%)	S—5 (5.7%) N—82 (93.2%) D—1 (1.1%)	Y—6 (6.8%) N—82 (93.2%)
Toyota (n = 72)	0.0 (1.7) −3.5– 4.8 0.3 [−0.4; 0.4]	4.5 (11.6) −3.4–8.6 2.9 [2.4; 3.0]	Y—39 (54.2%) N—33 (45.8%)	N—72 (100%)	F—1 (1.4%) N—70 (97.2%) H—1 (1.4%)	S—3 (4.2%) N—67 (93.1%) D—2 (2.8%)	Y—3 (4.2%) N—69 (95.8%)
Renault (n = 68)	−0.2 (2.4) −7.8–6.5 −0.5 [−0.8; 0.4]	4.0 (1.5) 0.0–6.9 4.3 [3.7; 4.4]	Y—33 (48.5%) N—35 (51.5%)	Y—10 (14.7%) N—58 (85.3%)	F—2 (2.9%) N—66 (97.1%)	S—15 (22.1%) N—50 (73.5%) D—3 (4.4%)	Y—10 (14.7%) N—58 (85.3%)
Peugeot (n = 59)	−0.5 (2.6) −7.6–5.3 0.0 [−1.1; 0.2]	3.2 (2.1) −3.2–6.7 3.4 [2.7; 3.8]	Y—27 (45.8%) N—32 (54.2%)	Y—12 (20.3%) N—47 (79.7%)	F—1 (1.7%) N—57 (96.6%) H—1 (1.7%)	S—10 (16.9%) N—48 (81.4%) D—1 (1.7%)	Y—8 (13.6%) N—51 (86.4%)
Fiat (n = 53)	0.9 (2.8) −5.2–8.6 1.0 [0.1; 1.6]	1.7 (1.8) −2.1–4.8 1.6 [1.2; 2.2]	Y—29 (54.7%) N—24 (45.3%)	Y—4 (7.5%) N—49 (92.5%)	F—3 (5.7%) N—49 (92.5%) H—1 (1.9%)	S—12 (22.6%) N—38 (52.8%) D—3 (5.7%)	Y—1 (1.9%) N—52 (98.1%)
Other (n = 454)	0.5 (2.7) −9.4–8.5 0.7 [0.2; 0.7]	2.9 (2.4) −7.5–8.0 3.2 [2.7; 3.1]	Y—169 (37.2%) N—285 (62.8%)	Y—50 (11.0%) N—404 (89.0%)	F—7 (1.5%) N—445 (98.0%) H—3 (0.7%)	S—32 (7.0%) N—406 (89.4%) D—15 (3.3%)	Y—18 (4.0%) N—436 (96.0%)
p-value	**0.0056** [1]	**0.0000** [1]	**0.0050** [2] **0.0049** [3]	**0.0111** [2] **0.0011** [3]	0.3265 [2] 0.2759 [3]	**0.0000** [2] **0.0040** [3]	0.0594 [2] 0.3127 [3]

[1] Kruskal–Wallis test. [2] Chi-squared Pearson test. [3] Chi-squared NW test.

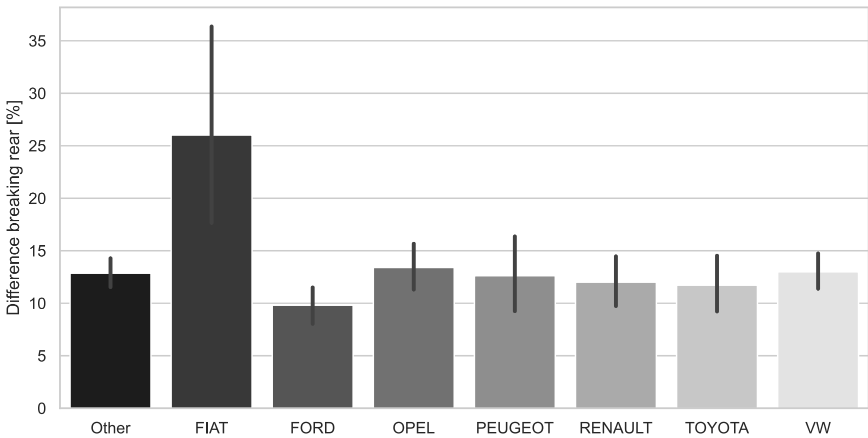

Figure 7. Difference breaking, rear [%].

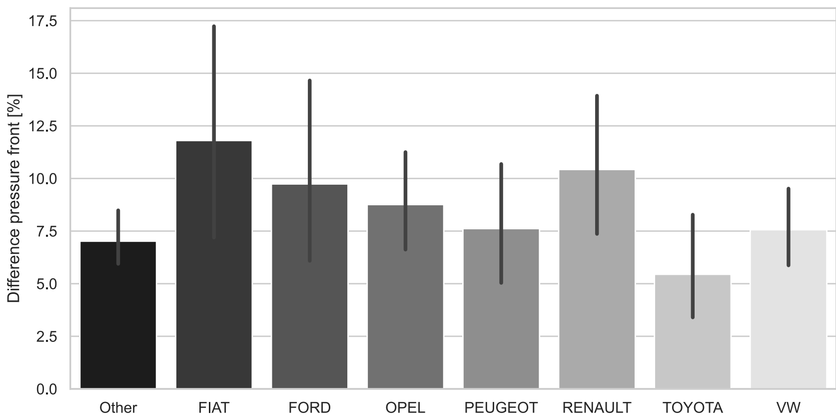

Figure 8. Difference pressure, front (%) (mean (SD)).

Figures 9 and 10 illustrate the pressure differences between the front and rear wheels. It can be seen that, in most cases, these differences do not exceed 25–30%, while there are isolated situations where the pressure difference is more than 100%.

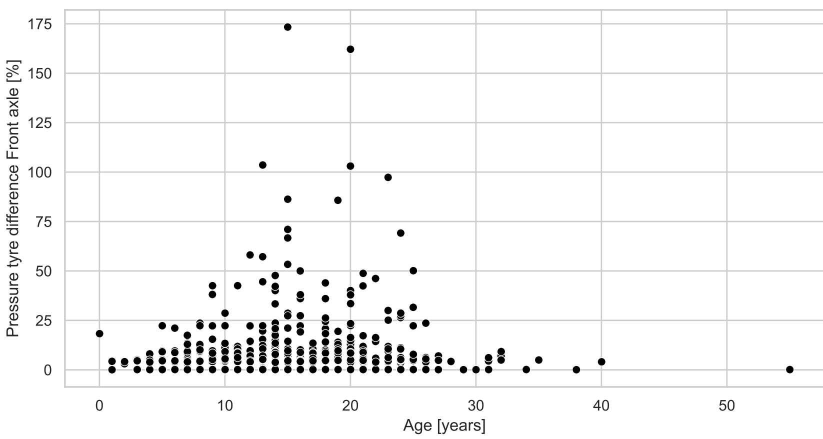

Figure 9. Pressure difference for tire front axle of 1067 cars (%).

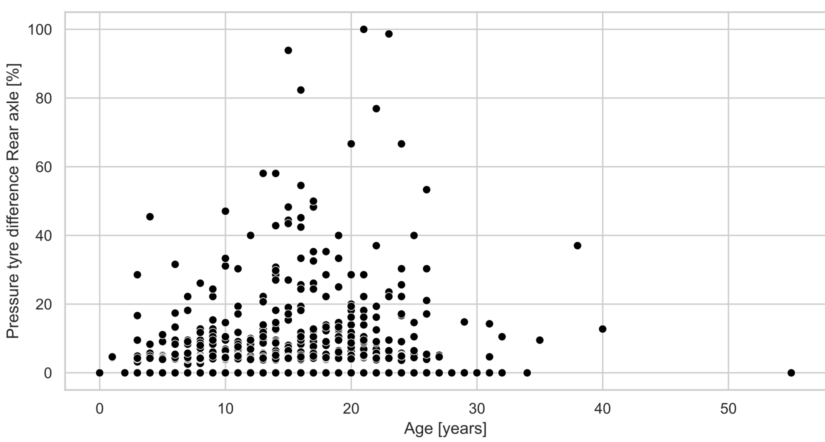

Figure 10. Pressure difference for tire rear axle of 1067 cars (%).

The lights were adjusted in a total of 469 cars (44.0%), with correct adjustment identified in 598 vehicles (56.0%). It is advisable to check and, if necessary, correct the lighting on every car maintenance occasion. Notably, for 1031 vehicles (96.6%), no instances of corrosion or corrosion perforation in chassis components were registered. Regarding oil leaks, none were detected in 911 vehicles (85.4%). Efficient lighting, concerning the operation of exterior lamps, was observed in 1011 vehicles (94.5%). Issues with the lights were found in 46 vehicles (4.3%), and one vehicle was equipped with English lighting, unsuitable for right-hand traffic. Detailed information is presented in Table 6.

4. Discussion

The execution of periodic technical inspections is imperative for ensuring safety, encompassing the well-being of drivers, passengers, and other road users. These inspections allow for the detection of faults that may not be immediately evident, often surfacing during the vehicle's operation. Timely identification of issues facilitates repairs before they escalate into more serious problems. Neglecting inspection can lead to substantial fines, reaching up to PLN 3000 (equivalent to 40% of the average monthly salary in Poland), and in case of a collision, insurers may deny or significantly reduce third-party liability (OC) and comprehensive (AC) benefits [20].

The analysis of diagnostic data offers a preliminary and broad assessment of a car's technical condition. The average age of passenger cars is approximately 15 years, with an average mileage of around 170,000 km. It is crucial to emphasize that a well-maintained car, even at 15 years with high mileage, can maintain an excellent technical condition, ensuring an adequate level of both active and passive safety. Noteworthy trends include the popularity of LPG-powered petrol cars, exhibiting comparable age and mileage to diesel-engine vehicles. Hybrid petrol–electric cars also demonstrate above-average mileage, comparable to their petrol, LPG, and diesel counterparts. The displacement of petrol-only internal combustion engines averages around 1600 cc, while hybrids tend to feature larger internal combustion engine capacities.

In western Poland, Fiats and Volkswagens stand out as the oldest cars, showcasing the durability of these vehicles and the efficacy of their repair capabilities. Volkswagens, in particular, record the highest mileages, highlighting the prevalence of diesel powertrains for this brand.

Observations included variations in braking forces for the front axle, rear axle, and auxiliary brake, with Fiat vehicles exhibiting the smallest braking force values. Some vehicles surpassed the permitted difference in braking force between the wheels of one axle, posing a hazard to traffic. Despite the average age of 15 years, a relatively low number of cars displayed visible chassis corrosion, emphasizing the importance of a comprehensive examination that may require the removal of covers and the use of endoscopic methods.

The authors suggest a study to evaluate the extent of corrosion in components constituting crumple zones, as corrosion in these areas plays a crucial role in dissipating impact energy during an accident. Air pressure in the wheels of test vehicles was also considered, with instances where pressure differences for wheels on the same axle exceeded 60 percent, albeit rarely.

Positive aspects included a low occurrence of oil leaks (less than 15 percent of surveyed cars), aligning with environmental safety considerations. While problems with vehicle lighting were infrequent, there is a relatively common occurrence of incorrect headlamp alignment, directly impacting road safety. In summary, despite the use of relatively old cars with substantial mileage in western Poland, their fundamental technical condition appears to be satisfactory.

5. Conclusions

In future research, there is a need to expand testing by incorporating more detailed assessments using reference equipment. Exact verification of suspension geometry, a meticulously conducted measurement of exhaust gas composition (under different engine loads), or routine tests of shock absorber damping would enable a more precise assessment of the actual condition.

Furthermore, it is essential to conduct a correlation analysis of the technical condition of cars involved in traffic collisions in Poland. Similar analyses in Norway revealed a correlation between the technical condition of cars and the number of accidents. While inspections were found to significantly reduce technical defects, there was no observed effect on the accident rate [21,22]. The authors suggest that car owners adapt their driving behavior to the technical condition of the car, and any impact attributed to technical defects before inspection may be influenced by owners less concerned about safety, neglecting their cars' technical condition. Similar analyses have also been attempted in Poland [23,24]. Results suggest that the system of periodic technical inspections may not have a statistically significant effect on the number of accidents, including those resulting in fatalities. However, the study should be repeated due to the increased number of cars on the road, particularly in Poland [25].

While statistically the overall technical condition of the tested cars is deemed good, special attention should be directed towards vehicles in the minority that exhibit defects exceeding tolerance limits. Such vehicles pose an increased threat to road safety, and concerted efforts should be made to promptly eliminate them from traffic.

Concluding a periodic technical inspection at a vehicle control station should involve issuing a report detailing the results of obligatory tests and their interpretation. Such a document would accurately certify the technical condition of the car, concurrently documenting the inspection entity's responsibility for the conducted tests.

Author Contributions: Conceptualization, S.G. and M.O.; methodology, M.O.; software, M.O. and D.K.; validation, S.G., M.O. and D.K.; formal analysis, S.G.; investigation, M.O.; resources, M.O.; data curation, M.O. and D.K.; writing—original draft preparation, S.G. and M.O.; writing—review and editing, S.G. and M.O.; visualization, S.G.; supervision, S.G. and M.O.; project administration, M.O.; funding acquisition, S.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Martín-delosReyes, L.M.; Lardelli-Claret, P.; García-Cuerva, L.; Rivera-Izquierdo, M.; Jiménez-Mejías, E.; Martínez-Ruiz, V. Effect of Periodic Vehicle Inspection on Road Crashes and Injuries: A Systematic Review. *Int. J. Environ. Res. Public Health* **2021**, *18*, 6476. [CrossRef] [PubMed]
2. Filipczyk, J. The inspections of cars in the scope of traffic safety and environmental protection—The present situation and the prospects of development. *Transp. Probl.* **2010**, *5*, 115–122.
3. Bazhinov, O.; Gerlici, J.; Kravchenko, O.; Haiek, Y.; Bazhynova, T.; Zaverukha, R.; Kravchenko, K. Development of a Method for Evaluating the Technical Condition of a Car's Hybrid Powertrain. *Symmetry* **2021**, *13*, 2356. [CrossRef]
4. Hudec, J.; Sarkan, B.; Czodorova, R.; Caban, J.; Droździel, P. The impact of roadside technical inspections on transport and logistics systems in the Slovak Republic. *Transp. Probl.* **2022**, *17*, 61–73. [CrossRef]
5. Kalmakov, V.A.; Andreev, A.A.; Martyanov, A.S. Remaining Vehicles Useful Lifetime Estimation Based on Operation Conditions Measurement. *Procedia Eng.* **2017**, *206*, 1716–1721. [CrossRef]
6. Hudec, J.; Šarkan, B.; Cződörová, R. Examination of the results of the vehicles technical inspections in relation to the average age of vehicles in selected EU states. *Transp. Res. Procedia* **2021**, *55*, 2–9. [CrossRef]
7. Bril, J.; Łukasik, Z. Diagnostyka pojazdów samochodowych. *Autobusy* **2013**, *3*, 203–211. (In Polish)
8. Wituszyński, K.P.; Jakubowski, W. Analiza stanu technicznego pojazdów samochodowych podlegających kontrolnym badaniom technicznym na Stacjach Kontroli Pojazdów w rejonie podlaskim. *Archiwum Motoryzacji* **2008**, *1*, 19–32.
9. Kozłowski, E.; Borucka, A.; Szymczak, T.; Świderski, A.; Gil, L. Predicting the Fatigue Life of a Ball Joint. *Transp. Telecommun.* **2021**, *22*, 453–460.
10. Malinowski, A.; Taryma, S. Badania Techniczne Pojazdów Zabytkowych w Stacjach Kontroli Pojazdów. *Autobusy* **2012**, *5*, 284–289.
11. Malinowski, A.; Szczepańska, P.; Mioduszewski, P.; Taryma, S. Pomiary skuteczności hamowania w stacjach kontroli pojazdów. *Eksploatacja Testy* **2019**, *20*, 39–41.
12. Karpievich, Y.D.; Bakhanovich, A.G.; Bondarenko, I.I. On-Board Monitoring of Technical State for Power Units of Wheeled and Tracked Vehicles. *Sci. Tech.* **2016**, *15*, 427–434. [CrossRef]

13. Filipczyk, J.; Kutrzyk-Nykiel, A. The Relation Between the Technical State and the Exaust Gasses Emission for a Group of Particular Vegicle Age. *J. KONES Powertrain Transp.* **2011**, *18*, 105–111.
14. Filipczyk, J.; Madej, H. The Application of on-board diagnostics systems for assessing the technical state of automotive vehicles. *J. KONES Powertrain Transp.* **2010**, *17*, 99–104.
15. Zhang, F.; Wang, Y.; Hu, J.; Yin, G.; Chen, S.; Zhang, H.; Zhou, D. A Novel Comprehensive Scheme for Vehicle State Estimation Using Dual Extended H-Infinity Kalman Filter. *Electronics* **2021**, *10*, 1526. [CrossRef]
16. Dobromirov, V.; Dotsenko, S.; Verstov, V.; Volkov, S. Methods of Examining Vehicle Electronic Systems in the Course of Automotive Forensic Expert Examinations. *Transp. Res. Procedia* **2017**, *20*, 143–150. [CrossRef]
17. Available online: https://www.heka.warszawa.pl/linia-diagnostyczna-heka-bolid.html (accessed on 26 December 2023).
18. Glowinski, S.; Bryndal, A.; Grochulska, A. Spinal pain in physiotherapists—Prevalence and risk factors. *PeerJ* **2021**, *9*, e11715. [CrossRef] [PubMed]
19. Available online: https://www.tuvsud.com/en/press-and-media/2022/november/tuev-report-2023-the-average-age-of-vehicles-on-the-road-is-now-over-10-years (accessed on 10 November 2023).
20. Auto Serwis Wadowicka. Car Inspection—Why Is It So Important? Available online: https://twojmechanik.com/en/blog_1/car-inspection-why-is-it-so-important/ (accessed on 26 December 2023).
21. Christensen, P.; Elvik, R. Effects on accidents of periodic motor vehicle inspection in Norway. *Accid. Anal. Prev.* **2007**, *39*, 47–52. [CrossRef] [PubMed]
22. Elvik, R. What would a road safety policy fully consistent with safe system principles mean for road safety? *Accid. Anal. Prev.* **2023**, *193*, 107336. [CrossRef]
23. Jasosiński, W. Periodic technical inspections of vehicles and road traffic safety with the number of road accidents involving fatalities. *Maint. Relaibility* **2014**, *16*, 105–111.
24. Gorzelańczyk, P. Assessment of technical condition of means of transport moving around Great Poland and their impact on road safety. *Tech. Sci.* **2020**, *23*, 233–252. [CrossRef]
25. Kołsut, B.; Stryjakiewicz, T.; Gadziński, J. Do Motorisation Statistics Reflect the Real Geography of Car Ownership in Poland? *Quaest. Geogr.* **2022**, *41*, 95–108. [CrossRef]