IMPACT OF SPECIFIC FACTORS ON THE STATE OF THE TIRE PRESSURE VALUE

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Abstract

The article presents the research on the impact of specific factors on the state of the pressure value in passenger car wheels in service. Data on how the vehicle was used was obtained based on a survey. The survey contained data on checking the condition of the vehicle tires and also measuring the tire pressure. The aim of the study was to investigate the relationship between the impact of specific factors on the state of the pressure value in passenger car wheels. The correlation analysis of the correctness of pressure in car tires and selected factors was carried out using the Kendall tau test. In addition, odds ratio (OR) analysis and the Hosmer and Lemeshow test were used to analyze the results. The work draws attention to the impact of improper tire pressure on tire durability and road safety as well as the functioning of other active safety systems. In addition, attention was drawn to drivers' awareness of the need to control the pressure in the wheels of the vehicle. Based on the analysis it was found, that the age of the vehicle used and the driver's knowledge have the greatest impact on the correct tire pressure. Studies have shown that in over 60% of the vehicles analyzed, the tire pressure was normal.

Keywords: road safety; tire; vehicle safety; maintenance

1. Introduction

Traffic accidents incur a large social and economic loses to countries, families and individuals [11]. The safety of transport participants is the most important element of any transport system. To ensure road transport safety, modern vehicles are equipped with complex mechatronic systems, such as passive and active safety systems. Initially the main motivation was to make driving easier or more comfortable, but world megatrends have oriented the development towards to lower fuel consumption, higher traffic safety and reduced environmental impact [28]. Active safety systems play an important role in ensuring the safety of road users and improve travel comfort. There are many studies in the literature on improving road safety in its various aspects [8, 21, 34]. Erd et al. [8],

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investigated effectiveness of disc brakes on various road surfaces in both dry and wet road conditions on the example of a passenger car equipped with different kinds of tires. Study of the economic cost of road accidents in Jordan was presented in work [11]. The centers of gravity impact on the level of active vehicle safety study was conducted by Skrucany et al. [26]. Stopka et al. in work [27] presented the issues of ensuring the quality of transport services, including comfort in public transport and the shipping industry, as a criterion of competitive advantage of a transport company.

As the accident statistics show, the technical failure of the vehicle was the cause of 38 accidents in 2018 in Poland. 7 people were killed and 55 people were injured [33]. It should be emphasized that technical defects are also revealed during the inspection of vehicles at the scene of the accident, despite the fact that they did not have a direct impact on its occurrence [33]. It should be added that the cause of an accident can be several faults at the same time. Among 108 faults, they occurred in the following vehicle systems:

- lighting – 44.4%;
- improper condition of tires – 24.1%;
- braking system faults – 15.7%;
- steering system faults – 5.6%;
- other – 10.2%.

However, it should be remembered that safety systems are part of the equipment of the vehicle, which does not release people from liability. It is the man who still makes decisions being a traffic participant and he is responsible for driving the vehicle, its technical condition etc. It should also be remembered that vehicle tires are the link between the road and the vehicle.

Tires are the only element ensuring vehicle contact with the ground. Many elements made of materials such as rubber, steel and textiles are used to build a modern car tire. Selection and quality of materials and manufacturing technology in the production process affect the functions of a tire, such as: transferring vertical loads, ensuring good handling and grip, transferring tractive and braking torque and ensuring damping [32].

Moving vehicles generates negative environmental effects among others in the form of noise. Its level is influenced by a number of factors, including the most important ones [10, 25]:

- traffic speed and intensity;
- typology of traffic streams;
- road surface type and condition;
- type of car tires;
- type of motor in the car and technical condition of the engine;
- vehicle drive train or other technical parts.

The contact between the tire and the road is the key enabler of vehicle acceleration, deceleration and steering [23]. During the vehicle motion the state of the tire and the road surface are responsible for the transmission of power from the vehicle [18]. Knowledge of tire–road friction conditions is indispensable for many vehicle control systems [24]. The technical condition of the tire affects many factors directly related to the vehicle (proper maintenance of the vehicle direction, traction, braking efficiency, ease of maneuvering the vehicle or traveling comfort) as well as affects road safety (braking distance, effectiveness of other vehicle safety systems, burst tires). In practice, drivers very often underestimate the technical condition of tires and the value of their pressure. The uneven tire pressure changes the stiffness of the tires both radial and longitudinal and transverse, as well as changing wheel rolling and load resistance provided by the vehicle to the ground [18]. Changes in the tire pressure value have a significant impact on driving comfort, fuel economy and road safety (e.g. braking distance). The braking distance of a vehicle also depends on several factors affecting the grip of the tire, such as weather conditions (rain, fog, lighting conditions), geographical (e.g. slope), speed, quality and type of tire [21]. Measuring the contact force of the tire with the road surface is the first step towards developing new control systems to improve the safety and performance of the vehicle [4]. The constructions of these systems are constantly being developed in terms of measuring systems (sensors) [2, 31], tire durability [29] and road safety [3, 4]. Thanks to early detection of a fault in a vehicle it is possible to prevent a failure and to improve of road safety [16].

For monitoring and informing the driver about the state of tire pressure in different types of monitoring systems of pressure are used. More information on vehicle tire pressure monitoring systems was presented in earlier publications [2, 7, 31]. The tire pressure monitoring system relieves the driver, but it does not relieve the driver from responsibility for regular control of the tire pressure [2]. Tire pressure monitoring can be an important parameter for the following vehicle control systems: anti-lock braking systems (ABS), autonomous emergency braking (AEB), electronic stability control (ESC), adaptive cruise control (ACC), as well as collision warning or collision avoidance systems [5, 9, 12]. The dependence of the value of tire pressure and tire contact with the ground was shown in Figure 1.

Fig. 1. Pressure values in the tire dependent on the contact surface

Driving a vehicle with too low pressure in the tire (Figure 1) causes the tire to bulge upwards in the middle so that only its outer surface optimally transmits the force to the road. As a consequence, there is strong heating of the tire, and thus there is the danger of damage to its structure, which shortens the lifetime of the tire and the vehicle has a longer braking distance [2]. In the tire with correct pressure value, the tire tread adjacent the whole width of the road (Figure 1). The tire tread wears evenly, it transforms into greater durability tires and potentially longer distance of kilometres. In addition, the vehicle retains the minimum braking distance and cornering stability. The passengers of this vehicle have greater driving comfort. Driving a vehicle with overpressure in the tire the area of contact with the ground occurs only in the centre (Figure 1). Driving such a vehicle results in irregular tread wear, reduction of tire lifetime and deteriorates driving comfort. Summarizing the considerations about the value of pressure, we can say that poorly inflated tires worse reacts to the action of lateral forces, resulting in a significantly worse driving and also has a longer wet braking distance than it does on dry surfaces, this is also confirmed by Rievaj et al. [22].

As commonly known, the value of tire pressure depends on the ambient temperature. The value of this temperature is influenced not only by atmospheric temperature but also by heat dissipation from friction elements of the braking system or engine cooling. Another factor influencing the pressure change may be the tire deflection due to contact with the ground. The dependence of the tire pressure change depending on the ambient temperature was shown in Figure 2.

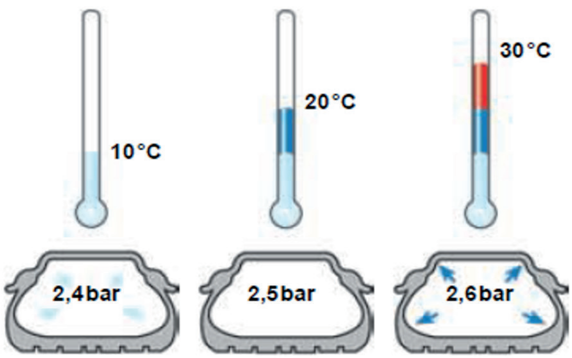


Fig. 2. Dependence of air pressure in the tire to change of ambient temperature [30]

Tire tests and the effect of pressure on their characteristics are presented in the literature [1, 15, 17, 19, 20].The first comprehensive work on the tires was presented by S. Clark and others [6]. One of the most important laboratories studying tire center in Delft (TNO Automotive - Netherlands) [18]. Similar tires studies were conducted in different laboratories, including lab CRREL (U.S. Army Cold Regions Research and Engineering Laboratory in Anchorage) [13]. As a result of the development of work on testing and modeling of tires, a model of cooperation between the tire and the road was created, known as MF (magic formula). One of the newest methods of testing tires is the PAC2002 model. PAC2002 is a semi-empirical tire model because it has both the empirical (mathematical formulas) and physical modeling components [14]. The PAC2002 tire model can describe the behavior of tires traveling over relatively smooth road surfaces and its dynamical behavior is valid for frequencies up to 12 Hz [14].The PAC2002 tire model can be used for analyzing parking behavior, low- and zero-speed applications, changing friction properties as well as in more dynamic analysis such as ABS braking.

The article presents statistical research on the impact of specific factors on the state of the pressure value in passenger car wheels in service. The data collection was conducted in the form of a survey and 80 vehicles constituted the research sample. The survey contained data on vehicle tire inspection and the tire pressure value was measured.

2. Methodology

The aim of the study was to investigate the relationship between the phenomena studied, i.e. the impact of specific factors on the state of the pressure value in the wheels of passenger cars in service. As part of the research, it was assumed that the dependent variable is the value of pressure in the wheels of the vehicle, and the independent variables were:

- vehicle age: 3 – to 5 years, 2 – 5 to 10 years, 1 – over 10 years;
- vehicle class: 1 – segment A and B, 2 – segment C, 3 – segment D, 4 – segment E and F;
- the actual value of the tire pressure: 1 – correct, 0 – incorrect;
- drivers' knowledge of the recommended tire pressure: 1 – knows the recommended pressure, 0 – does not know the recommended correct;
- convincing the driver of the correct tire pressure: 1 – correct, 0 – incorrect;
- frequency of pressure measurement: 0 – does not measure, 1 – sporadically, 2 during the workshop, 3 – regularly.

The main research problem concerned the following issues:

- verification of the relationship between the age of the vehicle and the level of pressure assuming a different value from the recommended level;
- the existence of a relationship between the vehicle class and the actual pressure and its deviation from the recommended level;
- the existence of dependencies between drivers' knowledge of the correct tire pressure and its actual state, which may differ from the recommended level;
- determining whether the pressure value in the vehicles analyzed was at an appropriate level.

Based on the research problems formulated in this way, a survey was prepared, thanks to which it was verified to what extent individual factors affect the level of pressure.

The anonymous survey form contained 4 questions and a part for saving the results of measuring the pressure in the set of tires in the vehicles under test (Figure 3). These questions took the form of both closed and open questions.

Nr porządkowy ………….

Marka	Model	Silnik	Rok produkcji

1. Czy wie Pani/Pan jakie ciśnienie w oponach zaleca producent tego pojazdu?

Koła przednie ……………..…. MPa

Koła tylne …………………..…. MPa

2. Czy może Pani/Pan powiedzieć, gdzie spośród podanych opcji można najłatwiej uzyskać informację o zalecanym ciśnieniu?

instrukcja obsługi ☐
tabliczka na karoserii ☐
specjalistyczny warsztat ☐
inne ☐, jakie ……..…………………..….

3. Z jaką częstotliwością mierzy Pani/Pan ciśnienie w oponach?

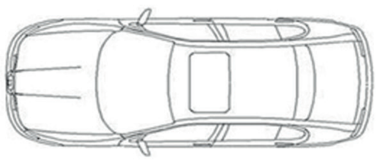
przy okazji pobytu w specjalistycznym warsztacie ☐
sporadycznie ☐
regularnie co 500 km (co 2-3 tygodnie) ☐
nie mierzę w ogóle ☐

4. Czy według Pani/Pana ciśnienie w oponach Pani/Pana pojazdu jest prawidłowe?

tak ☐
nie ☐ ewentualne uwagi ………………

POMIAR:

……... MPa ……... MPa



……... MPa ……... MPa

Fig. 3. Sample of the survey used in the research

Fig. 4. Clock manometer used to measure the pressure value

The tests were carried out in April 2018, in a workshop at the Faculty of Production Engineering, University of Life Sciences in Lublin. The pressure value was measured using a manometer, shown in Figure 4. The device is equipped with a clock type indicator with a measuring range up to 12 bar with a measurement accuracy of +/- 0.2 bar (2 psi/20 kPa/0.2 kg/cm^2). The pressure gauge can operate at ambient temperatures between -10°C and 40°C, regardless of other weather conditions.

3. Test results and analysis

This chapter presents the results of surveys and their quantitative and qualitative analysis, where the correlations between variables and whether they are significantly related were examined. 80 people from the city of Lublin and the surrounding area took part in the survey. The group of respondents included both women and men with diverse experience in driving. The survey was anonymous.

3.1. Quantitative analysis of test results

The vehicle tests were divided according to the cars belonging to a given segment. The most vehicles were class C – 24 vehicles, which accounted for 30% of the total number of tested vehicles. The second largest group were class D cars, i.e. the middle class – 22 vehicles (27.5% of tested vehicles). The third group, in which 18 vehicles (22.5%) were tested, were vehicles from the E and F segment, i.e. middle class cars. Class A and B vehicles were the smallest share – 16 vehicles, which represents 20% of all tested vehicles.

The tested vehicles were divided into three age groups. The first group consisted of cars up to 5 years old, the second group comprised cars between 5 and 10 years old, and the last most numerous group – vehicles older than 10 years. The oldest vehicles participating in the study constituted the largest group – 63.8%, the smallest share – 18.3% were vehicles from the average age group. Based on the analysis of survey results, it was found that the majority of drivers surveyed know what the correct pressure value should be in the vehicle in use. The group of drivers who provided the correct parameter was 71.3% of respondents.

Another question analyzed in the survey concerned the knowledge about the place where the information about the recommended tire pressure is contained. Analysis of the results showed that 41.3% of drivers look for this information in the vehicle's instruction manual. 40% of respondents look for this information in a plate stuck on the vehicle body (e.g. placed on the inside of the fuel filler flap, or on the center pillar of the vehicle). For this purpose, 15% of those surveyed will go to an authorized service or workshop, and less than 4% will look for this information online.

It was also examined how often drivers check the tire pressure of the used vehicle. The analysis of the survey results shows that most people as much as 50% check the tire pressure of a used car sporadically. 13.8% of the respondents do not check the pressure in the vehicle at all, and 16.2% of the respondents do it while in the garage. Only 20% of respondents check the pressure in a used vehicle regularly.

Drivers' beliefs about the tire pressure value of their vehicle were also examined. Survey results show that the vast majority of drivers (90%) believe that their vehicle tires' pressure is correct.

Figure 5 presents the results of the tire pressure measurement assessment of the vehicles tested.

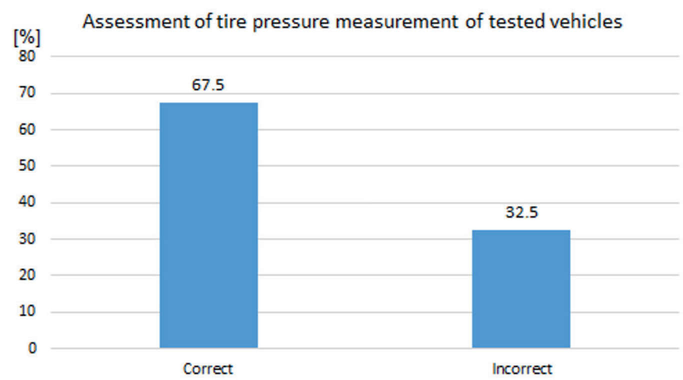


Fig. 5. The results of the tire pressure measurement assessment of the tested vehicles

3.2. Statistical analysis of test results

An analysis of the correlation between the correctness of pressure in car tires and selected factors was performed using the Kendall tau test using SPSS Statistics. The obtained results are presented in Table 1.

Tab. 1. Correlation coefficients of tire pressure regularity with the analyzed factors.

Parameter	Correlation coefficients	Significance level
Vehicle age	0.407	0.001
Vehicle class	0.202	0.049
Conviction the driver of the correct tire pressure	0.214	0.058
Driver knowledge of the recommended vehicle pressure	0.444	0.001

The obtained results inform that there are three important relationships between the pressure regularity and the analyzed factors. The relationships with the vehicle age category and the driver's knowledge of the recommended pressure in the vehicle have moderate strength (correlation coefficient, respectively: tau = 0.407; 0.444; significance level $p<0.001$). There is a significant low correlation in the case of a relationship between pressure regularity and vehicle class (tau = 0.202, $p<0.05$). Conviction the driver about the correct pressure in the vehicle tires, on the other hand, correlates with the pressure measurement result only at the significance level ($p=0.058$).

To determine the potential impact of the examined factors taken together, on the state of the pressure value in the wheels of passenger cars in operation, a multivariate logistic regression analysis was carried out. The pressure status (dependent variable) was coded according to the scheme: normal state = 1, incorrect state = 0. The obtained results are presented in Table 2.

Tab. 2. Logistic regression model predicted correct tire pressure in tested vehicles

Parameter	B	Wald(Z)	Significance level	OR
Vehicle age	1.686	6.086	**0.014**	5.395
Vehicle class	0.637	3.969	**0.046**	1.981
Driver knowledge of the recommended vehicle pressure	1.661	6.025	**0.014**	5.266
Where to find information on recommended pressure	0.191	0.269	0.604	1.210
Checking frequency	0.759	3.032	0.082	2.135
According to driver's pressure is correct?	0.883	0.744	0.388	2.419
Constant	-6.265	10.580	0.001	

There are three important factors that affect the proper pressure of car tires. They are all positive predictors. They are: vehicle class, vehicle age and knowledge of the recommended tire pressure. The analysis of the odds ratio (OR) as an effect measure informs that if the value of a given factor increases by 1 category, the chance of the correct pressure level increases in the case of the vehicle class – almost twice, and more than five times in the case of the vehicle age (the highest category – here means the youngest vehicle) and the driver's knowledge of the recommended tire pressure. In addition, there is a factor oscillating around the limit of significant influence – it is the frequency of checking the pressure by the driver.

The tested model turned out to be well fitted to the data, as evidenced by the value of the Hosmer and Lemeshow goodness test (χ^2=2.68, p=0.953, df=8). This means that the proposed prediction of the dependent variable based on the adopted factors is better than the prediction only on the basis of means. Based on this model, knowing the vehicle class, vehicle age and user's knowledge of the recommended tire pressure, the actual state of this pressure can be predicted with a probability of 82.3%.

4. Conclusions

Tires are one of the most important safety components on a vehicle [7]. Good technical condition of tires and proper pressure in the wheels of the vehicle influence the correct operation of other vehicle safety systems.

Obtained test results allow determine factors that are important for proper tire pressure of used vehicles, thus to improve road safety. According to the analysis, the age of the car and the driver's knowledge have the greatest impact on the correct tire pressure. This means that the greatest care for the state of tire pressure is observed in the case of new car owners (category 3 cars up to 5 years), thus the results of the tests inform that in the oldest cars (category 1 cars over 10 years), the most common tire pressure state is incorrect. This phenomenon is particularly worrying because this fact aggravates the poor general condition of old cars. Another factor that explains the correct care for the correct pressure to the greatest extent is the driver's knowledge of the value of the recommended tire pressure. This fact has a large educational dimension suggesting that knowledge of these requirements leads to appropriate operational practices. Finally, the vehicle class is another factor explaining the correct tire pressure. However, the impact of this factor is smaller than discussed above. This means that most often correct tire pressure is found in the highest class cars. This may be due to the fact that pressure sensors are used as standard in vehicles of higher classes. The results of the research allow to conclude that the correct state of tire pressure depends primarily on the driver's awareness. The most improper belief is that in older cars it is not worth to take care of the state of this parameter.

5. Nomenclature

A, B, C, D, E, F – car segment

ABS – anti-lock braking systems

ACC – adaptive cruise control

AEB – autonomous emergency braking

ESC – electronic stability control

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