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DETERMINATION OF THE ROLLING RESISTANCE COEFFICIENT UNDER DIFFERENT TRAFFIC CONDITIONS

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Abstract. *In this paper, an experimental study of the determination of the rolling resistance coefficient is carried out. The experiment tests a total of six different types of vehicles and calculates the rolling resistance coefficient depending on the condition of the surface and the type of tires. The main aim of the research is to introduce new values of the rolling resistance coefficient and its impact on fuel consumption in real traffic conditions. Motor vehicles are subjected to a "free stop" method on a horizontal road. In doing so, the vehicle speed is registered every 10 seconds from an initial speed to stopping. In order to eliminate an error of possible roadway inclination or wind impact, the experiment is repeated five times on the same road section as well as in the opposite direction. The experimental study was carried out during December 2016 and January 2017. Three sets of tires were used for each vehicle, the tires with tread depths of 8 mm, 6-7 mm and 4-5 mm, while the type of surface referred to dry and wet conditions of the roadway. Both hypotheses have been confirmed using Analysis of Variances. The results show that the tread depth of tires and the meteorological conditions affect increasing the values of the rolling resistance coefficient.*

***Key Words**: Rolling Resistance Coefficient, Vehicle, Traffic Safety, Fuel Consumption*

1. INTRODUCTION

The most significant aspect of the way in which the road has an impact on traffic accidents lies in the fact that it affects both the driver and the vehicle [1, 2], creates conditions for the influence of other factors, affects the severity of traffic accidents and, at the same time, determines the circumstances of traffic flow. Within the scope of transportation, a special place is taken by ecological impact on people and the environment [3] in which transportation is carried out, where, according to Trupia [4], one of the

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factors is the rolling resistance coefficient. The improvement of this impact can be achieved by reducing the levels of negative effects of influencing factors in the movement of motor vehicles. Amongst many influential factors, the surface and the tire are of significant importance, that is, the interaction of these two factors implies the reduction of rolling resistance R_f, i.e. of rolling coefficient f that contributes to the reduction of fuel consumption, as confirmed by Srirangam et al. [5] and Wei et al. [6]. This is also pointed out by the authors in the paper [7], who emphasize the knowledge of the surface characteristics and the interaction of the vehicle with the surface as a significant starting point for making a choice between the concept of a new vehicle and that of optimum utilization of an existing vehicle. The tires play a great role in the exploitation of vehicles. Their impact is most evident in large fleets of vehicles, when they are exposed to various conditions of exploitation and when they are expected to pass a large number of kilometers unobtrusively. Therefore, by experimenting with several types of tires, their pressures, and various loads of vehicles, the optimum rolling resistance can be achieved, in accordance with the road conditions as well as the type and purpose of a motor vehicle automatically saving fuel, tires and, what is most important in every business, costs. The force that prevents the movement of a vehicle is called "rolling resistance". The research has shown that one of five full fuel tanks, i.e. 20% of the total amount of fuel consumed, runs on resistance of the tire rolling on the surface. Reducing rolling resistance affects an increase in energy efficiency of road traffic, which reduces carbon dioxide emission and helps drivers reduce fuel costs.

The subject of the research is to determine the value of the rolling resistance coefficient and its impact on fuel consumption in real driving conditions on a non-deformable surface. Such research studies in literature are very rare; hence this study brings new values of the rolling resistance coefficient that can be used in the future research of the given traffic conditions. The tires play an important role in vehicle safety and environment [8] and usually represent a leading parameter in fleet maintaining costs. Fluid under pressure is a basic bearing component of the tires and receives up to 95% of the total external load for modern tires while the carcass and protector take over the remaining 5%. Inadequate pressure in the tires, higher or lower, makes the tires lose their performance and reliability. This affects the overall performance of vehicles and creates a possibility for traffic accidents. A reduced coefficient of friction between the wheels and the surface of a driveway causes a large number of traffic accidents [9]. The main goal of the research is to determine the influence of the tires/surface interaction on the value of the rolling resistance coefficient of motor vehicles since, according to Ejsmont [10], the rolling resistance coefficient is one of the most important parameters that affect the tires/surface interaction.

Apart from Introduction, the paper is structured in four sections. In Section 2 the research method is presented. This section describes hypothesis and Eqs. for calculating the rolling resistance coefficient. Section 3 represents the description and explanation of the experiment performed in this study. Section 4 implies results with an example of calculation while the last section represents conclusions with guidelines for future research.

2. Research Methods

The research consists of two parts, namely, the experimental (field research) and the theoretical (processing of results) ones. The experimental part includes the study of the dependence of the speed of movement on the deceleration time, since, according to Soliman [11], the resistance coefficient is not constant and depends on the speed of movement of the vehicle. The theoretical part of the research includes the processing of the data collected and testing of the hypothesis set. Experiment modeling and variance analysis are used to obtain relevant hypothesis data.

According to the subject and goals of the research, a research program was also developed. The central topic of this paper is the study of the tires/surface interaction and its influence on the value of the rolling resistance coefficient of motor vehicles. The main part of the research program is related to the study of the dependence of the speed of movement on the time of deceleration; on the basis of this, the modeling of the experiment and the analysis of variances need to be carried out. The research program is divided into two parts: the experimental research and the modeling of experiment and analysis of variances. The experimental research program was carried out on reference vehicles in real conditions whereby, during the driving process, the speed of the vehicle was registered for every 10 seconds (which allows a graphic display of the speed curve in the function of the deceleration time) from an initial speed to stopping. The modeling of experiment and the analysis of variances were performed with the limitations of the following factors: factor "A" - tire tread depth and factor "B" - meteorological conditions.

2.1. Hypotheses

Hypothesis 1: The tread depth of tires and meteorological conditions affect the increase in the value of the rolling resistance coefficient. The tread depth is an extremely important factor for tires, which, as legally defined, must be at least of 1.6 mm in summer and of 4 mm in winter. The Tread Wear Indicator (TWI) is an important tool for assessing the residual depth of the tire tread. The winter tires, for example, have an additional wear indicator at a depth of 4 mm because their performance significantly decreases when the tread depth reaches this limit or is below it. Worn tires significantly increase the risk of aquaplaning and poor vehicle braking on a wet driveway. If the driving mode is adjusted to winter conditions, it will help preserve safety, although the winter tires provide additional protection against unpleasant surprises in the winter. Compared to the summer tires, they provide greater safety, especially when braking, in cold and wet conditions, as well as in snow and ice conditions.

Hypothesis 2: The value of the rolling resistance coefficient affects fuel consumption up to 25%. The rolling resistance is the resistance that occurs when rolling a tire on a flat surface. The rolling resistance coefficient is a non-dimensional unit obtained when the force of rolling resistance is divided by a vertical tire load point. According to Glavaš [12], road traffic is approximately 23% of the world's total energy demand, from which the importance of the hypothesis can be noticed. By increasing the value of the rolling resistance coefficient, the rolling resistance itself increases as well as total resistances that oppose the movement of a vehicle. It is, therefore, necessary to consume more energy to absorb total resistances, resulting in fuel consumption increase.

2.2. The function and energy efficiency of tires

The function of tires is a motor vehicle movable support, absorption of vibrations due to unevenness on a driveway, transfer of kinetic engine energy to a driveway and tracking of the movement direction of a vehicle. The criteria that they should fulfill are safety on wet and dry surfaces (at high speeds and braking), comfort in terms of absorption of unevenness and noise reduction, fuel economy and durability. A tire is the only part of a car that is in contact with a driveway. A modern tire has over 200 individual components in its composition. However, most of these components can be classified into three basic groups: rubber (natural and synthetic rubber), fillers (silicon, etc.) and additives (vulcanizing additives, antioxidants, sun protection waxes, etc.).

Rubber is a mechanically solid and highly elastic material obtained by caoutchouc vulcanization, natural and synthetic. In the process of vulcanization by sulfur, strong chemical cross-linking occurs between polymeric caoutchouc chains with the opening of some double bonds. Caoutchouc then takes on elastic characteristics, and stretching strength is up to ten times higher than for unvulcanized caoutchouc. A mixture of natural (14%) and synthetic rubber (27%) make up approximately 40% of the components of a modern tire. The load distribution on the tire profile changes with respect to the speed of movement. By increasing the speed, the trace made by a tire changes its shape from a circle into a rectangle. At moderate speeds, the loss of energy in a form of heat is largely carried out over a tire surface. At higher speeds, the loss of energy is largely performed through inner lining and lateral sides.

Some countries and regions have introduced one or more programs of energy efficiency improvement but no country or region has a complete program that covers all aspects of energy efficiency of tires [13]. In order to achieve this, the following recommendations are given:

- Introduction of tire marking and their ranking;
  The introduction of tire marking and their ranking is an important first step towards improving energy efficiency of tires, as it allows final users to choose, and sellers and manufacturers to provide energy efficient tires.
- Setting the standards for energy efficiency of tires;
  As the introduction of tire marking and their ranking can stimulate the manufacture of high-performance tires, the setting of minimum energy efficiency standards for tires may stimulate the manufacture of energy efficient and economically acceptable tires.
- Introduction of testing and checking of energy efficient tires;
  Additional tire testing and checking would provide data that could improve accuracy and credibility of tire marking and ranking.
- Monitoring of pressure in tires;
  Proper pressure in tires is a prerequisite for achieving the maximum energy efficiency of tires, as well as a necessary condition for achieving safety in traffic.
- Introduction of comprehensive regulations;
  The introduction of comprehensive regulations, i.e. regulations containing several different standards, prevents compromises and unintended consequences that may arise by setting a requirement to meet a single norm. For example, reducing rolling resistance should not reduce safety.

To calculate the rolling resistance coefficient, it is necessary first to set the equation of motion:

$$\sum X_i = 0 \rightarrow F_O = R_f + R_u + R_v + R_a \tag{1}$$

where F_O – the tractive force, R_a – the acceleration resistance, R_f – the rolling resistance, R_v – the air resistance, and R_u – climb resistance. Setting R_u = 0 and assuming deceleration a with respect to the positive x-direction (hence, for a > 0 the inertial force acts in the positive x-direction), the equation of motion takes the following form:

$$F_O - R_f - R_v + R_d = 0 \rightarrow -R_d = F_O - R_f - R_v$$
$$-m \cdot a \cdot \delta = F_O - G \cdot f \cdot cos\alpha - \frac{C_x \cdot \rho}{2} \cdot A \cdot v^2 \tag{2}$$

where R_d – the deceleration inertial force, m – the mass of the vehicle, δ – the rotational mass coefficient (δ = 1.04 for excluded transmission), C_x – the air resistance coefficient, ρ – the air density, A – the front surface, v – the speed of vehicle, G − the vehicle weight, f – the rolling resistance coefficient, α – the ground inclination. Setting F_O = 0 because the engine is disengaged (vehicle coasting), and α=0, which implies that the coasting occurs on a horizontal ground, it follows:

$$a = \frac{g}{G \cdot \delta}\left(G \cdot f + k \cdot A \cdot v^2\right) \tag{3}$$

where g – gravity and k – reduced air resistance coefficient ($k = C_x \cdot \rho/2$).

By solving the above equations we obtain deceleration time t as:

$$t = \frac{G \cdot \delta}{g \cdot \sqrt{G \cdot f \cdot k \cdot A}} arctg \frac{\sqrt{\frac{k \cdot A}{G \cdot f}}\left(v_1 - v_2\right)}{1 + \frac{k \cdot A}{G \cdot f}\left(v_1 - v_2\right)} \tag{4}$$

where v_1 – the speed of vehicles at the beginning of interval t_n and v_2 – the speed of vehicles at the end of interval t_n, where n is the number of intervals (for more explanation see Fig. 1 and Table 2). Eq. (2) is obtained by using differential equation for deceleration motion. From Eq. (4), the rolling resistance coefficient can be obtained as follows:

$$f = \frac{G \cdot \delta}{g \cdot t \cdot \sqrt{\frac{W}{f}}} arctg \frac{\sqrt{G}\sqrt{\frac{W}{f}}\left(v_1 - v_2\right)}{G + \frac{W}{f} \cdot v_1 \cdot v_2} \tag{5}$$

$$f_1 = \frac{G \cdot \delta}{g \cdot t_1 \cdot \sqrt{\frac{W}{f_1}}} arctg \frac{\sqrt{G}\sqrt{\frac{W}{f_1}}\left(v_1 - v_2\right)}{3.6 \cdot \left(G + \frac{W}{f_1} \cdot \frac{v_1 \cdot v_2}{3.6^2}\right)} \tag{6}$$

$$f_2 = \frac{G \cdot \delta}{g \cdot t_2 \cdot \sqrt{\frac{W}{f_2}}} arctg \frac{\sqrt{G}\sqrt{\frac{W}{f_2}}\left(v_1 - v_2\right)}{3.6 \cdot \left(G + \frac{W}{f_2} \cdot \frac{v_1 \cdot v_2}{3.6^2}\right)} \tag{7}$$

where f_1 – the rolling resistance coefficient for first interval t_1 and f_2 - the rolling resistance coefficient for second interval t_2, W– the air resistance factor ($W = k \cdot A$), while the coefficient 3.6 in Eqs. (6) and (7) implies that speed is given in *m/s.*

3. EXPERIMENT

The experiment requires determination of the rolling resistance coefficient for certain motor vehicles under real driving conditions by a "free stop" method on a horizontal road. In doing so, the vehicle speed was recorded every 10 seconds (which enables a graphic display of the velocity curve in the function of the deceleration time) from an initial speed to stopping. In order to eliminate an error caused by possible roadway inclination or wind impact, the experiment was repeated five times on the same road section, as well as in the opposite direction, and then, after interpolation, the values were obtained, which are shown in tables. During the study, transmission was separated from drive wheels. Experimental study was carried out during December 2016 and January 2017. Three sets of tires were used for each vehicle, the tires with tread depths of 8 mm, 6-7 mm and 4-5 mm, while the type of surface referred to dry and wet condition of the roadway.

3.1. Models of vehicles on which the experiment was performed

In order to perform the practical part of the experiment, there were used vehicles subjected to an authorized technical inspection station, prior to the experiment where it was confirmed that all the vehicles were technically in a good condition. Models of motor vehicles used here are: Passenger vehicle 1 – Audi A4; Passenger vehicle 2 – Volkswagen Golf 4; Delivery vehicle 1 – Volkswagen Caddy; Delivery vehicle 2 – Volkswagen Caddy; Light cargo vehicle 1 – Iveco 35S13; Light cargo vehicle 2 – Iveco 50C14.

3.2. An example of determining the rolling resistance coefficient for a light cargo vehicle – Iveco 35S13 – the tread depth of 8 mm

For the first experimental study on light cargo vehicles, Iveco 35S13 was used, with its following characteristics: the year of manufacturing – 2002, the engine volume – 2800 cm^3, the engine power – 92 kW, the mass of the empty vehicle – 3500 kg, the total mass of the vehicle – 3590 kg (total mass of the vehicles implies sum of mass of the empty vehicle 3500 kg and mass of driver 90 kg), vehicle length – 5997 mm, width – 1800 mm, height – 2700 mm. The vehicle had Tigar tires, with the dimensions of 225/65 R16. For the experiment on a wet roadway, the temperature was 3.5 °C. By the experimental testing, the dependence of the speed of movement on the deceleration time was obtained, which is shown in Table 1.

Table 1 Dependence of the speed of movement on the deceleration time of Iveco 35S13, on a wet roadway

t (s)	0	10	20	30	40	50
v (km/h)	70	53	42	32	23	16

Fig. 1 shows the dependence of the speed of movement on the deceleration time from Table 1.

From Fig. 1 it is necessary to identify the speed interval and time. The vehicle slows down from a speed of 70 km/h to a speed of 16 km/h in 50 seconds and from a speed of 53 km/h to 16 km/h in 40 seconds.

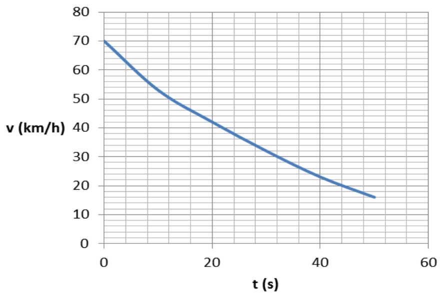

Fig. 1 Dependence of the speed of movement on the deceleration time of Iveco 35S13 on a wet roadway

Table 2 Speed interval and time

f_1	f_2
t=50 (s)	t=40 (s)
v_1=70 (km/h)	v_1=53 (km/h)
v_2=16 (km/h)	v_2=16 (km/h)

By adding the values from Table 2 into Eqs. (1-7), the values of the rolling resistance coefficient are obtained.

Table 3 Equation solutions for Iveco 35S13, on a wet roadway

w/f	0.09	0.16	0.25	0.36	0.49	0.64	0.81	1	2
f_1	0.0314	0.0312	0.0311	0.0310	0.0309	0.0308	0.0307	0.0306	0.0298
f_2	0.0266	0.0265	0.0264	0.0263	0.0262	0.0260	0.0259	0.0257	0.0249
w/f	3	4	5	6	7	8	9	10	11
f_1	0.0293	0.0285	0.0281	0.0273	0.0264	0.0255	0.0247	0.0238	0.0230
f_2	0.0243	0.0240	0.0234	0.0230	0.0227	0.0225	0.0223	0.0222	0.0221
w/f	12	13	14						
f_1	0. 227	0.0218	0.0215						
f_2	0.0220	0.0218	0.0216						

Fig. 2 presents the solutions of Eqs. (1-7). At the cross-section of the curves, there is a mutual solution which is f=0.0218.

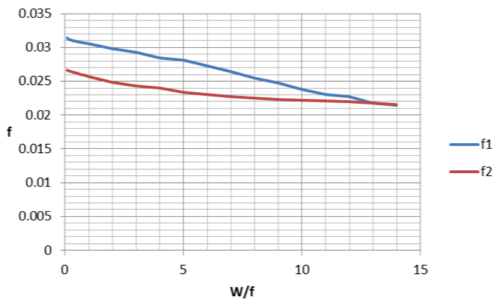

Fig. 2 Graphic display of equation solutions

For the experiment on a dry roadway, the temperature was 9°C. By the experimental testing on the roadway, the dependence of the speed of movement on the deceleration time was obtained, which is shown in Table 4.

Table 4 The dependence of the speed of movement on the deceleration time of Iveco 35S13, on a dry driveway

t (s)	0	10	20	30	40	50	60	70
v (km/h)	70	59	50	42	38	30	25	20

Fig. 3 presents the dependence of the speed of movement on the deceleration time from Table 4.

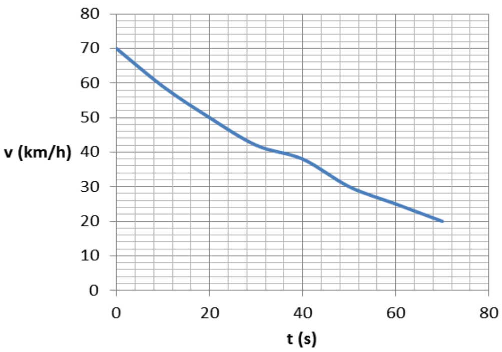

Fig. 3 The dependence of the speed of movement on the deceleration time of Iveco 35S13, on a dry driveway

From Fig.3 it is necessary to read the interval of speed and time. The readings are shown in Table 5.

Table 5 Intervals of speed and time

f_1	f_2
t=70 (s)	t=60 (s)
v_1=70 (km/h)	v_1=59 (km/h)
v_2=20 (km/h)	v_2=20 (km/h)

By inserting the values from Table 5 into Eqs. (1-7), the values of the rolling resistance coefficient are obtained.

Table 6 Solution of equations for Iveco 35S13, on a dry driveway

w/f	0.09	0.16	0.25	0.36	0.49	0.64	0.81	1	2
f_1	0.0207	0.0206	0.0205	0.0204	0.0203	0.0202	0.0200	0.0199	0.0195
f_2	0.0186	0.0185	0.0184	0.0183	0.0180	0.0178	0.0175	0.0173	0.0170
w/f	3	4	5	6	7	8	9		
f_1	0.0188	0.0183	0.0176	0.0168	0.0159	0.0153	0.0148		
f_2	0.0166	0.0163	0.0159	0.0157	0.0156	0.0153	0.0150		

Fig. 4 presents the solutions of Eqs. (1-7). At the cross-section of the curves, there is a mutual solution which is f=0.0153.

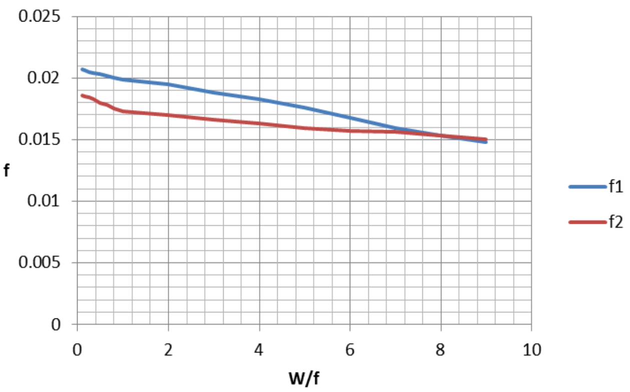

Fig. 4 Graphic display of equations solutions for Iveco 35S13, on a dry driveway

4. RESULTS AND HYPOTHESIS TESTING

After applying the same methodology as presented in the previous chapter for all the vehicles involved in the experiment, the values shown in Table 7 were obtained.

Table 7 The values of the rolling resistance coefficient obtained by the experiment

Tires	Vehicle type	Wet roadway	Dry roadway
Tread depth of 8 [mm]	Audi A4	0.0233	0.0097
	VW Golf 4	0.0111	0.0112
	VW Caddy	0.0248	0.0154
	VW Caddy	0.0301	0.0154
	Iveco 35S13	0.0218	0.0153
	Iveco 50C14	0.0248	0.0177
Tread depth of 6-7 [mm]	Audi A4	0.0202	0.0106
	VW Golf 4	0.0198	0.0182
	VW Caddy	0.0289	0.0159
	VW Caddy	0.0277	0.0175
	Iveco 35S13	0.0254	0.0152
	Iveco 50C14	0.0251	0.0208
Tread depth of 4-5 [mm]	Audi A4	0.0220	0.0155
	VW Golf 4	0.0207	0.0194
	VW Caddy	0.0303	0.0155
	VW Caddy	0.0308	0.0178
	Iveco 35S13	0.0284	0.0165
	Iveco 50C14	0.0270	0.0203

Table 7 shows the results of the whole experiment, which include the values of the rolling resistance coefficient obtained depending on the type of vehicle, the tread depth of tires and the condition of the roadway. Testing of the hypotheses is shown below.

H_1: The tread depth of tires and meteorological conditions affect the increase in the value of the rolling resistance coefficient.

H_2: The value of the rolling resistance coefficient affects fuel consumption up to 25%.

The results of the experiment, i.e. the values of the rolling resistance coefficient, as well as the sums of results by types and columns, are shown in Table 8.

Table 8 Results of the experiment

Factors	Wet driveway	Dry driveway	$\sum y_i$
Tires A	0.0233	0.0097	0.2206
	0.0111	0.0112	
	0.0248	0.0154	
	0.0301	0.0154	
	0.0218	0.0153	
	0.0248	0.0177	
Tires B	0.0202	0.0106	0.2453
	0.0198	0.0182	
	0.0289	0.0159	
	0.0277	0.0175	
	0.0254	0.0152	
	0.0251	0.0208	
Tires C	0.0220	0.0155	0.2642
	0.0207	0.0194	
	0.0303	0.0155	
	0.0308	0.0178	
	0.0284	0.0165	
	0.0270	0.0203	
$\sum y_j$	0.4422	0.2879	0.7301

The calculation of the sums of squares is made by the calculation of the total sum of squares, the sum of squares of each factor and the sums of squares of factor interaction.

$$SS_T=\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{l=1}^{n} y_{ijkl}{}^2-\frac{y_{...}{}^2}{abcn}=\left[(0{,}0233)^2+...+(0{,}0203)^2\right]-\frac{(0{,}7301)^2}{3\cdot 2\cdot 6}=0{,}01604-0{,}01481=0{,}00123$$

$$SS_A=\frac{1}{bn}\sum_{i=1}^{a} y_{i...}{}^2-\frac{y_{...}{}^2}{abn}=\frac{1}{3\cdot 6}\cdot\left[(0{,}4422)^2+(0{,}2879)^2\right]-\frac{(0{,}7301)^2}{3\cdot 2\cdot 6}=0{,}01546-0{,}01481=0{,}000656$$

$$SS_B=\frac{1}{an}\sum_{j=1}^{b} y_{j...}{}^2-\frac{y_{...}{}^2}{abn}=\frac{1}{2\cdot 6}\cdot\left[(0{,}2206)^2+(0{,}2453)^2+(0{,}2642)^2\right]-\frac{(0{,}7301)^2}{3\cdot 2\cdot 2}=0{,}0148-0{,}01481=0{,}000073$$

Table 9 shows interaction of factors used in this experiment, while Table 10 shows analysis of variance of applied factors.

Table 9 Interaction of factors

B A	Dry driveway	Wet driveway
Tires A	0.0847	0.1359
Tires B	0.0982	0.1471
Tires C	0.105	0.1592

$$SS_{AB} = \frac{1}{cn}\sum_{i=1}^{a}\sum_{j=1}^{b} y_{ij} - \frac{y_{...}^2}{abcn} - SS_A - SS_B = \frac{1}{6}\cdot\left[(0{,}0847)^2 + ... + (0{,}1592)^2\right] - 0{,}01481 - 0{,}000656 +$$

$$0{,}000073 = 0{,}01554 - 0{,}01481 - 0{,}000656 - 0{,}000073 = 0{,}0000093$$

Table 10 Analysis of variances

Source of variations	Sum of squares	Degrees of freedom	Mean of squares	F_O	$F_{O\ CRIT}$
A	0.000656	2	0.000328	20	3.35
B	0.000073	1	0.000073	4.451	3.35
AB	0.0000093	2	0.00000465	0.2835	2.73
Error	0.00049	30	0.0000164		
Total	0.00123	35			

Based on the model results, it is proven that both hypotheses are accurate. The tread depth of tires and meteorological conditions affect increasing the values of the rolling resistance coefficient. By calculating the values of the rolling resistance coefficient based on the velocities obtained by the interpolation of the velocities measured on a wet roadway, it can be concluded that the value of rolling resistance increases in 83% and decreases in 17% of the cases, while on a dry roadway, the value of the rolling resistance coefficient increases in 75% and decreases in 25% of the cases. The value of rolling resistance coefficient influences an increase in fuel consumption by up to 25%, which can be also confirmed by the research performed in [14], where Świeczko-Żurek et al. conclude that the rolling resistance coefficient can lead to an increase in fuel consumption by up to over 20%. The biggest increase in fuel consumption on a wet driveway was noticed for the VW Golf 4 passenger car and was 22%, and on a dry driveway with the same vehicle was 16%.

5. Conclusion

This paper presents the calculated value of the rolling resistance coefficient based on the research on dependence of the speed of vehicle movement on its deceleration time, and on this basis confirms the assumptions given in the paper. The number of the used factors in such research projects can be more than two which is one of the limitations.

By analyzing the data obtained throughout research using the methods implemented in this paper, it has been proved that the tread depth is an extremely significant factor for tires. The Tread Wear Indicator is an important tool for assessing the residual depth of the tire tread. Worn tires significantly increase the risk of aquaplaning and weaken vehicle braking on a wet roadway. Fuel savings can achieve significant economic and environmental improvements [15], can be determined on the basis of the rolling resistance coefficient and are assigned to one of seven grades at levels A to G, with A referring to the tire with the highest fuel economy rating and G referring to the tire with the lowest fuel economy rating. By increasing the value of the rolling resistance coefficient, the rolling resistance itself increases as well as the total resistances that oppose the movement of the vehicle. It is, therefore, necessary to consume more energy to absorb the total resistance, resulting in fuel consumption increase.

For the purpose of safer traffic, it is necessary to include an efficient social mechanism that will comprehensively achieve a desired goal throughout the measures of social intervention. Motor vehicle tires, as a system of vital importance, deserve special attention when checking the technical validity of a motor vehicle in order to increase the safety of road traffic and reduce rolling resistance, total resistance and thus reduce fuel consumption.

The main contribution of this study implies introducing new values of the rolling resistance coefficient under different traffic conditions. In future research of this subject, experimental research should be carried out through practical testing of vehicles under different conditions and circumstances. But for such research, a large financial support is needed. Future research needs to stimulate a better linkage between scientific research and practical application of research in order to ensure the realization of scientific research in real conditions. Also, one of directions for future research can be, for example, application of other approaches to the modeling of engine fuel consumption like adaptive neuro-fuzzy inference system (ANFIS) [16, 17] that has been processed in [18].

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