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PREDICTION OF ROAD ACCIDENT RISK FOR VEHICLE FLEET BASED ON STATISTICALLY PROCESSED TIRE WEAR MODEL

ABSTRACT

The goal of the paper is to investigate the impact of tire tread depth on road accident risk and to develop an accident rate prediction model. The state of 4288 vehicle tires using tread depth gauge was inspected and processed statistically. The tread depth of the most worn tire from each vehicle was registered for further analysis. Based on the collected data, a statistical tire tread depth model for an insurance company vehicle fleet had been developed. The conformity of the gamma distribution to the data was verified upon applying the Pearson compatibility criterion. The paper provides the histograms of the frequencies of tire tread depths and the theoretical curves of the distribution density. The probability of the accident risk depending on the tire tread depth (adaptive risk index) was calculated applying the formed distributions and risk index dependence on the tire tread depth for the inspected vehicle fleet. According to the developed prediction model, an upgrade of the regulation for the minimum allowed tire tread depth by 2 mm (up to 3.6 mm) could reduce road accident risk (caused by poor adhesion to road surface) to 19.3% for the chosen vehicle fleet. Such models are useful for road safety experts, insurance companies and accident cost evaluation specialists by predicting expenses related to insurance events.

1. INTRODUCTION

Road accidents are among the ten leading causes of death for different age groups and this position tends to rise, especially for young adults [1]. Even though over 1.35 million people die in road accidents each year [1], the positive trend of fatal accident reduction is observed for a higher proportion of countries [2]. However, based on the systematised data by International Traffic Safety and Analysis Group (IRTAD), the rate of reduction in road deaths has slowed from 3.3% in the period 1998–2008 to 2.3% in 2008–2018. Miscellaneous accident causation requires all possible road safety activities, where constructional vehicle safety usually ranks third, after road user behaviour and road infrastructure safety [3–5]. Nevertheless, all effective measures to reduce accident risk are meaningful.

Vehicle safety is often established upon applying a probabilistic assessment [6]. Tires of road vehicles present only one of the varieties of factors that impact the degree of road accident risk. However, road accidents related to tire failure contribute to more severe injuries; therefore, appropriate state-wide inspection programs are meaningful [7]. A seven-year study of Louisiana data showed that tire failure and worn tires together with defective brakes impact road crash severity to a great extent [8]. When driving on wet road, insufficient tire tread depth reduces the road surface grip considerably, so the stopping distance at the velocity of 80 km/h – based on the summarised data on the results of tests carried out by tire manufacturers – will be 12–15 m longer [9]. Thus, the goal of regulating minimal tire tread depth is to prevent road accidents that occur due to poor road grip conditions. However, research of driver behaviour under adverse driving conditions showed that most motorists rely on sufficient tire grip and still choose to drive at relatively high speeds during rain or snow [10].

Tire tread depth should ensure sufficient grip even in the worst conditions. On 1 June 1989, the EU approved the minimal tire tread depth of 1.6 mm [11, 12]. Wet grip performance is equated to a safety factor of the driver and the whole vehicle [13]. If a sufficient data sample is available, the formed probabilistic distribution enables predicting a model of dependence of the investigated variable (e.g. driver or vehicle) on possible road accident.

Establishing a tire tread depth that ensures safe driving is problematic because it is not the only factor affecting tire grip to the road surface. Tire ageing changes tread and sidewall hardness, thus negatively influencing stiffness properties and general grip [14]. In addition to tire design features and chemical composition, tire grip strongly depends on driving velocity, road surface type and negative factors such as water, snow, dirt etc. The aspects related to tire type, tread depth, air pressure, tire damage and age and their impact on driving safety were reviewed in a report of the Netherlands Organisation for Applied Scientific Research [12]. The report reviewed the data on vehicles with tires worn below the permissible limit collected in the approximate period 2010–2014. Different inspections showed that a share of such vehicles in some regions could vary from 4% up to 25%. In addition, 20–25% of vehicles are driven with improper tire pressure [15]; however, this indicator decreases because of mandatory use of tire pressure monitoring systems (TPMS) in new vehicles [16]. The critical tread depth for the stopping distance is about 3–4 mm. A National Highway Traffic Safety Administration report [17] summarises that the percent frequency of tire-related crashes according to vehicle type varies from 3.5% to 5.9%, and 26.2% of such events were caused by vehicles with tire tread depths not exceeding 2 mm.

One of three mandatory indicators for new tire labelling [18, 19] is braking performance on wet surface. However, in the course of wear of a tire, this indicator varies dramatically; moreover, next to rubber friction mechanism, predominating aquaplaning mechanism occurs [20]. When wear takes place, tire properties related to aquaplaning resistance vary considerably; however, the variation is not the same for all tires, and this circumstance can be observed already when braking starts from the initial velocity of 40 km/h. In this case, certain labelling on a new tire does not indicate that its adequate features will remain constant in the course of its use. The mandatory labelling of braking performance on new tires may be misleading also because of the influence of the type of road surface (its micro- and macrotexture) and the friction temperature [21].

Braking efficiency and road grip highly depend on tire tread depth and road surface state. If the road pavement is solid and rough, water drainage from tire surface is efficient enough, and tire tread depth becomes less important. However, when the pavement is smooth, the role of tire tread depth, as an element of water drainage, increases considerably because the braking performance on a wet smooth road surface is dramatically worse. Detailed modelling of tire structure and dynamics response on a smooth and rough surface based on finite elements shows that tire drainage grooves are efficiently filled with water when the vehicle is moving on a rough road surface and thus is efficiently protected against aquaplaning [22]. In addition, the numerical modelling showed that water was expelled from the contact between the tire and the smooth road surface with higher blasting velocity; however, upon such conditions, a water wedge tends to form in the front part of the tire contact. In case of contact with rough pavement, water is removed chiefly through cavities of the pavement. Despite complicated and highly-detailed mathematical models describing the tire interaction with the road, the natural measurements on a dedicated test bench and experimental

tests upon real driving conditions enable assessing a considerably higher number of parameters that affect the tire [23]. Complex tire tests on the road pavement of different textures covered with 0.4 mm water film showed that new non-worn tires generate the coefficient of friction up to 0.55 and the tires with tread depth up to 2–3 mm the coefficient of friction up to 0.35.

The influence of thermodynamic processes on the performance of tires (such as emergency braking) of different types and rubber mixes upon extreme conditions is theoretically complicated, so the most important variables upon the foreseen conditions are measured during the experimental tests. The performance of winter tires upon different ambient and road temperatures shows a very significant influence of the thermodynamic processes on emergency braking [24]. If a new winter tire with non-worn tread is used in a season other than the intended one (not cold season), it can worsen the braking acceleration almost by 1 m/s^2. In addition, an increase of the tire tread temperature by 12 °C was found in an emergency situation when braking from higher initial velocity lasts longer (5–10 s) and can negatively affect the thermodynamic stability of contacting surfaces, reducing dynamic friction.

In a paper published by International Tire Exhibition & Conference (ITEC), the results of the research on the dependence of the wet grip performance on tire tread depth (published in 1960–2013) were reviewed [25]. The systematised information showed that in the presence of a 0.5 mm water film a considerable decrease of the grip was found when the tire was worn to 3 mm of the tread depth. Upon such conditions, an increase in the rate of loss of control for passenger cars takes place. The research community agrees that recently introduced tire technologies improve wet grip performance; however, they do not reduce minimum tire wearing limit.

In many countries, statistical tests on the dependence of road accident rate on tire tread depth were carried out [7, 8]. In the course of investigation of road accidents, it was found that relative road accident probability depends on tire tread depth when road pavement is dry or wet. Organisational safety management process research into road transport companies revealed that tire faults, bad brakes and difficult observation lead to the main vehicle-related risk factors [26]. With an aim to establish the impact of aquaplaning on a specific road accident, experimental tests with an identical tire (including the de-gree of its wear) under the same conditions should be carried out; however, it is not a realistic task because of timing and cost difficulties, so probabilistic prediction models are applied, developed according to the available data such as tire aquaplaning properties in certain known modes of operation [27].

A survey of 450 drivers in Ghana shows that drivers properly identify the principal causes of road accident risks related to problems of tires (under- or overinflation, wear, overloading); however, they often do not know the minimum requirements set for tire tread depth or where the data on the tire age can be obtained [28]. These results are significant for countries where drivers are frequently involved in maintaining their vehicles or using commercial vehicles in their trade activities. Maintenance of tires in their use (including assembling and balancing) reduces the probability of defects. It even enables detecting the manufacturing faults, thus improving protection against potential driving risks [29]. In geographic regions with variable seasonality, the use of summer and winter tires instead of universal ones ensures higher driving safety in the relevant season, motivates more frequent inspection of the condition of tires (at the time of seasonal replacement) and provides a financial advantage in addition [30].

Mathematical prediction models are frequently applied to predict road accident risk. In such models, it is important to identify the principal variables and the character of their dependence on the values under prediction and the types of possible uncertainties [31]. Prior to predicting road accidents, reliable data sources need to be chosen or specific measurements need to be carried out. Analytic methods, such as batching and classification, are applied for the data analysis [32].

Over the years, researchers have applied a vast array of statistical methods to analyse accident-related data. Studies focusing on the statistical analysis of accident data have traditionally addressed one or more of three general objectives: (1) data analysis with the sole intent of quantifying the effect of statistically significant determinants (explanatory variables) on the likelihood and severity of accidents; (2) data analysis with the intent of using the resulting parameter estimates of the statistical model to forecast future accident likelihoods and severities, and (3) analysis of before and after data to evaluate

the effectiveness of a specific safety countermeasure or a change in a specific factor that may influence likelihood and severity of accidents [33].

The present work aims to investigate the models based on probability theory and mathematical statistics and their application in practice for statistical simulation of vehicle elements. In the second chapter, a statistical model of tire tread depth is developed upon using the collected data, and it is verified on a vehicle fleet; in the third chapter, a model for predicting road accident risk according to tire wear is formed. In the end, the conclusions are provided.

2. STATISTICAL MODEL

Important data and methodological issues have been identified in the crash-frequency literature over the years. These issues are a potential source of error in terms of incorrectly specifying statistical models, which may lead to erroneous crash-frequency predictions and incorrect claims relating to the factors that determine the frequency of crashes [34]. Statistical investigations of vehicles or their elements always involve specific tests; their results may provide confirmation or require further tests. When it comes to exploring theoretically and practically the faults of vehicle structure elements, the results are not exactly predictable; however, statistical models are usable for this purpose [35]. The implicit assumption in traditional statistical analyses is that an appropriately estimated model will both uncover causal effects and have the highest possible prediction accuracy [36]. Statistical prediction upon applying mathematical models is one of the most critical application areas of modelling. Without considerable expenses in terms of time and money, this method enables exploring the reliability of vehicle elements in a broad range of variation of reliability parameters where the realisation of natural tests is practically impossible. Statistical models for verification and validation are applied for the vehicle design stage or for any period of utilization [37, 38].

While developing a mathematical model of a vehicle or system under research, it is essential to define the system's limits, i.e. what elements will be a part of the system and what elements will remain out of the system [39]. While defining the system's limits, it is also cleared up what parameters should be considered internal parameters of the system and what parameters should be considered external. It is important to define constant and variable parameters when describing the system. In literature, many reliability prediction methods are provided. The applicability of a method depends on the available statistical information on the reliability of elements [39].

A vehicle is a complicated system that carries out specific functions that maintain the reliability parameters in certain limits. It consists of interconnected components, units and systems. Their reliability parameters predetermine the reliability of the total system (the vehicle). Therefore, when establishing the reliability of a vehicle, it is firstly divided into characteristic elements [40]. Then their external parameters as well as maintenance and diagnostic measures for reliability improvements are analysed [41]. The vehicle is divided into such elements that faults are not interrelated, i.e. a part's fault does not affect the other parts' reliability. After such a division, the mathematical model for establishing reliability becomes simple.

A vehicle tire is an irreparable product, i.e. a product that is replaced after its first fault (a certain level of wear) because driving stability and general safety directly depend on it [7].

2.1 Setting the initial parameters

The data for the statistical model was collected from the vehicle fleet of an insurance company. The tire tread depth of 4288 vehicles was inspected using a tread depth gauge. The tread depth of the most worn tire tread from each vehicle was registered for further analysis. M1 and N1 class vehicles were involved in the research as the most dominant in the fleet. These vehicle categories cover passenger cars and small commercial vehicles (here up to 2.0 t, avoiding commercial type tires). Tire wear data of 15–17 inch wheels with corresponding radial type tires (185–225 mm tire width range and 50–65 tire aspect ratios) was collected.

In the developed statistical model, tire tread depth corresponds to the random value H. After an inspection of tire tread depth for the total sample, the maximum value of the random value H, i.e. h_{max}=8.9 mm and its minimum value h_{min}=0.0 mm (completely worn tire) are found. Physically, the vehicle can move with completely worn tires (h_{min}=0.0 mm); however, the minimum tire tread depth is considered equal to 0.1 mm where

mathematical calculations with zero value are impossible. Then the range ΔL of the random value H is found:

$$\Delta L = h_{max} - h_{min} \tag{1}$$

Following that, the range of dispersion Δh of the tread depths is found:

$$\Delta h = \frac{\Delta L}{1 + 3.3 \ln(n)} \tag{2}$$

where n is the size of the sample.

The number of ranges j is calculated as follows:

$$j = \frac{\Delta L}{\Delta h} \tag{3}$$

The calculated initial statistical parameters corresponding to dispersion data of tire tread depths are provided in *Table 1*.

Table 1 – The initial statistical parameters of the tire tread depth

Statistical parameter	Value
Size of the sample, n	4288
Maximum random value h_{max} [mm]	8.9
Minimum random value h_{min} [mm]	0
Random value variation range ΔL	8.9
Range of dispersion Δh [mm]	1
Number of ranges, j	9

Statistical calculations were undertaken using the STATISTICA v.12 software. The obtained histogram of frequencies of empirical data is provided in *Figure 1a*. Upon comparing its external appearance to the theoretical curves of the distributions, the probabilistic distribution can be preliminarily guessed.
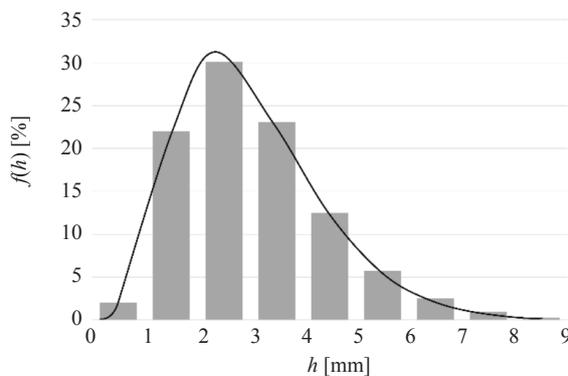
2.2 Establishment of the theoretical distribution

Describing mathematically the existing condition of tires of the vehicle fleet under research, a relevant theoretical distribution that corresponds to the degree of wear of tire tread is established. According to the histogram of the random value (*Figure 1a*), it is preliminarily predicted that the distribution of tire tread depths corresponds to the gamma law.

If random value H is distributed according to the gamma law, the range of its possible values is $(0, +\infty)$, and its density [39] shall be expressed as follows:

$$f(h) = \frac{\lambda^{\eta}}{\Gamma(\eta)} h^{\eta-1} \exp(-\lambda h) \tag{4}$$

where λ is a parameter of the scale of gamma distribution, η is a parameters of the shape of gamma distribution, $\Gamma(\eta)$ is a complete gamma function [40].

In the theory of reliability, the gamma distribution is frequently used. Herein, the durability characteristics of objects, such as the duration of operation of parts or products before the first fault, are analysed [40]. In the theory of reliability, the function $\lambda(h)$ is referred to as the intensity of failures [39]. When Δh is low, $\lambda(h) \cdot \Delta h$ approximately equals to a probability that a part having operated without faults before the moment h will fail in the range $(h, h+\Delta h)$. Therefore, the intensity of failures is expressed as follows:

$$\lambda(h) = \frac{f(h)}{1 - F(h)} \tag{5}$$

where $f(h)$ is the dependence of the relative frequency on tire tread depth, $F(h)$ is the dependence of the summarised relative frequency on tire tread depth.

a) Differential statistical model
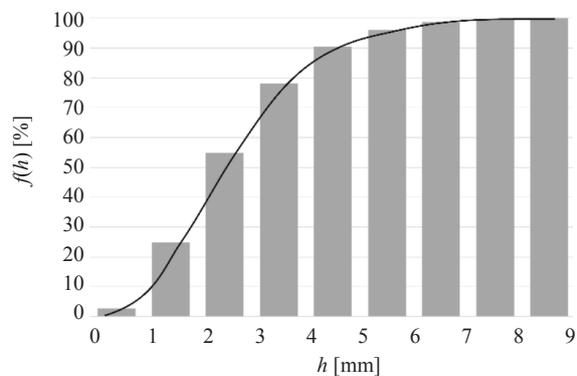
b) Integral statistical model

Figure 1 – Statistical representation of the vehicle fleet according to tire tread depth

In engineering reliability studies, data conformity to a theoretical distribution is approximately found from the external appearance of the histogram or in the course of an analysis of its characteristics. From the external appearance of the empirical data histogram (*Figure 1a*), it can be assumed that the random value H (tire tread depth) is distributed according to the gamma law. To establish the theoretical density of gamma distribution in *Equation 4*, the scale parameter λ and the shape parameter η of the said law are required. The mean value of tire tread depth is $\bar{h}$=3.09 mm, with dispersion amounting to σ^2=2.12.

Using the expression of the mean value $\bar{h}$ and parameters of gamma distribution as well as the expression of the dispersion σ^2 through the parameters of gamma distribution, a system of equations for establishing the parameters η and λ is formed:

$$\begin{cases} \dfrac{\eta}{\lambda} = 3.09 \\ \dfrac{\eta}{\lambda^2} = 2.12 \end{cases}$$

The obtained graphical representations of theoretical differential and integral functions of gamma distribution with the scale parameter λ=1.4575 and shape parameters η=4.504 are shown in *Figures 1a and 1b*. It is seen from the figure that the maximum tire tread depth of the significant part of vehicles (30%) is 2–3 mm. The ranges 1–2 mm and 3–4 mm of tire tread depths conform to 22% and 23% of the vehicles. The distribution of results of experimental tests is close to gamma distribution when the mode of the theoretical function of the differential statistical model is "moved" to the left (*Figure 1a*). It shows that tires with treads worn over 50% predominated in the researched fleet.

2.3 Verification of hypotheses

Approximating the empirical data of random values, the same data can be successfully approximated by different distributions. The compatibility criteria are applied to choose the best probabilistic distribution (that describes the data best).

The Pearson compatibility criterion is applied for verification of assumed distribution. The Pearson compatibility criterion is based on comparing the number of events found empirically with the number of events expected by a theoretical law in the given interval [39]. Verifying the null hypothesis by the criterion χ^2, the following operations were carried out:

1) On the basis of the hypothetic function, the probability p_i of access of the random value H to the given interval is calculated:

$$p_i = P(h_{i-1} \leq H \leq h_i) = \int_{h_{i-1}}^{h_i} f(h)dh = F(h_i) - F(h_{i-1}) \quad (6)$$

where i=1,2,…,k is the number of intervals.

2) The obtained probabilities p_i are multiplied by the sample n in that zone and the theoretical frequencies np_i (the expected frequencies, if the null hypothesis is verified), are obtained.

3) The compatibility criterion χ^2 is calculated:

$$\chi^2 = \sum_{i=1}^{k} \frac{(m_i - np_i)^2}{np_i} \quad (7)$$

When $n \to \infty$, the expression *Equation 7* is χ^2 distribution with the number of degrees of freedom:

$$\upsilon = k - r - 1$$

where k is a number of intervals, r is a number of parameters of the hypothetic function $F(h)$.

4) The number of degrees of freedom υ is established for each distribution.

5) The materiality level α=0.05 is chosen, and critical values of $\chi^2_{\alpha;\upsilon}$ are found in χ^2 quantile function tables [40].

6) It is verified whether $\chi^2 < \chi^2_{\alpha;\upsilon}$. If yes, there is no basis for rejecting the null hypothesis.

The calculated data for verifying the gamma distribution hypothesis is provided in *Table 2*.

Verifying the hypothesis that the distribution of tire tread depths conforms to the gamma distribution, the degree of freedom is found in *Equation 8*. The number of intervals k=9. Gamma distribution has two parameters (λ and η), therefore r=2. Thus, the obtained number of degrees of freedom υ=6. The established critical value $\chi^2_{0.05;6}$=12.592. Because the obtained value of the gamma distribution according to the compatibility criterion χ^2 is lower than the established critical value (*Table 2*) χ^2=11.586<$\chi^2_{0.05;6}$=12.592, there is no ground for rejecting the null hypothesis that the empiric data are distributed according to gamma law.

In the course of exploration of the condition of the vehicle fleet according to the tire tread depth, it was found that the following expression of Gamma distribution should describe the differential and integral functions of tire tread depth:

$$f(h) = \frac{1.4575^{4.504}}{\Gamma(4.504)} h^{4.504-1} \exp(-1.4575h)$$

Table 2 – The data for verifying the gamma distribution hypothesis

Interval	m_i	p_i	np_i	$(m_i - np_i)^2$	$(n_i - np_i)^2/np_i$
0…1	115	0.026	112.311	7.231	0.064
1…2	940	0.203	869.469	4974.622	5.721
2…3	1296	0.305	1305.983	99.660	0.076
3…4	993	0.237	1016.919	572.119	0.563
4…5	532	0.132	566.543	1193.219	2.106
5…6	246	0.060	258.171	148.133	0.574
6…7	108	0.024	102.933	25.674	0.249
7…8	44	0.009	37.314	44.703	1.198
8…9	14	0.004	18.358	18.992	1.035
Σ	4288	≈1			χ^2=11.586

After calculating the statistical parameters of the random value and establishing its distribution law, the complete information about the vehicle fleet condition according to tire tread depth is collected. The established theoretical tire tread depth distribution law shall be applied to the development of a road accident risk prediction model.

3. PROBABILITY OF ACCIDENT RISK

3.1 The impact of tire wear on the accident risk

Statistical analyses on the dependence of road accident rate on tire tread depth are essential and are frequently carried out in many countries [7, 8, 13]. Through road accident research, the relative probability of occurrence of a road accident on dry and wet pavements depending on tire tread depth was found (*Figure 2*). However, the likelihood that
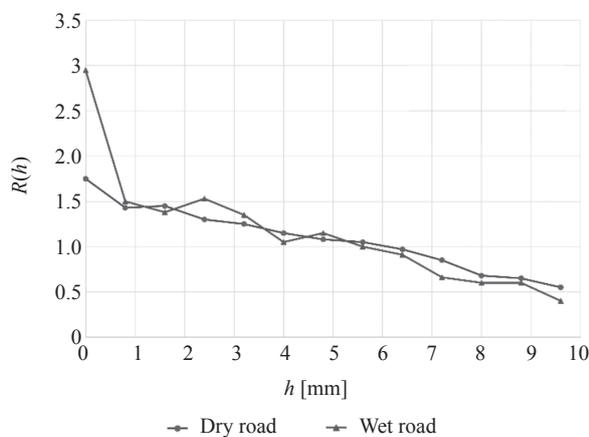

Figure 2 – Dependence of risk index on tire tread depth [43, 44]

drivers respond to changing road conditions by altering their behaviour is not assessed here [42]. Risk index (RI) is found as a percentage of vehicles that suffered a road accident compared to the total number of vehicles with the same tire tread depth.

It can be seen from *Figure 2* that the accident risk (as road accident rate) increases when the depth decreases and grows considerably when the depth is below 1 mm. When tire tread depth is below 1 mm, the probability of road accident on wet road for a vehicle with such tires is 40% higher, as compared to dry road (RI=2.9 and RI=1.7, respectively). When comparing the relative road accident risk for vehicles with tire tread depths equal to 7–8 mm and vehicles with tire tread depths equal to 0.8–1.5 mm, it is found that road accident risk for vehicles of the first group is about 3 times lower, as compared to the vehicles of the second group, regardless of the road conditions.

Having found a relative dependence of road accident rate on tire tread depth and the distributions of the depths, statistical prediction related to tire wear of the used vehicle fleet is further developed.

3.2 Road accident prediction model

It is important to mention that the relative frequency $f(h)$ and the summarised relative frequency $F(h)$ in *Figure 1* can be expressed through probabilistic parameters, i.e. the values h_i of tire tread depth found in the relevant range can be defined as a certain probability of appearance of this value. Function $f(h)$ can be considered a function of the spread of tire tread depth probabilities in the total

range of measurements. In addition, when exploring road accidents, the relative probability $RI(h_i)$ of road accident occurrence depending on tire tread depth in certain range was found (*Figure 2*). After summing up the products of $f(h_i)$ and $RI(h_i)$ in the ranges $h_i \leq h$ and dividing by the sum of probabilities of vehicles with tire tread depth h_i in the same ranges, the probability of road accident risk for the vehicle fleet depending on tire tread depth is calculated (*Figure 3*). Adaptive risk index ARI_h is calculated as:

$$ARI_h = \frac{\sum\limits_{h_i \leq h} (f(h_i) \cdot RI(h_i))}{\sum\limits_{h_i \leq h} f(h_i)} \qquad (8)$$

where $f(h_i)$ is the probability of vehicles with tire tread depth equal to h_i, $RI(h_i)$ is the accident risk for vehicles with tire tread depth equal to h_i in percentage.

The results of the calculated parameters of the developed prediction model according to the tire tread depth are provided in *Table 3*.

The established dependences show that the road accident probability for the inspected vehicle fleet with tire wear values up to 4 mm both on dry and wet road increases to the minimum extent and according to the same trend. For a higher degree of wear (the tire tread depth is 1–4 mm), an increase in accident rate is observed on wet road, and when tire wear achieves the critical level (< 1 mm), the accident rate on wet road rises up to 2.9%, i.e. becomes 1.7 times higher than for dry road. This follows from a decrease in the tire adhesion force because of aquaplaning. An increase in the accident rate on

dry road is not considerable; however, when the tire is worn, the said rate increases 1.37 times compared to a more minor degree of wear.

After analysing the existing condition of tire tread depth according to the collected empirical data, with the distribution of the random value known, it is possible to carry out predictive calculations. In various countries, it was found that if the minimum tire tread depth is increased from 1 mm to 2 mm, the probability of road accident decreases by 10–15% [43, 44]. After eliminating all vehicles with tire tread depths below 1.6 mm, the probability of non-occurrence of road accident grows – 50% on wet road and 30% on dry road.

The measurements of tire tread depths of the inspected vehicle fleet were carried out at the valid minimum allowable depth of 1.6 mm. Upon improving traffic safety, the said requirement related to the
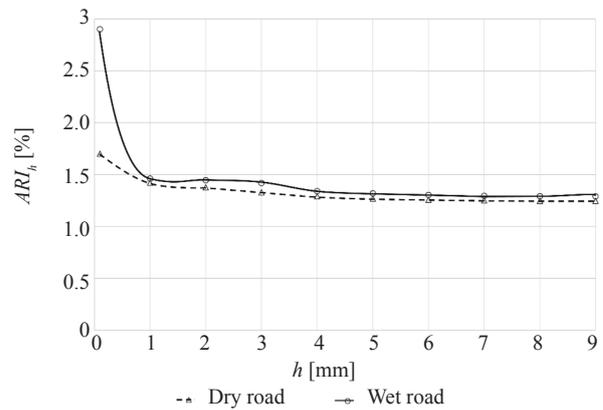

Figure 3 – The statistical model of road accident probability depending on tire tread depth

Table 3 – Risk index RI(h) and adaptive risk index ARI_h depending on the tire tread depth

h [mm]	$RI(h)$		$f(h)$ [%]	ARI_h [%]	
	Dry road	Wet road		Dry road	Wet road
0	1.7	2.9	0.01	1.7	2.9
1	1.42	1.46	10.92	1.4203	1.4617
2	1.36	1.44	28.84	1.3765	1.4455
3	1.26	1.38	27.80	1.3109	1.4106
4	1.14	1.04	17.73	1.2133	1.2476
5	1.06	1.12	9.02	1.1130	1.0670
6	1.0	0.96	3.98	1.0416	1.0710
7	0.87	0.72	1.59	0.9629	0.8915
8	0.67	0.6	0.59	0.8158	0.6875
9	0.63	0.54	0.21	0.66	0.5844

minimum allowable depth is increased by one and two millimetres, up to 2.6 mm and 3.6 mm. It was presumed that the random value remains distributed according to the gamma law with the same dispersion for making such a prediction. In this case, only the average of the random value will be increased by one and two millimetres, respectively. After the provided increase of the minimum allowable tire tread depth, no tires with the minimum tire tread depth remain in the mathematical model because the data distributions move to the right (*Figure 4*). For comparison, the primary theoretical curve of gamma distribution when the minimum allowable tire tread depth is equal to 1.6 mm is also provided.

According to the accepted assumptions on tire tread depth distribution, the Gamma distribution function (*Equation 4*) is recalculated with new average parameters: η/λ=4.09 for 2.6 mm and η/λ=5.09 for 3.6 mm. Then, adaptive risk index ARI_h in percentage is calculated for each tire tread depth range and each type of road. The approximated values of ARI_h for dry and wet roads are provided in *Figure 5*.

It may be seen from the provided predictive graphs of the condition of tires (*Figure 4*) and the dependence of risk index on tire tread depth (*Figure 2*) that the differences between the accident curves at small tire tread depths are minimal because the share of vehicles with such tires in the vehicle fleet is very small (up to 1.27%). When the minimum allowable tire tread depth of the vehicle fleet is increased up to 2.6 mm, the probability of accident for dry road decreases by 3–8% and when the minimum allowable tire tread depth of the vehicle fleet is increased up to 3.6 mm it decreases by 4.5–15% (when tire tread depths of 3–8 mm are observed) (*Figure 5a*). When the minimum allowable tire tread depth of the vehicle fleet is increased up to 2.6 mm for wet road, the probability of an accident of the vehicle fleet decreases by 1.4–9.3%, and when the minimum allowable tire tread depth of the vehicle fleet is increased up to 3.6 mm, the probability decreases by 2.1–19.4% (when tire tread depths of 3–8 mm are observed) (*Figure 5b*).

A developed model of accident rate prediction according to tire wear level is applicable not for a separate vehicle but for a particular vehicle fleet as a whole mobility unit. Model is useful for large transport companies (e.g. insurance companies) and specialists responsible for road safety management by predicting accident costs related to tire wear.
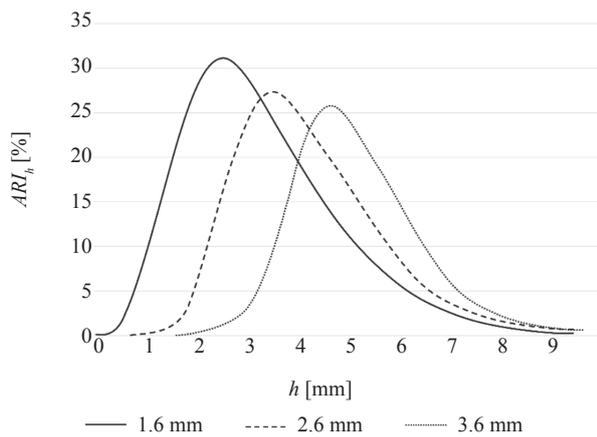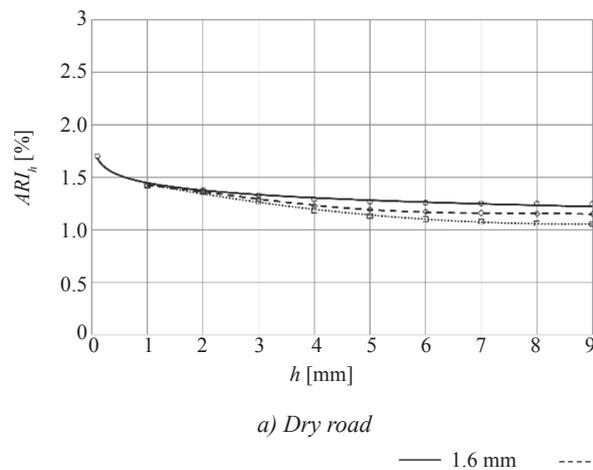

Figure 4 – The distributions that conform to the conditions of the tires of the vehicle fleet at different minimum allowable tire tread depths
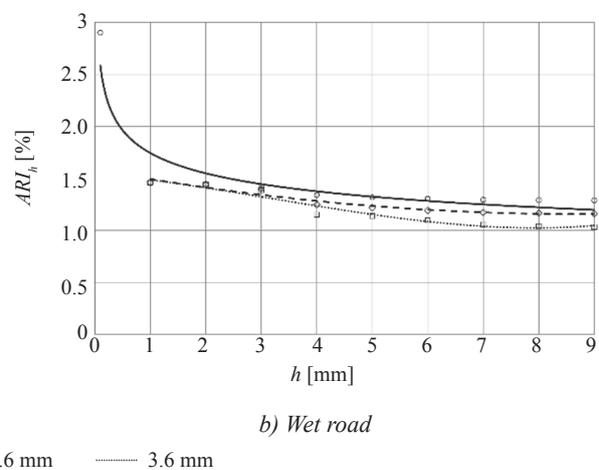

a) Dry road

b) Wet road

Figure 5 – Prediction of accident rate of used vehicle fleet according to the different requirements to the permissible minimum tire tread depth

4. CONCLUSIONS AND PROPOSALS

Tire state (including tread depth as the most important factor) has a significant impact on vehicle dynamics, handling and stability, which are critical during road accidents. The consequences of road accidents are attributed to tire state even if the initial cause of an accident was based on driver error or unfavourable traffic situation. The research covers only one, highly variable but critically important part related to vehicle performance during an accident (thread depth), applied to a whole fleet and during vehicle usage time. The target vehicle fleet of this research covers passenger cars and small commercial vehicles, which mostly use the same type and size tires; therefore, the collected data and obtained results are relevant enough.

After investigating the tire state of the inspected vehicle fleet, it was found that differential and integral functions of tire tread depth are distributed according to gamma law, which attests that tread wear over 50% predominates for the researched vehicle fleet.

According to the known risk index (RI) dependence and formed distributions of the data on tire wear, adaptive risk index (ARI) for the vehicle fleet was formed. This ARI_h shows that when tire tread depth is 1–4 mm, an increase of accident rate on wet road, as compared to greater tire tread depths, is observed; when a critical tire wear degree is achieved (< 1 mm), the road accident rate on wet road increases up to 2.9% and is 1.37 times higher, as compared to dry road.

The formed mathematical models for tire condition enable predicting a decrease of the accident rate when the minimum permissible tire tread depth is increased. Assuming that the regulation for minimum permissible tire tread depth is increased from 1.6 mm to 2.6 mm, the predicted accident rate of the vehicle fleet will decrease to 8% and 9.3% for dry and wet road, respectively. If the minimum permissible tire tread depth is increased from 1.6 mm to 3.6 mm, the predicted accident rate of the vehicle fleet will decrease to 15% and 19.4% for dry and wet road, respectively.

Accident rate prediction models described in the literature for a single vehicle do not allow assessing the overall accident rate of a certain vehicle fleet. According to tire wear degree, the developed model of accident rate prediction is applicable not for separate vehicles but for a particular vehicle fleet

as a whole mobility unit. The model can be used in activities of certain companies related to prediction of road accident losses.

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EISMO ĮVYKIO TIKIMYBĖS PROGNOZAVIMAS PAGAL AUTOMOBILIŲ PARKO PADANGŲ NUDILIMO STATISTINĮ MODELĮ

SANTRAUKA

Šio darbo tikslas yra ištirti lengvųjų automobilių padangų protektoriaus gylio įtaką avaringumui ir sudaryti avaringumo prognozavimo modelį. Naudojant profilometrą buvo išmatuota ir statistiškai apdorota 4288 automobilių padangų būklė. Tolesnei analizei buvo registruojamas kiekvieno automobilio daugiausiai nudilusios padangos protektoriaus gylis. Surinktų duomenų pagrindu sudarytas vienoje draudimo bendrovėje apdraustų automobilių parko padangų protektoriaus gylio statistinis modelis. Skirstinio dėsnio atitikimas duomenims tikrinamas pagal Pirsono suderinamumo kriterijų. Nustatyta, kad skirstinys gali būti aprašomas pagal Gamma dėsnį. Darbe pateikiamos padangų protektorių gylių dažnių histogramos ir teorinės skirstinio tankio kreivės. Panaudojus sudarytus skirstinius ir Rizikos Indekso priklausomybę nuo protektoriaus gylio, apskaičiuojama eksploatuojamų automobilių parko avaringumo tikimybė nuo padangų protektoriaus gylio. Pagal sudarytą prognozavimo modelį minimalaus leistino protektoriaus gylio reikalavimo padidinimas 2 mm (iki 3,6 mm), avaringumo riziką, skaičiuojamą pasirinktam automobilių parkui, dėl blogo sukibimo su kelio danga, galėtų sumažinti iki 19,3 %. Tokie modeliai naudingi eismo saugumo specialistams, draudimo bendrovėms ir transporto žalų specialistams, prognozuojant draudiminių įvykių išlaidas.

RAKTINIAI ŽODŽIAI

eismo įvykis, prognozavimas, padanga, protektoriaus gylis, skirstinys, avaringumas, eismo įvykio tikimybė.

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