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Assessment of Influence of Meteorological Parameters on the Risk of Accidents on Roads Outside Settlements

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Abstract. Road traffic accidents, especially occurring on road sections outside of populated areas, are characterized by high severity of consequences and, therefore, are one of the main safety problems of the technosphere. Studies of many authors confirm the importance of the influence of meteorological parameters on the accident rate. However, most results don't contain quantitative data demonstrating how risk of occurring a car accident depends on weather conditions. Research of this article assesses the impact of five main meteorological parameters on the accident rate using as example one of the Russian Federal roads. Nonlinear dependences of weather conditions and road accident risk were obtained by means of calculation of frequencies. The results are presented in the form of graphical dependencies. As a result of approximation there were found formulas that describe the relationship between values of meteorological parameters and the variation of a car accident risk. According to probability theory, the mathematical model can be based on the multiplication of risks caused by each meteorological parameter.

1. Introduction

One of the major problems in the field of technosphere safety is the high accident rate of road transport. Every year in the Russian Federation about 20 thousand people die in road traffic accidents, about 200 thousand people get injured, all over the world these figures are even higher, there are 1.2 million people and 50 million respectively [1]. Large-scale road traffic accidents rank first in the incident count among emergencies in the Russian Federation. The highest severity of consequences is on road sections outside of populated areas. Accidents on this road sections, especially on federal highways, which are characterized by high traffic, should be analyzed firstly as part of developing the measures to prevent emergencies involving road transport.

According to classical theory of the principles of road traffic safety there exist an influence of the complex DCRE (driver - car - road - environment) on the accident rate [2]. Among the parameters of the «environment» factor the most important ones are the weather conditions. Weather conditions are the main cause of road traffic accidents in every fourth case and a common cause of delays in the sphere of passenger and cargo transportation [3, 4].

This research examines the impact of main meteorological parameters on the risk of occurring a road traffic accident.



2. Preliminary analysis

In accordance with the definition of meteorological conditions (the state of the atmosphere, characterized by the values of meteorological elements at a certain time [5]) it makes sense to consider meteorological elements that are accepted as basic and should be subject to control at most meteorological stations. These include atmospheric pressure, air temperature and humidity, wind parameters, cloudiness, amount and type of precipitation, visibility, parameters of fogs, snowstorms and thunderstorms. Analysis of literature sources shows that several of the listed elements have the most influence on the accident rate, there are atmospheric pressure (t_1), air temperature (t_2), wind gusts (t_3), precipitation (t_4), visibility (t_5).

It is pointed out in the sources [6, 7] that a decrease in atmospheric pressure leads to an increase in the number of accidents.

Besides, the study [7] contains information about the complex nonlinear relationship between temperature and the accident rate. In the study [1] it is said that the inverse dependence of temperature on the accident rate prevails.

According to the study [8], the influence of the wind parameters has not been studied enough, but there is information that due to wind gusts the number of rollovers on the roads and the risk of accidents involving high trucks both increase.

Various researchers conducted analyses of visibility [8, 9]. They confirm that the formation of haze or fog increases the probability of road traffic accidents due to reducing of the visibility of the road, and also is a factor of reducing the coefficient of adhesion. In addition, under such conditions the driver experiences physical and psychological stress, which can lead to errors in assessing the traffic situation.

A significant direct effect of precipitation on the accident rate is confirmed in the sources [1, 4, 7, 8, 10].

3. Objective

A large number of studies, both in Russia and abroad, are devoted to the analysis of the relationship between meteorological conditions and road traffic accidents. However, a significant part of the results doesn't contain quantitative characteristics, that is, how much the variation of each meteorological element increases the risk of occurring a road traffic accident. Most of the studies, for example, [1, 6] is based on the assumption about the linear dependence of meteorological parameters and the accident rate, but the research by Tom Brijs [7] contains information that the relationship are nonlinear and it is necessary to conduct analysis for each meteorological parameter using the method of dividing into intervals. In addition, it is important to take into account the type of road, as the average speed, traffic characteristics and typical dangers for city roads and country roads are different. Studies devoted to the analysis of the relationship between the accident rate and weather conditions on roads outside of populated areas are not enough.

The objective of this research is to determine the influence of the main meteorological parameters on the risk of occurring a traffic road accident on road sections outside of populated areas.

4. Mathematical model

The Russian Federal road A-322 (Barnaul – Rubtsovsk – the state border with the Republic of Kazakhstan) was chosen as an object of research. The road is a transport artery connecting Western Siberia with the Republics of Kazakhstan, Kyrgyzstan and Uzbekistan, so ensuring safety for it goes beyond regional objectives and is an important condition for international cooperation. There was collected the information about road traffic accidents with victims and material damage that have been registered on the road in the period from 2012 to 2016. The information includes the date, time and place (the kilometer of the road) of the accident. The number of incidents is over than 1500. The average risk of occurring a road traffic accident on the road has been calculated and is equal 0.84 accidents per day. An archive with data about weather conditions for the same period was also

obtained from five weather stations near the road, and the values of the selected meteorological parameters were restored for each accident.

Due to the assumption of nonlinearity of weather influence on road traffic accidents, values of each meteorological parameter t_i are divided into n equal intervals (n should be calculated by the Sturges' formula). To calculate the quantitative characteristics of the relationship, it was chosen the method of comparing relative frequencies between two groups. There are the group of accidents (sample of values of the accident rate, which is defined as A) and the group of actual observations (general population, which is defined as G). For both groups (N_A and N_G) there were obtained frequency and then relative frequency within each interval. Then, the relative frequencies of two groups were compared, and the coefficient of influence of the meteorological parameter on accident rate in the interval $d...f$ was calculated using the following formula (1).

$$k_{d...f}^{t_i} = \frac{N_A}{N_G} \quad (1)$$

The coefficient $k_{d...f}^{t_i}$ nominally displays how much the risk of occurring a traffic road accident increases in comparison with its average value, when the value of the meteorological parameter is in the interval $d...f$. The analysis is based on the assumption that in the absence of the influence of the meteorological parameter on the accident rate, the relative frequencies in the two groups will coincide at all n intervals and the graphical form of the distribution $k_{d...f}^{t_i}$ will be a straight line parallel to the X-axis, intersecting the Y-axis at point with coordinates $[0, 1]$. The difference in the distribution of relative frequencies of the two groups will display the magnitude of the impact of the weather parameter on the accident rate.

5. Results and interpretation

As a result of calculating the coefficient $k_{d...f}^{t_i}$ for n intervals for each meteorological parameter t_i , the graphical distributions shown in Figure. 1 are obtained.

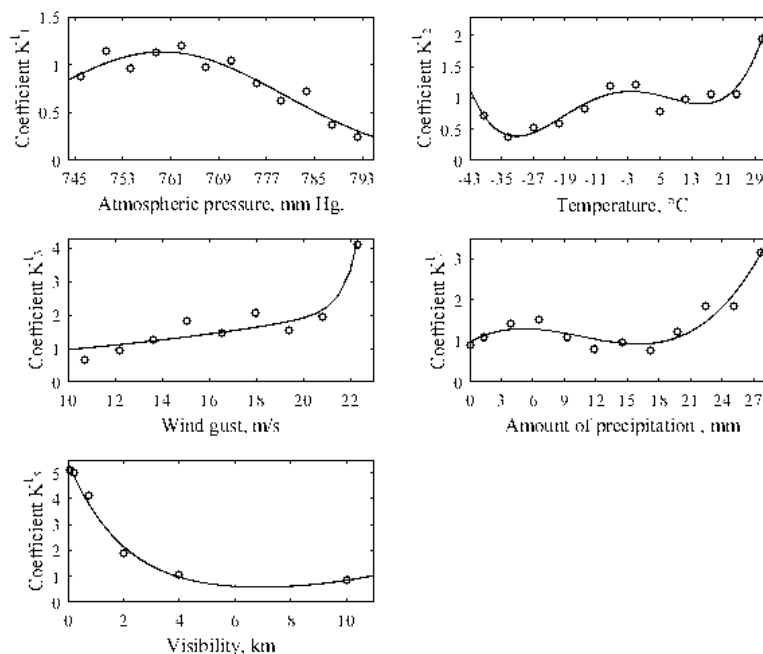


Figure 1. Distribution of coefficient $k_{d...f}^{t_i}$ by intervals for t_i meteorological parameter.

There was made approximation to obtain the coefficient K^{t_i} showing how much the risk of occurring a traffic road accident increases in comparison with its average value in dependence of a

certain value of the meteorological parameter. Therefore, since this mathematical operation was applied, it is possible not to determine the interval for calculating the risk of occurring a road traffic accident.

The first considered meteorological element is atmospheric pressure (t_1). The expression obtained as a result of the mathematical operation described above is the following formula (2):

$$K^{t_1} = a_1 \cdot \exp\left(\frac{-t_1 - b_1}{c_1}\right)^2; R^2 = 0.91 \quad (2)$$

The resulting expression describes the calculation results at an acceptable level. The analysis of the graph confirmed the results of the researchers showing that there are inverse relationship between the considered parameter and the accident rate. In low-pressure zones (approximately below 764 mm Hg), the risk of occurring a road traffic accident increases.

Then the calculation K^{t_i} for the air temperature (t_2) was made, resulting in the expression (3):

$$K^{t_2} = p_1 \cdot t_2^4 + p_2 \cdot t_2^3 + p_3 \cdot t_2^2 + p_4 \cdot t_2 + p_5; R^2 = 0.92 \quad (3)$$

Using the graph, it was found that the dependence of the accident rate from the ambient temperature is nonlinear and has several peaks. The risk of occurring a road traffic accident increases at a temperature about 0 °C (from -11 °C to +2 °C), the reason is forming of glaze ice on the roads. The next peak is registered at temperatures above than 28 °C due to the increasing intensity of traffic and also the physiological state of drivers in the heat (lowering of concentration, worsening of health).

With approximation of calculated results for wind gusts (t_3), there was obtained the following expression (4):

$$K^{t_3} = a \cdot \exp(b \cdot t_3) + c \cdot \exp(d \cdot t_3); R^2 = 0.91 \quad (4)$$

The resulting graph allows us to conclude that wind gusts increase the risk of occurring a road traffic accident, and strong storm gusts (above 22 m/s) increase the probability of that in 3 or more times.

The next analyzed meteorological parameter is the amount of precipitation (t_4). As a result of approximation, we get the expression (5), which describes received figures with a sufficient level of accuracy.

$$K^{t_4} = s_1 \cdot t_4^3 + s_2 \cdot t_4^2 + s_3 \cdot t_4 + s_4; R^2 = 0.92 \quad (5)$$

The graph shows that the influence of precipitation on the accident rate is also nonlinear. Weak and strong precipitation increase the accident risk the most, moderate ones affect to risk slightly. This can be explained by the psychological characteristics of drivers. When precipitation is low, drivers do not change the usual style of driving, whereas there are moderate ones they start to drive more carefully. Strong precipitation significantly increases the risk of occurring a road traffic accident due to objective reasons, the coefficient of adhesion and also visibility decreases.

The expression obtained in process of the visibility analysis (t_5) is represented as the formula (6).

$$K^{t_5} = h_1 \cdot \exp(h_2 \cdot t_5) + h_3 \cdot \exp(h_4 \cdot t_5); R^2 = 0.99 \quad (6)$$

There's an inverse relationship between the considered meteorological parameter and the level of increasing of the accident risk, which is consistent with the results of the studies.

6. Conclusion

Analysis of the impact of weather conditions on traffic collisions is a controversial issue, both in Russia and abroad. As a result of this research, it has proved that dependence of main meteorological parameters on the risk of occurring a traffic road accident on road sections outside of populated areas are nonlinear. In general, the obtained information is consistent with researches of Russian and foreign scientists. There were obtained the quantitative data demonstrating how risk of occurring a road traffic accident changes in dependence of the values of meteorological parameters. The mathematical model based on this quantitative data, according to probability theory, is the multiplication of risks caused by each meteorological parameter.

To increase the accuracy of the results of the research, it is necessary to carry out more analyses taking into account the type of road (city roads, suburb roads and road sections outside of populated areas). Information about the level of increasing the accident risk in dependence of changing the

values of meteorological parameters help prevent traffic road accidents, including large-scale ones. In case of bad weather conditions, local and temporary measures may be taken, including traffic restrictions and informing drivers via information displays and SMS alerts.

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