Evolution of requirements to state of order of automotive tires for traffic safety

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Abstract The paper presents the results of a study of the influence of the amendment of the requirements to the technical state of order of motor vehicles, specifically, to the design of the tires used on the front and rear axles of motor vehicles on the motor traffic safety. It has been determined that newly developed requirements aim on the reduction of the difference of the traction between the front and the rear axle for more prompt response of the braking mechanisms and improved braking efficiency. It has been demonstrated that the implementation of the design requirements to vehicles developed in 2010 and 2013 allows for reduction of the accident rates of motor vehicles using different tire types by 3%. Further tightening of the operational requirements to motor vehicles in this direction has a reserve allowing for max. 1% of further reduction of the accident rate whereafter the reserve of the traffic safety improvement will be deemed exhausted.

Introduction
For the time being, injuries and mortality of people in traffic accidents constitute one of the major negative development factors of our society. Scientific studies evaluate economic losses due to traffic accidents up to 5% of GDP, thereby, alone the mechanical repair works on the damaged vehicles weigh well 2.5%. During 2020 1.5 million people became COVID-19 victims, whereas in traffic accidents 1.25 million casualties were reported. The average global reduction of gross domestic products in 2020 makes up 6% [1]. That is, we confront comparable figures of the global economy losses due to COVID-19 pandemics and due to traffic accident, thereby, the priority in the countermeasures of the humankind is definitely shifted towards the struggle against COVID-19, whereas the matters of the traffic accident rates remain undeserved in the shadow of the struggle against the new threat. Along with that, it is worth saying that the effect of the improvement of the motor traffic safety will be no less important than the victory over COVID-19, that is why solving of problems relevant to the reduction of traffic accident rates is a vital research subject.

Overview of previous studies
The beginning of the studies on provisions for traffic safety is now associated with Ralph Nader's Unsafe at any Speed: The Designed-In Dangers of the American Automobile [2], thereby, in connection with the highest relevance of this problem for highly motorized countries, the majority of the studies have been made by American scientists [3,4,5]. In Europe, Swedish scientists score the leadership [5,6,7]. Individual interesting studies can be encountered in other countries, too [8]. In Russia, the improvement of the motor traffic safety has been the subject of studies by such scientists, as: V.V.Abartsumyan, O.P.Gudjoyan [9], V.I.Konoplyanko, O.P.Gudjoyan,
V.V.Zyryanov [10]. An important contribution was made by scientists of Nizhny Novgorod Technical University, such as A.Groshev, A.Vashurin, P.Musarskiy, A.Tumasov [11].

The results of the specified studies allow for conclusions that, for the time being, the problem is rather completely investigated with wide utilization of mathematical statistics for determining of the influence of any specific factor on the automotive traffic safety. However, the issue of the influence of combined use of different tire designs on the front and the rear axle of a motor vehicle on the automotive traffic safety has not enjoyed considerable interest, since it is deemed during the design of a motor vehicle that it should normally bear all identical tires, be tested on all identical tires and be delivered to the consumer on all identical tires. There are only few studies dedicated to problems of motor vehicle driving on a combination different design tires, whereas they touch upon mostly the operation of special mission vehicles [12]. The replacement of normally carried tires by tires of a different design is within the competence of technicians in charge of operation matters whose actions are guided by basic provisions on admission of motor vehicles to the operation being an integral part of Russian Traffic Rules [13,14].

Based on the document, the requirements to the carried tires were reviewed five times in the last 27 years, however, no papers substantiating the necessity for such revisions are publicly available.

Methods
A conducted analysis of amendments to the design requirements of a motor vehicle in terms of combined utilization of different tire types has revealed that, in 1993, it was forbidden to utilize tires with different tread patterns on one axle to prevent derapage of the vehicle at emergency braking in absence of a lateral force. In 2002, the tread pattern difference clause was completed by the prohibition of combining of studded and non-studded tires, tires with new and restored tread, frost-resistant and frost-sensitive tires on one axle. All these interdicts were also to prevent derapage at emergency braking in absence of lateral forces. In 2010, a requirement was developed concerning combining of different tire types between the front and the rear axle prohibiting any combinations of studded and non-studded tires in motor vehicles. In 2013, an interdict was adopted against the use of winter and all-season tires with less than 4 mm residual tread depth. In the same year, a technical regulation on safety of wheel-type motor vehicles forbidding combining of winter and summer tires, as well as the use of studded tires in summer and summer tires in winter was adopted. Beside that, banned were tires with twice restored tread pattern and tires with once restored tread pattern on the front axle. Thus, the evolution of the requirements to the technical state of order of motor vehicles aims, for the time being, uniform tiring in terms of the uniformity of their properties on all wheels of a motor vehicle. Thereby, the control properties of motor vehicles [15] are mostly influenced by changes in the stiffness of the tire structure, rather than by tire type and tread pattern. The limitation of the traction difference between the wheels is mostly intended for ensuring the vehicle stability during emergency braking.

The results of traction property studies of different tire models can be found in specialized automotive journals like "Autoreview", "Za Rulyom", "Auto-Bild", "Auto-Moto und Sport", etc. [16-19]. Analyzing the regulatory requirements to the tiring, it should be noted that till 2010 it was admissible to mount new studded tires onto the front axle with worn summer tires on the rear axle. Such a combination could have a traction difference of up to 0.19 between the front and the rear axis on ice, up to 0.3 on snow, up to 0.3 on wet asphalt, and up to 0.4 on dry asphalt. The ban of combined use of studded and non-studded tires allowed for a reduction of the traction difference down to 0.13 between the front and the rear axis on ice, down to 0.2 on snow, down to 0.2 on wet asphalt, and down to 0.3 on dry asphalt. The prohibition on combined use of winter and summer tires did not alter the obtained traction differences since the specified difference in the parameters of the interaction of the wheel with the road can occur due to different tire manufacturers. A further improvement of the automotive traffic can be achieved by use of tires by a single manufacturer. In this case, the traction difference could be reduced, due to non-uniform wear, down to 0.05 between the front and the rear axis on ice, down to 0.1 on snow, down to 0.1 on wet asphalt, and down to 0.15 on dry asphalt.

The derapage of a vehicle with a combination of different tires on the front and the rear axle is stipulated by early onset of wheel blocking of the rear axle wheels in respect to the front axle. Thereby, the lateral force leads to a drift of the rear axle. Thus, in order to prevent the derapage of the vehicle, it is important to strive for early front wheel blocking which is most difficult to realize in motor vehicles without automatic braking control, e.g., only with brake bias valves. It should be noted, that a braking action check should be carried out in full outfit when the blocking of the rear wheels is most probable. Driving with full payload forms big load on the vehicle axles preventing the blocking of the wheels, that is why we consider hereinafter only the travel parameters of vehicles in full outfit only for studies of emergency situations of derapage.

The author [20] has obtained for vehicles with such design dependencies for determining of the wheel blocking range reach time:
the magnitude of the required response time difference of the wheel brake system will, for this specific case, have
with the rear wheels with less traction, the response time of the wheel brake system shall be increased by 1.9, whereas at 0.3 traction
the front axle; G1 is the partial vehicle weight accommodated by the rear axle; k is the braking force distribution ration by the vehicle axes determined as follows:
\[
\frac{a}{L} + k = \varphi \frac{h}{L} + \varphi k \to k \left(1 + \varphi - \frac{a}{L}\right) \implies k = \frac{a-h}{L\left(1+\varphi-\frac{a}{L}\right)}
\]

Hence, considering the statutory limitation of the maximum duration of the deceleration growth in the brake mechanism, admissible limit values of B1 and B2 parameters can be obtained which represent the ratio of the pressure in the brake system of the front and rear wheels versus the brake force exerted on the respective wheels. The minimum values of these parameters can be determined based on the following equations:
\[
t_{12} = \frac{G_2 \varphi k}{B_1 \frac{1}{L} \varphi(1+k)K_0} \implies B_2 > \frac{G_2 k}{\varphi - \frac{h}{L}(1+k)K_0}
\]
\[
t_{11} = \frac{G_1 \varphi}{B_1 \frac{1}{L} \varphi(1+k)K_0} \implies t_{11} - t_{12} = \left(\frac{G_1}{B_1 \frac{1}{L} \varphi(1+k)K_0} - \frac{G_1}{B_1 \frac{1}{L} \varphi(1+k)K_0} \right)
\]
\[
t_{11} - t_{12} = \left(t_{11} - t_{12}\right) \left(\frac{1}{\varphi + \Delta \varphi} - \frac{h}{L}(1+k)K_0\right)
\]

That is, on dry asphalt, at 0.4 traction difference between the front and the rear wheels, with the rear wheels with less traction, the response time of the of the wheel brake system shall be increased by 1.9, whereas at 0.3 traction difference it should be increased by 1.6. On ice, at 0.19 traction difference between the front and the rear wheels, with the rear wheels with less traction, the response time of the wheel brake system shall be increased by 2.2, whereas at 0.13 traction difference it should be increased by 1.6. On snow and wet asphalt, at 0.3 traction difference between the front and the rear wheels, with the rear wheels with less traction, the response time of the wheel brake system shall be increased by 2.3, whereas at 0.2 traction difference it should be increased by 1.8. While using uniform tire model of a single manufacturer, the response time difference of the brake system would not exceed 1.3x on ice, 1.4x on snow, 1.3x on wet asphalt, and 1.3x on dry asphalt.

The necessity to ensure the stability of the vehicle under lateral acceleration leads to a necessity to consider that a part of the traction reserve of the wheels will be consumed by the compensation of the lateral force. Then, the magnitude of the required response time difference of the wheel brake system will, for this specific case, have the following appearance:
That is, on dry asphalt, at 0.4 traction difference between the front and the rear wheels, with the rear wheels with less traction, the response time of the wheel brake system at a lateral acceleration of 2.5 m/s² should be increased by 1.9, whereas at 0.3 traction difference it should be increased by 1.7. On snow and wet asphalt, at 0.3 traction difference between the front and the rear wheels, with the rear wheels with less traction, the response time of the wheel brake system shall be increased by 4, whereas at 0.2 traction difference it should be increased by 3. While using a uniform tire model of a single manufacturer, the response time difference of the brake system would not exceed 2x on snow, 1.3x on wet asphalt, and 1.3x on dry asphalt.

Considering that automotive vehicle designers envisage uniform tire having for even dry asphalt road conditions a response time of the wheel brakes equal to 0.5 s, then, combining of different tires will, for the time being, increase the response time of the brake system up to 0.8 s, whereas this value was equal to 1.0 s before 2010. Thus, a combination of tires with different traction between the front and the rear axle on dry asphalt will, for the time being, lead to an increase of the collision speed by 2.1 m/s (or 7.5 km/h), whereas, before 2010, this value was equal to 3.5 m/s (or 12.6 km/h).

Thereby, substituting in equation different traction difference values of the wheels, it was found out that the lateral acceleration does not essentially interfere this parameter.

Thus, the safety of the traffic in a vehicle with combined tire having for the front and the rear axle, as well as at driving in mixed cycle can only be provided for by incomplete use of the available brake force range. The influence of the traction difference between the wheels of the front and the rear axle of a vehicle on the accident rate of the automotive traffic can have the following appearance:

\[
U = \Psi U_\Sigma; \quad \Psi = 0.5 \left( 6 + \frac{3}{K\varphi} e^{3/2} \left( \frac{0.60 - 0.01}{K\varphi} \right)^{1.32} + \frac{0.94}{0.06 - 0.01} \right),
\]

where \(K\varphi\) is the utilization rate of the brake force equal to the ratio of the braking distance of the vehicle with different tiring of all the axles to the same vehicle with uniform tiring:

\[
K\varphi = \frac{S_0}{S_\Delta \varphi} = \left( \frac{1}{1 + \frac{2 \varphi \Delta t}{v}} \right),
\]

where \(\Delta t\) is the surplus time of the deceleration growth required to provide for stabilization of the vehicle with different tiring of the front and the rear axle.
Conclusions
The obtained results show unambiguous correlation of the reduction of traffic accidents by 3% from 2010 caused by motor vehicles combining different tire types on the front and the rear axle with the tightening of the requirements to the technical state of order of automotive vehicles participating in the motor traffic in terms of uniform tiring of the front and the rear axle. Additional measures of surveillance for prevention of non-uniform tiring of motor vehicles could reduce the number of traffic accidents by further 1%. Thereby, it will be the ultimate possible achievement in the traffic safety improvement since even tires of one batch have different wear after a certain operation period, stipulating a certain inevitable difference of traction between the wheels which could be compensated only by braking efficiency reduction by increased response time of the rear axle brakes.

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