A contribution to the issue of wheel base change of a motor vehicle during its modification for increased automotive traffic safety

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Abstract. The paper presents a study of the change of the transient duration, of the control sensitivity of the vehicle, of the gain and the response delay of N1 Cat. cargo vehicle at instant and harmonic steering control action. The changes are caused by vehicle modification via wheel base length extension. The wheel vehicle is represented by a flat single-mass calculation model. Based on the conducted calculation, additional influence of the driving speed as a risk factor has been revealed. In the summary of the paper, a conclusion is made on the presence of the influence of the vehicle wheel base length change on the automotive traffic safety.

1. Introduction and relevance
The relevance of the mortality and the injury rate reduction among motor traffic participants can scarcely be overestimated. The World Health Organization reports annually over a million casualties on the motor roads of our planet, whereas several dozens of million people get injuries of different severity within the same period. For Russia, this situation remains in the high level of tension, being of high socio-economic importance. For the time being, widely used are motor vehicles with design modifications undertaken by their owners which, in day-to-day intended operation, exert their influence on the automotive traffic safety along with the standard motor vehicles. One of the main risk factors considerably influencing the consequences of traffic accidents is the driving speed of wheel type vehicles which is limited both by the traffic rules, and by the vehicle manufacturer. Usually, design modifications of a vehicle leave unchanged its speed limit, whereas the modification proper is not considered as a reason for conscious speed reduction.

In the course of time, the popularity of modifications to vehicle designs is growing every year. So, in the Russian Federation, within the three years from 2015 to 2017, the number of modifications has grown more than by 10 times, from 29432 to 307882 cases [1]. Thereby, this trend is very dynamical. The absolute leader among the vehicle modification types is currently the replacement of the normally carried fuel system of the internal combustion engine. During the three indicated years, the number of such modifications has grown more than thrice, whereas the percentage has grown from 23.4% to 77.6%. Along with that, as experience shows, widely used is also such type of vehicle modification at which the wheel base length of the vehicle is changed (mostly extended). Based on authors' data, the number
of such modifications makes up to 15% of the total number of modifications. Hereinafter, we study the influence of the modified wheel base length on the controllability of the vehicle, that is, on the safety of the automotive traffic.

2. Theoretical research
For a preliminary analysis, we take the well-studied flat single-mass linear calculation motor vehicle model [2]. This model is limited in its use, nevertheless, it has a big advantage of simplicity and possibility of an analytical solution. For the evaluation of the influence of the undertaken design modification of the vehicle, we consider two cases of the control action (instant steering wheel turning by a certain angle and harmonic steering wheel manipulation). During modeling of the locomotion processes of the vehicle, the following was assumed: the vehicle has understeer, the driving speed is constant, the wheel slipper is linear. The applicability of the model was monitored by measurement of the wheel slipper angles, the turning angle of the steering wheel, and their non-exceeding of the admissible limits, as well as by calculation of the specific lateral load and its comparison with the admissible value. During the calculations, specifications of a N1 Category cargo motor vehicle were used for the case of the gross laden weight.

"Instant turn of steering wheel". In this case, we have evaluated the duration of the transient \( (t_{p}) \), caused by the vehicle steering control action of the driver and the dynamic response of the vehicle to the control \( (\mu_d) \). The specified parameters characterize the controllability of the vehicle as control object.

![Figure 1. Influence of vehicle wheel base on transient duration at different driving speeds](image1.png)

It is evident from the graphs in Figure 1 that a longer wheel base will lead to the transient duration growth affecting the vehicle controllability. The increasing of the driving speed also leads to the transient duration growth which is more intensively displayed at long wheel bases.

The dynamic steering sensitivity (see figure 2) characterizing the vehicle locomotion curvature change determined with the classic method [3], gets back in a non-linear manner with the growing wheel base also affecting negatively the controllability of the vehicle. The highest reduction of the sensitivity is observed at high speeds.
Further, we conducted a calculation of the dynamic sensitivity change at extension of the vehicle wheel base by 20%, 40%, 60%, 80%, and 100% which is vastly popular in the modifications of N1 Cat. motor vehicles. The calculation results are depicted graphically in Figure 3. It is evident in the Figure that the dependency is non-linear, thereby, the extension of the wheel base by 100%, that is, when it is doubled, the steering sensitivity of the vehicle is reduced by a half. The driving speed of the wheel type vehicle affects the steering sensitivity only insignificantly. This feature is a consequence of the fact that the center of gravity of the vehicle at full weight is located near the neutral steer point, at vehicle's outfit weight, the configuration will change slightly, and the speed factor will get more distinct. As for the transient duration, the doubled wheel base length will lead to a 10% longer transient process. Thus, for typical control action, the instant steering wheel turn by a certain angle one could conclude that the extension of the wheel base of the vehicle during its modification affects the controllability of the vehicle, thereby, this influence also depends on the driving speed.

"Harmonic steering action". Specific for such steering control action are amplitude vs. frequency and phase vs. frequency curves [4] determining the ratio of the output value amplitude (angular speed of the vehicle) to the amplitude of the input value (turn angle of the steered wheels) and, respectively, the delay of the output signal versus the input signal in the control frequency. The most typical frequency is 0.75 Hz. That is why we conducted calculations of the changes of such curves with the change of the wheel base.
base of a motor vehicle in 0.75 Hz frequency. Fig. 4 shows the dependency of the change rate of the output signal to the input signal (vehicle gain) in the specified frequency versus wheel base length.

![Amplitude-frequency response](image)

**Figure 4.** Vehicle gain change in fixed control frequency versus wheel base length

It is evident in the figure that the extension of the wheel base length is followed by a monotonous decrease of the vehicle gain. Thus, in identical driving conditions, a longer wheel base will be followed by a less angular speed of vehicle turning, consequently, by a less course angle affecting the maneuverability of the modified vehicle. The influence of the driving speed is only feebly marked within practically reasonable extension of the wheel base length. At decreased control frequency, this influence grows, and at increased frequency it goes down.

Figure 5 shows the dependency of the angular turning speed lag of the vehicle versus turning angle of the steered wheels in a typical control frequency. In the present case, for a practical modification range, the extension of the wheel base length will also lead to the growth of the vehicle lag. It also affects to a certain extent the maneuverability of the modified vehicle.

![Phase frequency response](image)

**Figure 5.** Vehicle lag change in fixed control frequency versus wheel base length
3. Results and conclusions

The conducted preliminary analysis of the influence of the wheel base length extension during the modification of the vehicle design demonstrates the following results. Firstly, the duration of the transient process gets longer, thus affecting the response of the vehicle as a control object, consequently, the control behavior of the motor vehicle worsens. Secondly, the dynamic steering sensitivity of the motor vehicle goes back also affecting the controllability of the vehicle. Thirdly, the vehicle control gain is decreased, and the response lag of the vehicle grows which also scarcely improves the controllability. Thereby, in many cases, the driving speed as a risk factor completes the overall worsening of the controllability of the vehicle.

Thus, for adequate automotive traffic safety, it is important to know the acceptable modifying range of vehicle's controllability due to the intended modification, as well as to additionally limit the admissible driving speed of the vehicle as required, to neutralize the pertaining risk factor.

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