Study of braking performance of M1 category vehicles within autotechnical expertise

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Abstract. The paper presents experimental results related to the study of braking parameters, namely the mean fully developed deceleration and its response time formed due to vehicle loading, presence (absence) of ABS and a trailer, type and condition of a road pavement, as well as due to vehicle-road adhesion – a tire and its seasonal type. It describes the mathematical models defining the studied values. Is also justifies the advisability of specifying the traffic accident reconstruction method by introducing the adjusting factors \( K_{dd} \) and \( K_t \) into the main estimated dependences to increase the reliability and objectivity of conclusions during traffic expertise.

1. Introduction

At present, Russian expert autotechnicians use methods of traffic accident (TA) reconstruction and expertise that were established over 30 years ago, which does not correspond to design features of modern vehicle and road conditions. The degree of culpability of a party involved in a traffic collision or even a more relevant problem of today – compensation for material damage to road users fully depends on the accuracy of settlements and reliability of expert findings. Since it is critical for experts to find a technical ability of a driver to avoid road accident, then all settlements within traffic accident reconstruction are reduced to defining the speed of a motor vehicle (MV) during a traffic accident. Knowing the MV traffic speed, an expert is able to calculate the MV stopping and braking distance and define the distance of the MV moving from the place of traffic accident. The critical parameters of such calculations include the mean fully developed deceleration and time of its increase during the MV emergency brake [1-6].

Currently, the experts utilize several options to choose the given values during traffic accident reconstruction:

- full-scale experiment using accepted tools in the conditions equal to a traffic accident;
- values recommended by the Technical Regulations of the Customs Union 018/2011 On safety of wheeled vehicles [15];
- average values contained in methodical recommendations of the Russian Federal Center of Judicial Examination (RFCJE) for vehicles manufactured before 1981 and later [6, 13].

The issue of applying the standard values of the mean fully developed deceleration and time of its increase, currently used in expert practice, is particularly relevant due to qualitative and quantitative changes of a vehicle fleet in the Russian Federation [2, 3].

The purpose of the experimental study was to find the dependence between factors and measured values of the mean fully developed deceleration and time of its increase and to obtain adequate mathematical models ensuring the modeling of the given values during traffic accident expertise.
2. Materials and methods

The analysis of literature sources [5, 6, 13, etc.] and works of modern researchers [4, 7, 10, 12, 14] made it possible to identify the most important and earlier not studied factors influencing the mean fully developed deceleration and time of its increase. Using a priory ranking method the authors defined the influence of the most critical factors on these values, such as: type and condition of a road pavement, seasonal type of tires, presence of the anti-lock braking system (ABS), MV loading and availability of a trailer. The expert survey was done by competent experts, and with 95% reliability it is possible to confirm that their opinions (Fig. 1) concerning the degree of influence of the studied factors appear to be in agreement with the concordance coefficient $W=0.71$ [2, 3].

![Figure 1. Rank diagram](image)

The StatGraphics statistics package was used to design the experiment, process the source data and analyze the obtained results [8].

The experiment was conducted during daylight in St. Petersburg at the section of the city highway. The road section had even asphalt pavement. The most frequently used in Russia M1 category vehicles with efficient brake system, such as Volkswagen Polo, Lada Granta, VAZ 21150, VAZ 2121 and Chevrolet Klan, as well as LAV 81011 trailer were involved in the study [11].

The Effect-02 inspection gage of Meta Company provided by Passazhiravtotrans was used to register the mean fully developed deceleration and time of its increase taking into account its modification in the form of a carrier [16, 17].

The entire experiment was carried out in two stages – ‘spring-summer’ and ‘fall-winter’ periods with different temperature modes and conditions.

The full factorial experiment (FFE) of the $2^4$ type ‘fall-winter’ (f-w) for the required parameters $y_{f-w}$ – mean fully developed deceleration and $y_{t(f-w)}$ – time of increase in the mean fully developed deceleration considered the following factors: $x_1(A)$ – pavement type and road condition (adhesion coefficient); $x_2(B)$ – seasonal type of tires; $x_3(C)$ – presence (absence) of ABS; $x_4(D)$ – MV loading.

The analysis of the obtained experimental data resulted in adequate mathematical models for the required parameters presented in Tab. 1.

The experimental data also made it possible to analyze the influence of factors on the studied values and to compare the experimental and recommended values. Figures 2, 3, 4 show the example of such comparative analysis.
Table 1. Mathematical models for mean fully developed deceleration and time of its increase in fall-winter conditions

| Measurement settings                                      | Regression equations, $y=f(x)$                                      | Determination coefficient, $R^2$ |
|----------------------------------------------------------|----------------------------------------------------------------------|----------------------------------|
| 1. MV mean fully developed deceleration in fall-winter conditions | $y_{(f-w)} = 3.37048 + 0.885714x_1 + 0.406536x_2 + 0.758857x_3 + 0.1985x_1x_3 - 0.140333x_1x_4 - 0.74975x_1(x_3)^2 - 0.95175x_1(x_3)^2$ | 91.2%                           |
| 2. Time of increase in MV mean fully developed deceleration in fall-winter conditions | $y_{(f-w)} = 0.156262 + 0.0487381x_1 + 0.02625x_2 + 0.0112619x_3 + 0.01125x_2x_3 + 0.002x_1x_3 - 0.02275(x_3)^2 + 0.00875x_2x_3 - 0.02975x_1(x_3)^2 - 0.0015x_1x_2x_3$ | 99.7%                           |

Figure 2. Comparative analysis of experimental and recommended average values of RFCJE and TR 018/2011 with 20% (driver) loading of a vehicle with all-season tires and without the ABS

Figure 3. Comparative analysis of experimental and recommended average values of RFCJE and TR 018/2011 with 20% (driver) loading of a vehicle with spiked tires and the ABS
Figure 4. Comparative analysis of experimental and recommended average values of RFCJE and TR 018/2011 with 20% (driver) loading of a vehicle with friction tires and the ABS

The analysis shows that the difference in values makes over 30% on average, hence, the difference in the expert’s conclusions, for example, regarding the MV speed at the time of traffic accident, may differ within the same range, namely it may be deliberately underestimated thus leading to poor reliability of the studied issue during traffic accident reconstruction.

Thus, the analysis of obtained experimental results made it possible for the authors to confirm the advisability of introducing $K_{j_{dd}}$ and $K_{t}$, which adjust the mean fully developed deceleration and time of its increase taking into account the studied factors, into the main estimated dependences used by expert autotechnicians in traffic accident expertise [1, 2, 3].

Tables 2, 3 show the examples of average adjusting factors of the mean fully developed deceleration $K_{j_{dd}}$ and time of its increase $K_{t}$ for M1 category vehicles.

Table 2. $K_{j_{dd}}$ adjusting the mean fully developed deceleration of M1 category vehicles at 20% loading

| Seasonal type of tire | Adhesion coefficient ($\varphi$) | 0.75 | 0.45 | 0.25 | 0.15 |
|-----------------------|--------------------------------|------|------|------|------|
|                       |                                |      |      |      |      |
|                       | ABS                            |      |      |      |      |
| all-season tire       | 1.0                            | 1.4  | 0.75 | 2.28 |
| friction tire         | 0.84                           | 1.23 | 2.01 | 2.96 |
| spiked tire           | 0.89                           | 1.18 | 1.15 | 3.01 |
|                       | ABS-free                       |      |      |      |      |
| all-season tire       | 0.91                           | 1.27 | 0.7  | 2.24 |
| friction tire         | 0.9                            | 1.17 | 1.06 | 2.28 |
| spiked tire           | 0.85                           | 1.15 | 1.02 | 2.43 |
Table 3. $K_t$, adjusting the mean fully developed deceleration of M1 category vehicles at 20% loading

| Seasonal type of tire | $K_t$ | $\phi$ | $K_t$ | $\phi$ | $K_t$ | $\phi$ | $K_t$ | $\phi$ |
|-----------------------|-------|--------|-------|--------|-------|--------|-------|--------|
|                       |       | 0.75   |       | 0.45   |       | 0.25   |       | 0.15   |
| all-season tire       | 0.9   | 1.16   | 0.8   | 2.0    | 0.9   | 1.08   | 0.8   | 3.0    |
| friction tire         | 0.85  | 1.08   | 1.5   | 2.4    | 0.9   | 1.08   | 0.8   | 3.0    |
| spiked tire           | 0.9   | 1.07   | 0.7   | 2.0    | 0.9   | 1.0    | 1.3   | 2.0    |
| ABS-free              | 0.85  | 1.0    | 1.13  | 2.2    |

3. Conclusions
The study confirmed the influence of the above-mentioned factors on the mean fully developed deceleration and time of its increase. It also made it possible to develop the mathematical models to define the studied values contributing to accuracy and reliability of traffic accident expertise involving M1 category vehicles. Besides, it proposed to specify the traffic accident reconstruction method according to braking parameters by adjusting the standard mean fully developed deceleration and time of its increase and their introduction to the main estimated dependences of the MV speed, stopping and braking distance, as well as the distance from the accident as such. In general, it was possible to make a more accurate and reliable conclusion on the driver’s technical ability to prevent traffic accidents.

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