Experimental study and evaluation of parameters of M¹ vehicle braking process

A S Afanasyev¹, N V Chudakova²
Saint-Petersburg Mining University, 21 Line, St. Petersburg, Russia, 199106
E-mail:¹a.s.afanasev@mail.ru,²chudakova00@gmail.com

Abstract. The article presents the results of experimental studies of the braking process parameters, namely, the values of steady-state deceleration and its rise time, formed from the actual load of a vehicle, the presence (absence) of the anti-lock brake system (ABS) and trailer, the type and condition of road surface, as well as the connecting element between a vehicle and road surface - tires and the type of seasonality depending on the meteorological conditions. The mathematical models defining the studied value are presented and their practical significance is described. The practicability of the clarification of the methodology for the simulation of road traffic accidents by means of introducing correction factors into the main calculation methods aimed at the increase of the reliability and objectivity of the findings during road-transport expertise was justified.

1. Introduction

Accident on road transport is an urgent problem of our country, since about 36 thousand people die on roads annually, 98 people daily, and 4 people of working age die every hour [11].

In this regard, in the Russian Federation there are the Federal Target Program “Improvement of road safety in 2013-2020” and the Road Safety Strategy for 2018-2024, implementing measures leading to zero road mortality [14, 18].

One of such measures to ensure road traffic safety (RTS) is the study of the causes of road traffic accidents (RTA). Experts deal with this issue during auto-technical expertise. In particular, it allows investigating and answering the questions about whether or not a driver has the technical ability to prevent accidents and whether his actions correspond to the requirements of the traffic regulations of the Russian Federation at the time before and the beginning of an accident [6, 15].

Nowadays in the existing expert practice, there are a number of significant disadvantages in the calculation methods, taking into account the parameters of vehicle braking process of M¹ category, in particular the steady deceleration of a vehicle and its rise time at the time of emergency braking.

Nowadays experts have several options for choosing the values for the simulation and examination of accidents:
- Carrying out a full-scale experiment using a certified instrument and measuring device under conditions equal to those under which an accident occurred. [6];
- Use of the recommended values of the Regulation of vehicles 018/2011 “On the safety of wheeled vehicles” [17];
Application of the averaged values presented in the guidelines of the Russian Federal Center for Forensic Examination (RFCFE) for vehicles produced before 1981 and after, developed by All-Russian scientific research institute of judicial investigation more than 40 years ago [5, 15].

The question of the application of the normative (averaged) values of the steady deceleration of a vehicle and the time of its rise, which are currently used in expert practice, is extremely relevant in connection with the qualitative and quantitative change in vehicle fleet of the Russian Federation [12].

The purpose of the experimental study was to establish the relation between the factors and measured values of the steady-state deceleration and the time of its rise, as well as to obtain adequate mathematical models to simulate the values during the examination of road accidents [1-3, 21].

2. Materials and methods

The most important factors that have not been studied previously, influencing the formation of steady-state deceleration values and its rise time were determined on the basis of the analysis of literary sources [5, 6, 15] and the works of modern researchers [4, 7, 10, 13, 16, 22]. Using an a priori ranking method, the authors determined the influence of the most significant factors on these values, such as: the actual load on a vehicle, the presence (absence) of the anti-lock braking system and trailer, the type and condition of road surface, and the seasonality of tires depending on meteorological conditions. The experts competent in this field of knowledge participated in this research and with 95% confidence it can be argued that their opinions (Fig. 1) regarding the degree of influence of the studied factors correspond to the concordance coefficient $W = 0.71$ [2, 3].

The development of the planned experiment, the processing of the initial data and the analysis of the results obtained in this work were carried out using the statistical package StatGraphics [8, 21].

Experimental studies were conducted during daylight hours in St. Petersburg on the area of the city highway. The road section had a flat asphalt concrete pavement. The experiments involved the most popular vehicles of category M1 in the Russian Federation with active braking system, such as Volkswagen Polo, Lada Granta, VAZ 21150, VAZ 2121 and Chevrolet Klan, as well as the LAV 81011 trailer [12].

For fixing the values of steady-state deceleration and the time of its rise, “Effect-02” the attested measuring instrument of “Meta” research-production company, provided by SUE SPb “Passazhiravtotrans” was used, taking into account modifications in the form of fastening devices [9, 19, 20].

![Figure 1. Rank diagram](image-url)
The experiment consisted of two stages - the period “spring-summer” and “autumn-winter” with different temperature modes and conditions.

In order to ensure the adequacy of the description of the regression models, the experiment was divided into 2 samples depending on the road and meteorological conditions and year season, namely “spring-summer” and “autumn-winter”. In each sample, a full-factor experiment (FFE) of 2⁴ type - “autumn-winter” and 2⁵ - “spring-summer” was conducted for the input parameters of the steady-state deceleration \( y_{sd} \) and for the time of its rise \( y_{r} \).

According to the results of the mathematical processing of the experiment, the mathematical models of the values of the steady-state deceleration and the time of its rise were determined, due to which it was possible to calculate these values for a specific vehicle of M category, presented in Table 1.

Table 1. Mathematical models for the parameters of the steady-state deceleration of a vehicle and the time of its rise in the “autumn–winter” and “spring-summer” period

| Measurement                                      | Regression equation, \( y=f(x) \)                                                                 | Determination coefficient, \( R^2 \) |
|-------------------------------------------------|-----------------------------------------------------------------------------------------------|----------------------------------------|
| Steady-state deceleration \( y_{sd} \) of M category and the time of its rise \( y_{r} \) in the “autumn-winter” period | \( y_{sd(w)} = 3.37048 + 0.885714x_1 + 0.406536x_2 + 0.758857x_1x_3 - 0.1985x_1x_2 - 0.140333x_1x_4 - 0.74975(x_3)^2 - 0.95175x_4(x_2)^2 \) | 91.2 %                                   |
|                                                 | \( y_{r(w)} = 0.156262 + 0.0487381x_1 + 0.02625x_2 + 0.0112619x_3 - 0.00288889x_4 + 0.01125x_1x_2 + 0.002x_1x_3 - 0.02275(x_2)^2 + 0.00875x_2x_3 - 0.02975x_4(x_2)^2 - 0.0015x_1x_2x_3 \) | 99.7 %                                   |
| Steady-state deceleration \( y_{sd} \) of M category and the time of its rise \( y_{r} \) in the “spring-summer” period   | \( y_{sd(sp)} = 5.60057 + 0.666579x_2 + 0.208489x_3 + 0.320513x_1x_2 + 0.0695625x_1x_4 + 0.5036875x_1x_3 + 0.477422(x_2)^2 - 0.112763x_2x_3 + 0.106088x_2x_4 + 0.0601875x_1x_2x_3 + 0.102232(x_2)^2 - 0.195328x_1(x_2)^2 + 0.0672657x_2x_3x_4 + 0.225684x_1x_2x_3 - 0.268542(x_2)^2 \) | 93.2 %                                   |
|                                                 | \( y_{r(sp)} = 0.274783 + 0.0262522x_1 + 0.0169398x_2 + 0.0058861x_3 - 0.0046875x_4 + 0.0024442x_5 - 0.0106125x_1x_2 - 0.0038125x_1x_3 + 0.001375x_1x_4 + 0.0144844(x_2)^2 - 0.0001125x_2x_3 - 0.0001875x_2x_4 - 0.00660937x_3(x_2)^2 - 0.00515937x_3x_2x_3 - 0.007125x_3x_2x_4 - 0.00139688x_4x_3x_4 + 0.00125x_1x_3x_4 - 0.00514687x_2x_3x_4 \) | 97.7 %                                   |

The practical significance of these models is in their use when measurements of steady-state deceleration and the time of its rise using a measuring instrument are not possible.

On the basis of the experimental data, the analysis of the influence of factors on investigated values was made, and the comparative analysis between the experimental and recommended values was carried out. The example of a comparative analysis is presented in Figures 2, 3, 4.
Figure 2. Comparative analysis of experimental and normative (averaged) values of steady-state deceleration at $\varphi \approx 0.75$ and the presence of the ABS system. Here and after RoV stands for Regulation of the vehicles (Russian standard), ARSRUIJ stands for All-Russian scientific research institute of judicial investigation.

Figure 3. Comparative analysis of experimental and normative (averaged) values of steady-state deceleration at $\varphi \approx 0.25$ and the presence of the ABS system.
Figure 4. Comparative analysis of experimental and normative (averaged) values of steady-state deceleration at $\varphi \approx 0.75$ and the presence of the ABS system and a trailer with 250 kg actual load

According to the analysis it can be seen that the difference in values is on average more than 36%, therefore, the difference in the conclusions of experts, for example, a vehicle speed at the time of an accident, may differ in the same range, namely, it is deliberately underestimated or overestimated, which leads to the lack of credibility of the investigated issue and the determination of the real cause of an accident in the production of automotive technical expertise.

Thus, in the course of the analysis of the experimental results, the authors justified the practicability of introducing the $K_{jsd}$ and $K_{tr}$ coefficients correcting the value of the steady-state deceleration and its rise time, taking into account the investigated factors of the main calculated dependencies used by automotive experts during the examination of an accident [1-3].

The examples of averaged correction factors of the steady-state deceleration $K_{jsd}$ and the time of its rise $K_{tr}$ for vehicles of M$^1$ category are presented in Table 2 and 3.

Table 2. $K_{jsd}$ coefficient correcting steady-state deceleration of a vehicle M$^1$ category at 20% load

| Season tire type | Type and condition of road surface / friction coefficient ($\varphi$) | Dry asphalt/0.75 | Wet asphalt/0.45 | Asphalt, covered with snow/0.25 | Asphalt, covered with ice/0.15 |
|------------------|-------------------------------------------------|-----------------|-----------------|------------------|------------------|
|                  | with ABS                                         |                 |                 |                  |                  |
| Summer           | 1.2                                              | 1.7             | -               |                  |                  |
| All-season       | 1.0                                              | 1.4             | 0.8             | 2.1              |                  |
| Frictional       | 0.9                                              | 1.2             | 2.0             | 2.7              |                  |
| Spiked           | 0.9                                              | 1.2             | 1.2             | 2.7              |                  |
|                  | without ABS                                      |                 |                 |                  |                  |
| Summer           | 1.2                                              | 1.7             | -               |                  |                  |
| All-season       | 0.9                                              | 1.3             | 0.7             | 2.0              |                  |
| Frictional       | 0.9                                              | 1.2             | 1.1             | 2.1              |                  |
| Spiked           | 0.9                                              | 1.2             | 1.0             | 2.2              |
Table 3. $K_t$ coefficient correcting rise time of steady-state deceleration of vehicle of M1 category at 20% load

| Season tire type | Type and condition of road surface / friction coefficient (Φ) | Correcting coefficient of rise time of steady-state deceleration $K_{t_{vp}}$ |
|------------------|-------------------------------------------------------------|--------------------------------------------------------------------------------|
|                  | Dry asphalt 0.75 / Wet asphalt 0.45 / Asphalt, covered with snow 0.25 / Asphalt, covered with ice 0.15 |                                                                      |
|                  | with ABS                                                      |                                                                              |
| Summer           | 1.0                                                         | 1.2                                                                         |
| All-season       | 0.9                                                         | 1.2                                                                         |
| Frictional       | 0.9                                                         | 1.1                                                                         |
| Spiked           | 0.9                                                         | 1.1                                                                         |
|                  | without ABS                                                  |                                                                              |
| Summer           | 1.0                                                         | 1.2                                                                         |
| All-season       | 0.9                                                         | 1.1                                                                         |
| Frictional       | 0.9                                                         | 1.0                                                                         |
| Spiked           | 0.9                                                         | 1.0                                                                         |

3. Conclusion
In the course of the research, with the help of a comparative analysis of the normative (averaged) and experimental values, the complex effect of the factors influencing the formation of the values on the steady-state of a vehicle and the time of its rise was justified. The mathematical models were developed that allow determining the predicted values, in the case when conducting a full-scale experiment using a vehicle of M1 category is not possible. The corrective factors of steady-state deceleration and the time of its rise were determined, with the help of which it was proposed to clarify the calculation methods for the reproduction of accidents in the study of the technical possibility to prevent a driver from accidents and to establish compliance with the traffic regulations of the Russian Federation. The experimental study, which allows clarifying the calculation methods for the reconstruction of accidents, allows specialists establishing the real causes of the road traffic situation, as well as to improve the reliability of the expert opinion on auto-technical expertise.

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