Influence of Road Conditions on Traffic Safety
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Abstract
We consider estimation of the impact of road conditions on traffic safety on the basis of the theory of the interaction of the driver with traffic environment. It is shown that the number of accidents is influenced by factors related to the environment, traffic, road users and the vehicle. The mismatch between the Therefore, when addressing the issue of improving traffic safety, it is necessary to pay attention to research methods, studying the patterns of behavior of the driver and allows to assess the impact of road conditions on the probability of an accident. On the basis of the conducted studies was established the relationship between the elements of road conditions and indicators of the functional status of the driver. Optimal speed for various road conditions is established. The optimality criterion is the reliability of the driver’s activity. The obtained results are the basis for the development of measures aimed at optimizing the elements of the environment movement, as well as practical methods of assessing damage from an accident in a changing operating conditions.

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Keywords: road; road conditions; traffic safety; traffic accident; throughput; speed; traffic flow.

1. Introduction

Road safety involves the quality of the road defined by the level of accidents and reflecting the degree of safety of traffic participants from road traffic accidents and their consequences. On the other hand, road safety can be understood as the result of the safe interaction of participants of traffic between themselves and the environment. Therefore, when assessing the safety of traffic on the roads you need to take into account the physiological and psychological capabilities of the driver.

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Numerous studies (Лобанов 1980; Селюков 1997; Чванов 2004) have proved that human factors can improve the efficiency of the transport process by 25–30% in 2–3 times to reduce the number of traffic accidents on highways. The development of methods for system design of highways (Гаврилов 1988) created objective conditions for the development of a new concept for the evaluation of traffic safety on the roads, in which the road is understood as the logical basis of the driver’s activity (Гаврилов 1988).

Analysis of the interaction between elements of the system “driver–vehicle–road–traffic environment” and study their mutual influence help to develop methods of optimization factors of road environment and traffic as well as get solutions that meet the requirements of the safety and comfort of movement.

The basis of the existing theories of the interaction between the car and the road is dominated by the kinematics and dynamics of a material point. However, in accordance with modern international trends, aspects of the study of industrial processes, one of which is the movement of the vehicle on the road, should include the human factor. Scientific direction, analyzing the interaction of the “road conditions” – “traffic flows” with the participation of the driver, isn’t developed deeply enough, therefore there is a need for a more thorough and detailed study in relation to problems of road safety. However, the development objective of robust indicators of traffic safety will provide an opportunity not only significantly extend the range of activities they provide, but also to estimate the new position of the design decisions and the level of traffic safety on existing roads, and to outline measures to improve it.

Therefore, the main aim of this work is to study the impact of road conditions on the indices of the functional state of the driver, which allows to assess the degree of accident risk road sections as during the operational phase and the design phase.

2. The main provisions of the interaction of the driver with traffic environment

Ergonomic assessment of the traffic conditions on the road is based on the theory of the interaction of the driver with traffic environment. The effect of the environment movement in the 90% is for informational purposes (Гаврилов 1976). The information means different kind of data, information obtained through observation or study. Information about the system “river–vehicle–road–traffic environment” limited knowledge of the technical parameters of the road and its operational characteristics. Bearers of abstract information, which uses the driver to focus on the carriageway of the road, are the angular speed of the driver and of the vehicle relative to the elements, road conditions, distance to the edge of the roadway (Гаврилов 1976; Гаврилов et al. 1988). The main result of the activity of the driver’s speed and trajectory of the vehicle. Changing speed and trajectory of the vehicle, the driver modifies the angular velocity of the object, thereby counteracts information action environment. In these processes is the essence of the interaction of the driver with traffic environment.

It is obvious that the movement of the vehicle is the result of subjective purposeful activity of the driver. Interacting with the environment movement, the driver implements the principles of their behavior due to the choice of driving modes. Thus, from the standpoint of traffic safety interaction of its members among themselves and with the traffic environment can be evaluated:

- the degree of complexity;
- level of organization;
- indices of the interaction of the driver with traffic environment.

The degree of complexity and interaction between the members of the movement with the traffic environment can be evaluated by functional state in which the driver while driving. The elements of the environment movement, forming an information driver download, affect its functional state, which in turn is an indicator of the reliability of the driver’s activity. Both low and very high level of information load driver lead to errors and emergencies. Optimal and, therefore, the safe should be considered the traffic environment, which provides the movement with optimal speed.

3. The model of interaction of the driver with traffic environment

The criteria environment movement ergonomic requirements is the normal functioning of the mechanisms of adaptation of the driver to the conditions of the activity. The purpose of the environment movement should be
directed at maximizing the reliability of the driver’s activity while reducing the cost of its abstract labour, that is, realization of the principle of least interaction of the driver with traffic environment.

According to research Gavrilova E. S., Golovanenko N. S. (Голованенко 1983) energy costs for managing the activities of the driver estimated by the shift state of the physiological systems of the body, which leads to a change in the quality of the driver’s activity. The indicators of the functional status of the body that allow us to judge the strength of his work, is the shift of tension and energy costs when moving relative to their background values (Голованенко 1983):

\[ \Delta \Phi_r = \frac{r - r_0}{r_0}; \]
\[ \Delta \Phi_\theta = \frac{\theta - \theta_0}{\theta_0}, \] (1)

where \( r, r_0 \) – is the heart rate of the driver when driving on the road and in the background state; \( \theta, \theta_0 \) – energy expenditure of the body of the driver when driving on the road and in the background state determined (Гаврилов 1976):

\[ \theta = 0.075S \cdot (C - C_0); \]
\[ \theta_0 = 0.075S \cdot C_0, \] (2)

where \( S \) – is the area of the body of the driver, \( m^2 \); \( C, C_0 \) – is the respiratory rate when moving in the background state, respectively, the cycle/min.

Thus, the shift nonspecific tension is determined by the frequency shift of the heart rate of the driver, the shift of the energy expenditure of the body – the frequency shift of breath. The research of Gavrilova E. S., Golovanenko N. S. has established that the frequency shift of the heart rate and the frequency shift of breath is related to a linear dependence of the form (Голованенко 1983):

\[ \Delta \Phi_\theta = a \cdot \Delta \Phi_r, \] (3)

where \( a \) – is the coefficient of proportionality.

The experimental data obtained Golovanenko N. S. (Голованенко 1983), allowed us to confirm that this dependence is linear and can be represented as:

\[ \Delta \Phi_\theta = 0.275 + 0.5454 \Delta \Phi_r. \] (4)

For quantitative assessment of functional state of the driver and the parameters of its interaction with the environment movement will use the indicator unit cost of abstract labor of the driver determined by the dependence (Голованенко 1983):

\[ Y = \frac{U}{W}, \] (5)

where \( U \) – is a mental coercion of the driver, which is a function of psychic energy cost of movement; \( W \) – the performance of the driver.

Mental compulsion \( (U) \) is formed motivational forces and can be estimated by the formula (Гаврилов 1990):

\[ U = \int M d\Pi = \frac{1}{2} \left[ m_0 \left( V_x - V_{x_0} \right)^2 + m_r \left( V_x - V_{x_0} \right)^2 \right]. \] (6)
where $M$ – is the power of motive; $II$ – is the need; $m_{z}, m_{c}$ – the rigidity of the motives driving safety and freedom of action accordingly; $V_{z}$ – set speed of the vehicle; $V_{n2}, V_{n3}$ – the rules of the speeds at which the force of the motives of security and freedom of action equal to zero.

The performance of the driver is defined as:

$$W = P_{v} V_{z},$$

(7)

where $P_{v}$ – is the probability of retention specified speed determined (Гаврилов 1990):

$$P_{v} = 1 \quad \text{at} \quad V_{z} < V_{0};$$
$$P_{v} = 1 - \gamma_{\beta}(V_{z} - V_{0})^{\beta_{1}} \quad \text{at} \quad V_{0} < V_{z} < V_{no};$$
$$P_{v} = 1 - \gamma_{\beta}'(V_{z} - V_{0})^{\beta_{2}}(V_{z} - V_{n3}) \quad \text{at} \quad V_{no} < V_{z} < V_{n2};$$
$$P_{v} = 1 - \gamma_{\beta}(V_{z} - V_{n3}) - \gamma_{\beta}(V_{z} - V_{n2})^{\beta_{2}} \quad \text{at} \quad V_{n2} < V_{z} < V_{n3};$$
$$P_{v} = 1 - \gamma_{\beta}(V_{z} - V_{n2})^{\beta_{2}} \quad \text{at} \quad V_{n3} < V_{z} < V_{n};$$
$$P_{v} = 0 \quad \text{at} \quad V_{z} > V_{n};$$

(8)

$$\gamma_{\beta} = \frac{1}{(V_{n} - V_{n2})^{\beta_{2}}};$$
$$\gamma_{\beta}' = \frac{1}{V_{n3} - V_{no}};$$
$$\gamma_{\beta} = \frac{1}{(V_{k} - V_{0})^{\beta_{1}}};$$

(9)

$$V_{k} = V_{n2} \quad \text{at} \quad V_{no} < V_{n2};$$
$$V_{k} = V_{n2} \quad \text{at} \quad V_{no} > V_{n2};$$
$$V_{0} = V_{n3};$$
$$V_{no} = V_{n3} - \frac{V_{n3}^{2}}{H_{m0} - 36};$$

(10)

$$\beta_{1} = 15.066e^{-0.025(H_{m0} - 36)};$$
$$\beta_{2} = 1+1.47694e^{-0.0124(H_{m0} - 36)};$$

(11)

where $V_{n2}, V_{n3}, V_{n}$ – is the norm of the velocities for security reasons, freedom of action and the maximum permissible speed indicators driver; $V_{z}$ – set (calculated) the speed of the vehicle; $H_{m0}$ – the maximum entropy field of perception of the driver when the load factor of the road traffic equal to zero.

Assume that the unit labor costs of the driver associated with the frequency shift of the heart rate dependence of the form:

$$Y = \alpha \cdot \Delta \phi_{z}.$$

(12)

Processing of the results of the experiment (Fig. 1) has shown that the frequency shift of palpitations associated with the estimates of unit costs of labor driver linear dependence of the form:
\[ \Delta \Phi = 0.08011 + 0.48867 \cdot Y, \]  

(13)

where \( Y \) – is the specific cost driver, Rel. unit; 0.08011, 0.48867 – empirical coefficients.

The correlation coefficient is 0.93113 that indicates the presence of a strong direct relationship between factors. Error of the correlation coefficient is:

\[ m_r = \sqrt{\frac{1 - r^2}{n - 2}} = \sqrt{\frac{1 - 0.93113^2}{6 - 2}} = 0.03084, \]  

(14)

where \( m_r \) – is the error of the correlation coefficient; \( r \) – is the correlation coefficient; \( n \) – is the number of the compared experimental pairs.

Criterion validity according to (13) defined by the formula:

\[ t_p = r \cdot \sqrt{\frac{n - 2}{1 - r^2}} = 5.106455. \]  

(15)

Fig. 1. The communication unit labor costs for the driver to shift the frequency of heartbeats.

The calculated value of \( t \) – test, significantly exceeds the limit value of the random fluctuations. Therefore, the dependence (13) is reliable. Thus, studies suggest that specific labor inputs of the driver are integral feature of its functional state, take into account the shift state of the physiological systems of the body, which in turn lead to changes in the reliability of the driver’s activity (Гаврилов et al. 2002):

\[ Y = \frac{\Delta \Phi_r}{W \cdot P_r}. \]  

(16)

Based on the foregoing, the strategy of the research on assessment of safety should be aimed at identifying elements of the environment movement, which has the greatest influence on the functional state of the driver.

4. Evaluation of the effect of road conditions on the functional state of the driver

Comparative analysis of experimental data and numerical simulation results allowed us to establish that with increasing speed, there is a decrease of the values of the indicators of the functional status of the body. The minimum frequency of palpatations, mental coercion of the driver, the unit cost of its abstract labor occur at speeds that are identified as summative rate (Гаврилов 1990). The movement with this speed provides an implementation
of the principle of least interaction of the driver with traffic environment. The reliability of the driver’s activity reaches its maximum value, which indicates the most efficient performance of functions by the driver. Then the task of ensuring road safety can be summarized as:

- defining the environment movement, that moves at speeds close to the summative normal speed, and therefore, providing the minimum unit cost of labor of the driver, the minimum mental coercion and maximum reliability of the driver’s activity;
- determining the limit of movement speeds, characterized by the limit values of indicators of the functional status of the driver.

Standards velocities, mental coercion, and unit labor costs of the driver, in turn, depend on the information elements of the field of perception. These include geometrical parameters of the plan, longitudinal and transverse profile of the road, visibility distance, traffic volume and composition of traffic, the condition of the coating. On the basis of the performed calculations, the relation between the environmental movement and the indicators of the functional status of the driver (Fig. 2–6).
Fig. 4. The relationship of the indicators of the functional status of the driver with visibility distance:
   a – mental coercion; b – typical.

Fig. 5. The relationship of the indicators of the functional status of the driver with the radius of the curve in terms of:
   a – mental coercion; b – typical speed.

Fig. 6. The relationship of the indicators of the functional status of the driver with the longitudinal bias and speed single car:
   a – mental coercion; b – the reliability of the driver’s activity;
   c – specific labor costs driver.
According to the results of numerical simulation of defined standards velocities in different road conditions. The speed at which optimum functional state of the driver, described as a rate of speed in data traffic conditions, and the corresponding unit costs of abstract labor as normal (Table 1). Velocities corresponding to the limit values of indicators of the functional status of the driver are defined as the upper limit, and the unit cost of abstract labor appropriate – as limiting (Table 2).

Table 1. Normal speed indicators of the functional status of the single driver of the car.

<table>
<thead>
<tr>
<th>Category of the road</th>
<th>IV</th>
<th>III</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Y_n ) ( \times 10^{-4} )</td>
<td>( U_n ) ( (\text{km/h})^2 )</td>
<td>( V_n ) ( \text{km/h} )</td>
<td>( Y_n ) ( \times 10^{-4} )</td>
</tr>
<tr>
<td>0</td>
<td>4.7</td>
<td>-0.0364</td>
<td>86.23</td>
</tr>
<tr>
<td>20</td>
<td>33.0</td>
<td>-0.163</td>
<td>79.11</td>
</tr>
<tr>
<td>40</td>
<td>33.0</td>
<td>-0.162</td>
<td>79.07</td>
</tr>
<tr>
<td>50</td>
<td>33.1</td>
<td>-0.163</td>
<td>78.87</td>
</tr>
<tr>
<td>60</td>
<td>33.8</td>
<td>-0.156</td>
<td>78.40</td>
</tr>
</tbody>
</table>

Table 2. Maximum speed indicators of the functional status of the single driver of the car.

<table>
<thead>
<tr>
<th>Category of the road</th>
<th>IV</th>
<th>III</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Y_n ) ( \times 10^{-4} )</td>
<td>( U_n ) ( (\text{km/h})^2 )</td>
<td>( V_n ) ( \text{km/h} )</td>
<td>( Y_n ) ( \times 10^{-4} )</td>
</tr>
<tr>
<td>0</td>
<td>0.110</td>
<td>-0.566</td>
<td>120.56</td>
</tr>
<tr>
<td>20</td>
<td>0.086</td>
<td>-0.339</td>
<td>98.82</td>
</tr>
<tr>
<td>40</td>
<td>0.082</td>
<td>-0.338</td>
<td>98.82</td>
</tr>
<tr>
<td>50</td>
<td>0.080</td>
<td>-0.336</td>
<td>98.82</td>
</tr>
<tr>
<td>60</td>
<td>0.079</td>
<td>-0.334</td>
<td>98.82</td>
</tr>
</tbody>
</table>

5. Conclusions

1. Synthesis of studies in the theory of the interaction of the driver with traffic environment has allowed us to develop an approach to solving the problem of traffic safety on the roads, taking into account not only the technical capabilities of the car, but also psychological and physiological peculiarities of the perception of the driver of the road environment.

2. The criteria environment movement requirements safety is the normal functioning of the mechanisms of adaptation of the driver to the conditions of the activity. Ensuring maximum reliability of the driver’s activity and is most likely to hold the set speed is an effective tool for improving traffic safety at the design stage of roads.

3. Further research strategy at the stage of estimation of traffic safety should be aimed at identifying the elements of the environment movement, which most affect the functional state of the driver, and the communication between the main indicators of the functional status of the driver and statistical indicators of road safety.

4. The obtained results can be used as the justification for the geometric parameters of the road at the design stage, and in the development of measures to improve traffic safety during operation of highways.

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