Ensuring road safety on the basis of engineering-psychological evaluation of drivers labour

S Zharov\textsuperscript{1}, V Vasilev\textsuperscript{1}, V Ovsyannikov\textsuperscript{1} and M. Deneko\textsuperscript{2}

\textsuperscript{1}Kurgan State University, 63/b, 4 Sovetskaya Street, Kurgan 640020, Russian Federation
\textsuperscript{2}Tyumen industrial university, 38, Volodarsky Street, Tyumen 625000, Russian Federation

E-mail: deneko2006@yandex.ru

Abstract. The analysis of the causes for the vehicle drivers’ faults is realized. It is established that the most significant cause of erroneous actions is a number of faults, caused by the unique feature task, as well as characteristics of the reduced information. This circumstance determines the use of engineering psychology methods. The engineering and psychological evaluation of the truck driver depending on the vehicle speed and the driving mode (overtaking the “leader” from the course and transition to the driving mode after the “leader”) is realized. These studies allow us to obtain the dependence of the average speed of information processing $S_{L}$ and the total complexity indicator of the $S_{D}$ algorithm on the movement speed. Recommendations on improvement of the driver’s labour organization which decrease the faults probability and increase the traffic safety are formulated.

1. Introduction

Numerous studies [3–4] show that the information processed by the vehicle driver is constantly increasing. Moreover, in addition to the information amount there is an overall increase in tension on the road due to the intensity of traffic flow. It creates an additional obligation on the driver, leading to faults and road accidents. In this case safety can be characterized by the reliability of safe functioning [5]:

$$P_{d} = 1 - \sum_{i} P_{opp} P_{Ida},$$

where $P_{opds}$ - the occurrence probability of a dangerous or harmful i-ro type production situation for a person; $P_{Ida}$ - the probability of incorrect driver actions in the I situation; $n$ - the total number of harmful and dangerous situations.

Harmful and dangerous situations can arise because of the technical factors and human fault. Their influence should be considered in determining the $P_{SL}$ indicator.

A fault can be determined as an unsuccessful performance of the prescribed action within the specified time and accuracy limits, which provokes the vehicle performance lesion.

The most common faults are:

- "admission" faults which imply that the prescribed action has not been performed (e.g. the driver has not pressed the brakes);
- "execution" faults, which is understood as the wrong execution of the prescribed action (for example, turning to the wrong direction);
"sequence" and "inopportunity" faults are the actions that violate the expected sequence.

By its nature, the driver faults can be divided into the following groups:
- faults that are typical for a person as a whole and do not depend on the characteristics of the performed activity (behavioural) (A1, see figure 1);
- faults caused by the nature of the activity (production) (A2, see figure 1);
- system faults generated by the features of a particular system "man – machine" (A3, see figure 1).

Three groups are emphasized as the main faults' causes [3-5]:
- faults caused by the wrong statement and the performance organization of the driver task setting (here is the wrong process organization of the information exchange within the man – machine system);
- faults due to individual psychological and physiological characteristics of a particular person (stress resistance, fatigue, temperament, etc.);
- faults caused by external adverse effects (microclimate, noise, vibration, etc.).

One of the most effective tools for analyzing the vehicle drivers' work, evaluation of the labour intensity, effectiveness of the information components exchange organization in the system "man – machine" is engineering psychology [3]. It is possible to work out various solutions for the driver's workplace organization for achieving the required level of neural-psychological labour tension.

Thus, it is possible to formulate the study purpose: the development of an approach to the driver's labour design in order to ensure the required level of safety.

To achieve this purpose, it is necessary to solve the following tasks:
- detection of the dominant causes of driver faults;
- elaboration of the driver's labour algorithm and assessment of the psychological tension level;
- development of recommendations to improve the psychological working conditions for drivers, reducing the likelihood in erroneous actions and as a result the road safety improving.

2. Method of research
Evaluation for the significance of the driver faults causes is based on the method of hierarchy analysis [7]. In this case, it is assumed to solve the problem for two levels of the hierarchy by choosing from three alternatives according to three criteria.

As alternatives, we consider the groups of operator faults’ causes that are mentioned above. The following criteria are formulated for analysis:
- difficulty of detection (K1);
- effectiveness of elimination (K2);
- frequency of manifestation (K3).

The general form of the complete dominant hierarchy is shown in figure 1.

![Figure 1. Full dominant analysis hierarchy of the driver faults’ causes.](image-url)

We use the following numerical indicators to quantify the drivers labour [1-6]:

- difficulty of detection (K1);
- effectiveness of elimination (K2);
- frequency of manifestation (K3).
1. Evaluation of the relative actions’ level that involve information analysis. The decision-making is performed by the logical complexity’s measure using:

\[ L = \frac{1}{N^I} \times \sum_{i} \frac{m^I_i}{m_i}, \]  

(2)

where \(N^I\) - the total number of actions in the algorithm; \(m^I_i\) – the number of logical actions in the complex group; \(m_i\) – the total number of actions in the group; \(n_L\) – the number of algorithm action groups containing logical conditions.

2. Evaluation of the algorithm members’ relative level, which involves the implementation of simple actions on the control vehicle elements. It is performed by the stereotyping indicator:

\[ Z = \frac{1}{N^D} \times \sum_{j} \frac{m^D_j}{m_j}, \]  

(3)

where \(n_D\) - the number of algorithm action groups containing stereotyped actions; \(m^D_j\) – the number of stereotypical actions in a complex group.

3. Characteristics of the control process intensity can be determined in the dynamics:

\[ V_H = \frac{N}{t}, \]  

(4)

where \(t\) - the total execution time of the vehicle control process algorithm; \(N\) - the algorithm length.

4. Entropy is a measure for assessing the uncertainty of the occurrence in a particular algorithm operator’s chain during driving:

\[ H^L_i = -P_i \times \log_2 P_i, \]  

\[ H^D_j = -P_j \times \log_2 P_j, \]  

(5)

(6)

where \(H^L_i\) - the entropy of the actions chain, containing logical conditions; \(H^D_j\) – the entropy of the actions chain’s occurrence, containing stereotypical actions; \(P_i, P_j\) – the probability of a logical condition (stereotyped action), respectively.

5. The following indicator is used to estimate the average information processing speed:

\[ S = \frac{(\sum_{i=1}^{n} H^L_i + \sum_{j=1}^{m} H^D_j)}{t}. \]  

(7)

6. The integral assessment of the algorithm complexity level:

\[ S_2 = \frac{V_H \times S \times Z}{L}. \]  

(8)

3. Research results

Tables 1-4 show the comparison matrices for the level of objectives and criteria.

**Table 1.** Matrix of paired comparisons for the target level

|       | \(K_1\) | \(K_2\) | \(K_3\) |
|-------|--------|--------|--------|
| \(K_1\) | 1      | \(1/4\) | \(1/5\) |
| \(K_2\) | 4      | 1      | 5      |
| \(K_3\) | 5      | \(1/5\) | 1      |

**Table 2.** Matrix of paired comparisons for the level of criteria “Difficulty of detection”

|       | \(B_1\) | \(B_2\) | \(B_3\) |
|-------|--------|--------|--------|
| \(B_1\) | 1      | 8      | 9      |
| \(B_2\) | \(1/8\) | 1      | 7      |
| \(B_3\) | \(1/9\) | \(1/7\) | 1      |

**Table 3.** Matrix of paired comparisons for the criteria level “Effectiveness of elimination”
Table 4. Matrix of paired comparisons for the criteria level “Frequency of manifestation”

| K₁ | B₁ | B₂ | B₃ |
|----|----|----|----|
| B₁ | 1  | 7  | 9  |
| B₂ | 1/7| 1  | 4  |
| B₃ | 1/9| 1/4| 1  |

Figure 2 shows the comprehensive analysis’ results of the cause significance degree in the driver faults:

Below there is an example of the actions’ algorithm performed by drivers during the overtaking and driving on the oncoming lane with the system of signs given in table 1.

The arrow ↑ indicates the transition if the logical condition is met, and the arrow ↓ indicates the place in the algorithm where the transition is made. If the logical condition is not met, the next standard action is performed in this case.

\[ P_R^{(E)} P_L^{(E)} d_{OL}^{20} A_{TRH}^{(E)} A_1^{(E)} P_R^{(E)} K_L^{(E)} P_L^{(E)} \]

P – interference check ahead; \( P_R^{(E)} \) – retention of the fuel pedals; \( R_S^{(E)} \) – steering wheel in the middle position; \( P_{OL} \) – interference check on the opposite lane; \( d_{OL} \) - security assessment of the distance before the vehicle; \( A_{TRH} \) – transferring the right hand on the control element (gear lever); \( A_1^{(E)} \) – impact on the toggle switch turn; \( P_P^{(E)} \) – pushing the fuel pedal; \( R_L^{(E)} \) – turning the steering wheel to the left; \( R_{RL}^{(E)} \) – retention of the steering wheel turning left; \( t_L \) – check of deviation from the set direction (moving left); \( V^{(W)} \) – vehicle speed mode monitoring; \( v \) – assessment of the set vehicle speed achievement; \( d_b \) – assessment of the safe distance behind the vehicle; \( P_{OL}^{(E)} \) – releasing the fuel pedal; \( B_R^{(E)} \) – transferring of the right foot to the control element; \( BP_P^{(E)} \) – pushing the brake pedal; \( \omega \) – everywhere, false logical condition.

Tables 5 and 6 show the results of the numerical evaluation in the algorithm parameters.

Table 5. Indicators of evaluation of the driver’s activity algorithm
### Table 6. Indicators for assessing the dynamic intensity of driver activity

| Variant of the algorithm | \( N_L \) | \( N_D \) | \( N \) | \( L \) | \( D \) |
|--------------------------|----------|----------|------|------|------|
| 1                        | 9        | 19       | 27   | 0.118| 0.53 |
| 2                        | 6        | 6        | 12   | 0.205| 0.313|

4. Discussion of results

Figure 2 shows that the maximum combination of criteria has an alternative A1 (faults generated by the task characteristics and by the properties of the managed information (volume, modality, degree of uncertainty, etc.)).

![Figure 3. Algorithm of the driver labour optimization.](image-url)
It should be noted that the first group faults are the most difficult to be eliminated when the system is already created. Therefore, the main option for overcoming them is to ensure the compatibility of the system elements “man-machine” at the designing stages for the interface between the driver and the vehicle.

The use of the algorithmic description for the drivers’ work makes it possible to numerically assess the compatibility in the "VEHICLE -DRIVER-ROAD" system. Analysis of the dependence for the $S_D$ coefficient as a function on $Z$ and on $L$, allows identifying the areas that characterize the driver's work aspects (figure 3).

5. Conclusion
Today, the interaction between the driver and the automobile is changing. The widespread introduction of systems such as “smart car” requires the development of new driver skills. The speed of movement and density of the flow of automobiles’ is growing. Therefore, the consequences of driver errors become more severe. The main way to ensure safety is to eliminate driver errors.

Thus, this approach makes it possible to quantify the psychological tension level of the driver’s labour. If necessary, the optimization directions of the driver’s labour algorithm can be determined for contributing to the road traffic safety.

References
[1] Zharov S P 1992 Development of the driver information support system for increasing fuel efficiency of the diesel truck, Dissertation, Kurgan
[2] Zharov S P 2013 Application of transport psychology to the system evaluation "VEHICLE -driver-road. Collection of scientific papers "Improving the operation and maintenance of vehicles." (Publishing of Kurgan State univerisity, Kurgan) pp 112–117
[3] Karan E D, Bobylev Yu O, Terentyev N M 1981 Algorithms of the road machine operators’ labour (Publishing of Moscow state automobile and research university, Moscow) p 115.
[4] Romanov A N 2002 Road transport psychology: Study letter for Universities and colleges (Academia, Moscow) p 224.
[5] Lomov B F 1982 Man and technique (Soviet radio, Moscow) p 463.
[6] Ovsyannikov V E, Vasilyev V I 2015 Algorithmic analysis of the diagnosing vehicles processes. Bulletin of the KuzGTU [Vestnik kuzbasskogo gosudarstvennogo teknicheskogo universiteta – in Russian] 2(108) 109–111
[7] Saaty T L 1993 Decision making. Method of hierarchy analysis (Radio and communication, Moscow) p 278.