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CHANGE OF DRIVERS' FUNCTIONAL CONDITION DURING DANGEROUS GOODS TRANSPORTATION

Summary. *The study of the human factors in traffic safety is a relatively young scientific field that began to develop several decades before the mass car advent. The origins of transport psychology and psychophysiology were mostly aimed at creating more comfortable and safe driving conditions due to the design of highways. Over time, there was a need to take into account drivers working conditions, namely the ergonomics of vehicles. The latest works have already taken into account previous experience and considered the issues of freight and passenger transportation technological processes, including the human factor. Among the objects and subjects of research in previous works were considered the processes of driving vehicles with different ergonomic characteristics and buses of different capacities, which created a kind of case matrix for planning experiments. When it comes to trucks, the matrix of cases became much larger, as the set of ergonomic and dynamic features of vehicles adds a much wider set of specialization of cargo and truck types. In this case, the most important issue is to determine the road conditions impact the driver's functional condition, engaged in the transport of dangerous goods, which is the purpose of this article.*

The research used: methods of field survey to establish the values of traffic flow on highways; methods of in-house research to determine the value of road capacity; electrophysiological methods to determine changes in the driver's functional condition.

The article describes the typing of road conditions according to their complexity, as well as the differentiation of drivers according to their psychological and professional qualities. Experimental studies of changes in driver's functional state of different age and socionic groups with different road conditions complexity, during dangerous goods transportation (second class of risk). The main results indicate that the analysis of traffic conditions' impact on the driver's functional state shows different dynamics of psycho-emotional stress change for people characterized by certain types of the nervous system and the ratio of their age to work experience.

Key words: *ergonomics of vehicles, road conditions, socionic typing, driver's functional state, driver's reliability.*

1. INTRODUCTION

The transport of dangerous goods by road is a potential and daily threat to people and the environment used for such operations. This is an issue of international importance, as the transportation of such goods and other goods is carried out according to specific established rules.

In the transport risk management system, the transport of dangerous goods has always attracted the attention of both theorists and practitioners, mainly because of the grander scale of possible consequences resulting from an undesirable event during transportation. Although in the world practice for most dangerous goods, the probability of an accident during their transportation is only 10^{-6} per mile,

the consequences of the incident, compared to the transport of other commercial goods, are more significant [1].

According to the law, the transport of dangerous goods on European roads is regulated by the International Agreement on International Carriage of Dangerous Goods by Road. This agreement divides hazardous goods into nine classes [2–3]. The cargoes considered in this work belong to the second class of danger.

The most common cargoes of this class of danger are: compressed and liquefied gases in cylinders, varnishes, and deodorants in aerosol packaging; compressed and liquefied cooled gases in cylinders or Dewar vessels – oxygen, carbon dioxide, nitrogen, oxygen, chlorine, mustard gas [4].

According to statistics, traffic accidents during the transportation of gases are a severe threat to the environment [5].

While analyzing the market of dangerous goods of the 2nd class, there is a tendency to increase the volume of gas transportation in cylinders on delivery routes. These substances are most often used in construction, metalworking, and related industries. The most dangerous goods on the list, which are most often transported in urban and regional communications such as "producer-consumer", "producer – warehouse", or "warehouse-consumer", are acetylene, technical oxygen, carbon dioxide, propane, and methane.

Conditions, restrictions, and various rules provided by regulations are mandatory, which imposes several additional obligations on cargo companies, especially on the driver, which significantly complicates the process of transportation.

2. RESEARCH STATEMENT

There are a large number of factors that affect the technological processes of cargo transportation. Most of them are divided into groups, which allows us to separate their features of influence on this process. In general, the list of groups of such factors taken into account [6] is shown in Fig. 1.

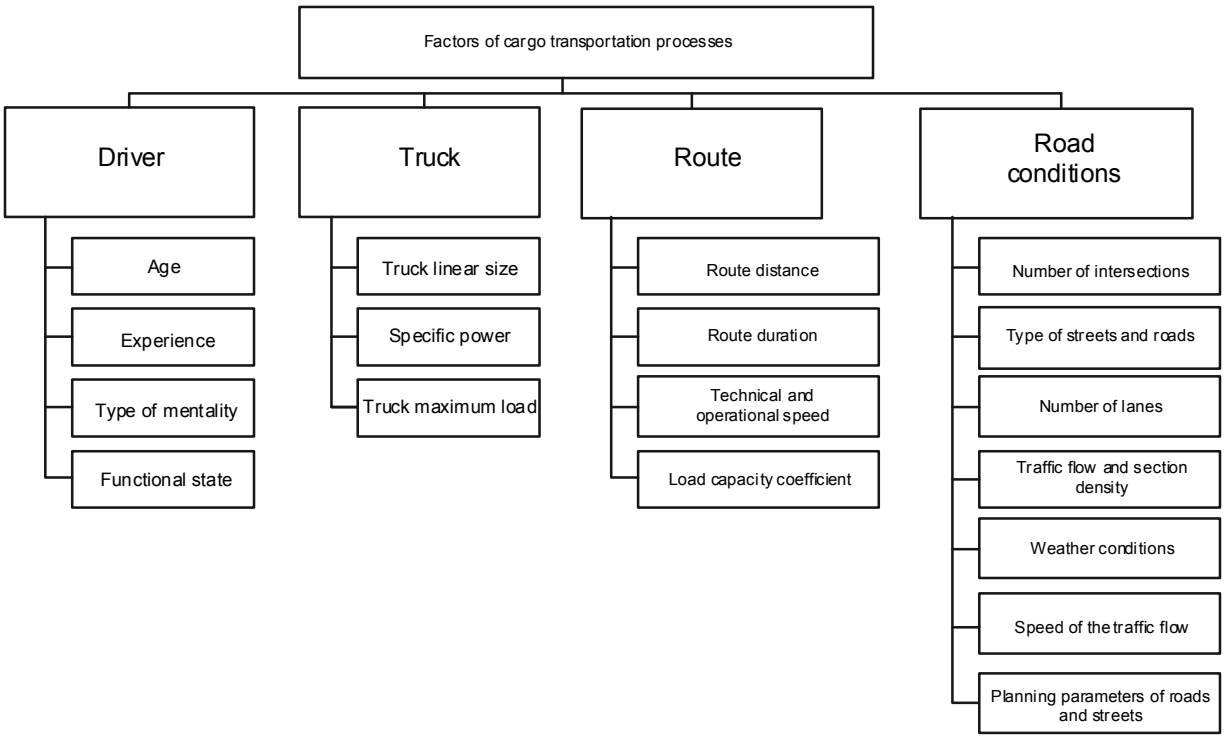

Fig. 1. The relationship of factors that affect the technological process of cargo transportation

It is known that during transportation, there are interconnected elements that form the system "driver – car – road – environment". If the technical parameters of cars and roads are known and predictable, then

the variable parameters of the environment and the driver are the least-studied elements of this system. When transporting dangerous goods, the cost of driver error is extremely high, as accidents that can involve such vehicles have serious consequences. However, this opinion indicates that an essential link between the groups of factors of the technological process of freight transport in terms of road safety is the dynamic feedback between the functional state of drivers and road conditions. It means that other factors affect transport safety more generally or indirectly.

According to the review of previous scientific works, this paper can be stated that the influence of the human factor (driver) on traffic safety during such specific transportation needs further study. Most of the research results concern mainly drivers of minibusses and cars and do not fully cover the impact of road conditions and types of cargo [7–9]. According to previous information, the research direction of the peculiarities of driver's functional state changes depending on road conditions during transportation of dangerous goods is relevant.

This research aims to determine the change in the functional status of drivers with different psycho types and professional qualities when driving trucks under other road conditions.

The main objectives of this article are:

- determination of basic indicators that characterize road conditions and functional condition of drivers;
- establish the relationship between these indicators on the basis of data collected during business flights;

To conduct a comparative analysis of the results obtained, taking into account drivers' psycho type and professional characteristics.

During the solution of the set tasks, the methods of field and in-house research of the functional state of drivers, video recording of traffic conditions, geoinformation assessment of the route, testing and typing of drivers on socionic grounds were used.

3. SURVEY CONDITIONS AND VALUES CALCULATION

The main subset of factors taken into account are those that characterize the driver, traffic conditions, and transportation technology, and the feasibility of taking them into account and the presence of communication in transport processes has been confirmed by previous studies on this topic.

These include indicators of traffic flows (intensity and density, load level); road conditions (their typology due to the geometric characteristics of roads); psychophysiological features, and their professional qualities.

Factors that are taken into account in their steady-state include some elements of the system "driver-car-road-environment", which are difficult to predict. Their variation may depend on the specific features of the technological processes of transportation. Among them are: hydrometeorological conditions (studies involve movement in daylight in the spring and autumn without significant precipitation); the shape of the road surface (the results obtained when driving routes are taken into account, where its condition is satisfactory); characteristics of vehicles (trucks with a certificate of admission to the transport of dangerous goods and equipped following all norms and regulations, with a capacity of 5–7 tons and similar technical characteristics); features of cargoes (transportation of freight, which are the most common objects of transport among the 2nd class of danger) was taken into account. The correct priority of taking into account the above factors allows you to get more specific results that will meet the research purpose.

To obtain reliable research results, you need to determine the number of measurements of the required values. In our case, this value is dependent on the above factors, namely the stress index (SI). This figure is similar to the voltage index of regulatory systems

V.M. Baevsky [10]. Typically, this figure is 80–150 c.u., with psycho-physiological loads that can increase several times (from 2 to 5 in proportion to the increase in work intensity) [11–12]. Determining the minimum required number of measurements described in [13] processed a test sample of SI drivers in 20 measures to assess the required statistical parameters. The results of the calculations are shown in Table 1.

Table 1

SI measure statistical parameters

Parameter	Value
Standard deviation	25.161
Arithmetic mean	202.8
Accuracy of measurements	0.027
Coefficient of variation	0.134
The minimum required number of measurements	87

Based on the calculated parameters of the test sample, it is possible to determine the number of measurements for the future, as these samples are normally distributed.

From the above, it follows that for the reliability of further studies for a confidence level of 0.95, the number of measurements of each observed indicator should exceed 87.

To properly select drivers for psychological interviews and research, it is necessary to calculate whether there is a sufficient number of nominated drivers. To do this, use the resource [14]. The general population in our case may be the number of drivers in Ukraine who have a permit to transport dangerous goods. Based on the available information on the registers for issuing tickets to transport hazardous goods, the total population will be 31.000 drivers [15].

The surveys involved 49 drivers who have a permit to transport dangerous goods and work with second-class goods at least once a month. Conducted surveys were at transport and chemical enterprises in the Lviv region. The results of the calculations are as follows: for several such drivers, the statistical error is not more than 12 %, with a confidence level of 0.9. Given the variable volume of traffic of this type of cargo, the obtained sampling parameters can be for research.

The age of drivers ranges from 31 to 57 years, and work experience – from 3 to 22 years. To carry out a more precise classification of drivers, in addition to professional qualities, it is necessary to take into account the peculiarities of their psyche.

According to the method given in the source [16], a survey of drivers was conducted to determine their socionic type. After analyzing the research results, all interviewed drivers can be divided into three groups to characterize the relationship between professional qualities and mental functions. The results of the summary are listed in the Table 2.

Table 2

Survey and grouping results of drivers

Group №	The ratio of age to work experience	Prevailing mental functions	Quota, %
1	Less then 5	extraversion – thinking	34
2	from 5 to 10	extraversion – intuition	41
3	more than 10	introversion – sensory	19
others	–	–	6

This distribution allows drivers to be clearly distinguished according to their characteristics to assess the level of their functional state during the performance of flights, taking into account traffic conditions.

Using the obtained results, we had to necessary to collect and analyze data correctly because the internal factors influencing the functional state of the driver can be manifested in different ways in other road conditions.

Should note that the drivers of the first group have the best psychological resilience in combination with high professional qualities. Similar results are observed in the second group, but it is isolated because the level of professional rates is more significant. The third group includes drivers with the least experienced, and the dynamic features of their psyche differ significantly from the previous two cases.

The following conditions characterized the considered routes of movement of vehicles:

- total length of the route – is 170–300 km, depending on the number of consumers and their location;
- the route was characterized by changes in traffic conditions during its follow-up. The following typical road sections should be identified:
- the first type: sections of roads with one or two lanes in one direction, which ran in the plains with radii of horizontal curves of more than 1000 m and cells of ascents with slopes up to 30 ‰ (meet light traffic conditions);
- the second type: sections of roads that passed from the plains to the mountains (or vice versa), where there were radii of horizontal curves in the range of 600–1000 m and sections with longitudinal slopes in the field of 35–50 ‰ for their length of 300–1000 m difficult traffic conditions);
- third type: sections of roads with limited visibility, elevations of more than 500 m above sea level, radii of horizontal curves less than 600 m, and longitudinal slopes greater than 50 ‰ for lengths of 500–1500 m (corresponding to dangerous road conditions).

Traffic intensity studies were conducted by video recording, and the load level was calculated as the ratio of intensity to bandwidth.

The functional state of the drivers was recorded using the Polar H7 device and the CardioMoodLite mobile application. The results were stored and processed in the CardioMood software environment.

As it is forbidden for unauthorized persons to be in the cab of the car when transporting dangerous goods, all accounting was carried out automatically. Before starting work, the driver fixed the device for recording functional status and connected it to the smartphone. The truck's position in space and time is obtained using a satellite receiver in the DVR. Processed records were in in-house conditions, and the reduced obtained data were in a systematic form for further analysis.

4. MAIN PART

Traffic outside the settlement is characterized by changing traffic conditions, as the studied route passes through sections of roads of different categories and in other areas. Should note that the vehicle's characteristics are stable, and only studies in good weather conditions were taken into account. The main factors influencing the driver were curves in the plan and profile and the level of road traffic.

The research results are presented in the form of dependences of SI drivers of different groups on the parameters of highways. It should be noted that load level values less than 0.5 and more significant than 0.5 differ and are given separately. The change of SI depending on the curve radii at a load level $Z < 0.5$ is shown in Fig. 2.

Analyzing the results, we see that traffic on highways outside the settlements significantly impacts the driver's stress level, but only in areas where the radii of horizontal curves are less than 500 m, which is often typical for mountain traffic. SI values greater than 400 c.u. indicate the state of severe load on the driver, which negatively affects the reliability of his work.

Should also note that the impact of traffic flow characteristics on drivers, in this case, is insignificant, as the load level did not exceed 0.5, and areas where traffic was, are easy and challenging road conditions.

In areas where road conditions are much more complex, the drivers of the second group are under the least psycho-emotional load, and the third – is under the greatest. This is because an active nervous system characterizes drivers of the first group, and their actions are usually balanced and careful. Unlike other types, such working conditions are expected for him, which are suitable for monotonous driving conditions with minimal variability.

Another essential characteristic of the highway is the magnitude of the longitudinal slope. While driving, the intensity of the driver's work is affected by the complexity of tasks to predict the road conditions. It can be especially noticeable when the amount of information about other traffic conditions is

minimal – such areas should include sharp rises with limited visibility. In addition, the vertical curves of small radii with high values of longitudinal slope have a significant impact on the indicators of the functional state of the driver.

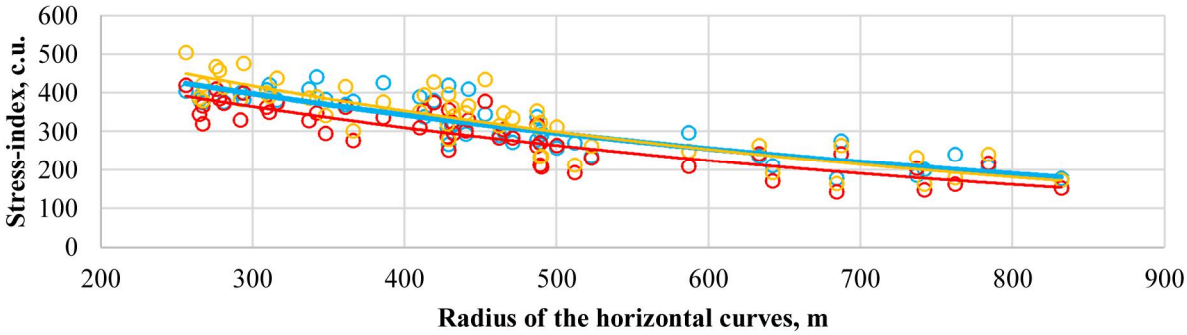

Fig. 2. Change of driver's SI, depending on the radius of the horizontal curves at the load level Z<0.5 when transporting dangerous goods by road for the studied groups:

– Group 1 – Group 2 – Group 3

The results of changes in the driver's functional state, which carry dangerous goods of the second class when driving on the road, depending on the value of the longitudinal slope at the level of its load Z<0.5, are shown in Fig. 3.

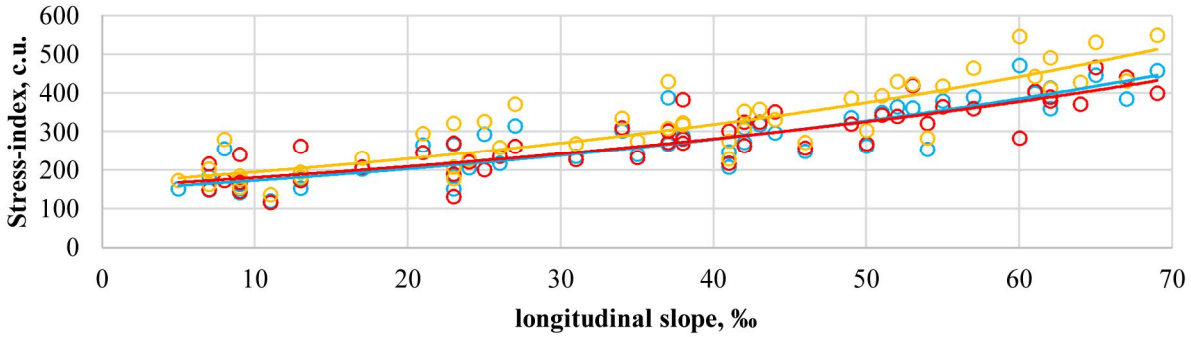

Fig. 3. Change of driver's SI, depending on the value of the longitudinal slope at the load level Z <0.5 when transporting dangerous goods by road, for the studied groups:

–Group 1 – Group 2 – Group 3

According to the dependencies described in Fig. 2–3, there is a tendency to increase the level of driver stress on-road sections where the longitudinal slopes are greater than 30 ‰. Under such conditions, SI increases more than twice the norm to 300 c.u. We should note that the drivers of the first and second groups are less stressed than the third, which indicates that the level of their work is somewhat more reliable.

Most of these patterns are also explained by the fact that drivers belonging to the first and second groups have better professional driving skills. In combination with sociotypes that correspond to stable nervous systems, this becomes noticeable concerning the performance of drivers of the third group.

At a load level Z>0.5, complicated by the geometry of roads, traffic conditions are classified as problematic. In this case, it is necessary to determine the impact of road performance on drivers' FS, as the nature of their work can vary greatly.

It should also be noted that at high values of the load level, large groups of vehicles can be observed in the opposite direction, which complicates the implementation of maneuvers and forecasting the road situation.

The results of studies of changes in SI drivers transporting dangerous goods of the 2nd class from the radius of horizontal curves are shown in Fig. 4.

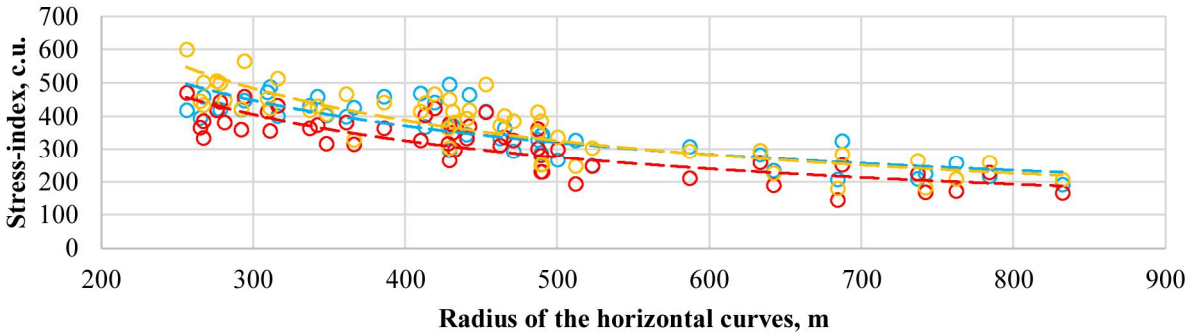

Fig. 4. Change of driver's SI, depending on the radius of horizontal curves at the load level Z> 0.5 when transporting dangerous goods by road, for the studied groups:

– Group 1 *– Group 2* *– Group 3*

As can be seen from the figure, at a load level of more than 0.5, the driver's SI is much higher, and the dynamics of its change are sharper with decreasing radii of the route. Drivers of the third group are in a more pronounced overvoltage than others. Still, this trend is observed only when the radii of horizontal curves are reduced to 400 m and more negligible. Under other conditions, the SI of the drivers of the first and third groups varies almost to the same extent. We should note that the SI of drivers of the second group is the lowest among the studied group. This is due to the better perception of such traffic conditions by drivers of certain sociotypes.

Similar to previous studies, the change in FS indicators of drivers of different sociotypes depends on the magnitude of the longitudinal slope of the highway. According to the typology of road conditions given in the second section, at a load level greater than 0.5, it is necessary to pay attention to areas with slopes greater than 30 ‰, as traffic conditions in such cases are complicated. Such dependencies are shown in Fig. 5.

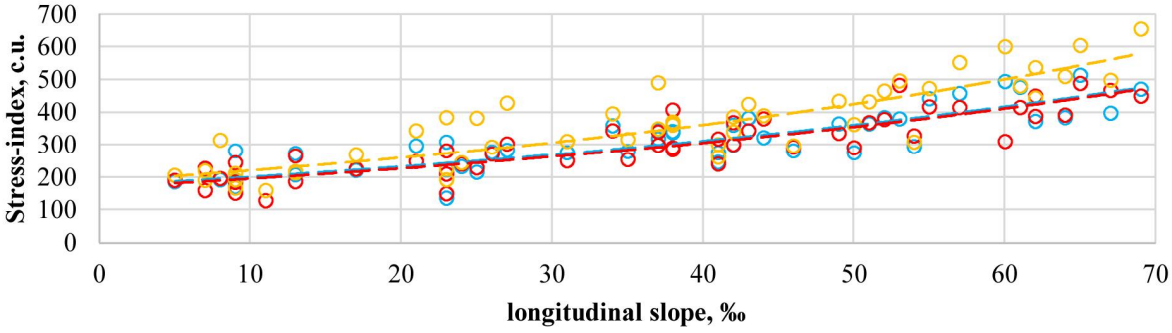

Fig. 5. Change of SI drivers, depending on the value of the longitudinal slope at a load level Z > 0.5 when transporting dangerous goods by road, for the studied groups:

– Group 1 *– Group 2* *– Group 3*

The research results show that in challenging road conditions, the SI of drivers of the third group, when driving vertical curves with a slope greater than 30 ‰, increases to values greater than 300 c.u., which indicates the onset of overvoltage and a constant decrease in its reliability work. The other two drivers react to traffic conditions almost equally, and the state of their pronounced voltage is observed at slopes greater than 40 ‰.

Based on the obtained data, it can be noted that the parameters of traffic flow significantly affect the nature of nervous and emotional stress of drivers, which correlates well with the typology of road conditions. In addition, it was determined that the functional state of drivers of the third group deteriorates much more markedly than in the other two. This is due to the dynamics of the environment in which they are, as the optimal psycho-emotional state of this type of driver is more likely to be observed on roads where the nature of traffic is calmer and monotonous.

The general results of the research should be presented in the available Table 3, according to which it is possible to provide a quantitative assessment of the reliability of a group of drivers depending on traffic conditions.

Table 2

General results of the survey

Road condition type, when Z<0,5	Drivers group	SI, c.u.			Road condition type, when Z>0,5	Drivers group	SI, c.u.		
		min	min	min			min	max	avg
Type 1	1	163	274	201	**Type 5**	1	181	311	233
i < 30 ‰	2	165	221	190	i < 30 ‰	2	161	237	204
R > 500 m	3	176	265	205	R > 500 m	3	185	291	237
Type 2	1	273	429	349	**Type 6**	1	284	480	391
i > 30 ‰	2	261	412	336	i > 30 ‰	2	276	460	365
R < 500 m	3	276	529	382	R < 500 m	3	302	564	434
Type 3	1	203	285	262	**Type 7**	1	200	303	280
i < 30 ‰	2	199	269	240	i < 30 ‰	2	220	317	266
R < 500 m	3	222	359	285	R < 500 m	3	243	410	325
Type 4	1	249	405	311	**Type 8**	1	285	429	357
i > 30 ‰	2	256	350	305	i > 30 ‰	2	272	398	330
R > 500 m	3	276	402	340	R > 500 m	3	301	425	385

As can be seen from the results, the most significant impact on the driver's functional state is exerted by conditions in which the values of longitudinal slopes are less than 30 ‰. At the same time, the radii of horizontal curves are less than 500 m, and the load level exceeds 0.5. The average SI of all group drivers can also compare with the current road conditions.

5. CONCLUSIONS AND RESEARCH PERSPECTIVES

Studies have shown that when driving on highways, the parameters of horizontal and vertical curves significantly affect the intensity of drivers, to varying degrees for other groups. However, when in difficult and dangerous road conditions, SI of all drivers indicate the state of their excessive stress, which certainly complicates their nature of work in general.

The road sections' load level with the same geometric parameters differently affects the driver's functional state. Excessively high SI values are observed in areas where the load level is greater than 0.5, the values of longitudinal slopes exceed 30 ‰, and the radii of curves in the plan are less than 500 m.

SI values range from 165 to 561 c.u. depending on traffic conditions and the group of drivers who drove the vehicle. We should note that the highest (weighted average) level of psycho-emotional stress of drivers is observed when working in difficult road conditions (type 2 and type 6). SI of the first group drivers is 20–25 % less than the exact figure in the same road conditions for drivers of the third group. However, in such situations, the human is most likely to make a mistake in driving. The most negligible impact on the functional state of drivers is observed when driving in light road conditions (average SI values are 200 and 225 c.u., respectively, for cases with a load level of less than 0.5 and vice versa).

The results obtained are also valuable in organizing the professional selection of drivers for the transport of dangerous goods. Given the possibility (by conducting a socionic questionnaire) to determine the psycho type of drivers, they can be differentiated into groups to make the right personnel choice when analyzing future transportation routes. Research indicates that when road conditions are difficult, drivers

whose age-to-work-age ratio is less than 10 and mental functions such as extraversion-thinking/intuition are better able to withstand significant psycho-emotional stress.

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ЗМІНА ФУНКЦІОНАЛЬНОГО СТАНУ ВОДІЇВ ПІД ЧАС ПЕРЕВЕЗЕННЯ НЕБЕЗПЕЧНИХ ВАНТАЖІВ

Анотація. *Дослідження ролі чинника людини в безпеці руху є відносно молодим науковим напрямком, який почав розвиватись за декілька десятиліть до появи масового автомобіля. Витоки транспортної психології та психофізіології водіїв здебільшого мали на меті створення максимально комфортних та безпечних умов руху за рахунок композиції автомобільних доріг. З часом надійшла потреба враховувати самі умови праці водія, а саме ергономіку рухомого складу. Найбільш пізні роботи вже враховували попередній досвід і розглядали питання технологічних процесів вантажних та пасажирських перевезень з урахуванням чинника людини. Серед об'єктів та предметів дослідження у попередніх працях розглядались процеси керування легковими автомобілями з різними ергономічними характеристиками та автобусами різної вмістимості, що створювало своєрідну матрицю випадків для планування експериментів. Якщо ж говорити про вантажні автомобілі, матриця випадків, які треба дослідити, має значно більші розмірності, оскільки до множин ергономічних та динамічних особливостей рухомого складу додається значно ширша за масштабами множина спеціалізації вантажів та рухомого складу. В такому випадку найбільш важливим є питання визначення впливу дорожніх умов на функціональний стан водіїв, які здійснюють перевезення небезпечних вантажів, що є метою цієї статті.*

У роботі під час досліджень використовувались: методи натурних досліджень для встановлення значень інтенсивностей руху транспортних потоків на автомобільних дорогах; методи камеральних досліджень для визначення значення пропускної здатності автомобільних доріг; електрофізіологічні методи для визначення зміни функціонального стану водіїв; методи системного аналізу для опрацювання результатів проведених досліджень та їх інтерпретації.

В статті здійснено типування дорожніх умов за їх складністю, а також диференціацію водіїв за їхніми психологічними та професійними якостями. Проведено експериментальні дослідження зміни показників функціонального стану водіїв різних вікових та соціонічних груп за різної складності дорожніх умов під час перевезення небезпечних вантажів другого класу. Основні результати вказують на те, що при аналізі впливу умов руху на функціональний стан водіїв спостерігається різна динаміка зміни рівня психоемоційного напруження для людей, які характеризуються окремими типами нервової системи та відношенням їхнього віку до стажу роботи.

Ключові слова: *ергономіка рухомого складу, дорожні умови, соціонічне типування, функціональний стан водія, надійність роботи водія.*