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Traffic conditions and their impact on the functional state of the bus driver

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Annotation. Problem. *The study of the human factor in transport systems is increasingly important, given the rapid level of motorization and the development of the transport industry in general. Accordingly, there is a task of ensuring the appropriate traffic safety level. Today, in this area, the road conditions and the road`s design parameters are usually taken into account, but often miss the role of the "human factor". At the same time, with the development of methodologies and technical items, these issues are partly researched and solved. Thus, during considering issues related to traffic safety, it is necessary to pay attention to the drivers` functional state (FS) and psychophysiological qualities, their reliability, factors of negative impact on their body, etc.* ***Goal.*** *The research aims to establish how the bus driver`s FS changes under the influence of various traffic conditions` factors.* ***Methodology.*** *The approaches adopted in the paper, which are necessary to solve the goal, are based on theoretical and practical principles for determining the indicators of a human`s FS during professional activity, their regulatory values, allowable ranges of change, etc.* ***Results.*** *The obtained mathematical and graphical dependences take into account the change of transport process operator`s FS under the influence of such factors as the bus`s speed, the altitude of the highway and the duration of the driver work. The stress index (SI) is selected as the driver`s status indicator. It is established that its values range from 87 to 342 c.u. It was studied that the increase in speed leads to an increase in the driver's SI by about 35%. During the statistical data analysis, it was also found that the highest values of SI were observed on sections of roads at an altitude of 250 - 320 m and 420 - 500 m. At the same time, during the increase of the driver's work duration, the value of the SI increased by about 25% and could approach the value of 250 c.u. In accordance with the above, it can be argued that there is an influence of the driver`s driving conditions and work on his FS.* ***Originality.*** *The obtained regularities reflect the impact of drivers' working conditions on the value of their FS, which affects the probability of their accident-free operation and, as a result, traffic safety.* ***Practical value.*** *The obtained results allow the creation of recommendations for developing schedules of drivers` work and rest taking into account the traffic conditions on the route and the conditions of driver's work.*

Key words: *functional state, driver, traffic safety, electrocardiogram, stress index.*

Introduction

Today, road transport plays an important role in the economy of any country, in particular by providing the needs for passenger transportation both within settlements and in long-distance connections. This is due to the fact that buses are one of the most common and popular types of public transport. However, the question of providing the appropriate transportation services' timeliness and quality often arises. Accordingly, there are some problems of the need to improve the services` quality during the implementation of bus transportation. At the same time, one of the key indicators, in this case, is to ensure the appropriate level of traffic safety and reduce the probability of traffic accidents.

The probability of an accident usually depends on the existing preconditions. It includes complete or partial disruption in the functioning of the system "driver – car – road – environment". While the parameters of the links "car", "road", and "environment" of this system can be studied in detail and predicted, the link "driver" remains the least researched. According to the statistics of road accidents and existing scientific articles, it is established that the "human factor" in transport systems remains the main cause of accidents on roads. This is primarily because the

driver`s actions often influence the traffic safety of this process` participants. In turn, the correctness of the driver`s decisions in specific road situations, the duration of his reaction, and the reliability of his work depend on his body's FS.

Bus drivers have special responsibility for compliance with traffic rules and creating safe conditions for the movement of passengers. During work, their body and FS are affected by a significant number of different factors. Under such action, the level of the driver`s working capacity and reliability can decrease. In difficult road conditions, this can lead to losing control over the transport process and making the wrong decisions. As a result, it can lead to a traffic accident. That is why studying the drivers' psychophysiological indicators is an important aspect in ensuring the correct functioning of transport systems. Also, the urgent task is to identify and eliminate factors that have a negative impact on the body of transport operators.

Analysis of publications

Today, road transport is one of the critical elements in ensuring the proper functioning of the countries` economy. However, during its development and the increases in motorization rate, new problems arise. Also, they need a comprehensive analysis and solutions through the use of modern approaches and equipment. Thus, an essential task in transport is to ensure an appropriate level of traffic safety. Despite several advantages, road transport needs further improvement, in particular, reducing traffic accidents on all categories of roads and streets remains relevant [1, 2].

Accordingly, with the increases in motorization rate, more and more people are becoming road users. Accordingly, there are more and more conflicts between the participants in this process, which can be a prerequisite for a traffic accident with varying severity at complicated road conditions. At the same time, disadvantages in traffic management, violation of traffic rules, inadequate road infrastructure, noncompliance with the norms of the duration of the drivers` work and rest, bad weather conditions, etc. are often the causes of such situations [3, 4].

Based on the processed statistics, the authors of [4] found that the most common perpetrators of accidents are vehicle drivers. The main reason for this is their incorrect actions in difficult and unpredictable road situations [5]. However, it should be noted that often bus drivers are the perpetrators of such accidents much less. It can be explained by the small share of buses in the overall traffic flow and that drivers are more responsible for professional activities. In addition, the important causes of accidents due to the "human factor" in road transport can also include the following [6, 7]:

- low drivers` qualification;
- non-compliance with traffic rules;
- non-compliance with the passengers and cargo transportation`s regulations;
- lack of proper control over the drivers` work and rest time;
- unsatisfactory physical state of drivers and technical condition of vehicles.

At the same time, to increase the level of traffic safety, it is necessary to introduce some measures:

- improve the parameters of vehicles;
- improve the parameters of roads and eliminate its existing dangerous parts;
- establish proper control over compliance with traffic rules and the process of the driver`s work organization;
- comply with the requirements for the driver`s health and physical condition;
- create appropriate working conditions for drivers.

It should be noted that a significant impact on the professional activities and reliability of the driver has FS of his body. This factor affects the driver`s reaction time, processing of information, behaviour in different traffic situations, etc. [5, 8].

The FS of the driver is a complex indicator that directly or indirectly reflects the interaction of the organism`s functional systems at the performance of any activity [8, 9]. From the view of the driver's professional activity, this indicator reflects his ability to perform the tasks set before him and to adapt to changes in traffic situations and conditions. In this case, it often acts as an indicator of the body's response to emotional and physical stress [8].

I. Afanasyeva in the scientific article [10], had found that the driver is significantly affected by the psycho-emotional state and information flows parameters during his work. They can reduce its response to the environmental influence and, as a result, increase the probability of a traffic accident. This article establishes that the advertising location in the driver`s field of view and his use of a mobile phone distract him from performing professional activities. Also, it is noted, that this duration of distraction from driving the vehicle can reach values from 0.23 s to 4.77 s.

The importance of the influence of driver`s

FS on traffic safety is noted by a large number of scientists in their researches. Thus, M. Boikiv, in the article [11], notes that FS affects the duration of the driver's reaction at different periods of the day and at varying levels of roadway lighting. O. Lobashov and O. Prasolenko in [12] note the influence of the vehicle's technical speed on the change of the driver's FS. These authors use the shift in heart rate and changes in galvanic skin response as an indicator of FS. This study was conducted within the settlement in the general traffic flow and reflects the impact of road capacity ratio and traffic delays on the driver's FS.

The authors of [13, 14] note the importance of a psychological selection of drivers and the impact of their emotional state and personal characteristics on the reliability of their work. At the same time, while analyzing the driver's activity, it is also necessary to consider such indicators as attention and perception, speed of reactions in different road situations, the process of thinking, etc.

In [13], M. Afonin noted the importance of considering the "human factor" in forming the routes for dangerous goods delivery. This is because the driver`s reliability and his proper FS determine the conditions for safe execution of the technological process of transportation. At the same time, he proposed a method of creating routes for dangerous goods transportation, which, in contrast to existing ones, allow taking into account the driver's FS and the difficulty of road conditions.

Several other scientists in the studies [15-17] consider that a number of factors influence the driver's FS during his work:

- traffic conditions and terrain;
- lighting level, temperature and humidity;
- noise and vibration;
- high-altitude position of the road, etc.

Following the above, it can be argued that the driver's FS is one of the key indicators, which reflects the reliability of his work and, as a consequence, the probability of accident-free operation. Today, various methods and approaches are used to study driver`s FS. Most of them are based on the registration of a significant number of human`s different psychophysiological indicators. Also, the most widely used electrophysiological methods, in particular, are the following [5, 8, 9, 13, 15]:

- electrocardiography (ECG);
- electroencephalogram;
- electromyography;
- electrooculogram;
- galvanic skin response.

In transport studies, for the research of a driver`s FS, the ECG recording method and analysis of its parameters are often used. An ECG is a recording of changes in electrical potentials that occur due to excitation of the heart muscle and is displayed in the graphical form [13, 18]. This technique allows determining the influence of external factors on the driver's body and its adaptation to them. In this case, one of the most informative characteristics obtained from the ECG recording is heart rate variability (HRV), which is based on the analysis of heart rate. It reflects the interaction of the nervous and cardiovascular systems and the influence of external factors on the human body [13]. The studies of driver`s FS often use stress index (SI), which can be calculated based on statistics obtained from HRV. The calculation of SI is carried out with the formula [9, 13]:

$$SI = \frac{AMo}{(2dX \cdot Mo)}, \quad (1)$$

where AMo – mode amplitude – the value of mode in percent; dX – variation range – takes into account the difference between the largest and smallest value of R-R intervals; Mo – mode an indicator that reflects the number of R-R intervals that are most common.

According to this indicator, E. Gavrilov divided the driver's FS into the groups [19]:

Table 1. Phases of the driver`s FS [19]

Driver`s state	Indicators of the driver's FS		Model assessment of operating conditions
	SI, c.u.	Heart rate, r.u.	
Great monotony	< 30	< 0.03	Unsatisfactorily
Moderate monotony	30 – 50	0.03 – 0.05	Satisfactorily
Slight monotony	50 – 100	0.05 – 0.10	Good
Functional comfort	100 – 160	0.10 – 0.16	Well
Tension of adaptation mechanisms	160 – 200	0.16 – 0.20	Good
Overvoltage of adaptation mechanisms	200 – 300	0.20 – 0.30	Satisfactorily
Failure of adaptation. stress	> 300	> 0.30	Unsatisfactorily

The value of SI is expressed in c.u. Its rate ranges from 80 to 150 c.u. SI is sensitive to any load, and a slight emotional or physical impact increases this indicator in 1.5-2 times and significant loads – in 5-10 times [13].

Purpose and Tasks

The research aims to identify the pattern of changes in the driver`s FS while driving a bus under various traffic conditions factors. To achieve this, it is necessary to solve the following problems:

- to analyze bus routes on which research of the driver`s FS will be carried out;
- to conduct research of the bus drivers` HRV and to establish necessary values for the further calculation of SI;
- to make records concerning geolocation of the vehicle and its speed during measurements of the drivers` FS indicators;
- to establish regularities of the driver's SI change depending on the bus speed, height position of the road and duration of his work.

Conditions of the driver`s functional state research

The following factors were selected as indicators of influence the driver's FS that need to be investigated:

- speed of the bus;
- high-altitude position of the road;
- duration of the driver`s work.

The study of drivers' FS was carried out on four bus routes, the parameters of which are given in Table. 2.

Table 2. Parameters of bus routes

Route number	The length of the route, km	A number of bus stops, units	Duration of movement, h	Movement interval, min
1	201	60	6.58	35
2	195	46	6.75	40
3	253	56	6.25	25
4	202	51	7.24	90

On the above-mentioned routes run buses of brand "Etalon". Drivers` age was in diapason from 32 to 55 years and driving experience from 10 to 35 years.

The buses` speed was recorded using a "Garmin Dash Cam 56" video recorder. Also, this device was used to register the geolocation of the vehicle. The obtained statistical data were analyzed in the laboratory. The obtained coordinates were used to determine the bus`s high-altitude position in different periods of time. In this case, the online resource "Elevation Maps" was used (Fig. 1) [20]. The value of the altitude at which the vehicle is located affects the driver's FS, which may change his physical and mental performance.

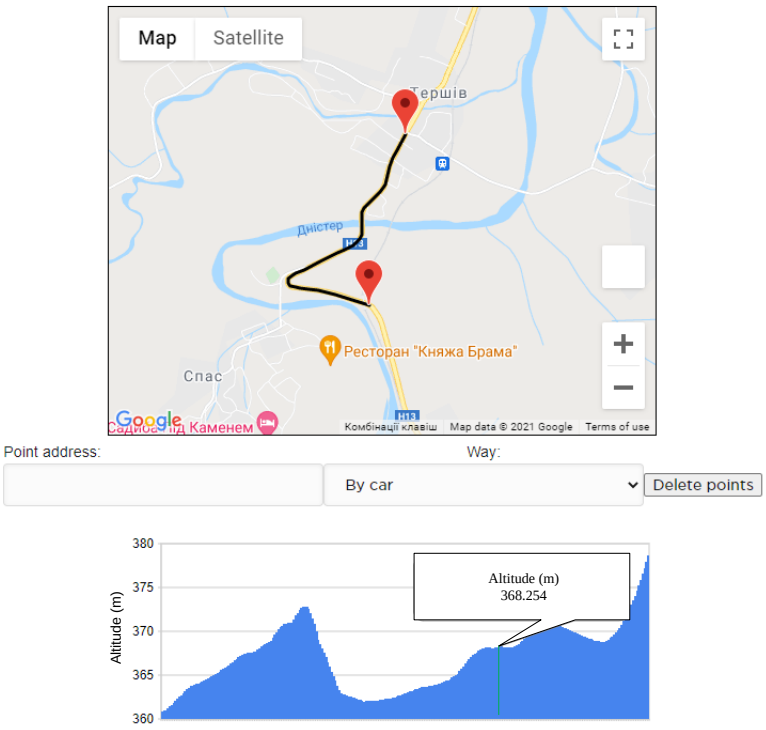

Fig. 1. Fragments of the online resource "Elevation Maps" interface [17]

To create a graph in the online resource "Elevation Maps", which reflects the change in the high-altitude position of the road, it should be entered at least two points.

As for the registration of the driver's HRV, which were later used to calculate the SI, they were obtained using the device Polar H10. It works via Bluetooth with a smartphone on the Android platform. The HRV lite mobile application was used to record this data. The analysis of input data for the calculation of the drivers` SI was carried out in laboratory conditions.

The results of the driver`s FS study

As mentioned, the Garmin device was used to record speeds at intervals of 1 min. Registration was carried out through the whole route of the bus. During the same period, HRV readings were recorded using a Polar H10 device with similar intervals. The obtained values were processed in the MS Excel software and, based on this, the SI values were calculated by the (1). The obtained data are displayed as a graphical dependence, which is shown in Fig. 2.

Using the obtained data about the bus's position coordinates in certain periods of time and using the online resource "Elevation Maps", the value of the high-altitude position of the road had been set. Similar to the previous part of the research, the HRV of drivers was recorded during this study. Based on this, the dependence of the driver's SI change on the road`s high-altitude position is established (Fig. 3).

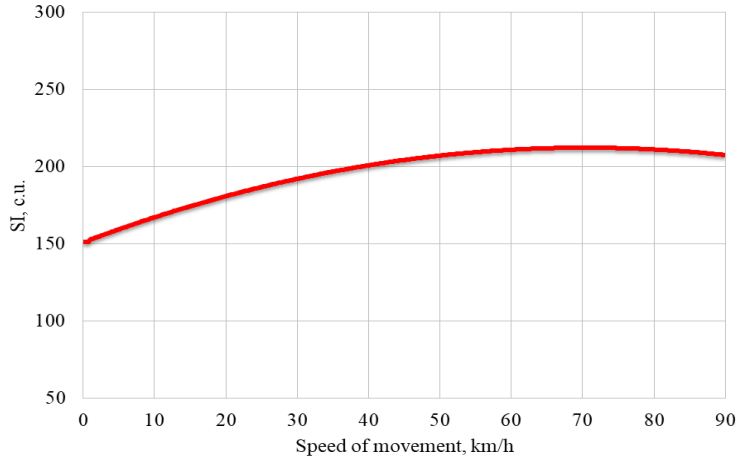

Fig. 2. Change of the drivers` SI under the influence of the bus movement speed

Another indicator that was taken into account in these studies was the duration of drivers` work. It affects the reliability of his work and the probability of error-free operation in the different conditions of movement. In this case, the researches were carried out on a common section of the routes – from Lviv to Sambir cities. The average duration of movement, in this case, ranged from 65 to 70 min. The established dependence of the change in SI is shown in Fig. 4.

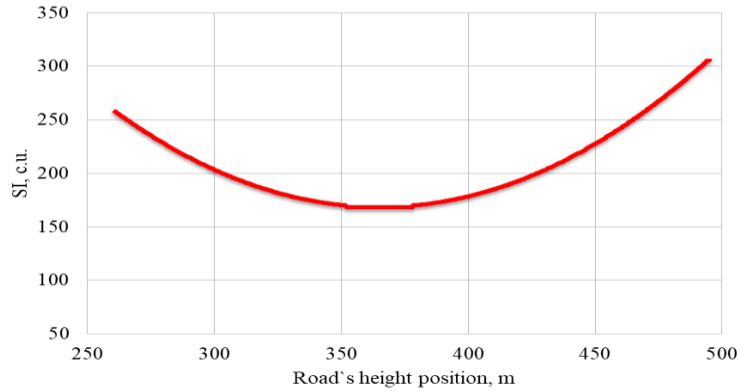

Fig. 3. Change of the drivers` SI under the influence of the road`s high-altitude position

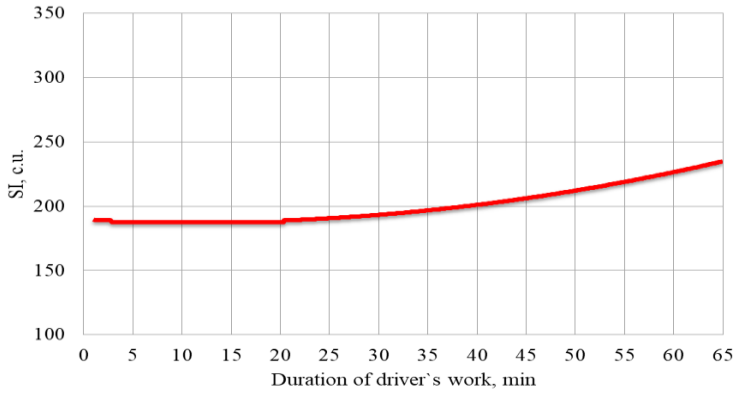

Fig. 4. Change of the drivers` SI under the influence of his work duration

According to the data shown in Fig. 4, bus drivers were usually in a state of the adaptation mechanisms` tension at the beginning of the working period. At the same time, after the start of the driver`s work, the value of his SI increased by about 25% and could approach the value of 250 c.u.

Discussion of the study results

Based on the conducted research, the HRV indicators used to calculate the drivers` SI are established. Accordingly, to this, graphic (Fig. 2-4) and mathematical dependencies were created. Thus the change of driver`s SI depending on the bus`s movement speed has such mathematical expression:

$$SI = -0.0124V^2 + 1.7391V + 151.23, \qquad (2)$$

where V – bus speed, km/h.

The coefficient of determination value of the dependence given in formula (2) is 0.74. Given the fact that transport systems are quite probabilistic, this value can be considered as acceptable. Also, from the data shown in Fig. 2, it is established that at lower values of the bus's speed, the driver's SI is lower and increases with increasing speed parameters. This confirms the effect of speed on the driver`s FS, as its growth requires more attention from the operator. At the speed of the bus 0, passengers were boarding and alighting, and the driver's body in these conditions was able to restore its resources for adaptation.

The change of driver`s SI depending on the road`s high-altitude position has such mathematical expression:

$$SI = 0.0082H^2 - 5.9973H + 1263, \qquad (3)$$

where H – the road`s high-altitude position, m.

The coefficient of determination value of the dependence given in formula (3) is 0.78. From the data shown in Fig. 3, it is established that the driver's body was in a state of stress and overstrain of adaptation mechanisms. In such conditions, the SI values were observed on sections of roads that were at an altitude of 250-320 m and 420-500 m. This is due to the fact that in the first case, the road passed through transitional settlements, and the distances between them were small. This required the driver to pay more attention. Instead, road conditions became more difficult in the second case, and visibility distances decreased, frequent changes in the road plan and profile appeared, etc.

The change of driver`s SI depending on the duration of his work has such mathematical expression:

$$SI = 0.0166T^2 - 0.3845T + 189.68, \qquad (4)$$

where T – duration of driver`s work, min.

The results of the study indicate that the duration of work significantly affects the driver's SI. Accordingly, it can be concluded that the driver`s working time should be organized, taking into account his FS and working conditions.

Conclusions

The research of the bus driver`s FS was carried out on long-distance routes that had similar parameters. During the analysis, the routes length, number of transport stops and duration of the movement was taken into account. This study involved drivers aged from 32 to 55 years and with more than ten years of driving experience.

The Polar H10 device was used to study drivers' FS. This made it possible to record the values of HRV. This data was digitized using the online resource "Cardio Mood" and processed in the Microsoft Excel software. There

were taken into account only that HRV indicators which are necessary to determine the driver`s SI.

After analyzing the obtained values of SI, it was found that it ranged from 87 to 342 c.u. Based on the collected data, graphic and mathematical models were created. They show the change of the bus driver`s SI depending on the following factors: the speed of the bus, the road`s high-altitude position, and the duration of work.

The obtained dependencies allow creating recommendations about the need to take into account the conditions of the driver`s work while creating schedules of his work and rest. This will reduce the negative impact of external factors on the bus driver`s FS and, as a consequence, increase the reliability of his work and reduce the probability of traffic accidents appearance.

Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Умови руху автобуса та їх вплив на функціональний стан водія

Анотація. Проблема. *Дослідження чинника людини у транспортних системах набувають все більшої актуальності. враховуючи зростання рівня автомобілізації та розвиток транспортної галузі загалом. Відповідно до цього постає завдання. щодо забезпечення належного рівня безпеки руху. На сьогодні у цій сфері зазвичай першочергово враховують особливості дорожніх умов та конструктивні параметри автомобільних доріг. проте часто упускають роль «фактора людини». При цьому. з розвитком методологій*

та технічних засобів. ці питання піддаються дослідженням та частково вирішуються. Таким чином. під час розгляду питань щодо забезпечення безпеки дорожнього руху. необхідно приділяти значну увагу ФС та психофізіологічним якостям водіїв. надійності роботи. чинникам негативного впливу на їх організм тощо. ***Мета.*** *Метою роботи є встановлення закономірності зміни ФС водія який керує автобусом під впливом різних чинників умов руху.* ***Методологія****. Прийняті в роботі підходи. які необхідні для вирішення поставленої мети. базуються на теоретичних та практичних засадах щодо визначення показників ФС людини під час виконання професійної діяльності. їх нормативних значень. допустимих діапазонів змін тощо.* ***Результати.*** *Отримані математичні та графічні залежності враховують вплив таких чинників як: швидкість руху автобуса і висотне положення автомобільної дороги та тривалість роботи водія. на ФС оператора цього транспортного процесу. В якості індикатора стану водія обрано ІН. Встановлено. що в цих умовах його значення коливаються в межах від 87 до 342 у.о. Виявлено що зростання швидкості руху призводить до підвищення ІН водія приблизно на 35%. Під час аналіз статистичних даних. також встановлено. що найбільші значення ІН спостерігалися на ділянках доріг на висоті 250 – 320 м та 420 – 500 м. над рівне моря. При зростанні тривалості роботи водія. значення ІН збільшувалося приблизно на 25% та могло наближатися до значення у 250 у.о. Відповідно до вищезазначеного. можна стверджувати наявність впливу умов руху та роботи водія на його ФС.* ***Оригінальність.*** *Отримані закономірності відображають вплив умов праці водія на показник його ФС. який у знаній мірі впливає на ймовірність безаварійної діяльності та. як наслідок. на безпеку всіх учасників дорожнього руху.* ***Практичне значення****. Отримані результати дозволяють створювати рекомендації. щодо врахування умов руху на маршруті та роботи водія під час створення графіків його роботи та відпочинку.*

Ключові слова: *функціональний стан. водій. умови руху. електрокардіограма. індекс напруження.*

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