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SURVEY OF DRIVER'S FUNCTIONAL STATE CHANGE, CONSIDERING MOVEMENT THROUGH MOUNTAIN PASSES

Summary. *According to traffic accident statistics, the main causes are violations of traffic rules. Based on scientific research, it is clear that the main reason for these events is the drivers' incorrect assessment of the road situation and their inadequate response. Assessing road conditions depends on drivers' qualifications, skills, work experience, reaction time, and other physiological factors. The functional state of drivers is important to consider. It reflects their ability to work reliably and affects both fatigue levels and how fatigue builds up. Factors that impact decision-making speed and quality are crucial when evaluating the risks of the transportation process, particularly those associated with human behavior. This study investigates the safety of freight transportation for drivers, road users, third parties, and the environment. The study focuses on road traffic characteristics in mountainous conditions at high altitudes. The study aims to analyze how drivers' performance is affected while navigating challenging sections of mountain roads in the Ukrainian Carpathians. Four different routes will be examined. The research will provide graphic analysis of the results. It will show the main patterns of changes in drivers' functional state based on the route's complexity. The research aims to analyze indicators of drivers' functional state and their impact on their performance reliability. It allows for a more detailed evaluation of transport routes and planning of truck drivers' work and rest schedules on suburban routes.*

Key words: *stress index, functional state, mountainous terrain, highway, freight transportation, human factor.*

1. INTRODUCTION

Currently, there is a decreasing amount of scientific research on how human behavior affects traffic safety. Many international scholars are now studying autonomous vehicles like cars, buses, and trucks. In many countries, the driver`s role in transportation safety will continue to be important for the next decade. Delays in deploying technology and high transportation costs hinder autonomous driving.

Within the traffic system, the driver is the least studied element responsible for controlling certain aspects of this system. Therefore, the relevance of research in this field is unquestionable. Despite some scientific findings by domestic [1–2] and international researchers [3-4] on the influence of human factors on road safety, there is a need to explore this area.

2. RESEARCH STATEMENT

Research focusing on assessing the psychophysiological characteristics of drivers is widespread in Latin America, China, and Europe [4-6]. One of the most valuable results is the datasets accessible in PhysioNet SRAD (drivedb) [7]. This dataset comprises over 1000 cases of vehicle operation under varying stress levels. The objective of many studies is to measure changes in driver stress across different road

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conditions and compare them with the results available in PhysioNet's SRAD (drivedb). An example of output from such a database is illustrated in Fig. 1.

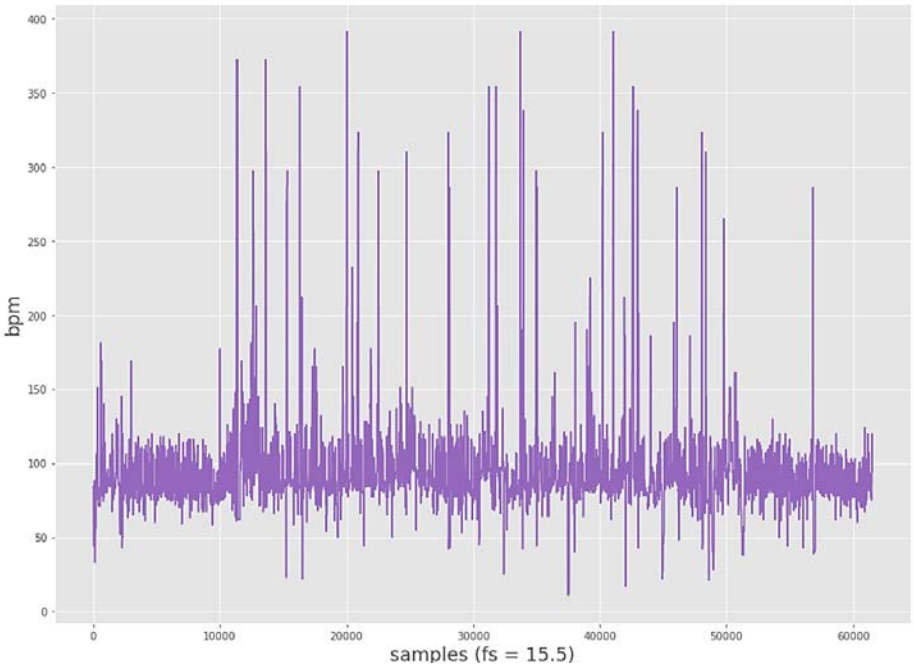

Fig. 1. Research results on changes in drivers' heart rate rhythm under complex road conditions according to drivedb. [8]

This dataset is notable for being a benchmark to differentiate stress levels in three scenarios:

3) city driving;
4) highway driving;
5) resting state.

When discussing different research conditions, referring to the drivedb dataset may not always be appropriate, as there is a lack of clarification regarding road altitude or weather conditions.

Unlike in [8], the functional state indicator (FS) may not be simply the heart rate but rather the intervals between heartbeats (RR), as shown in Fig. 2 and explained in [9].

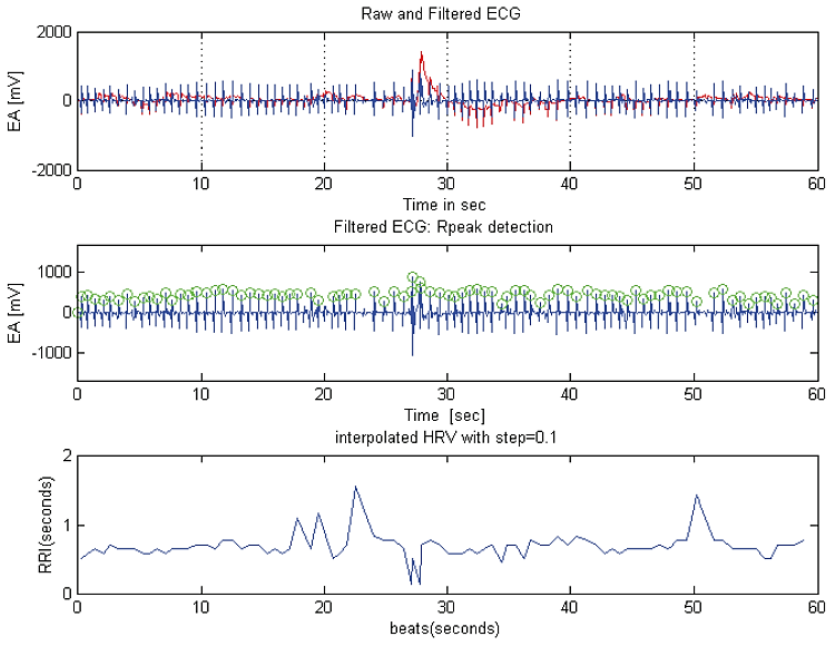

Fig. 2. Determining drivers' stress levels using electrocardiography based on RR interval analysis [9]

Movement under non-standard conditions and its impact on changes in drivers' psychophysiological indicators have also been investigated. For example, in studies [10–11], driving in mountainous terrain was examined based on observations of driver attention. These studies primarily focused on identifying patterns of fixation point distribution during movement along horizontal curves.

The most relevant study to this investigation, as presented in [12], involves analyzing changes in drivers' fatigue indicators during movement at high altitudes (Fig. 3).

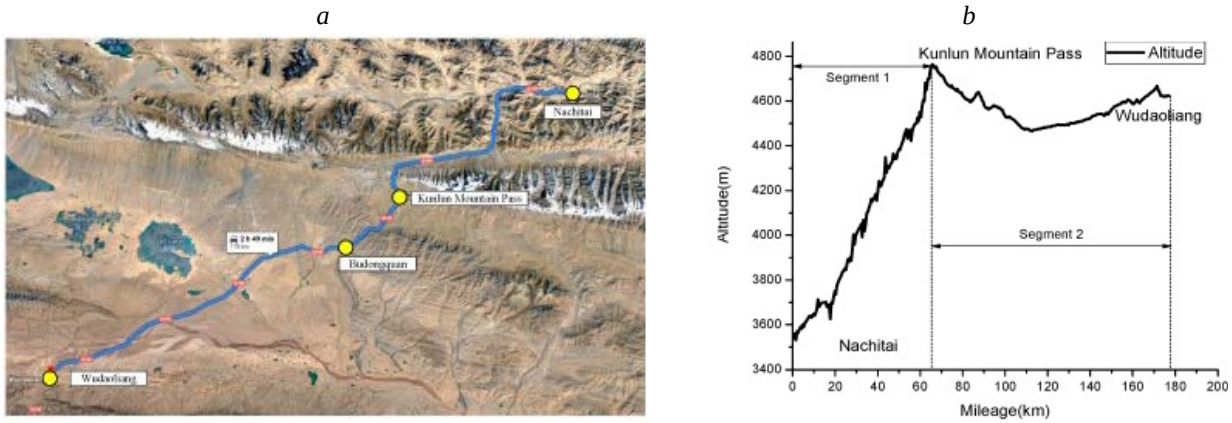

Fig. 3. Experimental route layout (a) and altitude profile graph (b) [12]

This study was conducted on roads in China that traverse high-altitude mountain ranges at elevations ranging from 3500 to 4800 meters above sea level. The researchers aimed to determine the impact of atmospheric conditions (air pressure) on drivers.

Researchers in Ukraine conducted a study [13] to examine how drivers' FS changes at various altitudes in the Carpathian Mountains. However, instead of using a comprehensive metric, they focused on heart rate frequency as an indicator of stress for the drivers.

The importance of studying the psychophysiological characteristics of driver performance is confirmed in the referenced studies. Nonetheless, significant differences were observed compared to this research, such as the altitude range in [12] and the insufficiently informative nature of FS change indicators in [13]. The professional characteristics of drivers, the type of vehicle being driven, and the range of measurements are also pertinent. This article proposes short measurement ranges to focus on overall driver fatigue levels and on peak stress levels arising from challenging road conditions in the Ukrainian Carpathian mountain passes at 800–1000 meters above sea level. The relevance of the article's topic and scientific direction can be emphasized, considering previously obtained results and their deviations from expectations.

Based on the analysis of the current state of research, this study`s objective is to identify patterns of change in drivers' FS when traversing low-altitude mountain passes.

The study focuses on light-duty truck drivers navigating mountainous roads, investigating changes in their level of fatigue.

The following tasks need to be addressed to achieve the research objective:

6) select segments of mountain roads differing in altitude characteristics but similar in length and road conditions;
7) collect data and perform statistical analysis using the driver's FS evaluation methodology and key indicators;
8) identify patterns of FS change for each of the investigated segments of mountain roads, enabling the determination of how route parameters influence drivers' levels of functional strain.

The expected outcomes of the conducted research and its analysis include conclusions regarding the impact of vehicle direction (ascent or descent) and route steepness on drivers' FS in light-duty trucks.

3. CHARACTERIZATION OF RESEARCH OBJECTS AND METHODS

Three travel routes where drivers from an office supplies distribution company operate were selected to conduct a comprehensive assessment of the impact of specific segments of mountain roads. The selection of study segments was guided by the following algorithm:

9) length of 20–25 km;
10) presence of switchback turns (serpentine);
11) low driving speed;
12) both ascents and descents present;

The data for segments on these routes are provided in Fig. 4.

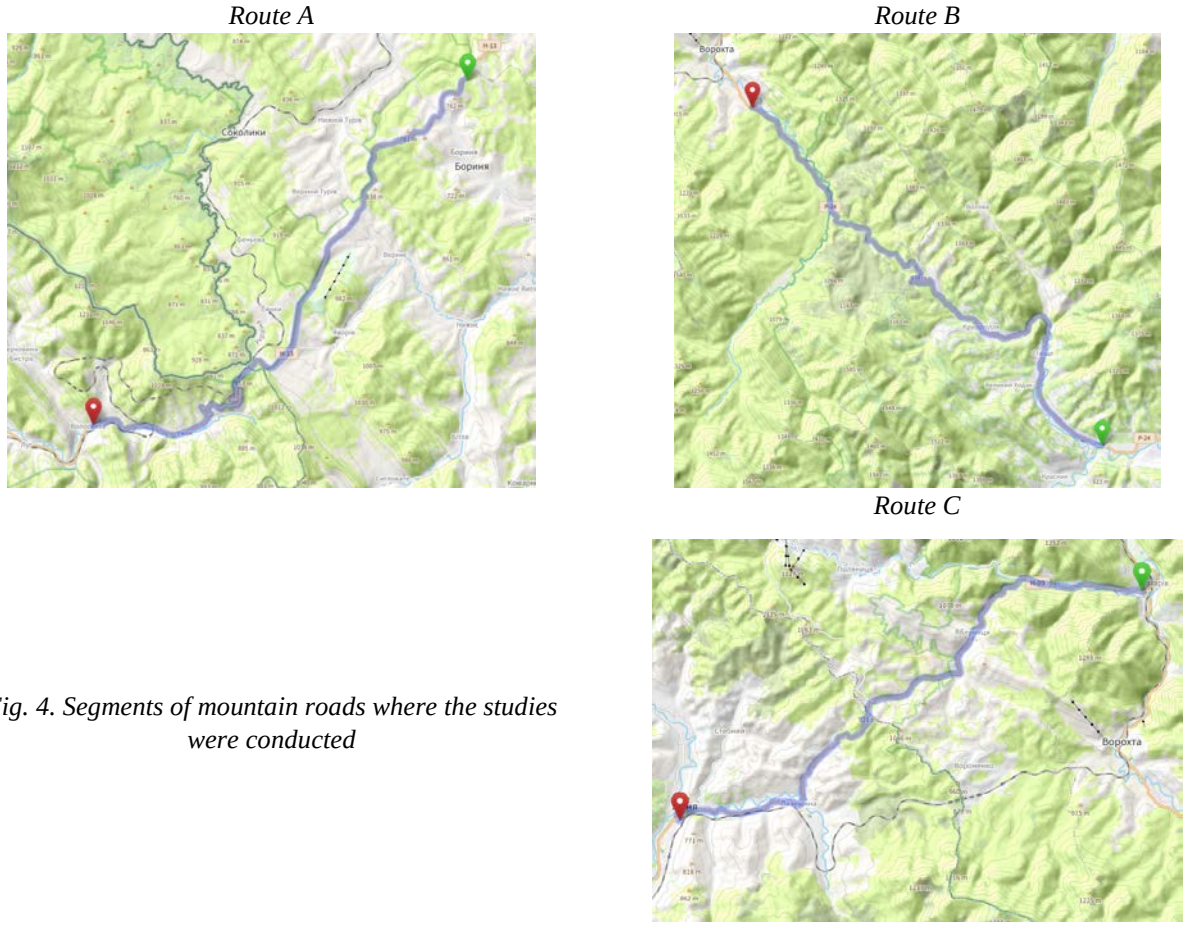

Fig. 4. Segments of mountain roads where the studies were conducted

The road segments under investigation display different road surface conditions and pass through mountainous areas. Small settlements are partially passed through, but their role in the overall driver's experience is not decisive due to the relatively low driving speeds. The terrain relief in the Ukrainian Carpathian Mountains is similar across all road segments. Each approach to a pass is generally less steep than the subsequent descent.

The studied segments of mountain roads are of national and regional significance and, therefore, not designed for high speeds, owing to the route's challenging terrain. The research was done in dry and clear weather, and road visibility was limited by its geometry, not the weather.

A detailed characterization of these road segments, including the main geodata and road profiles, will be presented in comparative Table 1. This table includes data from the OpenStreetMap application, including elevation marks at the beginning, end, and pass of each studied segment. Only route A is less than 900 meters, but in mountainous areas, complexity is determined by relative changes in elevation rather than absolute altitude.

Table 1

Trasological Comparison of Investigated Segments of Mountain Roads

Segment	**A**	**B**	**C**
Road	H-13	P-24	H-09
Start	Borynia	Iltsi	Tatariv
Finish	Volosianka	Vorokhta	Yasinia
Length, km	22	21	20
Starting altitude, m	684	779	690
Overpassing altitude, m	925	1004	951
Finishing altitude, m	590	651	666
Accumulated height, m	241	225	261
Altitude decrease (after overpass), m	335	353	285
Distance from start to overpass, km	14	10	12
Distance from overpass to finish, km	8	11	8
Overall slope (before overpass), ‰	17.2	22.5	21.8
Overall slope (after overpass), ‰	41.9	32.1	35.6
Slope amplitude, ‰	-24.7	-9.6	-13.9

Segment A is the most difficult because it has large changes in altitude over a short distance. Segment B has the highest elevation. Driver testing was done to assess professional qualities at the transport company. It ensures that the research results are accurate.

Drivers were tested on their knowledge of traffic rules and safe vehicle operation to assess their professional skills. Test results revealed gaps in the examined drivers' knowledge in various areas:

13) general terms and regulations (45 % correct answers);
14) left turn and U-turn (40 % correct answers);
15) road markings (18 % correct answers);
16) prohibitory signs (27 % correct answers);
17) traffic regulation and intersection crossing (50 % correct answers);
18) towing of vehicles (27 % correct answers);
19) speed limits (9 % correct answers);
20) vehicle operation (55 % correct answers);

For the research, drivers who scored above 60 points in a four-level test were selected, specifically nine drivers out of twenty-five, who achieved the highest scores in the theoretical test.

The vehicles they operate are light-duty cargo vehicles of the 6th generation Iveco Daily model from 2015–2019 with a manual transmission, a 3.0-liter diesel engine, and a payload capacity of up to 4900 kg. The vehicles are modern, ergonomic, have a curb weight of up to 7200 kg, and have sufficient engine torque, making them well-suited for mountainous terrain. These vehicles can't brake on mountains because this feature is not included in the factory configuration.

The stress index (SI), or regulatory stress index, is the best indicator of drivers' stress levels, quantitatively assessing their functional and psychoemotional stress levels. In a state of calm and moderate tension, its value should not exceed 100-150 units. Heart rate variability indices were recorded using the Polar H10 device [14], and the results were analyzed using Kubios software [15].

During mountain driving, drivers activated a specialized mobile application that began recording. Simultaneously, the journey was recorded in the Open Street Map application to synchronize heart rate variability metrics with the vehicle's position in space and time.

4. MAIN PART

The main body of research results for the three examined segments is presented in Table 2. Subsequently, a statistical analysis and visualization of the results are conducted. It is also worth noting that each timestamp corresponds to the averaged SI value of all drivers who traveled this route.

Table 2

Survey results

Travel time, min	Distance, km	SI, c.u.		
		Route A	Route B	Route C
2	1,3	94	76	80
4	2,7	99	82	89
6	3,3	95	84	86
8	5,3	102	86	85
9	6	98	120	102
10	6,6	120	144	103
11	7,3	115	158	85
12	8	125	195	108
13	8,6	183	225	104
14	9,2	228	201	108
15	10	245	192	172
16	10,6	296	186	210
17	11,2	255	177	262
18	11,9	200	155	212
19	13	164	130	188
20	13,2	135	120	165
21	14	120	125	145
22	14,5	115	115	123
23	15,2	119	96	103
24	15,9	121	84	102
25	16,5	110	93	112
26	17,2	105	80	108
27	17,8	109	89	106
28	18,5	101	87	89
29	19,2	105	90	98
30	20	110	90	84

The visualization of the obtained results, considering the altitude profile of the mountain road sections, is provided in Fig. 5–7.

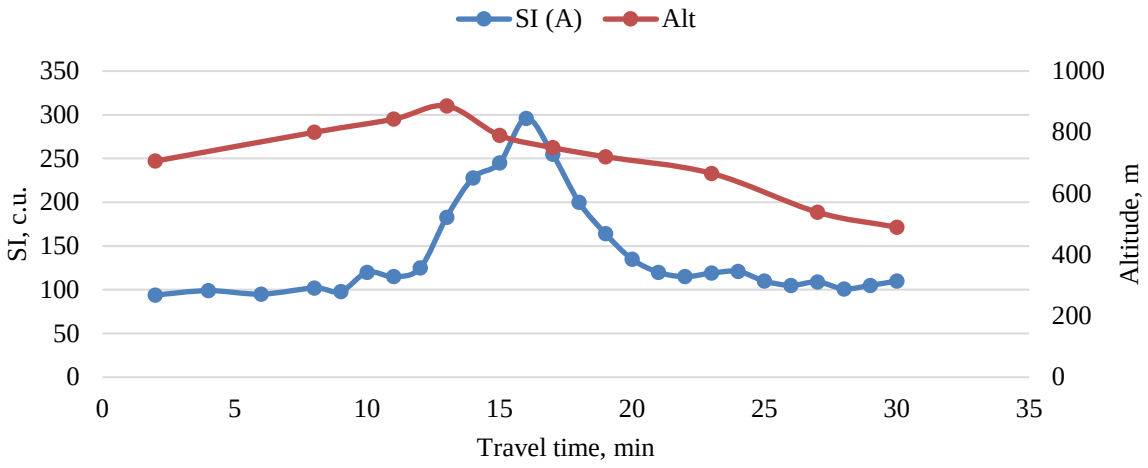

Fig. 5. The change of driver's SI on the first investigated segment (Route A)

The first study results indicate peak SI values occurring just 2 km after crossing the mountain pass, specifically on the downhill switchback section. Near the descent from the pass, SI values reach their maximum at 228–296 units, which is three times higher than the normative levels.

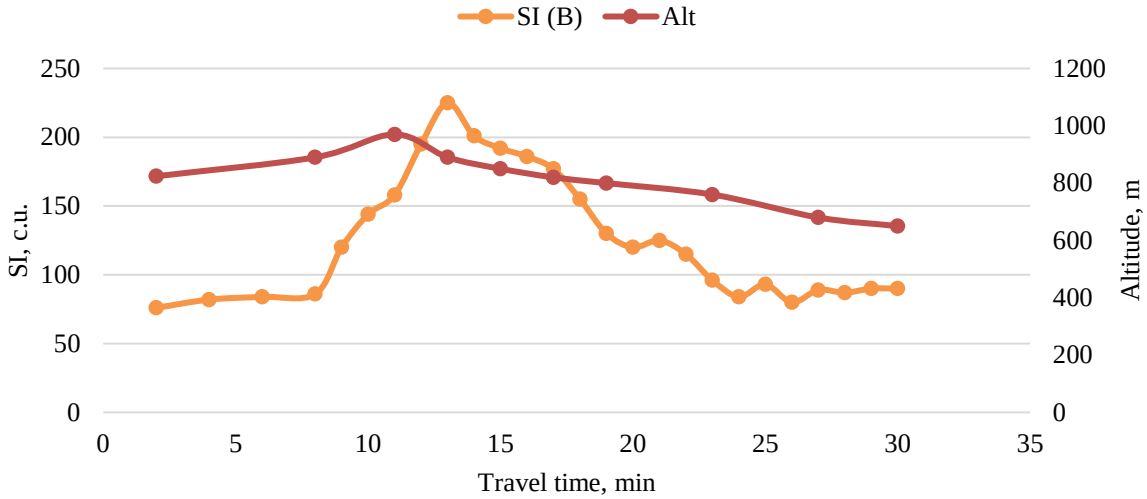

Fig. 6. The change of driver's SI on the second investigated segment (Route B)

In this scenario, the threshold SI values are somewhat lower, ranging from 195-245 units, indicating a high emotional stress level among drivers.

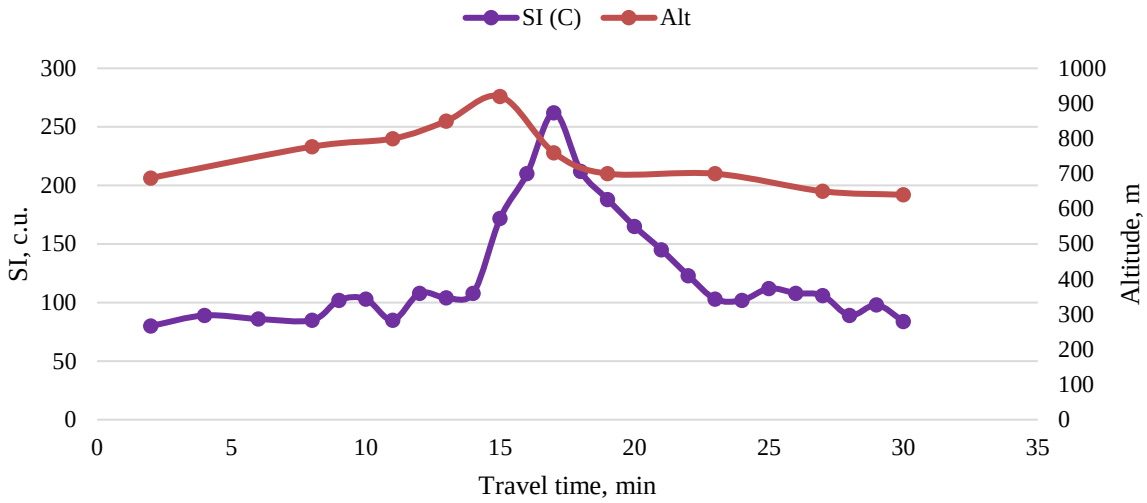

Fig. 7. The change of driver's SI on the third investigated segment (Route C)

While traveling on mountainous section No. 3, we can observe a relatively high stress level among drivers, particularly evident on the downhill section after the pass. It can be attributed to the complexity of navigating the switchbacks and tight curves. In this case, the SI fluctuates between 210-262 units.

A comparative analysis of all three sections becomes feasible due to their similar length, speed range (35–45 km/h), and comparable travel duration. The graphs also depict spikes in driver stress at pass areas and in approach sections. As seen from the figures, all three mountain road sections exhibit characteristic peaks corresponding to maximum SI values. It is explained by the fact that when driving on mountain roads in vehicles lacking mountain brakes and automatic transmissions, drivers must maintain precise control of the road and exert significant effort to maneuver trucks.

The peak SI values do not correspond to the highest point of the route, unlike the heart rate frequency in reference [13]. Instead, they occur on the most challenging section for truck maneuvering, which is the descent on the switchback. While the heart rate frequency of drivers reaches its highest point at the pass, its variability indicates that navigating the following section is challenging.

5. CONCLUSIONS AND RESEARCH PERSPECTIVES

The study provides a review of previous research related to the study of psychophysiological characteristics of drivers. During this analysis, it was found that research methodologies and their geographic locations vary, and it is important to consider regional contexts in such studies. It is particularly relevant for studies on mountain roads, as their altitude characteristics, and hence additional factors influencing drivers, differ.

The tools used in the research are described, along with the segments of mountain roads where they were conducted. Three sections of mountain roads were selected for the study: Borinya – Volosyanka, Vorokhta – Iltsi, and Tatariv – Yasinya within the Ukrainian Carpathians. All sections are approximately 20 km long, with average gradients uphill to passes at 1.7–2 % and 3–4 % downhill after overcoming the pass.

The main focus of the study is to obtain results regarding changes in the functional state of drivers specifically selected by qualification while driving in mountainous terrain. It was found that the greatest impact on drivers' psychoemotional load occurs on sections of steep descents after crossing passes. Quantitatively assessing the results, it should be noted that with normative stress index values ranging from 80–120 units, this indicator, after passing the passes and traveling down steep descents with numerous switchbacks and horizontal curves, reaches 220-300 units depending on their steepness. Increasing the gradient on the descent and making the route segment more complex can increase the SI value by 30 % compared to simpler road sections. At altitudes below 1000 m, the road height above sea level does not affect drivers' workload.

The main reasons for changes in drivers' stress index are steep gradients and the frequency and steepness of turns.

The results we got will help further research in this area because the graphs clearly show how drivers' stress levels change after passing through a mountain pass. The amplitude of drivers` stress in depends on the route's parameters.

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ДОСЛІДЖЕННЯ ЗМІНИ ФУНКЦІОНАЛЬНОГО СТАНУ ВОДІЇВ ПРИ РУСІ ЧЕРЕЗ ГІРСЬКІ ПЕРЕВАЛИ

Анотація. *Зважаючи на статистику дорожньо-транспортних подій, основними їх причинами є порушення тих чи інших правил дорожнього руху. Але, зважаючи на певний досвід наукових досліджень у цій сфері, можна впевнено стверджувати, що основною причиною цих подій є неправильна оцінка дорожньої обстановки, і, відповідно, некоректна реакція з боку керуючої системи, тобто водія.*

Якість оцінки дорожньої обстановки може залежати від багатьох чинників, таких як кваліфікація водіїв, їхні навички, досвід роботи, час реакції та інші психофізіологічні фактори. Варто також окремо виділити функціональний стан як індикатор надійної роботи водіїв, оскільки від нього залежить не лише рівень втоми, але і динаміка її накопичення. Ці чинники впливають на якість і швидкість прийнятих рішень і є вирішальними аспектами оцінювання ризиків транспортного процесу, пов'язаних, власне, з чинником людини.

У роботі проаналізовано технологічний процес вантажних перевезень з погляду його безпеки як для водія, так і для інших учасників дорожнього руху, а також третіх осіб та навколишнього середовища зокрема.

Дослідження охоплює окрему тему особливостей дорожнього руху в гірських умовах, частково обмежених, зі значним регіональним контекстом, оскільки ці умови є особливими й унікальними для доріг, які проходять значними висотами відносно рівня моря.

Завдання дослідження – вивчення зміни функціонального стану водіїв під час проходження складних ділянок гірських доріг на прикладі чотирьох досліджуваних маршрутів, які пролягають Українськими Карпатами. Очікувані результати досліджень – їх графічний аналіз, який допоможе визначити основні закономірності зміни функціонального стану водіїв залежно від складності маршруту.

Також у дослідженні акцентовано на виявленні відносних значень показників функціонального стану водіїв, які прийнято вважати індикаторами їхньої надійної та безвідмовної роботи. Це дасть можливість детальніше оцінити маршрути перевезень та планувати періоди роботи і відпочинку водіїв вантажних автомобілів на заміських маршрутах.

Ключові слова: *індекс напруження; функціональний стан; гірська місцевість; автомобільна дорога; вантажні перевезення; чинник людини.*