Для підвищення рівня безпеки руху поїздів розроблений алгоритм моніторингу стану машиніста з використанням індивідуальної норми та математичної моделі системи контролю операційної діяльності. Винайдено механізм визначення ступеня відхилення від нормального стану для конкретного машиніста у процесі ведення поїзда. Запропоновані обґрунтовані рішення щодо відповідного коригування його дій. Представлено перспективний напрямок підвищення надійності «людського фактору» в управління тяговим рухомим складом без застосування додаткових технічних пристроїв, які підвищують психофізіологічне навантаження машиніста

Ключові слова: машиніст поїзда, індивідуальна норма, людський фактор, безпека руху, моніторинг стану, контроль пильності

Для повышения уровня безопасности движения поездов разработан метод мониторинга состояния машиниста с использованием индивидуальной нормы и математической модели системы контроля операционной деятельности. Разработан механизм определения степени отклонения от нормального состояния для конкретного машиниста в процессе ведения поезда. Предложены обоснованные решения по корректировке действий машиниста. Представлено перспективное направление повышения надёжности «человеческого фактора» в управлении тяговым подвижным составом без применения технических устройств, увеличивающих психофизиологическую нагрузку на машиниста

Ключевые слова: машинист поезда, индивидуальная норма, человеческий фактор, безопасность движения, мониторинг состояния, контроль бдительности

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DEVELOPMENT OF THE METHOD OF EFFICIENT MONITORING OF THE MAIN ACTIVITY OF A TRAIN DRIVER

V. Samsonkin
Doctor of Technical Sciences, Professor, Academician of the Transport Academy of Ukraine
Department of Organization and management
State Economy and Technology University of Transport
M. Lukashevich str., 19, Kyiv, Ukraine, 03049
E-mail: samsonkin1520mm@gmail.com

Y. Petinov
Master, Train Driver
Railway engine shed Kiev-Passenger
South-West Railway
P. Krivonosa sq., 4, Kyiv, Ukraine, 03035
E-mail: ustas-ural@mail.ru

1. Introduction

Functioning of the rail transport is directly connected with the risk as a result of the action of many objective and subjective factors. This is unavoidable; therefore, accidents at transportation are completely objective. Due to this, the problem of ensuring the safety of the transport systems will always be urgent.

Accidents involving railway transport both in Europe and in Asia, Australia, and America [1–4] happen through the human fault or a "human factor" in 70–90 % of the cases by different estimations.

The introduction of high-speed motion on the world railroads of peace led to the need for the additional safety measures of the motion. Under these conditions, the activity of a train driver is becoming increasingly important, taking into account the constantly growing moral-psychological and professional-technological loads [5].

A number of transport accidents is not decreasing while their toll is increasing: according to the data on international catastrophes database of the Center of studies of the epidemiology of emergencies [6], over 100 years (from 1910 to 2009) on the world railroads a number of catastrophes, in which 10 people died and/or more than 100 people were injured, is steadily increasing from 23 in the period of 1910–1949 to 467 in 1970–2009.

Furthermore, the overwhelming majority (87 %) of transport railroad accidents in Europe, reflecting the worldwide tendencies, present the two most dangerous kinds [7]: collisions and trains derailing (61 %) and accidents at the level crossing (26 %). Therefore, it is becoming increasingly urgent to develop new approaches to ensuring the effective control in the main profession responsible for providing the safety the train motion – that of a train driver.

2. Analysis of scientific literature and the problem statement

The traditional technical means of guaranteeing control of a train driver vigilance, by which the majority of the units of the traction rolling stock of the most developed railroad companies (in Europe, Asia, USA) are equipped, did not principally undergo substantial changes in recent decades. Only the beginning of the application of control system of the trains motion ERTMS/ECTS (and of its analog in the USA) led to a certain development of these traditions [8, 9]. They are based on the simplest principles of wakefulness control by, for example, the pressure in the specific situations of buttons, handles, pedals, etc. [10].

Besides, Complex standardized safety device (further – CLSD-S) [11, 12], the innovations of which are the possibility of applying an electronic card, algorithms of vigilance checking when moving against forbidding signals, the signs of a speed decrease, etc. can be referred to contemporary devices.

A Telemetric system of wakefulness control of a train driver (TSWCED) [13] approaches somewhat closer to monitoring the "human factor", offering the original technology of defining the physiological state of active wakefulness. Using it, a train driver is rarely distracted to the periodic vigilance checks and gets less tired.

In the study [14], the wide spectrum of computer onboard systems, used by traction rolling stock driver, is examined: the system of control of devices and the system of interaction of the locomotive with the infrastructure. However, among the examined devices, the systems of control of the functional state of a train driver are not used.

The interrelation between the design of transport vehicles and the road infrastructure, their state and the fatigue of a human, controlling the means of transport, which leads to the emergency, was investigated in [15]. The methods and mathematical models of estimating and forecasting the failure rate of the human operator of transport vehicle is suggested. The model is also based on the statistical approach. At the same time, the concept of individual standard is not examined here and the practical interest is more focused on the field of automobile transport.

The behavior of a train driver at a railway crossing is analyzed in detail in [16]. The concept of a standard is also used, but the problem statement is significantly limited and does not cover a wide spectrum of the investigated problem.

In [17] the behavior of a human controlling a means of transport regarding the warning devices is examined. Existing and new variants of these devices are compared. This work is of interest within the investigated problem, but the scope is limited as it studied only one of many other elements which closely interact with a human who drives a transport vehicle.

The general transport cycle in real time is examined in [18]. A special attention was paid to the interaction between the train driver and the dispatchers, the control system of the train motion with the subsystem of providing the urgent information for a train driver was suggested. The quality of the train control by train drivers is examined only briefly, without taking into account their specific features.

The authors of the study [19], who distinguished one of the basic elements – the transport noise – came somewhat closer to the investigated problem. Noise has a harmful influence on the psycho-physiological state of engine-drivers.

In [20] it was established that an increase in the duration of a work week, a lower educational level, family problems, employment on the temporary contract are the factors of the potential risk for the negative attitude of train drivers to their work. This directly influences the quality of their work, the safety state and labor protection.

At the same time, neither the existing means nor latest developments solve the common problem of high level of accidents involving rail transport. The used appliances and devices are based on the average statistical approach of the determination of a train driver's state. They do not consider individual features, which is a crucial moment of ineffective application of the methods of control of the state in real time. It is a train driver, who is a kind of the last instance when making a decision regarding the train control. Whether s/he will reach the destination station safely depends on the totality of individual features and the actual state at a certain moment.

Therefore, monitoring of the state of a train driver that considers many factors of the external (the infrastructure, the interference of operational – dispatcher apparatus, the stress factors, etc.) and internal medium (the actual psycho-physiological state, the level of tiredness and others), its individual features, is a complex and urgent direction of raising the safety level of motion on the rail transport.

3. The purpose and objectives of the study

The conducted research set the aim of developing an effective method of monitoring professional activity of a train driver directly regarding the train control with the use of individual standard and contemporary digital automated instruments and devices of traction rolling stock.

To achieve the aim, the following tasks must be solved:

– selection of parameters of control, methods of their obtaining, updating the individual standard;

– development of the criteria of evaluation of a train driver's state;

– substantiation of justified interference in the actions of a train driver.

4. Materials of designing a method of monitoring professional activity of a train driver

Control of traction rolling stock of the main rail transport (further – "train control") is a complex dynamic system of indistinct processes, which includes a great number of internal and external factors.

The responsibility for the direct train control lies with a train driver (a motor– carriage or a special self-propelled rolling stock). The final result of this transport process implies: safe train motion, health and life safety of passengers, the integrity of the transported load and of a rolling stock, transport infrastructure, etc.)

Taking into account contemporary tendencies of a substantial increase in the speeds of the trains motion, the complexity of construction and the systems of controlling the rolling stock, lengthening of traction arms, the increase in psycho-physiological load on a train driver, providing the train motion safety is becoming increasingly complex. The existing methods of a train driver's vigilance control have obviously become outdated, they do not meet considerably changed conditions of the medium and technological parameters, they are based on the stereotype averaged ideas and technical devices.

4. 1. Source material for developing a method of control

Examining the ergatic system "a traindrive" – "a locomotive" – "infrastructure", let us determine the most efficient way of controlling its most unreliable link – a train driver.

It is known from the theory of control that meeting established requirements by any system is determined by the comparison with the standard. In this case, the main characteristic in the aspect of the investigated problem is the train motion safety. By normalizing the safety of a transport system, the establishment of the regulated requirements for its components, which are important for ensuring safety, is understood.

On the basis of special features of the operational work and the effectiveness of control, the actual speed of the train motion at a certain moment is defined as the most important component for monitoring organization.

In our study, "the standard" of the operating activity of a train driver regarding direct control of the locomotive implies a stereotype of controlling the train. It is determined by the indicator of adequate state of the investigated system: "standard as functional optimum", i. e. the zone of the optimum functioning in the interaction with environment. Further, for the sake of brevity, we will use the term "standard" or "individual standard", which is always used in the sense of the "functional optimum".

Because as the input parameter, the actual speed of the train motion ν is chosen, the basic control parameter – the difference of the actual and set speeds at a moment of time t is determined by the expression:

$$\delta_t = (\nu - \nu_z)_t. \tag{1}$$

Then, in accordance with the theory of norm [21], the rule of formation of functional optimum will be as follows:

$$F_{Opt} = \left[\overline{\delta_i} - \sigma_i, \overline{\delta_i} + \sigma_i\right], \tag{2}$$

where $\overline{\delta_i}$ and σ_i are respectively arithmetic mean and mean-square deviation of the set M_i.

Depending on the set speed ν_z^i, the totality of the control parameter values δ_t will be stored and processed in the appropriate set M_i. In this case, the sets of formations of the standard M_i realize the principle of tolerance of a system approach [22].

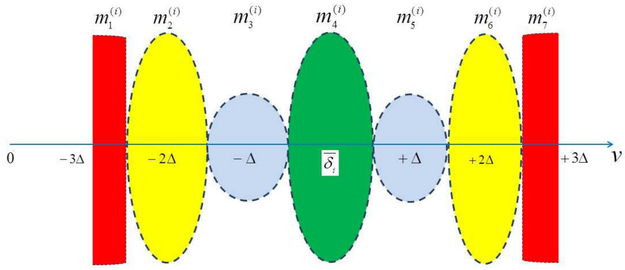

Fig. 1. Method of formation of the sets M_i of the control parameter values δ_t (with the subsets $m_k^{(i)}$: ■ – standard, ■ – preventive, ■ – warning, ■ – critical)

Let us designate the level of tolerance (discernability) by Δ:

$$\Delta = \frac{\max\delta - \min\delta}{6}, \tag{3}$$

where $\max\delta$ and $\min\delta$ are respectively maximum and minimum control parameter value δ_i with the set ν_z^i.

Then the method of formation of the sets M_i of the control parameter values δ_t will take the form, represented in Fig. 1.

The basic input parameter is the actual speed of the train motion movement ν, it is read in real time with the help of digital microprocessor device, with which the traction rolling stock is equipped (further – TRS). In this work, one of such devices – CLSD-S – was used. Interpretation and transmission of values were carried out with the help of the program CMM-S, which is a constituent of the program-apparatus part of the complex CLSD-S (green line in Fig. 2).

One of the variants of the set motion speed in certain cases can be maximum permissible speed (red line in Fig. 2) in the given section (a stage, etc.).

Fig. 2. Reading input parameters

4. 2. Designing a method of individual monitoring of a train driver's activity

To visualize the idea of the essence of the method of individual monitoring a train driver's professional activity, corresponding functional diagram, which is the algorithm of control from obtaining primary data till decision making was built up. The formalized algorithm in the form of the functional diagram is represented in Fig. 3.

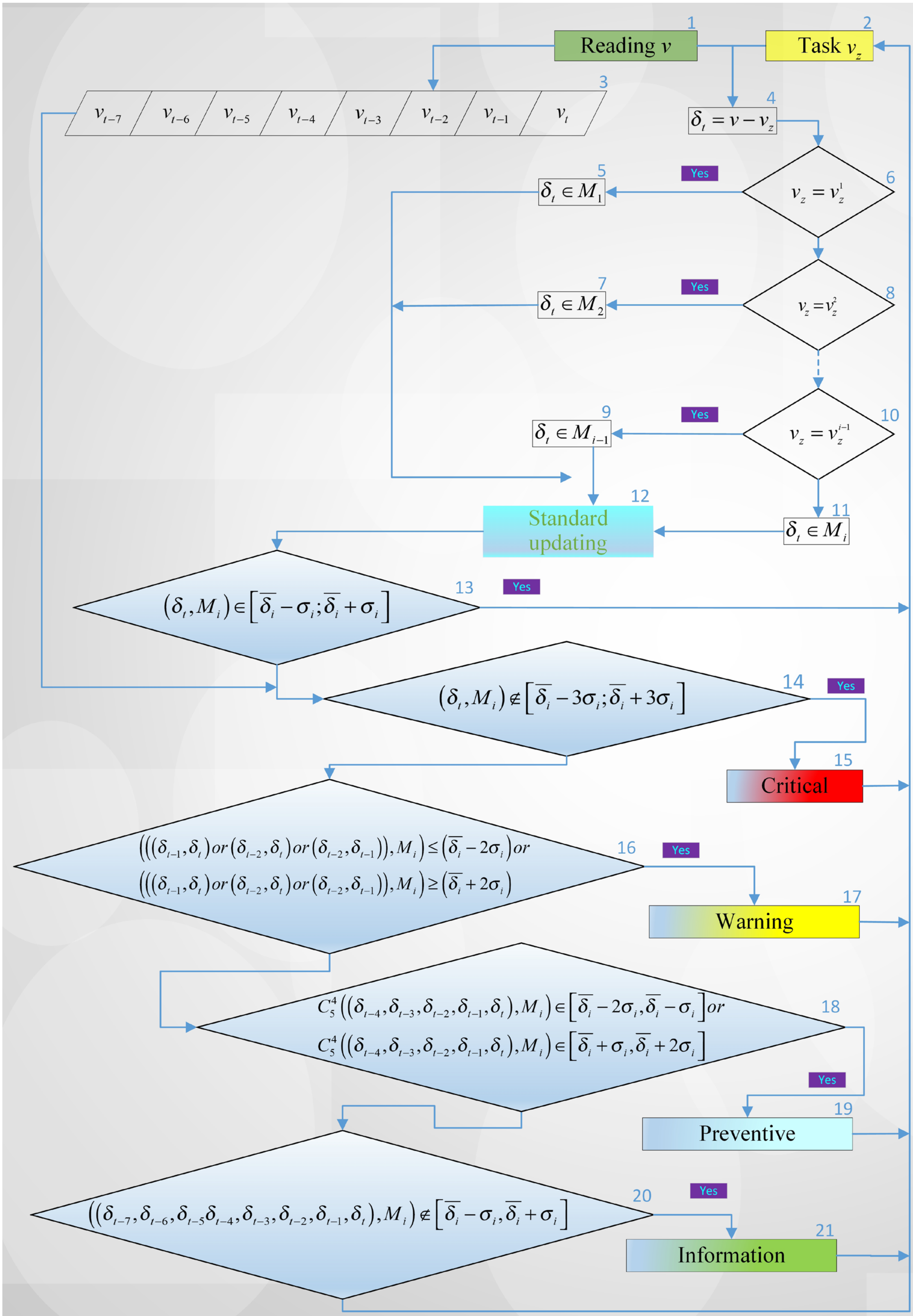

Fig. 3. Functional diagram of the method of individual monitoring a train driver's professional activity

Let us examine the diagram elements in more detail.

Unit 1: reading the basic “input” parameter – of the actual speed of the train motion movement v.

Thus, technological parameter of the operating activity, which is read automatically, independently on a train driver, is selected as the control parameter. This neither load the person with additional actions, nor distracts from the main activity, it does not involve any special measuring devices (sensors on the body, lamps / a handle / buttons on the control panel, etc.).

Unit 2: setting (calculated or maximum permissible) the motion speed. It can be automatically performed by different methods depending on the locomotive light signal, maximum permissible motion speeds according to the conditions of the infrastructure, the train motion schedule and other parameters, as well as “manually”.

Unit 3: 8 latest read values of the actual motion speed, which are used in further calculations are constantly found in the working storage of system

Unit 4: calculation of the basic control parameter δ_t in accordance with (1).

In the first case, when the set speed takes the value v_z^i, i. e. $v_z = v_z^1$, (unit 6), the control parameter enters for the storage and subsequent processing into the set M_i, i. e. $\delta_t \in M_1$ (unit 5). Similarly, the distribution by the sets M_i in units 7–11; depending on the required speed v_z^i, the set of the control parameter values will be stored and processed in the appropriate set M_i.

In unit 12, an individual standard for the correspondent set speed v_z^i is updated. It is necessary due to the fact that the standard constantly changes throughout the human life generally and the engine driver in particular. Thus, the functional optimum constantly tracks special features of professional activity of a train driver.

Updating is achieved automatically; therefore no additional actions of the personnel are necessary. Periodicity can be different: once a week, monthly, quarterly or annually. However, it is more effective to carry it out in on-line mode, i. e., after each measured control parameter value.

Then in accordance with (1)–(3), after each newly entered value of the actual motion speed v, the parameter δ_i is calculated again and the functional optimum F_{Opt} t is corrected to the appropriate actual state at a certain moment of time t. In this case, the process of changing the standard will be performed, only if there has not been any substantiated interference in the control process of the train. Otherwise, the value of standard is accepted as it was formed at the last moment preceding the interference in the control process of the train on the basis of the revealed significant deviations from the standard.

In unit 13, the main operation – the identification of the state of a train driver by comparing the space of the individual standard F_{Op} and the current deviation – the value of the control parameter δ_t at the given moment t:

$$(\delta_t, M_i) \in \left[\overline{\delta_i} - \sigma_i; \overline{\delta_i} + \sigma_i\right]. \qquad (4)$$

If (4) is fulfilled, the state of a train driver is “within the standard”, in other words, a train control process takes normal course. Otherwise, additional testing of the degree of deviation from the standard is necessary.

Thus, at this stage, preliminary estimation of the engine driver’s state correspondence to his/her standard is made. This determines the necessary but not sufficient condition for substantiated interference in the train control process.

In units 14, 16, 18 and 20, additional checking of the degree of the deviation from the standard for substantiation of making the correspondent decision regarding the correction of the train control process is sequentially performed. The methods of this checking are based on the practical application of Shewhart’s Charts [23] in the estimation of the state of the system. This is completely reasonable, since it sufficiently corresponds to the subject of the study, because monitoring is performed by the control parameters, which are random values, and the law of the probability density distribution is described by the normal law or the law of Gauss.

Four out of eight criteria of Shewhart’s Charts are used for the control of the system.

These criteria divide the set M_i (Fig. 1) into the appropriate subsets $m_k^{(i)}, k \in [1,7]$. In units 14, 16, 18 and 20, the sequential testing of four conditions according to the method of Shewhart is carried out.

The probability of the event occurrence, described in unit 14, makes 0,0027 (0,27 % of the general population of the control parameter variants) in accordance with the Gaussian distribution. In this case, a critical situation is identified: inadequate train control or the uncommon actions of a train driver because of a sudden change in the environmental infrastructure, emergency braking, slipping, etc. Then unit 15 is carried out.

Unit 16: if any two of the three sequential values of the control parameter $\left((\delta_{t-1}, \delta_t) \text{or} (\delta_{t-2}, \delta_t) \text{or} (\delta_{t-2}, \delta_{t-1})\right)$ do not fit the interval $[-3\sigma, -2\sigma]$ or $[2\sigma, 3\sigma]$, the probability of which according to the normal distribution makes 0,0428, this testifies to unsatisfactory engine driver’s state (for example, significant worsening in the wakefulness level, inadequacy of some actions regarding train control) or about random ejections. Then the system moves on to the fulfillment of unit 17.

Unit 18: if a totality (marked as «C_5^4» (Fig. 3) of any 4 out of 5 sequential values $(\delta_{t-4}, \delta_{t-3}, \delta_{t-2}, \delta_{t-1}, \delta_t)$ of the control parameter δ_t are located in the interval $[-2\sigma, -\sigma]$ or $[\sigma, 2\sigma]$ $[-2\sigma, -\sigma]$ or $[\sigma, 2\sigma]$, and the remained – in the zone F_{Opt}, this testifies to the beginning of the exit from “the space” of standard. This can be caused by the fatigue of a train driver or by random actions, etc. Then the system moves on to the fulfillment of unit 19.

And finally, in the last case, if the condition of block 20, with which 8 sequential values δ_t are located in the intervals $[-2\sigma, -\sigma]$ and $[\sigma, 2\sigma]$, the oscillating process is caused. In accordance with the theory of the stability [24], the fluctuation with the increasing amplitude testifies to the unsteady state of the system (“unstable focus”). If this situation is not interrupted, it will gradually or sharply lead to the passage into another, inadmissible state. Then unit 21 is carried out.

As a result, with the suggested method, the state of a train driver in motion can be immediately defined and making the appropriate decisions whether to interfere or, vice versa, not to interfere into the process of control can be substantiated – blocks 15, 17, 19 and 21.

In unit 15 (critical level of interference), it is necessary to provide additional checking of the reason for the fulfillment of the unit 14 conditions. For example, if a train braking (special or emergency) occurs, this is determined by the pressure sensors either in the brake cylinders or in the main brake line, or in the acceleration sensors and so on. In this case, the interference in a train driver’s actions is not required. If the value of the control parameter exceeds the "upper" limit of the functional optimum, it is necessary to verify the chance of this event. This is accompanied by a warning sound signal, voice announcement, etc. A sharp increase in the motion speed can be caused by sudden slipping. Then a train driver can confirm the adequacy of his/her actions, for example, by pressing a vigilance lever (the pedal) in response to additional checking of the control system.

This checking must be performed repeatedly in the short intervals of 5–7 seconds, but not more than twice (i. e. until the speed becomes normal). If within this period, a train driver does not take necessary measures to stop slipping, or a sharp increase in the motion speed of a train is caused by his/her inadequate state, the system will immediately start emergency braking of the train with impossibility of its interruption.

Unit 17 (preventive): it is necessary to warn a train driver about the detection of inadequate state. This can be a voice announcement, a visual signaling, a sound signal. An appropriate return action, confirming the adequacy restoration must be received in reply. For example, the decrease in the motion speeds to the set ones, special braking, etc. It is expedient to repeat the warning through the short time intervals until the exit from this state.

If the control parameter of control exceeded the upper limit of standard and, there is no reaction of a train driver after the first two warnings, the automatic emergency braking of a train with the impossibility of its interruption is necessary.

In unit 19 (preventive) the state of a train driver is additionally checked (by the sound or visual method) with the requirement of a response reaction, for example, pushing of the upper knob (handle) of vigilance.

Unit 21 (informative) does not require serious interference in the control process of a train; however, a short sound and (or) visual warning must be given to a train driver for his/her attention mobilization with likely unfavorable course of events.

5. Discussion of the method of monitoring the state of a train driver

The suggested algorithm of the vigilance control of a train driver is built with the use of existing microprocessor onboard instruments and devices of the traction rolling stock. Besides, for ensuring safety of train motion, the system approach and a corresponding mathematical model are used. This made it possible to form a fundamentally different and scientifically substantiated method of monitoring, as a result of which:

– the use of not a physiological, but a technological parameter of the control of the state of the monitoring system became possible;

– a mechanism of the determination of the deviation degree from the standard state of a train driver's behavior in the process of controlling the train is developed;

– substantiated solutions regarding the correction of a train driver's actions were suggested, i.e. the criterion of the state evaluation is differentiated;

– it was proved that the dynamic state of the system "a traindriver – train – medium" can be not only immediately and qualitatively determined, but also on this basis, it is possible and necessary to interfere in the control process of train in cases when this is objectively necessary and substantiated.

Furthermore, the developed method does not distract a train driver from the direct train control in the customary mode – no additional sensors, bracelets, buttons and handles in the operator's cab are required. Consequently, there is no need for "shunting", examining or disconnecting anything.

Thus, on the one hand, no additional psycho-physiological load on a train driver is created, and on the other hand, it does not require any significant capital investments for introducing the soft and hardware device on the basis of the developed method of monitoring.

It should also be noted that the performed developments are also based on the previously conducted practical investigations of the authors [25, 26] with the use of the accumulated experience of the operational work both personal, and that of the network. The obtained method is practical and can be integrated into the general system (totality of instruments, apparatuses and devices) of providing the motion safety of the traction rolling stock of mainline rail transport.

However, to consider the suggested algorithm to be completely comprehensive would be somewhat premature – only the main directions of making reasonable decisions regarding the correction of the train control process are suggested. For obtaining the most complete spectrum of such solutions and the concrete effective corrective influence on the control system, it is still necessary to conduct a number of scientific studies.

6. Conclusions

1. A technological, but not physiological parameter of checking the state of a train driver is selected. This considerably increases the monitoring quality and the effectiveness, and deprives a "human factor" of the possibility to negatively influence obtaining and processing the parameters of the system. The individual standard is updated in the process of dynamic monitoring of a train driver's state, which makes it possible to take the quality of control to a maximum possible level.

2. In the process of the motion safety control on the mainline rail transport, the systems approach was used in practice; this approach is based on the use of the dependence of dispersion on the functional state of the system and on the use of Shewhart's Charts. On the basis of this, the criteria of the evaluation of a train driver's operating activity are obtained. In particular, the individual standard, the current deviation and the state tension should be distinguished among them.

3. Directions of justified interference in the process of controlling the train are designated in accordance with the special features of a train driver's work under contemporary conditions. The detailed correcting actions of the system can be determined for a definite type of the TRS. The use of existing microprocessor devices on TRS made it possible to build up the algorithm of the monitoring, during which the additional load on the main activity of a train driver is minimized.

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