N. B. Chernetska-Biletska, Doctor of Science (Eng.), Professor; I. O. Baranov, Cand. Sc. (Eng.); M. V. Miroshnilova; S. G. Kuzhel

THEORETICAL SUBSTANTIATION OF «ENGINE-DRIVER-TRAIN-TRAFFIC OPERATOR» SYSTEM IMPROVEMENT

The paper presents the mathematic model which reflects various factors of negative impact on the quality of the decisions taken by the operator of the transport system, its components are: professional training, labour conditions and work place organization, operation mode and rest mode, degree of uncertainty of the information, arriving to the operator. The concept of the description of the fault-free operation system is suggested. Algorithm of obtaining different variants of operators labour activity protection against faults emergence and the algorithm of the selection of the most rational variant are determined. Analysis of the results of the social studies regarding the problems of the most labour-consuming operator functions is carried out. On the base of the analysis of the set of factors, which influence the quality of the decisions taken by the operator of the transport system, the system, providing the error-free operation of both train operator and engine-driver is suggested, the base of the system is mathematic model. Mathematic model, simulating the error-free operation of the transportation process and technical facilities with the necessary reliability, is developed. The technique of transport system operator training in order to obtain qualitative training with the needed reliability is highlighted. Reliability dependences of the transport system operator professional training on the number of training cycles and different matrices of transient probabilities are obtained, the approach, regarding the determination the time (training cycles), necessary for achieving the preset training reliability is formed on their base. The parameters of the environment which provide the necessary probability of the correctness function realization by the operator, are determined. Calculations of the resulting function of error-free work of the transport system operator, using all the elements are carried out. Optimal reliability of the operator is determined on the base of consideration of n^{th} number of different variants of the environment parameters and selection of the variant with minimal total expenses.

Key word: *rail road transport, transport system operator, mathematical model, traffic operator, professional training, correctness function.*

Introduction

Railway is one of the key branches of Ukrainian economy. Share of the railway transport at the fright market is approximately 80 %, and the share of passenger transportation – 40 %, that is why, proceeding from this, the important task is well organized functioning of all branches.

As compared with other branches of national economy, railway transport is characterized by the reliability, regularity of transportation with high speed and the level of energy expenses, wide possibilities of transportation process automation and ability to transport bulk cargoes at large distances put it at the first place in the transport system of the country.

However, special attention should be paid to the provision of the transportation security both regarding the maintenance of the transportation facilities and the improvement of the operation efficiency of engine drivers and train dispatchers.

Train movement on the section is the most responsible dynamic part of the transportation process, progress of which is determined, on one hand, by the clear interaction of the train dispatcher and engine driver and on the other hand – by the level of the professional training and coordination of the engine crew operation. The success and safety of the travel depends on the interaction of the machine driver and his assistant, how they complement one another, compensate the drawbacks, inherent each person. The coordination of the work of the engine driver and dispatcher, alertness and creativity of the engine crew, correct assessment of the situation, punctuality and high responsibility are important components of the traffic safety.

The results of the social survey, regarding the most labour-consuming dispatcher functions are presented in the form of circular diagram in Fig. 1. Selection of the variants of the dispatcher regulation of the trains handling (1) and obtaining of the information from the separate points and keeping the time schedule of the executed motion (2); train operation plan (3). Additional points are (4) the coordination of the locomotive work and collection of the data regarding the state at the stations (5) and establishment of the routes during the automatic traffic control (6).

As a result of the studies, carried out it is established that for the enhancement of the operation quality of the train dispatcher and improving his working conditions the following functions were automated [1]:

- keeping the schedule of the realized motion;
- keeping the supplements to the schedule (obtaining and recording of the data, regarding the train set);
- selection of the variants of the dispatcher regulation – on-line elaboration of the train motion schedule and its current correction (elaboration of the forecast schedule). Operation «Elaboration of the trains handling on the section at the beginning of the shift» is added;
- elaboration and registration of the traffic orders;
- preparation of the routes;
- obtaining and transfer of the information, regarding trains arrival .

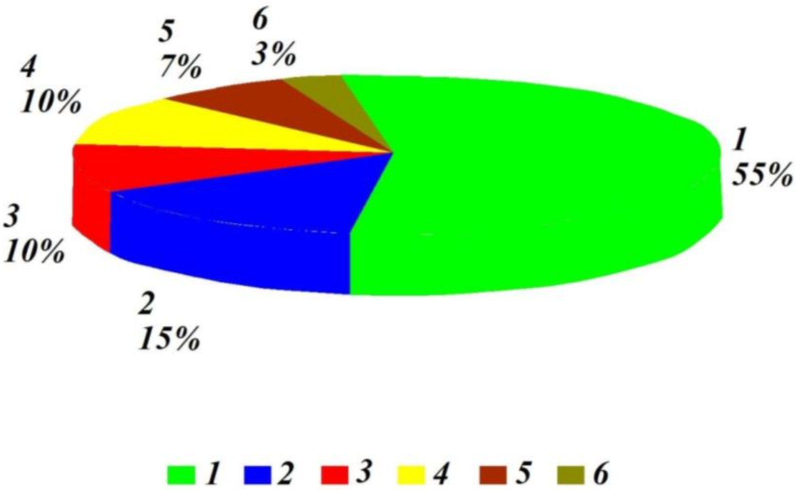

Fig. 1. Percentage ratio of the most labor-consuming dispetcher functions assessments (by the results of the social survey)

As the research showed, for the execution of the functions, suggested for the automation, the train dispatchers spend, on the whole, from 45% to 65% of the shift duration at the loaded sections with the automatic blocking or semiautomatic autoblocking, and from 50% to 70% – at the sections with the centrelized traffic control.

On totality of the factors, influencing the quality of the decisions made by the operator of the transport system (OTS), the problem of the development of the system, providing the error-free operation both of the train dispetcher and the engine driver, on the base of mathematical model, can be discussed.

It is impossible to exclude entirely the errors of the transport system operator, but it is possible to reduce them to minimum, concentrated on the qualitative index-probability of the execution by the operator of the correctness functions and considering his errors as the consequences of the protection system failures, perform the functions, entrusted on it .

The aim of the given paper is to develop scientifically-grounded complex of the technical facilities and their components, as well as organization-technical measures, aimed at the improvement of «engine-driver-train-dispatcher» system .

Modelling of the professional training process of the transport system operator

The developed mathematical model simulates error-free operation of the transportation process and technical facilities with the needed reliability.

The system for the provision of the error-free operation (EFO) of the transport system operator comprises the set of the components, that have the connections, interactions and limitations, which must provide the quality of the decisions, taken by the dispetcher at the preset level. Main components of the system are professional training (PT); labour conditions and organization of the work place (LC and WPO); mode of operation and rest (MOR); degree of the information uncertainty (DIU) that can be expressed by the dependence [2]:

$$EFO = f\left(PT, LC \text{ and } WPO, WRM, DIU\right) \tag{1}$$

In the process of the creation of the given mathematical model analytical dependences of the mathematical security (MS) theory were used [3, 4]. Such an approach on the whole is justified, because with its help the class of the system components can be mathematically described with sufficient for practical calculations accuracy. Probability of the execution of the error-free functions by the operator depends on the great number of various factors and, in general case, can be determined by the formula:

$$P_{EFO} = P_1 \cdot P_2 \cdot P_3 \cdot \ldots P_n = \prod_{i=1}^{n} P_i\,, \tag{2}$$

where P_i – probability of the execution of the correctness function by the operator, depending on the impact of the i^{th} factor; n – number of factors.

Reliability of the given system operation will be provided by the simultaneous combination of these factors. However, in case of the failure to fulfil by one of the components of the system, the efficiency of the error-free operation will be minimal (in this case, it is foreseen, that the operator of the transport system passed professional selection and is recommended for the work on such specialty). In our case P_{EFO} equals [5, 6]:

$$P_{EFO} = P_{PT} \cdot P_{LC} \cdot P_{WRM} \cdot P_{DIU}\,, \tag{3}$$

where P_{EFO}, P_{LC}, …, P_{DIU} – probability of the correctness function execution by the operator, depending on the state of the corresponding factors.

The research, carried out, showed that approximately 60% of all the errors in the work, falls on the dispatchers, whose work experience is less or equals one year, this can be explained by the insufficient professional training. The technique of the transport system operator training is given below, this technique allows to improve the quality of education.

The training process is considered as a random process, for the description and study of which the theory of Markov processes is applied, in particular : homogeneous Markov process (HMP) with the discrete states $S_1, S_2, \ldots, S_n$ and discrete time τ_0.

In accordance with this theory the training process is determined by the matrix of the transient probabilities:

$$P_{ij} = \begin{vmatrix} P_{11} & P_{12} & P_{ij} & \ldots & P_{1n} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ 0 & 0 & P_{ij} & \ldots & P_{in} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ 0 & 0 & \ldots & 0 & P_{nn} \end{vmatrix}, \tag{4}$$

where P_{ij} – is the probability of the training process transition from the state *i* into the state *j* in the time interval τ_0; «0» –is the probability of the transition from higher level to low level; n –is a number of different factors, influencing the quality of the decisions, made by the operator of the transport system.

States S_1, S_2, ..., S_n mean professional training of the operator with the probability of the correctness functions execution (probability of high quality decision making) correspondingly P_1, P_2, ..., P_n. Graph of the states of the professional training of the transport system operator is shown in Fig. 2.

States probabilities in the training process change and they are determined in the time interval τ by the formula:

$$P_i(k) = P_i(k-1)\sum_{j=1}^{n} P_{ij}(k-1), \tag{5}$$

where $P_i(k-1)$ – probability of the professional training of the dispatcher during $(k-1)$ cycles.

Curve 1 denotes the level of the professional training of the transport system operator at the phased transition from the first state to the fifth state (Fig. 3).

Curve 2 denotes the level of the professional training of the transport system operator at the phased transition from the first state into the third state, then into the fifth state.

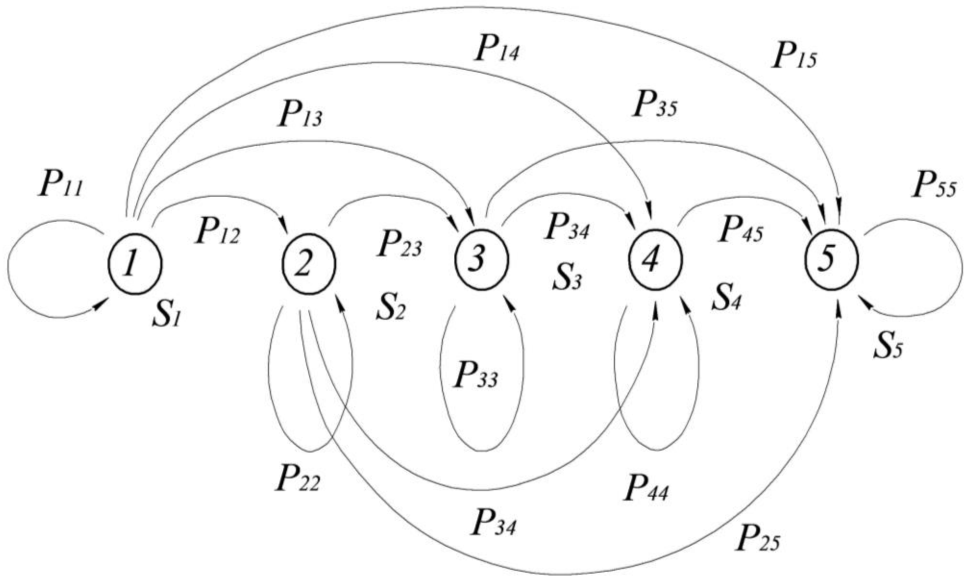

Fig. 2. Graph of the professional training states of the transport system operator

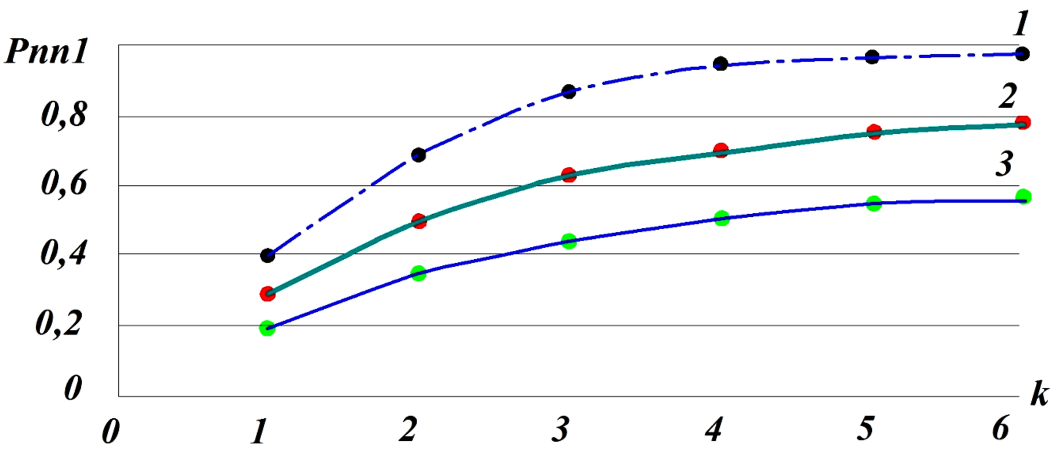

Fig. 3. Reliability dependence of the professional training of the transport system operator on the number of training cycles and different matrices of the transient probabilities

Curve 3 denotes the level of the professional training of the transform system operator at the phased transition from the first state into the second, from the second into the third state, after that from the third state into the fourth, and from the fourth state into the fifth state.

The probability of the P_{PT} value during k training cycles can be determined by the formula:

$$P_{PT}(k) = 1 - \prod_{j=1}^{k} \left(1 - P_{PTj}\right), \tag{6}$$

where P_{PTj} – probability of the professional training of the transport system operator at each cycle of training.

Taking into account the level of the initial knowledge (probability p_l = 0.9; and 0.8 is set) and the number of training cycles, by means of «STATISTIKA» program the probability of the professional training of the operator at each training cycle can be defined.

The output data are obtained as a result of the processing of the transport system operators survey (answers to the questionnaire, intended for determining the level of the professional training of the transport system operators (TSO), which contains one hundred questions): «0.5; 0.8; 0.9» – probability that the transport system operator after the training cycle did not study anything; «0.5; 0.2; 0.1» – probability that the transport system operator after the training cycle studies the material; «1.0» – probability that the transport system operator passed the course of training and did not forget anything; «0» – probability that the knowledge of the transport system operator after the training cycle drop on the level lower.

The greater the probability of the transition at the last stage to the knowledge is, the less is the difference by the degree of the reliability. The curves enable to determine how much time (training cycles) it will take to reach the preset reliability of the training.

In this case the value P_{nn} will correspond to the value $P_{nn}(k)$. Another component and at the same time the factor, determining the probability of the correctness function execution by the dispatcher are labor conditions and organization of the working place of the dispatcher.

In the given case the value P_{PT} and OPM will correspond to the value of P_i (x_1, x_2, ...x_n). Dependence of the errors emergence intensity in the work of both the dispatcher and engine driver on the parameters of the environment can be approximated by the following equations:

$$\lambda = a_0 + a_1 x_1 + a_2 x_2 + ... + a_n x_n, \tag{7}$$

where a_0, a_1, a_2, ..., a_n –are the regression coefficients, determined on the base of the experimental data; x_1, x_2, ..., x_n – are the parameters of the environment.

Probability of the execution of the correctness function by the dispatcher, depending on i^{th} parameters of labor conditions and organization of the work place can be determined by the formula:

$$P_i\left(x_1, x_2, ... x_n\right) = \exp\left(-\lambda_i\right), \tag{8}$$

where λ_i –is the intensity of errors emergence in the work of the dispatcher , corresponds to i^{th} parameter of the labor conditions and organization of the work place.

Selecting the parameters of the environment the necessary probability of the realization of the correctness function by the dispatcher can be achieved. Optimal reliability of the dispatcher is determined on the base of consideration of n^{th} number of different variants of the environment parameters and selection of the variant with the minimal total expenditures for the formation of the environment and social-economic losses, caused by the emergence of errors in the process of the decision making by the dispatcher:

$$E_I = C_{CO_I} + v_i, \tag{9}$$

where C_{COI} –are the expenses for the formation of the i^{th} environment; v_i –are social-economic losses, stipulated by the emergence of the dispatcher errors in the process of the decisions making.

Mode of the work and rest influences greatly the labor efficiency of the dispatcher and the probability of the correctness function realization by him [7, 8]. Mode of the work and rest is characterized by two main indices: duration of the continuous operation τ and breaks for the rest t_{rest} [9]. Duration of the rest depends on the time of the uninterrupted work of the dispatcher and equals:

$$t_{rest} = k \cdot \tau \, , \tag{10}$$

where k –is the coefficient of the proportionality,which is determined depending on the degree of the labor intensity.

The intensity of errors emergence in the process of an uninterrupted work τ is:

$$\lambda(\tau) = a + b\tau \, , \tag{11}$$

where a, b –are the coefficients.

In the given case the value P_{WRM} will correspond to the value $R_i(\tau_i)$. The reliability of the dispetcher, regarding the execution of the correctness functions, corresponds to i^{th} work and rest mode, will equal:

$$R_i\left(\tau_i\right) = \exp\left[-\int_0^1 (a + b\tau)d\tau\right]. \tag{12}$$

Setting the necessary reliability of the dispatcher R_{dur}, the admissible duration of the uninterrupted work τ_{dur} can be determined. We obtain:

$$\ln R_{dur} = -\int_0^1 (a + b\tau)d\tau \, . \tag{13}$$

Having substituted the obtained expression in the equation and performed the necessary transformations, the equation for time τ determination is obtained:

$$\tau^2 + \frac{2a}{b} \cdot \tau + \frac{2}{b} \cdot \ln R_{dur} = 0 \, . \tag{14}$$

Where:

$$\tau_{1,2} = -\frac{a}{b} \pm \sqrt{\left(\frac{a}{b}\right)^2 - \frac{2}{b}\ln R_{dur}} \, . \tag{15}$$

Probability of the correctness function execution by the dispatcher depends on the level of the uncertainty of the information. In the systems of the dispatcher control the sources of the uncertainty are the properties of the so-called communication channel, physical environments and processes, which provide the collection, transfer and transformation of numerous messages into a preset totality of the obtained messages [10, 11, 12].

First, we will determine, what is the average volume of information, transferred along the channel with every sent message. Let us assume, that the infinite inputs $X=\{x\}$ and outputs $Y=\{y\}$ are given. Further, we will assume, that each sent x corresponds single y and serial pairs $x - y$ are independent.

The studies showed that the direct dependence exists between the number of the dispatchers errors and the degree of the uncertainty of the of the information, arriving to the dispatcher (Fig. 4).

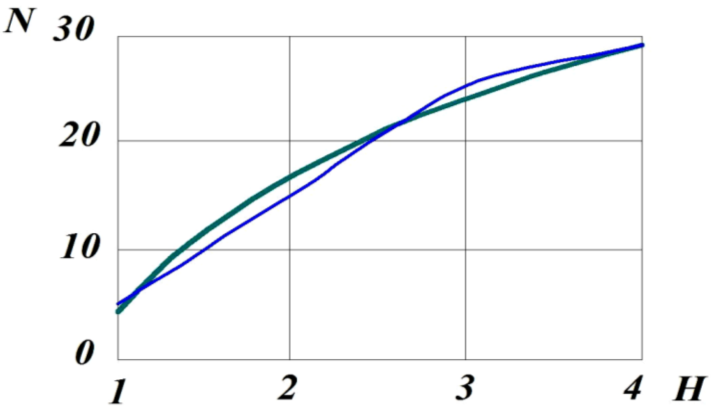

Fig. 4. Dependences of the number of errors in the work of the transport system operator *N* on the uncertainty of the information *H*, arriving to the operator

In the process of using the degree of the uncertainty for the quantitative assessment of the information uncertainty, the dependence of the intensity of the dispetcher errors is of curvilinear character and can be presented in Fig. 5.

Fig.6 shows the dependence of the dispetcher reliability on the degree of the information uncertainty and coefficient *b*.

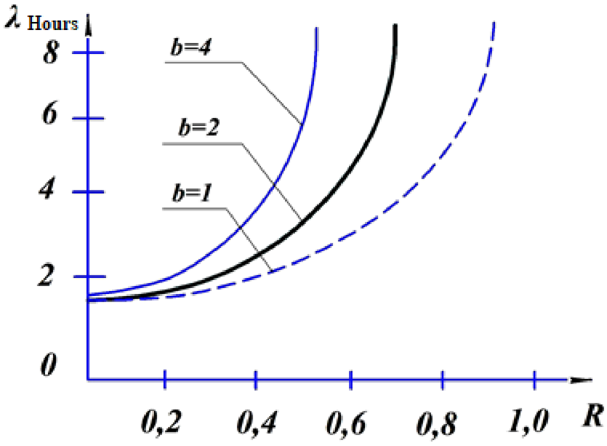

Fig. 5. Dependence of the dispetcher errors intensity on the degree of the information uncertainty (if $a = 1$)

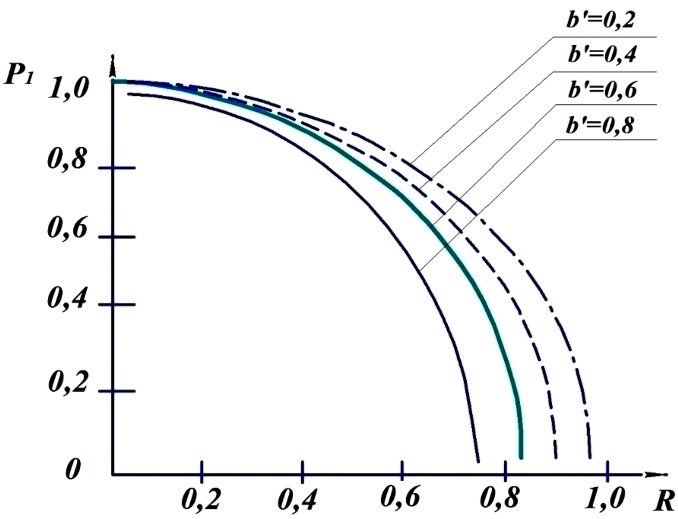

Fig. 6. Probability dependence of the correctness functions execution by the dispetcher on the degree of the information uncertainty (if *a*=0)

The resulting correctness functions of the transport system operator work was calculated, using all the elements. As a result of calculations the performance and reliability coefficient of this system that equals 0.97, was obtained . In certain cases, when one of the components is smaller than the preset ones, it is necessary to carry out the complex of the organizational-engineering measures, aimed at the improvement of the reliability and operation capacity of each separate component for the given system. In the developed system, the dispetcher, in general case, will be responsible for various by complexity correctness functions. The dispetcher must not have any contra-indications to the execution of the correctness functions. The obligatory condition is the successful professional training (experimental studies, using modern computer technologies). The suggested mathematical model for the description of the system of the error-free operation support enables to obtain different variants of the protection of operators work against errors and select the most rational variant of the protection. The recommended model can be used for the calculations in the process of the design of the applied problems in different systems.

Conclusions

The given research presents the mathematical model that enables to describe different factors of the negative impact on the quality of the decisions, made by the operator of the transport system (train dispatcher and engine driver), the components of the model are: professional training, conditions of work and rest, degree of the information uncertainty, arriving to the operator. The suggested mathematical model , describing the system which provides error –free operation enables to obtain different variants of the operators` labor activity protection against errors and select the most rational variant.

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Chernetska-Biletska Natalia – Doctor of Science (Engineering), Professor, Head of the Department «Logistic control and traffic safety», e-mail: logistyka.snu.edu.ua@gmail.com.

Baranov Igor – Cand. Sc. (Eng.), Assistant Professor with the Department «Logistic control and traffic safety»,e-mail: baranov_90@ukr.net.

Miroshnikova Marija – Senior lecture of the Department «Logistic control and traffic safety», e-mail: citroen4ik@gmail.com.

Kuzhel Sergiy – Master Student of the Department «Logistic control and traffic safety».
V. Dal Eastern-European National University.