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DEVELOPMENT OF THE STRUCTURE OF AN INTELLIGENT LOCOMOTIVE DSS AND ASSESSMENT OF ITS EFFECTIVENESS

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Abstract:

The purpose of the article is developing the locomotive structure of intellectual system of support of decision-making and to find a criterion by which to adequately assess different control action to the train. System of decision support for locomotive crew is seen as a complex structure with complex interactions located at a great distance, on-board locomotive systems. The quality of the organization determines the effectiveness of the system as a whole. To solve the problem of creating the optimal structure of the DSS applies the aggregate-decomposition method that involves two steps: decomposition of the problem into a number of subproblems and aggregating the partial results. To evaluate the quality control of a locomotive used the concept of control strategy with specific indicators. Design is developed and structure of locomotive DSS is obtained, taking into account peculiarities of operation of railway transport. To account for not only quantitative but also qualitative characteristics of activity of the locomotive or intellectual systems of decision support, it is proposed to use methods of fuzzy logic. So were able to deduce and calculate the additive criterion of the quality control activities of the intelligent system. Formal indicator of the quality of the train control process using different strategies is received. In the work theoretically grounded definition of the weighting factors for each partial criterion of the quality of train control. Using the dependencies derived, the nature of the influence of the value of partial criteria on the quality of train control in relation to a strategy. The results of the work allow to more accurately simulate the operations of a locomotive crew, which in the future will serve as the basis for the development of autonomous intelligent systems of locomotive control. The developed method is shown to be three main criteria which values the safety, energy consumption, and execution time schedule. However, for more flexible and accurate model, this approach allows to enter additional criteria, and the simplicity of the calculation provides the necessary speed when implemented on on-board locomotive computers.

Keywords: *control strategy, train, intelligent system, decision support*

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1. Introduction

The development of modern information technologies, methodology for modelling complex systems and solving problems for controlling transport processes makes it possible to create a DSS for locomotive crews to ensure traffic safety when driving a train and increase the efficiency of using locomotives. The development of this system is an urgent, rather difficult task associated with the development of informed decisions in conditions of limited time, incomplete certainty of a number of factors, including the preferences of the decision maker. A successful solution to this problem can be ensured only with an effective combination of experience, knowledge, intuition and a person's ability to make informed decisions with modern mathematical methods for solving problems and simulation of the processes under consideration.

One of the main directions of improving the control activity of the driver, as a human operator, is the development of intelligent locomotive decision support systems. In this case, the system creates a number of scenarios for the further activities of the driver, predicts the results of the implementation of each of these scenarios and issues the sequence of control actions on the train, which is the most desirable (useful) in a particular train environment. The problem of improving the quality of control is currently being solved by increasing the level of training of locomotive crews, developing protective systems, creating the necessary incentives as well as working conditions for a person. However, the direct process of train control, namely the phase of making a control decision and its assessment, is currently not sufficiently covered.

2. Analysis of recent research and publications

There are several approaches to assessing the efficiency of locomotive control. The most common assessment of energy (fuel) consumption for traction is in (Asabin et al., 2020), (Soofastaei, 2019), (Baklanov, 2005). The paper (Andronchev et al., 2020) examines existing approaches to assessing locomotives based on energy efficiency and proposes a new integrated energy efficiency index of vehicles, a method for calculating this index, a method for representing train traffic in limited a set of modes of movement of one train. However, the relationship between operational efficiency, traffic safety and the human factor remained unclear. It is also possible to evaluate the operation of the locomotive in terms of maintenance costs in accordance with the assessment of its efficiency (Kulbovskyi, 2019), and operating costs (Szkoda et al., 2020), (Egamberdiev et al., 2016). In works (Kukulski, et al., 2019) and (Kuric, 2020), an assessment of the information component of running a train was made. Target of article (Szkoda, 2016) is a cause and effect assessment of the occurrence of undesirable events, the determination of selected reliability indices and identification of the weakest components of rail vehicle that affect the downtime and technical availability most strongly. Also, more and more scientists are developing the direction of diagnostics using fuzzy logic (Manafov 2020). However, even in these works, traffic safety is not included in the research models. In (Sapronova, 2017), a set of scientific and technical solutions is proposed to improve the safety of the rolling stock of railways. But at the same time, the main attention here is directed to the development of appropriate solutions for non-traction rolling stock, and there is no indication of how to control safety and operational efficiency. At present, the formalization of a parameter that estimates the state of traffic safety has been completed, which can be included in the forecast of the consequences of one or another control decision when driving a train (Nowakowski et al., 2019), (Gorobchenko et al, 2018). At the same time, it became possible to create an additive criterion for the efficiency of train control, which would include the parameters of energy consumption, fulfillment of the schedule and traffic safety (Tartakovskyi et al., 2016):

$$Q = \sum_{i=1}^{3} \gamma_i I_i \tag{1}$$

where I_1 is the partial criterion for traffic safety, I_2 is the partial criterion of energy consumption for traction of trains, I_3 is the partial criterion for compliance with the train schedule, and γ_i is the weighting coefficient of the i-th particular criterion.

Decision making when driving a locomotive depends on many circumstances (Tartakovskyi et al., 2016), (Li et al., 2019). It is proposed to determine the main train control strategies that can be applied in various train situations.

Based on the main tasks performed by the locomotive economy, it is possible to single out the main control strategies shown in Table 1.

The analysis of publications allows to say that the development of locomotive decision support systems is a promising direction for improving the quality and safety of transportation. However, universal approaches to their design, creation of a general structure and assessment of the quality of functioning, taking into account the peculiarities of railway transport, have not yet been developed.

3. Formulation of the aim of the article

Thus, the problem arises to develop the structure of an intelligent locomotive decision support system and find a criterion with which one can adequately assess one or another control effect on the train. For this, it is necessary to substantiate the values of the weight coefficients for various train control strategies based on the model of predicted values of characteristic indicators.

4. Description of research methods

Complex solution of control problems of multilevel systems in conditions of hierarchical subordination of levels should correspond to special criteria of optimality. When developing locomotive DSS with many criteria, it is advisable to carry out a hierarchical reconstruction of the future system with a proper assessment of the future behaviour of the DSS and recommendations for train control.

It is known that the main problems solved in the creation of such systems are the comparison of the descriptions of the states of the decision-making object (control object) with the truth conditions of the products, as well as determining the sequence of viewing and analysing the products when making decisions (Russell and Norvig, 2002). Depending on how these problems are solved, situational systems, they advise, are divided into two classes with fuzzy logic: "situation - action" (S-A) and "situation - control strategy - action" (S-MS-A). The problem of comparison of descriptions is solved in the same way in systems of both classes: there is a set of reference descriptions of the states of the control object in the form of fuzzy situations – fuzzy sets of the second level on a set of features.

A distributed DSS for locomotive crews is a complex system with a complex interaction of onboard locomotive systems located at a great distance and the quality of its organization determines the efficiency of the system as a whole.

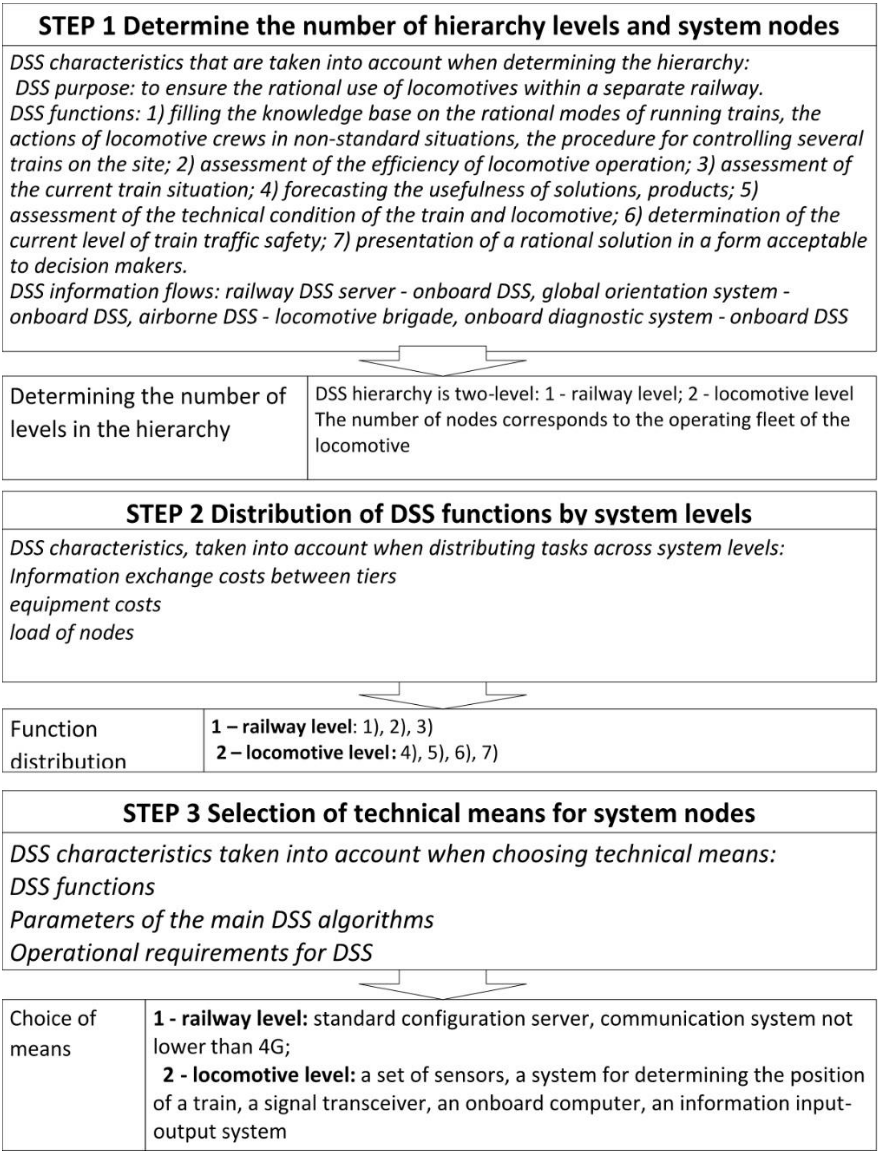
If P is a set of possible principles of $n \epsilon P$ for constructing a system and its elements; F is a set of interrelated functions performed by the system; A is a set of interconnected on-board locomotive systems, then, according to (Tsvirkun, 1982), the task of synthesizing a rational structure of a distributed DSS is to determine a set of principles of construction ($n \epsilon P$), a set of functions performed by the system ($f \epsilon F(n)$), a set of elements capable implement the selected principles and perform the functions ($\bar{A} \epsilon A$), as well as the optimal mapping of the elements of the set f to the elements of the set $\bar{A}$. When choosing a variant of the structure of a complex system, two types of mapping $f \rightarrow \bar{A}$ are possible: the first, when each task is performed by only one of several possible system nodes, and the second, when the task is performed by several system nodes. The operating conditions of locomotive systems require their implementation according to the second option.

Table 1. Train control strategies

No.	Strategy name	Strategy characteristics
1	Traffic schedule fulfillment	Striving to minimize the time gap between the established and the current schedule
2	Maximum driving safety	The desire to minimize the risk of a traffic accident: reduced speed, increased control over the state of the track and signals, the use of brakes with a margin of braking intensity and time to restore the charging of the brake line.
3	Minimum power consumption for traction	Reducing the time of operation in transient modes, maximizing the use of the kinetic energy of the train, operating the equipment in the modes of maximum efficiency.
4	Maximum level of rolling stock reliability	Prevention of locomotive equipment overloading, avoidance of modes of abnormal operation of equipment (skidding, overheating, increased vibration, etc.), increased control over the technical condition of the locomotive.

In practice, to solve the problem of creating an optimal DSS structure, the aggregate-decomposition method (Tarasov et al., 2007) is widely used, which includes two stages: decomposition of the problem into a number of particular problems and aggregation of partial results. Thus, the design of the optimal DSS structure will mean the process of gradual solution of the problems of synthesis of the main elements and parts of the system (Fig. 1).

The tasks shown in Fig. 1 are solved iteratively due to their interrelation, incompleteness of the initial data and the need to correct the obtained solutions.



STEP 1 Determine the number of hierarchy levels and system nodes

DSS characteristics that are taken into account when determining the hierarchy:
DSS purpose: to ensure the rational use of locomotives within a separate railway.
DSS functions: 1) filling the knowledge base on the rational modes of running trains, the actions of locomotive crews in non-standard situations, the procedure for controlling several trains on the site; 2) assessment of the efficiency of locomotive operation; 3) assessment of the current train situation; 4) forecasting the usefulness of solutions, products; 5) assessment of the technical condition of the train and locomotive; 6) determination of the current level of train traffic safety; 7) presentation of a rational solution in a form acceptable to decision makers.
DSS information flows: railway DSS server - onboard DSS, global orientation system - onboard DSS, airborne DSS - locomotive brigade, onboard diagnostic system - onboard DSS

Determining the number of levels in the hierarchy	DSS hierarchy is two-level: 1 - railway level; 2 - locomotive level The number of nodes corresponds to the operating fleet of the locomotive

STEP 2 Distribution of DSS functions by system levels

DSS characteristics, taken into account when distributing tasks across system levels:
Information exchange costs between tiers
equipment costs
load of nodes

Function distribution	**1 – railway level**: 1), 2), 3) **2 – locomotive level:** 4), 5), 6), 7)

STEP 3 Selection of technical means for system nodes

DSS characteristics taken into account when choosing technical means:
DSS functions
Parameters of the main DSS algorithms
Operational requirements for DSS

Choice of means	**1 - railway level:** standard configuration server, communication system not lower than 4G; **2 - locomotive level:** a set of sensors, a system for determining the position of a train, a signal transceiver, an onboard computer, an information input-output system

Fig. 1. Synthesis scheme of the structure of an intelligent locomotive DSS

Locomotive DSS perceives the external environment with the help of sensors x_1, x_2, ... x_m and influences it with the help of executive organs z_1, z_2, ... z_m, similarly to how a person perceives the external environment with the help of organs feelings and affects it with the help of such parts of the body as arms, legs, etc.

The normal influence of the system on the environment is a reaction, and the system's perception of the environment is perception. If each executive body z_j is compared with the output variable of the same name z_j, which takes a set of values y_j, and each such value is called a microreaction, then the reaction will be a set of values y_1, y_2, ... y_n. Similarly, if each sensor x_i is compared with the variable xi of the same name, which takes a set of values α_i (microperception), then the perception will be a set of values α_1, α_2, ... α_m. The behavior of the intellectual system consists in the processing of perceptions in reaction. This processing is carried out using a special solver that functions on the basis of the knowledge embedded in it.

As a result of the analysis of existing types of intelligent systems, hierarchies and algorithms of their work (Pedrycz, 2018), taking into account the operating conditions of locomotive crews and railway transport in general, the parameters of intelligent DSS are developed (summarized in Table 2).

5. Presentation of the main material and obtaining scientific results

The paper proposes the structure of the onboard locomotive DSS, shown in Fig. 2. The human-machine interface is designed to ensure user interaction with the system. There are input systems and information display systems.

A fuzzy classifier is necessary for monitoring, recognizing and transferring images to the system of situations in which the train is in motion. Information to it comes from the interface part of the DSS, the purpose of which is to convert physical signals of various monitored quantities into a form acceptable for perception by the system.

The inference subsystem, using formalized knowledge, develops recommendations for locomotive control. Here, a certain strategy for choosing rules is implemented, associated with the method of representing knowledge in the DSS and taking into account the peculiarities of railway transport. When the inference subsystem is unable to solve problems due to lack of knowledge, the description of the problem is passed to the decomposition and aggregation subsystem. This subsystem defines other DSS, the knowledge of which is necessary to solve this problem. After the partial solutions are made, it aggregates them into a solution to the original problem.

The training subsystem provides a primary set of rules and algorithms for the DSS operation and further adjusts this set depending on the operating conditions and based on the experience of using other locomotives. Information from it goes to the railway server in the metabase through the knowledge base control subsystem. This provides access to updated rules for all airborne DSSs.

The knowledge base control subsystem is the main information-transforming element of the system, which provides access to other knowledge and data subsystems.

Table 2. DSS characteristics for locomotive crews

The feature, by which DSS is categorized	Parameter name	Parameter description
Type of structuring of the problems solved	Poorly structured	Output parameters include both quantitative and qualitative elements
Character of distribution	Spatially and functionally distributed	Consists of separate linked local locomotive DSS, which can solve a general problem together only
Character of assessing decision results	Decisions which are objectively assessed	Assessment of result is based on clearly assigned criteria that determine goal achievement: fuel consumption, distance run between overhauls, traffic safety, etc.
Character of situation in which DSS makes decision	Situation if emergency	Decision making about driving a train is characterized by lack of time and rapidly changing situation.
Type of computer analysis of situation	Dynamic	There is a set of scenarios of train driving, of which the most effective in the given moment is chosen

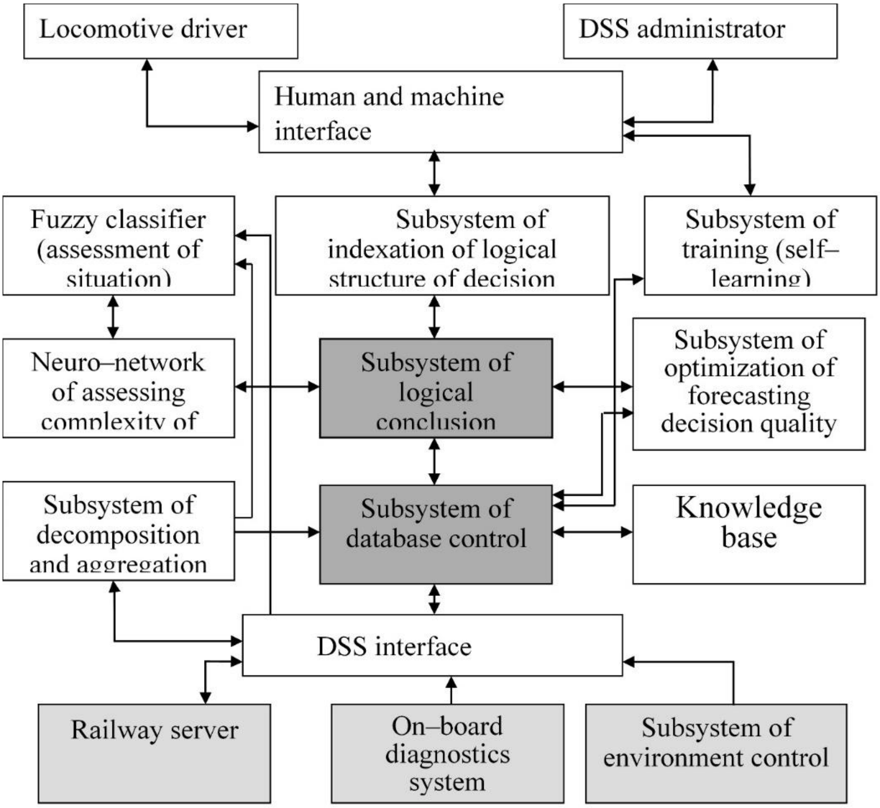


Fig. 2. On-board locomotive DSS structure

The neural network for assessing the complexity of emergency situations provides constant monitoring of traffic conditions for safety. It assesses the severity of the emergency and, when it becomes threatening, ensures that decisions are made to reduce the hazard.

To assess the quality of control decisions when controlling a train, let's introduce additional sets that include characteristic indicators for each modelled control strategy.

So for the strategy s_l, there are a number of indicators by which the quality of the implementation of this strategy is assessed. For example, for the "Maximum traffic safety" train control strategy, the key indicator will be the number of incidents per million kilometres travelled. Also, using the theory of risks, it is possible to determine the mathematical expectation of damage from incidents, accidents or disasters.

Let's represent the control strategy as a set containing its characteristic indicators:

$$s_l \in (\pi_1, \pi_2, \dots, \pi_j) \tag{2}$$

where π_j is the j-th indicator for assessing the implementation of strategy s_l.

There are functions $\pi_j = f(I_i)$ that determine the impact of each criterion on the performance of a given control strategy. The influence of the value of one or another criterion of control efficiency on the indicator πj, characterizing a separate strategy, is proposed to be evaluated by comparing the derivatives $\frac{d\pi_j}{dI_i}$. And the general influence of the criterion I_i on the strategy s_l is proposed to be represented as the arithmetic mean of the derivatives:

$$A_{I_i/s_l} = \frac{\sum_{j=1}^{k_{s_l}} \frac{d\pi_j}{dI_i}}{k_{s_l}} \tag{3}$$

where A_{I_i/s_l} is the magnitude of the influence of criterion I_i on the control strategy s_l, and k_{s_l} is the number of indicators of the strategy s_l.

Thus, the absolute indicators of the influence of each criterion of control efficiency on the implementation of individual control strategies have been obtained.

To obtain the values of the weighting coefficients when calculating the control efficiency for different strategies, it is necessary to use the known transition from absolute to relative indicators:

$$\gamma_i(s_l) = \frac{A_{I_i/s_l}}{\sum_{i=1}^{n} A_{I_i/s_l}} \tag{4}$$

where $\gamma_i(s_l)$ is the weighting coefficient of the i-th criterion for the l-th strategy, A_{I_i/s_l} is the magnitude of the influence of criterion I_i on the s_l control strategy, and $\sum_{i=1}^{n} A_{I_i/s_l}$ is the total absolute value of the influence of all n criteria of control efficiency on the implementation of the l-th strategy.

This is how a formalized indicator of the quality of the train movement control process was obtained using various strategies.

The implementation of such an approach to determining the weighting coefficients requires the presence of approximated functions $\pi_j = f(I_i)$. As an example, here's how to get a specific function.

Let's consider the control strategy "Minimum power consumption for traction", which has the following main implementation indicators:

- π_1 – absolute fuel (electricity) consumption for the trip;
- π_2 – ratio of the operating time in transient modes to the operating time in steady-state modes;
- π_3 – the current value of the locomotive efficiency;
- π_4 – ratio of freewheel time to load time.

Finding clear dependencies $\pi_j = f(I_i)$ in practice is a difficult task, and sometimes not possible. Therefore, it is proposed to determine this function using the method of expert assessments (Shtovba, 2001), (Marcus, 2013), that is, on the basis of linguistic variables, which will be characterized by its experts in the control of rolling stock.

A linguistic variable is specified by the five <x, T, U, G, M>, where x – name of the variable; T – term-set, each element of which (term) is represented as a fuzzy set on the universal set U; G – syntactic rules, often in the form of grammar, generating the name of terms; M – semantic rules defining membership functions of fuzzy terms generated by syntactic rules G.

Let's consider a linguistic variable π_1 called "absolute fuel consumption per trip". Then the remaining four <T, U, G, M> can be defined as follows:

- universal set U = [10; 600] kg;
- term-set T {"few", "average", "many"} with the following membership functions with:

$$\mu«\text{few o}»(u) = \frac{1}{1+\left(\frac{u-10}{100}\right)^2} \tag{5}$$

$$\mu«\text{average}»(u) = \frac{1}{1+\left(\frac{u-300}{100}\right)^2} \tag{6}$$

$$\mu«\text{many}»(u) = \frac{1}{1+\left(\frac{u-590}{100}\right)^2} \tag{7}$$

- syntactic rules G generating new terms using the quantifiers "not", "very" and "about";
- semantic rules M, in the form of table 3

Table 3. Semantic rules for the linguistic variable "absolute fuel consumption per trip"

No.	Quantifier	Membership function (u∊U)
1	not t	$1-\mu_t(u)$
2	very t	$(\mu_t(u))^2$
3	about t	$\sqrt{\mu_t(u)}$

As a result, let's obtain graphs of the membership functions of the terms "few", "average", "many" with different quantifiers (example in Fig. 3)

The next step is to obtain expert information. For this, tables have been developed, the form of which is given in table 4. In the cells of the table, the expert enters assessment of the influence of the criterion of control efficiency Ii on a separate parameter of the control strategy π.

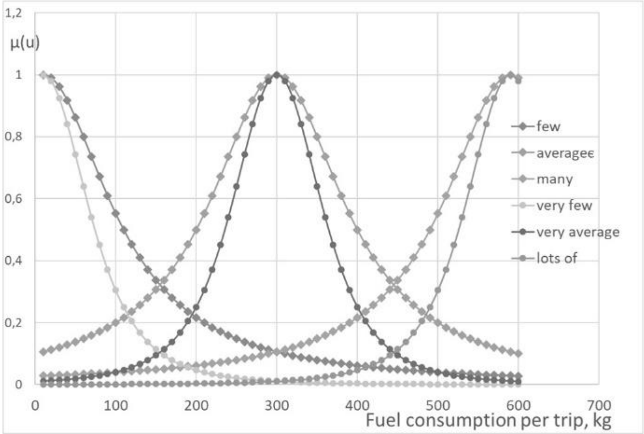


Fig. 3. Linguistic variable "fuel consumption per trip" with the "very" quantifier

Table 4. Tabular assignment of functions in the form of linguistic variables for the "Minimum power consumption for traction" control strategy.

Value name	Value					
I_1	0	0,2	0,4	0,6	0,8	1,0
π_1	Very few	Average	Not a little	Not a little	Lots of	Average
π_2	Very few	Average	Not a little	Not a little	Few	Average
π_3	Average	Not much	Average	Few	Few	Very few
π_4	Average	Average	Not a little	Lots of	Average	Average

After receiving information from several experts, it is necessary to carry out the defuzzification procedure (Butko et al., 2015). In our case, defuzzification is proposed by the centre of gravity method. The centre of gravity (CoG) or centroid of the area is calculated by the formula (Arun and Mohan, 2017):

$$y = \frac{\int_{min}^{max} x \cdot \mu(x)dx}{\int_{min}^{max} \mu(x)dx} \qquad (8)$$

where y is the defuzzification result, x is the variable corresponding to the original linguistic variable and μ (x) is the membership function of a fuzzy set corresponding to the original variable after the accumulation stage. Min and Max are the left and right points of the interval of the support of the fuzzy set of the considered output variable.

After processing the expert data, let's have several linguistic variables that characterize the influence of control efficiency criteria on the strategy parameters. That is, each cell of the pivot table will contain several variables (by the number of experts).

When defuzzifying the data obtained, it is necessary to first perform the procedure of conjunction of all linguistic variables characterizing each parameter π for different values of criterion I. That is, the final value of the defuzzified value in the pivot table will be:

$$\pi_j' = \frac{\int_{min}^{max} x \cdot \bigcap_{i=1}^{k} \mu(x_i)dx}{\int_{min}^{max} \bigcap_{i=1}^{k} \mu(x_i)dx} \qquad (9)$$

where k is the number of experts, x is the variable corresponding to the original linguistic variable, and μ(x) is the membership function of a fuzzy set corresponding to the original variable after the accumulation stage. Min/ Max are the left and right points of the interval of the carrier of the fuzzy set of the output variable.

Thus, a table of the dependence of the parameters of of the control strategy implementation on the control criteria is constructed. For the control strategy "Minimum power consumption for traction" such a dependence on the partial criterion of traffic safety is given in Table 5. Next, it is necessary to obtain analytical expressions for each dependency , which is performed by approximating the table values.

Table 5. The defuzzification result of the magnitude of the influence of the partial criterion of traffic safety on the parameters of the control strategy "Minimum energy consumption for traction"

Value name	**Value**					
I_1	0	0,2	0,4	0,6	0,8	1,0
π'_1, kg	54	269	221	345	408	279
π'_2	0,09	0,063	0,047	0,0514	0,0059	0,0341
π'_3	0,163	0,165	0,194	0,189	0,116	0,073
π'_4	0,181	0,304	0,189	0,385	0,2409	0,1340

After approximating the function by the methods of linear, quadratic and cubic regression (having previously normalized the fuel consumption values in the interval [0; 600]), it is found that the most qualitatively presented tabular data is described by quadratic regression. Therefore, let's take it as the main one in further calculations of analytical dependencies $\pi_j^{'} = f(I_i)$. But in some cases, to simplify calculations, it is allow to use the results of linear regression.

Using well-known mathematical methods, a set of expressions is obtained that describe the dependence of π (parameters for implementing the train control strategy) on I1 (partial criterion of traffic safety):

$\pi_1' = -0.952 \cdot I_1^2 + 1.3496 \cdot I_1 + 0.1118$,

$\pi_2' = 0.0708 \cdot I_1^2 - 0.1347 \cdot I_1 + 0{,}09$,

$\pi_3' = -0.2832 \cdot I_1^2 + 0.1973 \cdot I_1 + 0.1551$,

$\pi_4' = -0.5663 \cdot I_1^2 + 0.5341 \cdot I_1 + 0.1795$.

Based on the above calculations, using formula (3), let's write an expression to determine the influence of the motion safety criterion on control when the strategy “Minimum energy consumption for traction” is executed. After simplification, let's obtain the expression:

$$A_{I_1/s_1} = 0{,}303 I_1 + 0{,}487 \qquad (10)$$

In a similar way, let's obtain expressions for the influence of the partial criterion I_2 (energy consumption for traction of trains):

$$A_{I_2/s_1} = 1{,}112 I_2 + 1{,}087 \qquad (11)$$

and for the influence of the partial criterion I_3 (adherence to the schedule):

$$A_{I_3/s_1} = 0{,}902 I_3 + 0{,}73 \qquad (12)$$

Using expression (4), let's obtain the values of the weight coefficients:

$$\gamma_1(s_1) = \frac{0{,}303 I_1 + 0{,}487}{0{,}303 I_1 + 1{,}112 I_2 + 0{,}902 I_3 + 2.304} \qquad (13)$$

$$\gamma_2(s_1) = \frac{1{,}112 I_2 + 1{,}087}{0{,}303 I_1 + 1{,}112 I_2 + 0{,}902 I_3 + 2.304} \qquad (14)$$

$$\gamma_3(s_1) = \frac{0{,}902 I_3 + 0{,}73}{0{,}303 I_1 + 1{,}112 I_2 + 0{,}902 I_3 + 2.304} \qquad (15)$$

Using the above dependencies, the nature of the influence of the value of partial criteria on the quality of train control in relation to a certain strategy is obtained (example in Fig. 4-6).

6. Results and discussion

The work defines the stages of synthesis of the DSS structure for locomotive crews. Using these stages, a system design has been created, which will improve the efficiency of locomotive operation by defining and storing rational control techniques in the knowledge base. While driving the train, the driver is offered to apply a certain mode that best matches the current value of the track profile, train mass, traffic light readings, weather conditions, etc. The main elements of the system are a fuzzy classifier (monitors and recognizes images of train situations), a logical inference subsystem (develops recommendations for locomotive control, taking into account the chosen strategy).

A feature of this structure is the presence of a unit that assesses the current degree of complexity of an emergency situation, which makes it possible to develop solutions not only from the standpoint of reducing energy costs, but also to take into account the impact of the implementation of these solutions on traffic safety.

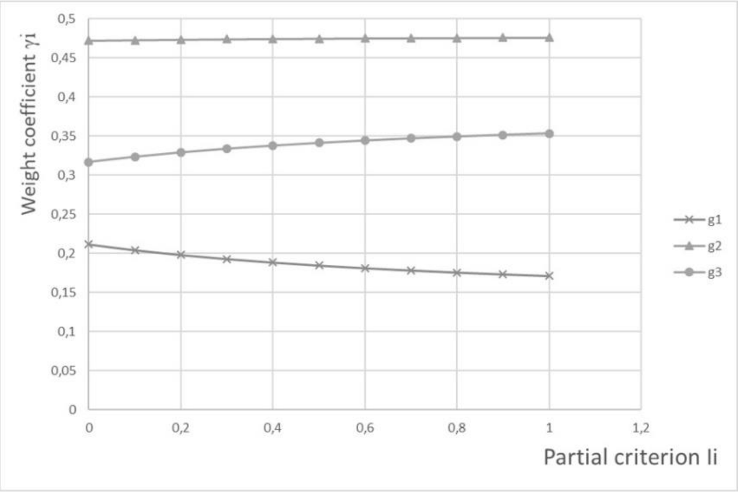


Fig. 4. Dependencies of weighting coefficients on particular criteria I_i

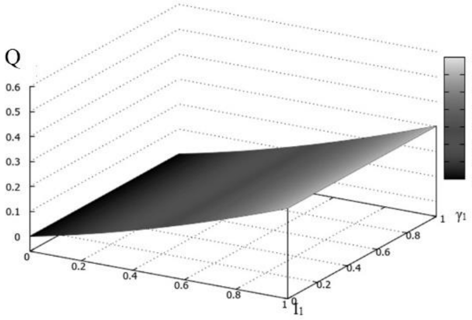


Fig. 5. Dependency Q(I_1; γ_1) at I_2=I_3=0

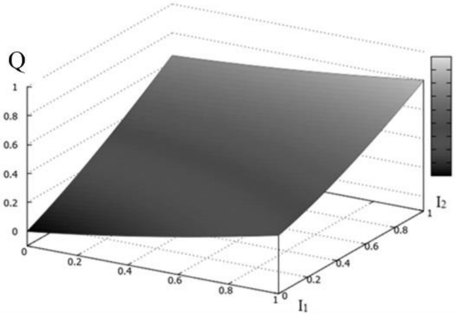


Fig. 6. Dependency Q(I_1;I_2) at I_3=0

Decision making when driving a locomotive depends on many circumstances. The paper proposes to determine the basic train control strategies that can be applied in various train situations. Based on the main tasks performed by the locomotive economy, the following control strategies have been determined in the work: adherence to the traffic schedule, maximum traffic safety, minimum energy consumption for traction, maximum level of rolling stock reliability.

The criterion for the efficiency of train control during operation is presented in the form of a ratio of various efficiency indicators reflecting various properties of the system. Evaluation of the train control efficiency according to several criteria is rather difficult to formalize by means of classical mathematics. Therefore, to take into account not only quantitative, but also qualitative characteristics of the activity of a locomotive driver or an intelligent decision support system, it is proposed to use methods of fuzzy logic. So it is possible to derive and calculate the additive criterion of the effectiveness of the control activity of the intellectual system. Each of the particular criteria is a functional, contains the vector of the technical state of the locomotive, the control vector, the vector of setting influences, the vector of initial conditions, the vector of the final state, the quality of the locomotive crews, the time during which the system is studied. However, in real operating conditions, this is not enough. For different conditions, the drivers apply different approaches to control (it is proposed to call them train control strategies) and those actions that are considered correct in one strategy can be harmful to another.

As a result of this work, a justification is obtained for calculating the weight coefficients when predicting the best control action, taking into account the current control strategy. This makes it possible to model the activities of the locomotive crew of higher quality, which in the future will serve as the basis for the development of autonomous intelligent locomotive control systems. The developed method is given for three main criteria of work, taking into account safety, energy consumption and compliance with the traffic schedule. However, for a more flexible and accurate model, this approach allows one to introduce additional criteria, and the simplicity of the calculation provides the required speed when implemented on onboard locomotive computers.

References

[1] ANDRONCHEV, I. K., ASABIN, V. V., KOSSOV, E. E., GORDEEV, I. P., TSELIKOVSKAIA, V. S., PLOKHOV, E. M., 2020. *The energy performance efficiency of locomotives*. Russian Electrical Engineering, 91(3), 175-178. DOI: 10.3103/S106837122003 0049.

[2] ARUN, N. K., and MOHAN, B. M., 2017. *Modeling, stability analysis, and computational aspects of some simplest nonlinear fuzzy two-term controllers derived via center of area/gravity defuzzification.* ISA transactions, 70, 16-29.

[3] ASABIN, V. V., KURMANOVA, L. S., PETUKHOV, S. A., PLOKHOV, E. M., LETYAGIN, P. V., 2020. *A Method for Determining the Energy Efficiency of Self-Contained Locomotives with Electric Power Transmission*. Russian Electrical Engineering, 91(3), 179-182.

[4] BAKLANOV, A., 2005. *The energy balance of the movement to address the problem of reducing energy consumption for traction*. Transport: science, technology, control/VINITI, 6, 32-35.

[5] BUTKO, T., BABANIN, A., GOROBCHENKO, A., 2015. *Rationale for the type of the membership function of fuzzy parameters of locomotive intelligent control systems*. Eastern-European Journal of Enterprise Technologies, 1(3), 4-8. DOI: 10.15587/1729-4061.2015. 35996.

[6] EGAMBERDIEV, B., LEE, K., LEE, J., BURNASHEV, S., 2016. *A Study on Life Cycle Cost on Railway Locomotive Systems*. International Journal of Railway, 9(1), 10-14.

[7] GOROBCHENKO, O., FOMIN, O., GRITSUK, I., SARAVAS, V., GRYTSUK, Y., BULGAKOV, M., ZINCHENKO, D., 2018. *Intelligent locomotive decision support system structure development and operation quality assessment.* Paper presented at the 2018 IEEE 3rd International Conference on Intelligent Energy and Power Systems, IEPS 2018 - Proceedings, 2018-January, 239-243. DOI: 10.1109 /IEPS.2018.8559487.

[8] KUKULSKI, J., GOŁĘBIOWSKI, P., PYZA, D., JACHIMOWSKI, R., WYCHOWAŃSKI, W., 2019. *Selected aspects of the selection of data sent to the vehicle in automatic rail vehicle driving systems.* Zeszyty Naukowe. Transport-Politechnika Śląska, 103, 43-52. DOI: 10.20858/ sjsutst.2019.103.4.

[9] KULBOVSKYI, I., SAPRONOVA, S., HOLUB, H., TKACHENKO, V., AFANASIEVA, I., SAFRONOV, O., 2019. *Development of a model for managing the quality of repair and maintenance of rolling stock in transport infrastructure projects*. In Transport Means - Proceedings of the International Conference, 2019-October, 201-205.

[10] KURIC, I., GOROBCHENKO, O., LITIKOVA, O., GRITSUK, I., MATEICHYK, V., BULGAKOV, M., KLACKOVA, I., 2020. *Research of vehicle control informative functioning capacity*. OP Conference Series: Materials Science and Engineering, 24th Slovak-Polish International Scientific Conference on Machine Modelling and Simulations - MMS 2019, 3-6 September 2019, 776, 012036.

[11] LI, G., LIU, Y., HUANG, J., LIU, Y., 2019. *Study on train energy-efficient automatic driving from learning human driver patterns*. Hunan Daxue Xuebao/Journal of Hunan University Natural Sciences, 46(4), 128-140. DOI: 10.16339/j.cnki.hdxbzkb.2019.04.019.

[12] MANAFOV, E., 2020. *The use of a fuzzy expert system to increase the reliability of diagnostics*

of axle boxes of rolling stocks. Scientific Journal of Silesian University of Technology. Series Transport, 107, 95-106. DOI: 10.20858/sjsutst.2020.107.7.

[13] MARCUS S., 2013. *Automating knowledge acquisition for expert systems.* Springer Science and Business Media.

[14] NOWAKOWSKI, W., BOJARCZAK, P., ŁUKASIK, Z., 2019. *Safety assessment using event tree analysis for railway traffic control systems*. Paper presented at the Transport Means - Proceedings of the International Conference, 2019-October, 1387-1391.

[15] PEDRYCZ, W., 2018. *Granular computing: analysis and design of intelligent systems*. CRC press.

[16] RUSSELL, S., NORVIG, P., 2002. *Artificial intelligence: a modern approach*. Pearson International Content.

[17] SAPRONOVA, S., TKACHENKO, V., FOMIN, O., HATCHENKO, V., MALIUK, S., 2017. *Research on the safety factor against derailment of railway vehicles*. Eastern-European Journal of Enterprise Technologies, 6 (7(90)), 19–25. DOI: https://doi.org/10.15587/ 1729-4061.2017.116194.

[18] SHTOVBA, S. D., 2001. *Introduction to the theory of fuzzy sets and fuzzy logic*. Ukraine, Vinnitsa, UNIVERSUM-Vinnitsa.

[19] SOOFASTAEI, A., 2019. *Energy-Efficiency Improvement in Mine-Railway Operation Using AI.* Journal of Energy and Power Engineering, 13, 333-348.

[20] SZKODA, M., KACZOR, G., 2016. *Reliability and availability assessment of diesel locomotive using fault tree analysis.* Archives of Transport, 40, 65-75. DOI: 10.5604/ 08669546.1225470.

[21] SZKODA, M., SATORA, M., KONIECZEK, Z., 2020. *Effectiveness assessment of diesel locomotives operation with the use of mobile maintenance points*. Archives of Transport, 54(2), 7-19. DOI: 10.5604/01.3001. 0014.2622.

[22] TARASOV, V., GERASIMOV, B., LEVIN, I., KORNIYCHUK, V., 2007. *Intelligent Decision Support Systems: Theory, Synthesis, Efficiency*. Kyiv: International Academy of Computer Science and Systems.

[23] TARTAKOVSKYI E., GOROBCHENKO O., ANTONOVYCH A., 2016. *Improving the process of driving a locomotive through the use of decision support systems.* Eastern-European Journal of Enterprise Technologies, 3(83), 4-11.

[24] TSVIRKUN, A. D., 1982. *Fundamentals of structure synthesis of complex systems.* Moskow: Nauka.