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MODELS AND INTELLECTUAL TECHNOLOGIES USED FOR ANALYSIS AND PROCESS MANAGEMENT UNDER UNCERTAINTY

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ABSTRACT

Objectives: *Modern production activity of railway transport of Ukraine (RTU) is characterized by high the level of complexity of processes and a wide range of conditions of uncertainty. The article is devoted to the tasks of development of unified automated intelligent analysis and control technologies indeterminate RTU processes in case of uncertainty.* ***Methods / Approach:*** *To achieve the goal a new model of the concept of formation of automated intellectual technologies of RTU is offered, implementation of which is based on a modular platform of unified analytical services designed for effective solution of certain typical tasks (diagnosis, classification, forecasting, management, etc.). The concept as a system includes stages of research of properties of processes, theoretical and methodological basis and methods of modeling and automated control, scenarios and intelligent acceptance procedures decisions in case of uncertainty.* ***Results:*** *As examples of application of the concept to the formation of unified technologies RTU presented intelligent services for diagnosing processes with several categories of uncertainty, as well as analysis and forecasting the parameters of anti-resistance processes. The analysis procedures developed in the article differ using the scheme of fuzzy control method Takagi-Sugeno adapted for diagnostic tasks with the uncertainty of different types (statistical, fuzzy, etc.), which is provided by the use integrated indicator – the reliability index, as well as the formal capabilities of the individual accounting for the importance of controlled variables of the process model together for all rules of diagnosis, and for each rule separately. By aggregating the levels of time series of non-deterministic RTU processes developed and researched correct mathematical models and algorithms designed for unified procedures classification and research of properties of anti-persistent processes of railway transport.* ***Conclusions:*** *In order to develop unified intelligent automated technologies RTU developed a concept analysis and management of non-deterministic RTU processes in case of uncertainty based on the platform analytical services. In work at formation of the specified services of the automated intellectual The technology has developed advanced diagnostic procedures that use Takagi-Sugeno-type models for several categories of uncertainty, as well as methods for classifying anti-persistence processes, algorithms interpolation of levels within aggregation ranges, analysis models and short-term forecasting processes designed to develop the theoretical basis and means of improving automated systems RTU.*

Keywords: railway transport, unified intellectual technologies, non-deterministic processes, uncertainty, diagnostics, anti-persistence processes, accuracy of classification.

JEL classification: C02, C05, R42
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INTRODUCTION

Modern production activity of railway transport (RT) of Ukraine is characterized by a wide range of branches, a high level of complexity of processes and related management systems, a wide range of uncertainties. In the current conditions, the most productive direction of RTU technology development is the use of economic and mathematical methods and models in combination with methods of systems analysis, nonlinear dynamics, etc., implemented using the latest information technologies. Comprehensive analysis of conditions and effective management of complex non-deterministic processes, in particular railway transport (RT), using only classical methods of mathematical and statistical modeling are impossible. The distribution and complexity of RT processes (train formation, technologies of freight transportation and repair, operation of transport infrastructure and its facilities, etc.) lead to events and situations with fundamentally indeterminate parameters. These and other factors determine the reasons for the lack of common mathematical models for many RT processes of technological and economic content. Due to the complexity and indeterminacy of numerous RT processes, one of the main ways of their initial description is to present data in the form of values of the main measured characteristics of time series (TS) ordered by stages and intervals. Examples of such TS for the railway can be the parameters of wagon flows of different categories at landfills and stations, estimates of costs of different types of resources by periods, parameters of freight flows, the sequence of events of operational processes, and others.

Formation of conceptual and methodological bases for creation of technologies of automated intellectual management of indeterminate RTU processes. Let's focus on the current scientific and applied task of creating and using a variety of intellectual resources to improve the efficiency of procedures for analyzing the state of RT objects and their management. In particular, on the development and formation of the information environment of analytical servers (AS) of the system ASK VP UZ-E. Problems concerning formation of conceptual and methodological bases of the organization of the automated intellectual management for separate basic technological and economic processes of RT are devoted to works. (Skalozub et al., 2013; Zhukovyts'kyy, et al., 2018a; Zhukovyts'kyy et al., 2018b). In particular, the tasks on automation of management of processes of operation of parks of technical systems (PTS) of RTU are considered. Despite the diversity of PTS (cars, locomotives, electric motors, etc.), a number of formalized technological and information tasks were identified, the implementation of which will ensure the creation and operation of intelligent PTS control systems (Chen et al., 2020). An example of a basic unified task and functions of AS, which is widely used for management in conditions of uncertainty, including the management of the processes of operation of vehicle fleets, is the task of diagnosis. Construction of AS procedures for diagnostic tasks (AS-D) significantly depends on the characteristics of the data (X, Y), their volume, accuracy, consistency, reliability, etc. Let's define the following task concerning formation of unified diagnostic procedures for rather widespread in the conditions of production processes. The structure and functioning of AS-D significantly depend on the models of mapping the conditions and methods of obtaining results – a logical conclusion (Katkova, 2018). In general, the creation of common and effective intelligent technologies for the management of non-deterministic RT processes requires the formation of an appropriate scientifically sound concept.

The concept of estimation, forecasting and economic-mathematical modeling of processes of activity of RTU enterprises in the conditions of uncertainty contains system of the following components (Fig. 1).

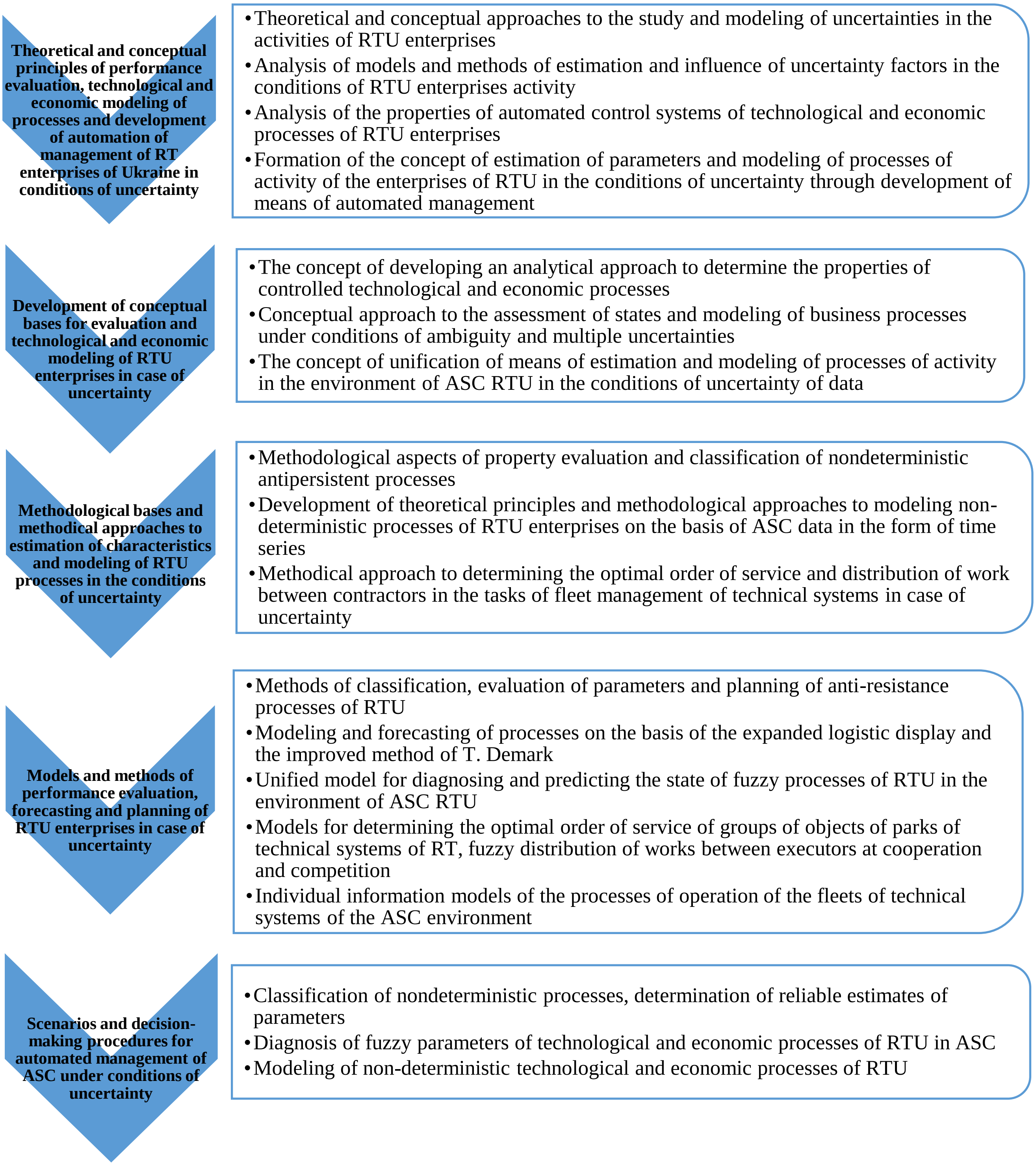

Figure 1. The concept of estimation, forecasting and economic-mathematical modeling of processes of activity of the railway transport enterprises of Ukraine in the conditions of uncertainty

Source: Author's illustration

According to the concept (Fig. 1) and the tasks of formation of AS platform technologies in Fig. 2 presents the implementation model, stages of research and theoretical and methodological basis for modeling and development of information technology management processes of production and economic activities of railway enterprises, taking into account the conditions of uncertainty.

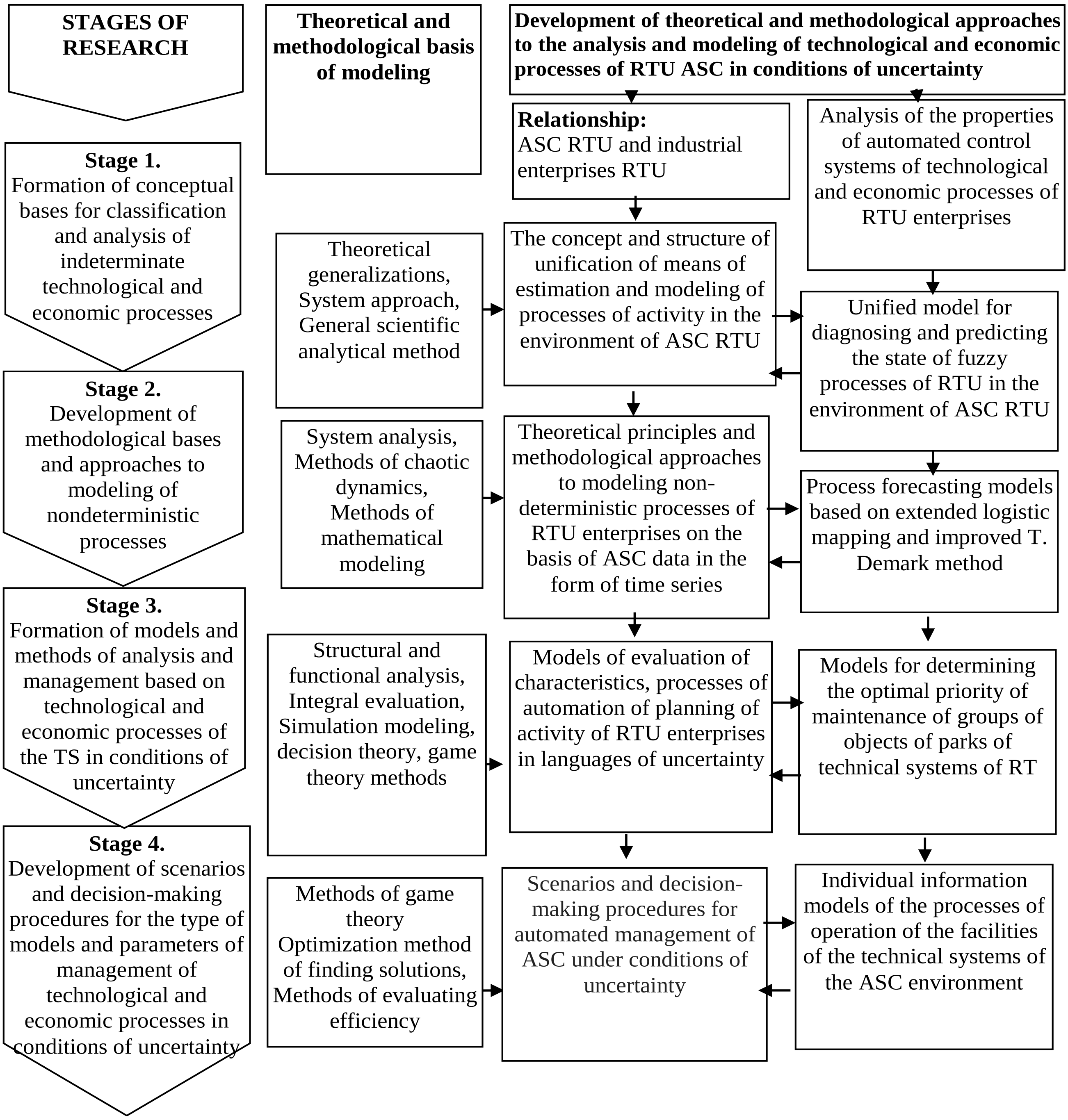

Figure 2. Model of the concept of formation of intellectual technologies of RTU

Source: Author's illustration

At formation of the conceptual approach to the decision of a complex of problems on formation of intellectual technologies, and also the further development of automation of management of activity of the enterprises of RTU in the conditions of uncertainty, the scenario approach is offered. This approach is based on unified procedures of the AS platform - diagnosing, classifying, forecasting and planning with statistical and fuzzy parameters of technological and economic processes of RTU, which may take into account the possibility of using different models based on existing databases and objectives (Fig. 1). Significantly, the set of methods and models of management automation envisaged by the concept includes unified procedures for diagnosing, classifying, forecasting, planning and managing the current RTU processes. Integration and unification of intelligent functions minimizes the operating costs required to implement the management of RT processes.

Unified procedures of AS-D for diagnosing the parameters of nondeterministic RT processes in case of multiple data uncertainties. Consider cases of modeling and diagnosis, when one or several different types of uncertainty in the assessment of data characteristics (X, Y). That is, there is a repeated uncertainty of the parameters of the model of the controlled system: randomness, inaccuracy, fuzzy, interval estimates of values, their combinations (Chernyak et al, 2016; Ramazanov et al., 2019; Bajbuz et al., 2019; Nazzal et al., 2018).
In terms of content, the tasks of diagnosis (and information technology to ensure) are that based on the use of measurement results of a set of controlled parameters of the object $X = \{(x_i), \quad i = 1,2,\dots,m)\}$ визначити його стан щодо діагностування із множини determine its state of diagnosis from the set of possible $Y = \{(y_k), \quad k = 1,2,\dots,l)\}$. In this case, to ensure the completeness of the task of diagnosis, it is necessary to include all conditions - both serviceable and inoperable. Methods and procedures for diagnosing the state of systems and processes are a significant and important component of many technological and economic management systems in various industries (Skalozub et al, 2017; Voronina et al., 2016). To apply the scheme of the fuzzy control method Takagi-Sugeno (T-S) in the uncertainty of different species in our work used in (Chernyak et al, 2016) integrated indicators – reliability indices $d(x)$, species:

$$d(x) = \left[d_{D_1N}(\bar{x}_1) \cdot d_{D2N}(\bar{x}_2) \cdot \ldots \cdot d_{DnN}(\bar{x}_n)\right]^{1/n} \qquad (1)$$

In (1) $d(x)$ is a generalized estimate of the degree of reliability of the n-dimensional vector of input variables (X), rules of the T-S model, ie rules of the form (2). Individual components (X) take values from sets $[0, 1]$. This index (1) is further used in the TC method, similar to the degree of affiliation for fuzzy quantities (Byt'ko et al, 2015; Boyko et al, (2013).

$$R^{(1)}: IF(x_1 is D_1^1 AND x_2 is D_2^1 AND \ldots x_n is D_n^1) THEN y_1 = f^{(1)}(x_1, x_2, \ldots, x_n) \qquad (2)$$
$$R^{(N)}: IF(x_1 is D_1^N AND x_2 is D_2^N AND \ldots x_n is D_n^N) THEN y_N = f^{(N)}(x_1, x_2, \ldots, x_n)$$

Consider the formation of the model of the task of diagnosing and creating a unified procedure of the AS-D platform. To simplify the presentation of the material instead of reliability indices (with multiple uncertainties of data (1)) we will use fuzzy values. The procedure consists of the following stages:

- formation of sets of controlled parameters(X) and diagnosed conditions (Y), $Y = \{(y_k), \quad k =$

$1,2,\ldots,l)\}$, which further represent the term-sets of the linguistic variable RESULTS;

- formation of membership functions of parameters (X) term-sets of values(Y) variable RESULTS:
  $(\mu_1(x_i),\mu_2(x_i),\ldots,\mu_l(x_i)),\quad i=1,2,\ldots,m$ (3)
- determination of indicators of significance $Gx(i)^k$ (relevance) of variables $X=\{(x_i),\ i=1,2,\ldots,m\}$ for diagnostic rules $R^{(k)}$, $k=1,2,\ldots,l$:
  $\left(Gx(1)^{(k)},Gx(2)^{(k)},\ldots,Gx(i)^{(k)},\ldots,Gx(m)^{(k)}\right),\ \ i=1,2,\ldots,m$ (4)
- definition (for example, by the method of analytical hierarchies (Saaty T., 2016)) for each term set $y_k\in(Y)$ «individual» weights of importance of parameters (X) ($R^{(k)}$):
  $W^{(k)}=(w_{1k},w_{2k},\ldots,w_{mk}),\quad k=1,2,\ldots,L\,;\quad \sum_j w_{jk}=1$ (5)
- get the value of a controlled set of parameters,(X) perform a calculation of the set of values of membership functions for each term set of values (Y) variable RESULTS, or similar estimates for variables (1):
  $(\mu_1(x_{i*}),\mu_2(x_{i*}),\ldots,\mu_l(x_{i*})),\quad i=1,2,\ldots,m$ (6)
- calculate the values of the resulting indicators of thermal sets (possible states) taking into account the indicators of relevance (4) and weights $W^{(k)},\quad k=1,2,\ldots,l;$
  $V^{(k)}=\sum_i Gx(i)^{(k)}\times w_{ik}\times\mu_{ik}(x_{i*})\,,\quad k=1,2,\ldots,l.$ (7)

Dimensions $\{V^{(k)}\}_l$ represent weighted estimates of the degree of affiliation (or indices (1)) of the input set (X) to the corresponding term sets$y_k\in(Y)$ variable RESULTS, the maximum of which determines the outcome of the diagnosis:

$$V^{(\text{rez})}=\max_k(V^{(k)}(Y)) \quad (8)$$

Model (7) - (8) is a form of the T-S method (Vertelieva, 2019), where the activity indicators of individual rules of diagnosis (7) are the results of the application of functional transformations of the original data (X). Note that to diagnose certain conditions (Y), $Y=\{(y_k),\quad k=1,2,\ldots,l)\}$ several rules $R^{(k)}$of the form (7) with different parameters can be.

Based on the values (6), (7), various indicators can be formed, which determine the relative or comparative estimates of the results (8), for example, the normalized percentage and so on. In work (Kozachenko et al., 2013) such indicators determine the comparative reliability of individual term-sets(Y)namely:

$$\nu^{(k)}=\frac{V^{(k)}}{\sum_{(k)}V^{(k)}} \quad (9)$$

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As mentioned above, indicators (9) and similar in model (3) - (9) can be obtained on the basis of complex estimates – reliability indices $d(x)$ (1). It is important that in the General case, the values of (1) can be formed by indicators of different categories of uncertainty of the components of the input vector (X). In addition, for a single variable , $X = \{(x_i),\ i = 1,2,\ldots,m\}$ it is possible to use the characteristics of different categories of uncertainty, ie to consider them as separate, for example, in different rules (7). When comparing indicators (7), (9) with the established levels or among themselves, it is possible to diagnose several states (Y) of the system. For example, the group of diagnosed conditions includes those whose values (9) differ from (8) by a set percentage.

The unified diagnostic procedure can be implemented on the basis of the created information-analytical platform ANS-D environment ANS. The general structure of this module is shown in Fig. 3.

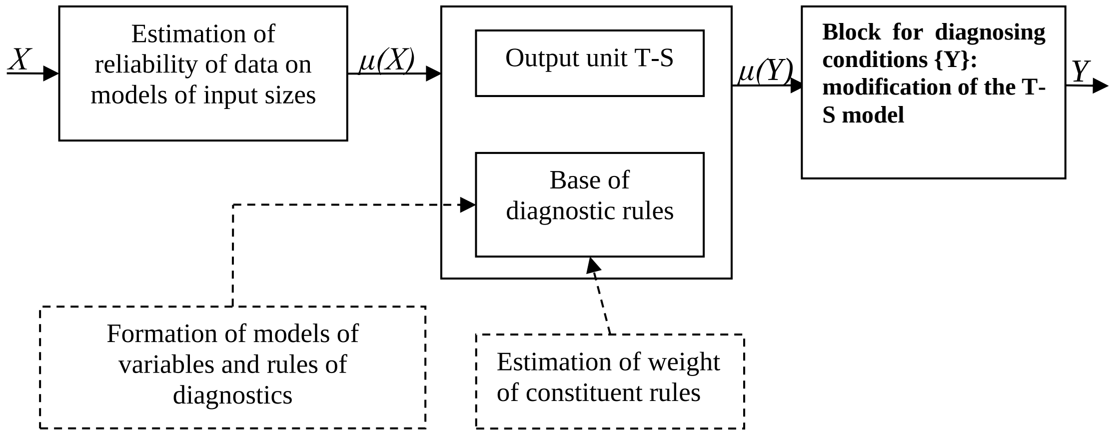

Figure 3. Unified control module of the AS-D environment

Source: Author's illustration

Module blocks (Fig. 3) correspond to the components of the diagnostic model (3) - (9). It also evaluates the reliability of data on models of input values, which in the general case may be different types of uncertainty.

Procedures for classification and short-term forecasting of RT processes. Here is another example of unified procedures of the platform AS – procedures for analysis, classification and forecasting of nondeterministic processes represented by time series, according to chaotic dynamics. The ramifications and complexity of RT processes and systems lead to the emergence of events and situations with fundamentally indeterminate parameters. One of the main ways of their initial description is to present the data in the form of values of the main measured characteristics of TS arranged by stages and intervals. Models and methods of analysis and forecasting of states and parameters of complex systems based on the TS have been recognized and widespread, find new forms of implementation. TS of RT processes and requirements for the results of their analysis are specific in comparison with natural (biological, atmospheric phenomena, cardiac processes, etc.). First, these TS's are "short" (up to 250 levels); secondly, the requirement for the "suitability" of procedures for reliable production and technical forecasting and planning. To study the general properties of the TS, fractal analysis methods are currently used, in particular, the calculation of the Hirst index. (H), which

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allows to distinguish between processes (persistent or trend-resistant, anti-persistent, where "breaking" tendencies are expected, processes of a random nature). For the study of anti-persistent TS (ATS), specialized procedures have been developed that allow to differentiate and classify such processes.

Formation and interpretation of ATS data sequences requires determining the possibility of correct formation of computer models, procedures for estimating the parameters of process states, methods of studying the properties of TS, accuracy and reliability of constructed models, etc.

The development of research on models, algorithms and software for ATS is currently of scientific and practical interest. For the AS environment, the issues that ensure the development of algorithmic and instrumental software for correct and numerically effective research and classification of ATS, the formation of short-term forecasting procedures are important and relevant.

In the rational management of non-deterministic processes of arrival or departure (Fig. 4) of cars of a certain category from the station, the tasks of modeling, analysis and forecasting of such processes based on their TS (TS-C) are important.

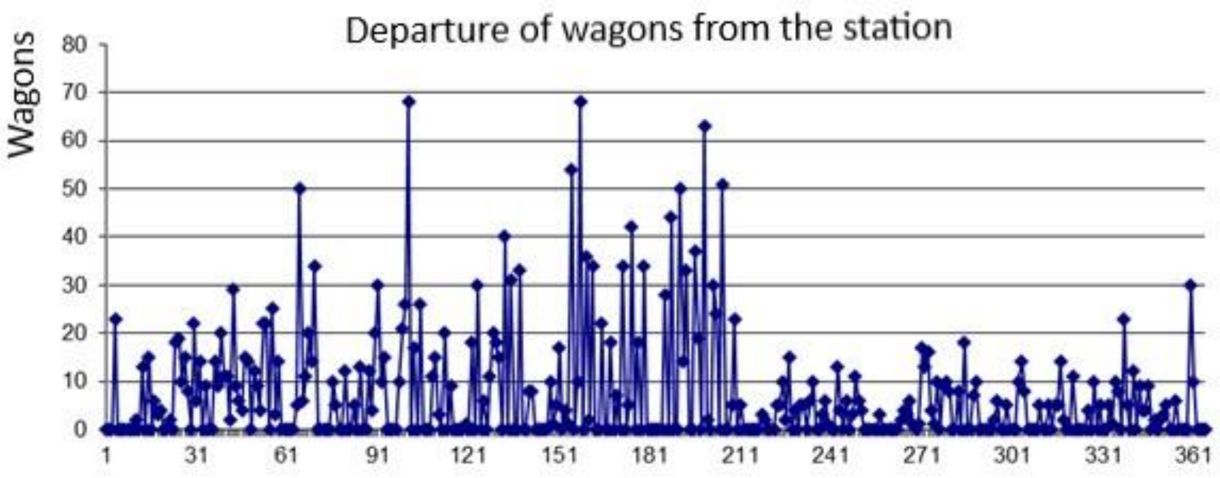

Figure 4. Dynamics of departure of wagons from the station for the year

Source: Author's illustration

To ensure the reliability and adequacy of mathematical models of these and similar processes, it is first necessary to establish the general properties of TS-C. To do this, use the Hurst index (10) (Qi et al., 2011; Dlask et al., 2018), the values of which allow us to establish the category of TS processes – persistent (trend-resistant), anti-persistent ("breaking" trends, returns), the random nature of processes

$$H = \frac{\log(R/S)}{\log(a * N)} \tag{10}$$

where: H – Hurst index; S – standard deviation of a number of observations; R – the scope of the accumulated deviation; N – number of observation periods;

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«*a*» – set constant, for "short" TS $a = \frac{\pi}{2}$ (Skalozub et al., 2016; Skalozub et al., 2018).

Studies of the TS of some processes of transportation and maintenance of wagon flows of RT of Ukraine (Fig. 4) allowed to classify them as ATS. Consider the task of creating a service platform AS for classification, modeling and short-term prediction of ATS, using the procedure of the article (Skalozub et al., 2016). It proposed a theoretical and methodological approach and a specialized procedure aimed at solving the problem of differentiation of ATS and their classification. Classification of ATS allows to reveal additional signs of processes at the expense of what to increase reliability and accuracy of results of the analysis and forecasting of nondeterministic processes. The basis of the approach is the sequence of transformations of the ATS by procedures of generalization of adjacent levels of source data sequences.

At the same time, a methodology was developed, as well as basic procedures for classifying the studied processes were formed.

The following procedure of classification of a series (PCS) by its transformation is offered (Skalozub et al., 2016). Schematically, a series of new $TS_i(k)$ is formed on the basis of PCS data based on the original TS data, k = 2, 3, 4, 5 .... In the $TS_i(k)$ series, the parameter "k" indicates the number of consecutive levels of the series, which are used to construct one next level of the transformed series (as the average value of k levels) at the stage of analysis "i". That is, "i" means the number of the PCS stage for the formation and study of $TS_i(k)$. In the next (*i+1*) and subsequent stages, the PCS procedure is applied to the new ones formed in the previous stages of $TS_i(k)$. The construction of $TS_i(k)$ series is terminated if for some value of "k" the corresponding $TS_i(k)$ becomes trend-resistant according to (10). A similar condition for the completion of the PCS is the requirement: $H(TS_i(k))> H^*$ (10). When the PCS stop conditions for the $TS_i(k)$ series are provided for several generalizations of the "k" levels, the TS are assigned to a class with a smaller "k". Next, to the obtained in stage "k" modified series apply the methods of correlation-regression analysis (Skalozub et al., 2018b), build a regression model of the formed $TS_i(k)$. The coefficient of determination (R^2) acts as a measure of the reliability of each of the models.

Examples of aggregate TS-C models and their regressions are shown in Fig. 5 and Fig. 6. The original ATS-C became persistent (H = 0.587) by aggregation of 5 consecutive levels of ATS, with the $TS_i(5)$ model. In Fig. 5 shows the ATS-C of the 7th class, ie the elements of the model were formed by aggregation of 7 (k = 7) levels of the ATS.

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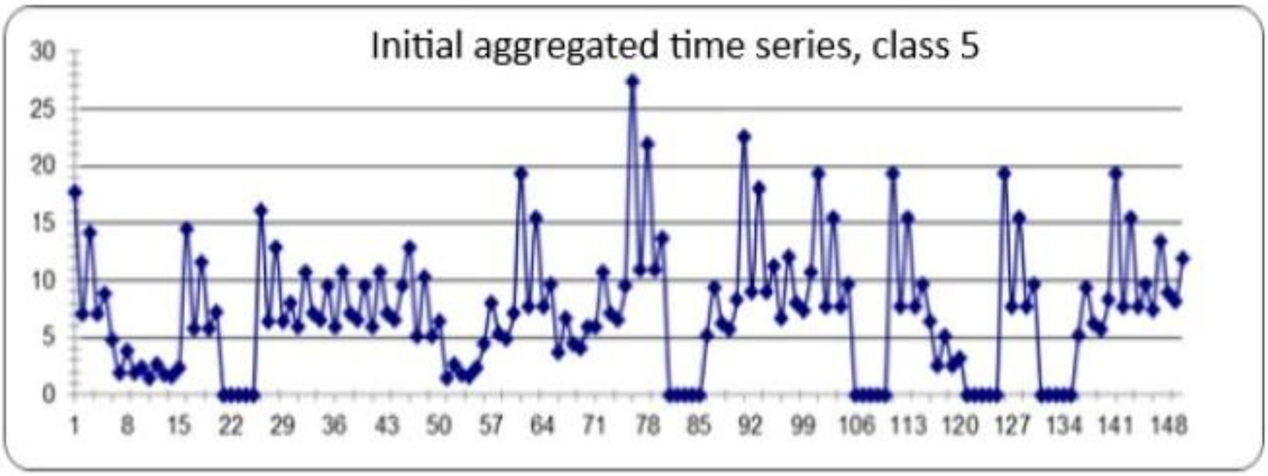

Figure 5. Initial aggregated ATS of the 5th class, $TS_i(5)$, H = 0.587

Source: Author's illustration

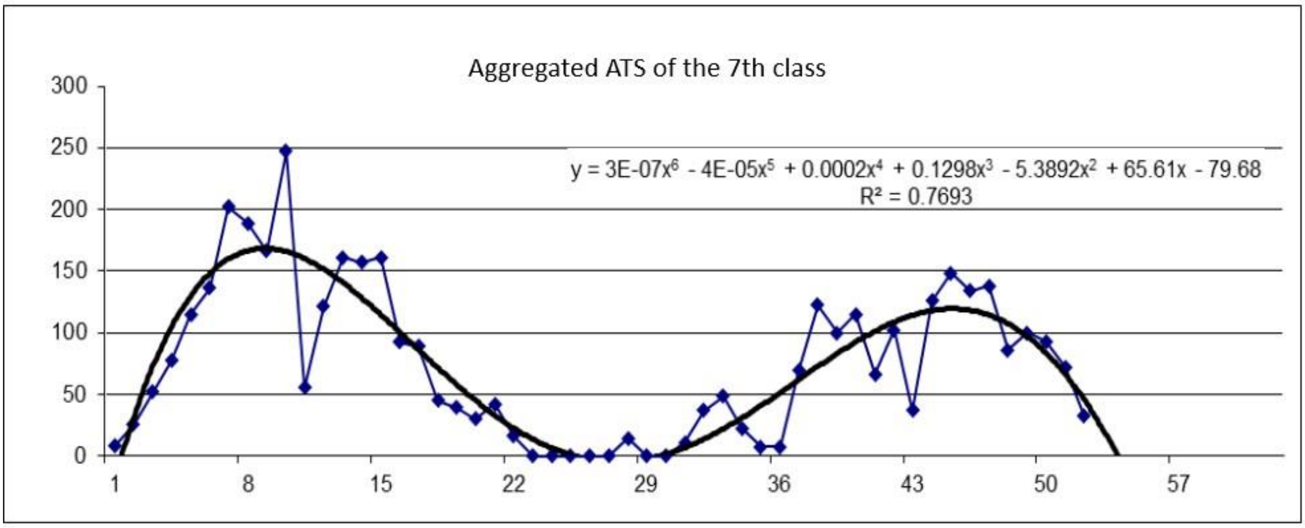

Figure 6. Regression model for aggregated ATS of the 7th class (k = 7)

Source: Author's illustration

The polynomial regression model of ATS 7th class has a coefficient of determination (R^2 = 0.7693). Also, the value of the class (k = 7) has a meaningful interpretation – the volume of cars per week.

The trend-resistant $TS_i(k)$ models formed by the PCS allow to estimate the ATS indicators generalized for the period "k", which is often insufficient for practice. When planning, it is necessary to have not only group data, but also estimates of levels for all periods. The problem of estimating the parameters of ATS processes at all levels is solved by forming a procedure for interpolation of values in the aggregation ranges (Skalozub et al., 2018a). For the justified application of models (1) of TS processes for the AS of RT platform, it is necessary to develop specialized procedures that allow:

• unambiguously and computationally efficient classify ATS;

• perform interpolation of the values of the levels of the ATS indicators within the aggregation intervals;

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- perform procedures for short-term forecasting of the values of total volumetric indicators of the modified series for the established interval (period of data aggregation), as well as estimates of values at all steps of the primary ATS process.

The essence of the interpolation procedure in the classification of the TS is the formation of several newly formed sequences of class "k", which are offset from each other by several levels. So they have the same class "k", but different level numbering and mathematical models of trends. By shifting the models, it is possible to interpolate values by levels using a system of equations or iterative procedures.

To form an interpolation procedure for estimating and refining the internal levels of ATS with certain means of PCS class "k" we use the following system of equations formed on the basis of the initial TS:

$$\begin{cases} Y_1(1) = \left(\frac{1}{k}\right)\sum_{i=1}^{k}\Delta_i; \\ Y_2(1) = \left(\frac{1}{k}\right)\sum_{i=2}^{k+1}\Delta_i; \\ \dots \quad \dots \quad \dots \\ Y_k(1) = \left(\frac{1}{k}\right)\sum_{i=k}^{k+k}\Delta_i. \end{cases} \tag{11}$$

That is, when calculating estimates of indicator levels within the aggregation interval for ATS class k>1, it is necessary to form "k" of new sequences with elements (11). The following elements of aggregate models are calculated similarly to (11), but for other sequences of indexes of TS elements. For example, for processes 5th class $TS_i(5)$ the following formation schemes are possible (from fa (5)):

f_a : $ua_1; ua_2; ua_3; ua_4; ua_5; ua_6; ua_7; ua_8;$ (12)

$f_b(5)$: $(ua_1+ua_2+ua_3+ua_4+ua_5)/5; (ua_2+ua_3+ua_4+ua_5+ua_6)/5;$ (13)

$f_c(5)$: $(ua_1+ua_2+ua_3+ua_4+ua_5)/5; (ua_3+ua_4+ua_5+ua_6+ua_7)/5;$ (14)

$f_d(5)$: $(ua_1+ua_2+ua_3+ua_4+ua_5)/5; (ua_4+ua_5+ua_6+ua_7+ua_8)/5$ (15)

$f_f(5)$: $(ua_1+ua_2+ua_3+ua_4+ua_5)/5; (ua_6+ua_7+ua_8+ua_9+ua_{10})/5$ (16)

As the number of the ATS class "k" increases, the number of variants of aggregation schemes of models of the form (13) - (16) increases. There are two significantly different types of such schemes - "without overlap" members of ATS (13), in which consecutive elements of aggregated models do not contain previous elements, as well as with overlap (repetitions) of members of TS (12) in newly formed sequences of TS models (k), (13) - (15). (13) - (16) give examples of several initial levels of time series variants $TS_i(k)$. Examples of data aggregation schemes (12) testify to the content and wide possibilities of forming process models in the form of $TS_i(k)$. At the same time, in order to create the AS platform, it is necessary to establish, firstly, in which form of aggregation the possibility and accuracy of classification of source TS is provided, and secondly, to propose algorithms for forecasting aggregate models. Such algorithms should also allow interpolation – to calculate the internal levels of indicators of $TS_i(k)$ processes.

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Unified procedures for interpolation and forecasting of ATS are designed to calculate the internal levels of ATS processes, using estimates of integrated values obtained from the models of the corresponding trends of $TS_i(k)$. For different variants of aggregation (13) – (16) it is necessary to form a separate procedure of interpolation - calculation of values of internal levels on the basis of forecast values for the whole range., Obtained on the basis of the system of equations (11). Thus, for (k=3) to calculate the intra-interval values of levels, it is possible to use (k-1) the initial values of the ATS instead of solving the system of equations of the form (11). Then to interpolate the ATS levels instead of solving the systems of equations (11) it is sufficient to use successive relations of type (16):

$$Y_1 = \frac{y_1 + y_2 + y_3}{3}, \text{ then} \rightarrow \; y_3 = 3Y_1 - y_1 - y_2,$$

$$Y_2 = \frac{y_2 + y_3 + y_4}{3}, \text{ then} \rightarrow \; y_4 = 3Y_2 - y_2 - y_3 \qquad (17)$$

$$Y_3 = \frac{y_3 + y_4 + y_5}{3}, \text{ then} \rightarrow \; y_5 = 3Y_3 - y_3 - y_4$$

As a result, the following general algorithm is used when constructing the forecast: For the process Y_1, the k-levels of the initial TS are selected, starting from i=1, n over k. For Y_2 – i=2, n, for k, etc., for all Y_j, j = 1, k, depending on the aggregation scheme of the form (13) – (16). The Hurst index (10) is determined, the forecast is constructed according to the polynomial model of $TS_i(k)$ and the coefficient of determination is calculated (R^2). According to the obtained models, the internal interval values of the forecast levels are calculated, for the determination of which the initial values of the series Y are used (k-1). For example, for (k=3) of the form (17). Studies of the functional efficiency of $TS_i(k)$ modeling algorithms have shown that different aggregation schemes give different (though quite similar) mathematical models of the same process that can be used for operational forecasting under uncertainty.

Various variants of $TS_i(k)$ formation schemes (with overlapping and without overlapping levels) were investigated for many ATS. For example, in Fig. 7and Fig. 8 shows the aggregate models of ATS of the third class of $TS_i(k=3)$ with Hurst index (10), H = 0.479. The figures show the initial members of the new sequences with different numbers of common elements in the aggregate levels (11). Namely, one common element of MA(3_1) fig. 7, without intersection of elements MA(3_3) fig. 8. The figures also show polynomial models of trends calculated by the method of least squares, as well as estimates of the reliability of polynomial models (R^2). Similarly, these analytical models represent generalized processes formed from the initial ATS.

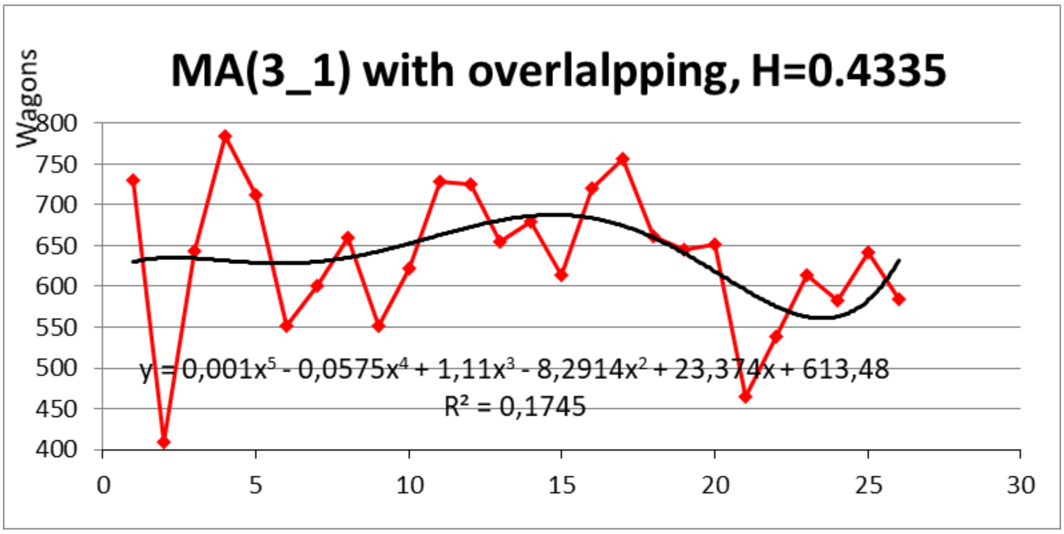

Figure 7. Aggregate model of $TS_i(k=3)$ with one common element (15)

Source: Author's illustration

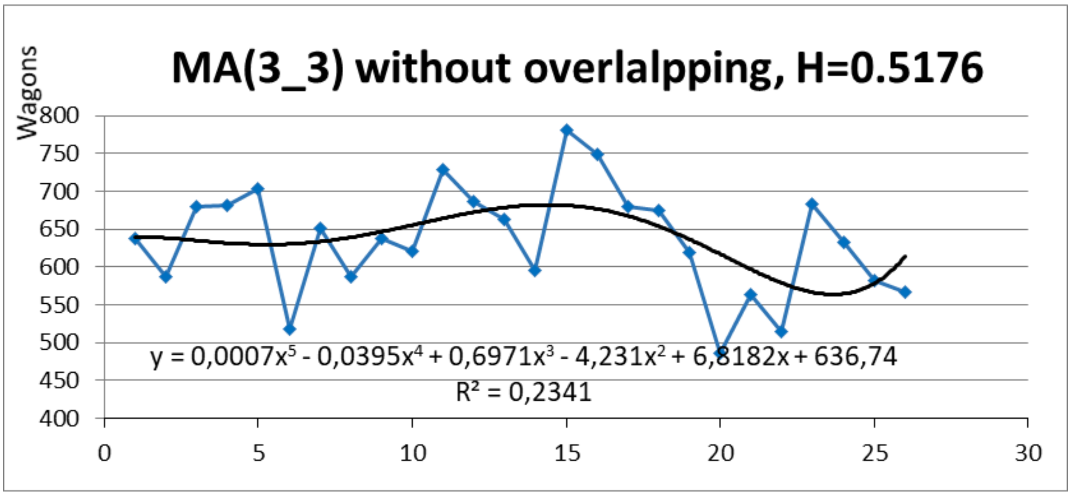

Figure 8. TS model of $TS_i(k=3)$ for the scheme without overlapping levels (16), polynomial model and reliability estimates (R^2).

Source: Author's illustration

In the vast majority of computational experiments, aggregation schemes with overlapping levels had class k = 2. Such schemes were "insensitive" to the data in the classification of the TS. Classification schemes for aggregation without "intersection" of successive levels of the species (16) allowed to identify different classes of ATS. Modeling and analysis showed the advantage of the aggregation scheme without overlapping levels, which ensured the reliability of the classification of ATS and the accuracy of interpolation procedures. It is the classification schemes of the TS in aggregation without "intersection" and the corresponding interpolation procedures are proposed for the formation of the AS platform. The performed computational experiments showed the possibility of using the proposed classification of $TS_i(k)$ only for short-term forecasts. To implement these algorithms for interpolation and forecasting the levels of ATS processes, it is necessary to have an appropriate structure of their software implementation, which provides the formation of a model sequence of quantities containing all previous levels of TS. Such components of automated systems are implemented by modules of the AS platform of the RTU.

CONCLUSION

A modern and effective direction of development of automated railway transport systems of Ukraine is the formation of intelligent technologies for analysis and control of indeterminate processes in case of uncertainty. The article proposes a concept and methodology designed to create technologies for automated control of non-deterministic processes, the implementation of which is based on a system of unified analytical services. Examples of intelligent services for diagnosing processes with several categories of uncertainty, as well as analysis, classification and forecasting of parameters of anti-resistance processes, revealing the essence of the tasks of building intelligent technologies of automated RT systems of Ukraine. Improved Takagi-Sugeno models for several categories of uncertainty have been obtained in the formation of services for diagnosing the parameters of RT states. The procedure of classification and short-term forecasting of anti-persistent RT processes is proposed, and its properties of correctness and efficiency are investigated. The developed models and methods provide formation of the corresponding services of intellectual technologies of the automated systems of RT of Ukraine.

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Conflict of interests

The authors declare no conflict of interest.

References

Bajbuz, O.G. & Dolgih, A.O. (2019) Comparative analysis of time series forecasting models effectiveness by means of a multi-criteria procedure on the example of financial indicators. “The Journal of Zhytomyr State Technological University” / Engineering, (1(83): 130–141. https://doi.org/10.26642/tn-2019-1(83)-130-141

Boyko, R. O., Zagorovska, L. G., & Yarova, T. V. (2013) Informative providing of task of prognostication of feasibility indicators of functioning of technological complex. Eastern-European Journal of Enterprise Technologies, 3(10(63): 62–64. https://doi.org/10.15587/1729-4061.2013.14866

Byt’ko T. V. & Prokhorchenko H.O. (2015) Formuvannia protsedury avtomatyzovanoi pobudovy hrafiku rukhu poizdiv na osnovi alhorytmu shtuchnykh bdzholynykh kolonii. [The formation procedure automation development train scheduling algorithm based on artificial bee colonies], Transport systems and transportation technologies, 9: 10-15. https://doi.org/10.15802/tstt2015/49348

Chen, X., & Siau, K. (2020). Business Analytics/Business Intelligence and IT Infrastructure: Impact on Organizational Agility. Journal of Organizational and End User Computing (JOEUC), 32(4), 138-161. http://doi.org/10.4018/JOEUC.2020100107

Chernyak O.I. & Zakharchenko P.V. (2016). Prikladni aspecty prognozuvanya rozvitku skladnyh socialno-economochnih sistem. [Applied aspects of forecasting the development of complex socio-economic systems]. Vydavets Tkachuk O.V. Berdyansk, 512p. https://doi.org/10.31812/0564/1252 (UA)

Dlask M., Kukal J. (2019) Hurst exponent estimation from short time series. SIViP 13, 263–269. https://doi.org/10.1007/s11760-018-1353-2

Katkova T. I. (2018). Modeli i metody otsinky, prohnozuvannia ta upravlinnia stratehichnoiu diialnistiu pidpryiemstva v umovakh nevyznachenosti [Models and methods of assessment, forecasting and management of strategic activities of the enterprise in conditions of uncertainty] (Doctoral dissertation, NTU "KhPI") (http://repository.kpi.kharkov.ua/handle/KhPI-Press/35128)

Kozachenko D.V. & Hermanyuk Y.V. (2013) Matematychna model dlia doslidzhennia perevezennia vantazhiv u mizhnarodnomu spoluchenni. [Mathematical Model for Research of International Railroad Goods Transportation] Transport systems and transportation technologies, 5:28-32. https://doi.org/10.15802/tstt2013/19273

Nazzal, Mohammad & Saad, Mohammed. (2018). A general framework for sustainability assessment of manufacturing processes. Ecological Indicators. 97: 211-224. https://doi.org/10.1016/j.ecolind.2018.09.062

Voronina, A.V. & Kopyl O.V. (2016) Pryjniattia stratehichnykh rishen' v umovakh nevyznachenosti ta ryzyku. [Making of strategic decisions in the conditions of uncertainty and risk]. Molodyj vchenyj 1 (28): 35-39. http://nbuv.gov.ua/UJRN/molv_2016_1(1)__10 (UA)

Qi Jingchao & Yang, Huijie. (2011). Hurst Exponents For Short Time Series. Physical review. E, Statistical, nonlinear, and soft matter physics. 84. 066114. http://dx.doi.org/10.1103/PhysRevE.84.066114

Ramazanov S.K., Stepanenko O.P., Chernyak O.I, Tishkov B.O. (2019) Forecasting models and technologies and the problem of designing the future: state analysis and individual results,(Ed.) Chernyak O.I., Zakharchenko P.V., Actual problems of forecasting the development of socio-economic systems, Melitopol, ISBN: 978-966-197-654-1,pp. 164-191

Saaty T. (2016). The Analytic Hierarchy and Analytic Network Processes for the Measurement of Intangible Criteria and for Decision-Making, (Ed.) Greco S., Ehrgott M., Figueira J., Multiple Criteria Decision Analysis: State of the Art Surveys, Springer New York, NY, http://dx.doi.org/10.1007/978-1-4939-3094-4_10, pp. 363-419

Skalozub, V. V., & Klymenko, I. V. (2018a). Method for planning non-determined operation processes of railway technical system park. Science and Transport Progress, (5(77): 7–18. https://doi.org/10.15802/stp2018/141430

Skalozub, V. V., Zhukovitskiy, I. V., Klymenko, I. V., & Zaets, A. P. (2018b). Creation of Intellectual Decision Support Systems in a Unified Automated System for Managing Rail Freight in Ukraine. Systemni tekhnolohii: Rehionalnyi mizhvuzivskyi, 3(116): 153-162.

Skalozub V. V. & Ilman V. M. (2013) Prykladnyi systemnyi analiz intelektualnykh system transportu [Applied system analysis of intelligent transport systems] Dnipropetrovsk, DNURT named after academic V. Lazaryan, p. 214. (RU)

Skalozub V.V., Shynkarenko V.I., Tseitlin S.Y., & Cherednychenko M. S. (2017). Modeli ontolohychnoi pidtrymky avtomatyzovanykh system keruvannia vantazhnymy zaliznychnymy perevezenniamy v Ukraini. [Models of ontological support of automated control systems of freight railway transportation in Ukraine.], *System Technologies*, Vol. 5 No. 112: 153-165.

Vertelieva O. V. (2019), Matematychne modeliuvannia ekonomichnykh protsesiv v umovakh paradyhmalnykh zrushen. [Mathematical modeling of economic processes in conditions of paradigmal dispatches], *Investytsiyi: praktyka ta dosvid*, vol. 12, pp. 48–56. https://doi.org/10.32702/2306-6814.2019.12.48

Zhukovyts'kyy I. V., Skalozub V. V., Ustenko A. B. & Klymenko I. V.(2018a) Formation of intelligent information technologies of railway transport based on models of analytical servers and ontological systems Information and control systems at railway transport 6: 3-11. DOI: https://doi.org/10.18664/ikszt.v0i6.151635

Zhukovyts'kyy I. V., Skalozub V. V. & Ustenko A. B. (2018b). Intelektualni zasoby upravlinnia parkamy tekhnichnykh system zaliznychnoho transportu [Intellectual Means of Control by the Parks of the Technical Systems of Railway Transport]. Dnipro, Standart – Servis, p. 190. (UA)

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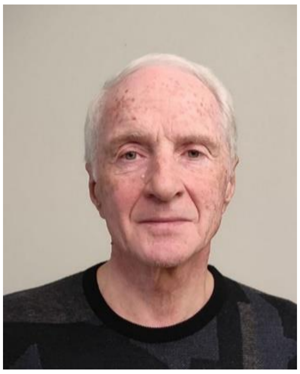

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