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Choice of Model Class and Method of Modeling the Resilience of Agricultural Machinery

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Summary. In the article the requirements to the mathematical model of the process of technical operation of agricultural machines selected by model class and the method of modeling. It is possible to develop the formalized description of the process of recovery of agricultural machinery, is investigated to justify the form of performance indicators and the optimality criterion is to implement the mathematical formulation of specific problems of the study.

On the basis of a formalized description of the mathematical model of process of technical exploitation of the object of agricultural machinery in the regenerative recovery process. The analytical dependence of the parameters on the parameters of the maintenance system for the case of single-stage periodic monitoring of performance. The obtained expressions to calculate asymptotic estimates of the selected performance indicators with exponential distributions of uptime object of agricultural machinery and time independent manifestations of failure in operation.

Stochastic models are usually classified as random processes and can represent processes with discrete States (set of States finite or counted) and continuous set of States (set of States is in one-one correspondence to the set of points of a numerical interval), discrete time (random sequence) and with continuous time. Currently being developed by a large number of stochastic models used to describe the operation of complex technical systems, the main classes which are: logical, linear, Gaussian, automatic, aggregation, Markov, semi-Markov, regenerative, multi-component models in the form of systems of mass service.

Examines the case of multi-stage maintenance subject to the full control of the technical condition of objects of agricultural machinery.

Key words: modeling, technology, model, method, restoration, agricultural machine.

INTRODUCTION

Stochastic models are usually classified as random processes and can represent processes with discrete States (set of States finite or counted) and continuous set of States (set of States is in one-one correspondence to the set of points of a numerical interval), discrete time (random sequence) and with continuous time [1]. Currently being developed by a large number of stochastic models used to describe the operation of complex technical systems, the main classes which are [2]: logical, linear, gaussy, automatic, aggregation, Markov, nephwrack, regenerative, multi-component models in the form of systems of mass service.

In the framework of probabilistic Boolean model assumes that the functioning of a technical system can be represented in the form of series-parallel circuits with input and output, as well as a specified number of intermediate nodes (contacts), isolation of which is interpreted as the event that is modeled. It is clear that such a simple interpretation of the functioning of technical systems does not allow the use of probabilistic logic for the adequate quantitative description of the process of technical operation of objects. This class of models generally used for the simplified probabilistic calculation of reliability of technical systems are investigated in [3]. Thus, a Boolean probabilistic model satisfies only the requirements of 3.4.

The difficulty with linear [4] and gaussy [5] probabilistic models to describe the process of technical operation of agricultural machines is the complexity of the justification of a linear relationship between the parameters describing the operating rules and indicators of its effectiveness, as well as in the severity of the agent linear transformation (the transfer function). It is obvious that the application of these classes of models allows to satisfy requirements 1 and 3 [6].

Thus, using the logical, linear and gaussy probabilistic models the process of functioning adequately described only for a limited range of technical systems, subject to stringent laws that are appropriate to the models assumptions regarding the probabilistic nature of random processes is considered [7].

Automatic statistical and probabilistic models are based on the concept of technical systems, which are modeled as finite state machines (units) [8]. Functioning of real technical systems in the framework of automatic (statistical) model is described by the transition operator and the operators, and outputs, as well as diagrams of the combinations, characterized by the combination of contact sets and operators combinations. Probabilistic automata (units), typically used to assess complex technical systems with unreliable elements, systems with variable time-random structure and systems, structure and status of which at some point time not known and cannot be described only in terms of probability theory [9]. Like any universal system, aggregative approach leads to an overload of the model, which is a significant drawback for the system, consisting of hundreds of elements, which is the system of exploitation of the park. In addition, a model is built as a modular system loses visibility [10], which can be a significant barrier to its active use. Thus, the use of these classes of models allows to satisfy the requirements 1 and 2 [11].

Research has shown [12] that for real stochastic systems that change their state abruptly, characterized by a finite number of possible transitions determined by a finite number of random factors changing the state of the system. Each of these factors is characterized by a certain random time effects, that depends, as a rule, from the state of the system. In this regard, many stochastic models of systems are highlighted Markov, nephwrack and regenerating system [13].

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

The process of docum functioning of technical systems S in a Markov model describes a Markov process $S(t)$, which can be represented as a random process with discrete or continuous states, discrete or continuous time [14]. In practice, to describe the process of functioning of real technical systems, typically use a Markov process (MP) FPS with discrete and continuous time [15]. In this case, it is assumed that the simulated system S can be in finite set of states $E=\{e_1,e_2,\ldots,e_N\}$, where is the number of all possible states. The process of evolution of the system S by changing its states $S(T)=S_n$ due to the transition from one state e_i to another e_j [16]. Markov process is determined Markovsky property that is created by the independence of the transition probabilities of the system from a given state from all the previous evolution of the system before falling into this state and independent of the distributions of length of stay in the state Θ_n from all preceding this condition of the system evolution [17]. However, the strong restrictive assumption in Markov models is the assumption about exponential distribution of length of stay of the simulated system Θ_n, in any of model states $E=\{e_1,e_2,\ldots,e_N\}$ [18].

Studies have shown [19], the formal description of most technical systems such that knowledge of any previous history of this system does not significantly affect its state in the future, in connection with the class of Markov systems have been widely used for the mathematical description of processes of functioning of different technical systems. This is also due to the high visibility of the Markov model, the adoption of a relatively small number of assumptions, simplicity of the mathematical apparatus of analysis.

However, the condition exponentialist the distributions of the residence time in model States which provides the effect of lack pclady Markov process, in practical tasks of technical operation, which involves performing various operations and repair, is rarely performed. Primarily, this is due to the presence in the process of operation States of the planned checks and controls, various types of maintenance etc. with specified time and nawaseri flow that takes the system from state to state [20]. Thus, the Markov model satisfies the requirements 1, 3, 4, but does not satisfy the requirement 2 that do not adequately describe the real process of technical operation of agricultural machinery within a Markov probabilistic model.

Probabilistic model is characterized by the fact that it is free of restrictions on the law of distribution of residence time in model states [21]. In this regard, the class napumsaka systems is more suitable to describe the operating rules of real complex technical systems, in which change of state occurs under the action of random factors, accessible to observation and mathematical description. NMZ insufcient effective mathematical apparatus for the analysis and represent an immediate generalization of Markov chains to the case of arbitrary distributions of time spent in states [22]. Along with the fact nephwrack models require quite a considerable statistical material to adequately specify the distributions of the residence time in model states, which is not always possible and leads to significant errors due to subjective assumptions of the researcher about FRC stay in the states [23].

In the vast number of problems of applied nature of the use of the Markov approximation yields solutions with an accuracy of within the accuracy of the input data. Modeling of PTE of complex technical systems using Markov processes (napumsaka) recovery have shown that in most cases, this error is limited to 3...5%. Therefore, a class napumsaka models meets the requirements 1, 2, 4 due to requirements 3, 6.

OBJECTIVE

The process of technical exploitation of fleet is a complex interconnected stochastic process of functioning of separate objects of agricultural machinery in the vessel. Such a system can be described by classes of regenerating, multi-component stochastic systems and queueing systems.

THE MAIN RESULTS OF THE RESEARCH

Class of multicomponent systems stands out from a wide range of stochastic systems because the evolution of such a system is set napumsaka model that adequately describes it, and yet sufficiently affordable and efficient in the analysis of the operation [79]. In this case l^k, it $k=\overline{1,L}$ is assumed that the system which is investigated, consists of a finite number of objects, each of which can be in a finite number of N_k, $k=\overline{1,N_k}$ possible states. The functioning of each object l^k is described by semi-Markov process $\left(l^k{}_n,\Theta^k{}_n;n\geq 0\right)$ in a finite phase space of states (FPS) $E^k=\overline{1,N}$. This assumes that each object operates independently of the other objects in the system. Multicomponent system is set to a finite collection of independent napumsaka (NM) $\left(l^k{}_n,\Theta^k{}_n;n\geq 0\right)$ updates with the ultimate FPS $E^k=\overline{1,N}$.

This class of systems has an effective unit of analysis that when using the NM model of the process of technical operation of a single object of agricultural machinery as part of the fleet of vessels makes it relatively easy to estimate the desired characteristics of the Park of the same objects of agricultural machinery. Class of multicomponent systems satisfies the requirements 1, 3, but not entirely consistent with requirement 2 and does not satisfy the requirement 4.

From the assumption of independence of the functioning of the individual objects are deprived of the models constructed in the form of systems of mass service (SMO). The functioning of a complex system describes the SMO is represented as a certain set of service channels with a particular service mechanism that receives a stream of service requests with a given discipline of the queue. A characteristic problem of the theory of mass service is the relationship between the nature of stream applications, the performance of individual channels and the efficiency of the service.

Currently, the analytical solution of the characteristics for SMO with a simple discipline turns and elemental structure, as a rule, is characterized by the Markov properties of the process under study. Thus, the class of stochastic models in the form of the CFR satisfies the requirements of 1.4 but not fully satisfies requirements 2, 3.

The other broad class of models are models that use regenerative stochastic processes. These models are based on the assumption that the examined technical object during operation with a probability in finite time (cycle duration) is some condition (time of regeneration), in which all previous history ceases to affect its further evolution. The functioning of a technical object describes a regenerative process with a finite set of regeneration cycles, each of which consists of a finite multiple of the number of phases (States) in the ultimate FPS , and not necessarily to the process in each first cycle went through all the phases. The cyclical nature of these random processes facilitates the study of their asymptotic properties, which is consistent with the purpose of this study. Furthermore, unlike Markov models do not put forward strict restrictions on the distribution of the residence time in model States. But the idea of PTE in the form of a regenerative process involves that the stream of recoveries is recurrentis.

This class of models has an effective unit of analysis, that the representation of the process of technical operation of complex technical systems in the form of regenerating makes it easy to determine stationary characteristics for a fleet of similar objects SK. The class of models regenerative processes satisfy the requirements 1 - 4 and does not meet the requirements 5, 7.

The results of the analysis of stochastic models of functioning of objects of operation, are used to create mathematical models of PTE of complex technical systems, allow you to choose the class of models that use regenerative repair processes. The use of models of this type allows to solve successfully the problem of choice of rational strategies and repair, and in some cases can be solved the problem of optimization.

Definition of probability characteristics of stochastic models can be handled in various methods of simulation of random processes. Distinguish between analytical, simulation and combined methods.

Analytical models are usually used in cases when the number of parameters characterizing the studied process, is not very big, any dependence between them is not very difficult. They allow using algebraic, differential, difference and other equations to establish the formulae of dependence between the main determinants of the studied process and the indicators of its efficiency. They are also convenient and the fact that their construction and study, you can apply different mathematical methods and techniques.

Methods of analytical and stochastic analysis provide the formulation and solution of systems of differential equations for the probabilities of possible States of PTE, which allows to satisfy the requirements of consistency and reliability, due to the possibility of obtaining the distributions of the desired characteristics of the model and the values of the desired performance indicators according to the results of the calculations can be obtained with a single value of confidence and zero – confidence interval. In addition, this method provides controllability results and low complexity computing.

In probability theory differential equations are made taking into account the state of each object operation and its characteristics that technical systems large scale (Park courts or its components) leads to a sharp increase in the number of equations. As a consequence, the model loses clarity and does not meet the requirements regarding ease of creation and control of simulation results.

A common disadvantage of the analog-to-stochastic and theoretical mornong modelling techniques is the inability to develop on their basis a universal adaptive model of PTE of objects SK, due to the fact that any changes in the composition of the state space the operating rules or the distribution functions of time (FRC) stay in the model state leads to the need to re-output all required analytical dependences for the evaluation of performance indicators. That is actually to create a new model.

Dynamics of average method allows for a large number of possible states docum complex technical system (the functioning of the individual elements is described by the processes of recovery in the final FFS) to evaluate average characteristics of the system. It can be used to circumvent the computational difficulties associated with the joint decision of a large number of differential or algebraic equations for finding the probabilities of the States of a complex system which is investigated. The essence of the dynamics of average method is that during the process of mathematical analysis of complex multicomponent systems are considered the state of the system as a whole and its separate elements. This is based on the assumption of independence of event streams, sending part of the system from state to state, from the number of items in this and other States. It is obvious that this assumption can be done if the individual elements of the system operate independently of one another, or options FRCH stay a separate element of the system in any of model States before moving to the adjacent set taking into account the interactions (dependencies) of processes of functioning of the remaining elements of a complex system. In addition, this assumption can be relaxed through the use of the principle quaeso, as well as by taking into account the replenishment of the total number of states. Thus, the main disadvantage of the dynamics of average method is the disparity between the requirements of consistency.

Along with analytical simulation methods are the most common tools of control theory and operations research for the management efficiency of complex systems [114]. Simulation is the representation of the dynamic behavior of docum system by moving it from one state to another in accordance with clearly defined operating rules. The changes of system state occur either continuously or at discrete points in time, that is the basic concept of the simulation system that is seen is a reflection of the change of its States over time. An important advantage of simulation is the ability to lock the intermediate values of different parameters during simulation just as it occurs during the operation of the real system. Simulation models typically are used for design, analysis and evaluation of the functioning of complex systems. The simulation is based on the concept of building an iterative model in which the model changes by adding new or eliminating some of its elements and (or) interrelationships between them. This assumes that the system can be described in terms that are understandable to a computing system.

Deterministic simulation (detailed) model, based on the development of deterministic counterpart of the process is investigated. But due to the fact that the process of technical operation of objects of SK is categorized as stochastic, they can not be used to create a mathematical model of PTE of objects SK.

In statistical models relatively simply count discrete, continuous, logical parameters and their nonlinear relationships, and a variety of random factors and to influence the process of technical operation, which allows to meet the requirements of adaptability, versatility and ease of creating a model that is being developed. Statistical modeling method provides for a multiple run of a simulation model for a set of statistics that allows to satisfy also the requirements of accuracy and consistency of simulation results. Until recently, the main disadvantage of statistical models considered the need for time-consuming to conduct the simulation experiments (large volume of calculations) to obtain reliable characteristics of the studied process. But the emergence in recent high-speed personal computers has made this drawback is immaterial.

A common drawback of simulation models is the lack of control results due to the fact that the simulation model is built on the principle of “black box”.

Combined modeling methods combine the advantages of statistical and analytical modeling.

So when “direct modeling” is a preliminary calculation results for many conditions statistical method, and then constructed tables or approximating functions for quick calculations and regression models models method of group accounting of arguments and things. These models meet the requirements of the low complexity of the calculations. At the time of creation of the model the reliability of the results corresponds to the reliability of the statistical model. However, the change of conditions, methods of operation, that is, the emergence of a new source of data leads to unreliable results of calculation and requires significant expenses for revision regression models by collecting new statistics and its approximation that does not satisfy the requirements of adaptability. In addition, aproximaci dependence usually does not have a clear physical meaning, so the model does not satisfy the requirements regarding the verifiability of the results and consistency.

Analytical and statistical models represent a set of methods of accelerated modeling, based on a combination of analytical and statistical methods.

Analytical and statistical methods based on the method of small parameter among the output characteristics of the operation process that is simulated, is determined by TA, which can be selected as a small parameter ε. Then using various analytical methods, the desired characteristics of the process (performance indicators) are presented in the form of a series in powers of ε, the coefficients of this series are interpreted as the mathematical expectation of functional from some auxiliary random processes and are defined using the method of statistical modeling. Basically, this method developed for evaluation of reliability of highly reliable systems. Obviously, when developing mathematical models of PTE of objects of SK these models do not satisfy the requirements of adaptability and versatility, it does not fully satisfy the requirements of verifiability of the results and ease of creation.

The results of the analysis of the methods used for the simulation of the operation of the CCC with the selected class of stochastic mathematical models allow to choose the methods of analytical modeling and midrange.

As shown above, the actual scientific problem is the rationale for the selection of one of the variants of the organization of the recovery system on the basis of appropriate assessment and prediction of changes of indicators of technical and economic efficiency of operation of the machine, including taking into account the possible implementation and operation of advanced means of monitoring and diagnosing.

It is obvious that the solution of specified research tasks should be based on appropriate mathematical models (MM) process and repair of objects of SK, because the practical application of various options for system recovery due to the risk of material losses. Thus the mathematical model is developed (applied) must take into account how the organization (construction) of the recovery system with a variety of options, and the application of various tools for monitoring and diagnosing.

In the study of the effectiveness of the recovery system as the object of SK taken constructively-removable units (assembly, unit, module) machines.

Use the approach outlined and present formally the task of estimation and forecasting of technical and economic efficiency of implementation of different options for system recovery machine IC to justify their introduction into a system that reflects the relationship of the main elements of the decision-making process and the sequence of formation of the partial tasks:

$$\langle U,\ \Lambda,\ H,\ G,\ Y,\ \Psi,\ W,\ K,\ \Im,\ \Theta \rangle,$$

where: U – set of variants of the organization of the recovery process, Λ – the set of values of certain Λ_F and uncertain Λ_E factors influencing the process of technical operation (PTE) of objects of SK, G – number of possible outcomes of PTE of objects SK, Y – vector of characteristics of the result, i.e. numeric expression of result objects PTE-IC, H – model, i.e. the mapping that compliance with the many options for organizing the recovery process of U and factors Λ many results Y(G) W – an indicator of technical and economic efficiency, Ψ – operator matching result, K – criterion of efficiency, $\Im$ – model the properties of the decision maker (DM) on the elements of the set $V=\{U,\Lambda,G,Y,W,K\}$, Θ – information about the operating rules of objects of SK that is available.

It is known, the system of vessels typical of various types of works, preparations and repairs to maintain given equal reliability and usability:

– regular maintenance,

– scheduled (average and capital) repairs of objects of SK,

– unscheduled repairs related to the elimination of identified failures and malfunctions,

– work on periodic control and diagnostics of objects of SK and the like.

Thus, operation of objects of SK represents a succession of stages such as use, maintenance, repair, and storage. expectations are falling in each of these stages. Therefore, we represent formally the process and repair the machine in the process of changing various process States technical operation in accordance with the adopted strategy strategy and the exploitation that it corresponds to.

Under the state process and R cars will understand the appropriate stages of technical operations, characterized by the impact machine of the personnel who performs maintenance or the external environment. The structure and nature of the process and repair, and thus the state space of the process of technical operation, determined by the accepted strategy and repair, which generally represents a set of principles and rules that provide a predetermined control of the process of technical operation.

For a formal description, let us characterize the operation of the object SK two interrelated processes: an objective process of change of its technical condition and the subjective process of its operation.

Due to the fact that FS machine consists of a finite number of elements and can be in a finite number of different states, differing technical conditions, as well as operations on the elements (control during maintenance, rehabilitation, etc.), describe the process of technical operation of objects of SK a finite set E states e_i, created by breaking down $D\subseteq E$, where $i\in I$, and items I the identified elements of the breakdown D. We assume that the state e_i some are assigned in accordance with the emerging state of the object SK ω_k and the process of technical exploitation of mashine $e(t)$ created by the sequential change of states of PTE e_i. That is, assume that $e(t)$ is some reflection of the process $\omega(t)$:

$$e_i(\Omega):\Omega\to\omega_k(E).$$

In turn, the object of the SC, introduced in the state PTE, act of external influence in this state so:

$$\omega_k(E):E\to e_i(\Omega).$$

That is, we assume that the technical condition of objects of SK cause the appropriate status of PTE. In turn, the technical condition of objects of SK arise due to the influence of external conditions defined by the corresponding condition of PTE.

If the object SK is characterized by a finite set of states $n+1$: $E=\{e_0,e_1,\dots,e_i,\dots,e_n\}$, where e_0 – the state of health of the object, e_n – a state of complete denial, you can select a subset of the States corresponding to various levels of efficiency of object SK. In this case $e_0\in A_1, e_n\in A_3$, where A_1 – a subset of states, which corresponds to maximum efficiency, A_3 – a subset of States of a complete failure, which is equivalent to the minimum performance level. Many working conditions $e_i\in A_2$, $i=1,2,\dots,n-2,n-1$.

Random events of type $e_j[\omega_k(e_i)]$, $i\le j$ define the transitions between process States technical operation is determined by the particular operating conditions. The sequence of transitions e_{ij} before the return of the object in a state e_0 determines the probability space of the process $\omega(t)$. Not necessarily that the process $\omega(t)$ in each cycle passes through all the States, that is neviluna that $P\{e_i=0\}>0$. If θ_i – nonnegative random variables, in the General case are dependent on each other that determine the residence time of the object in the state e_i, that $\omega(t)$ it's hit value:

$$\xi_n=\sum_{k=1}^{n}\theta_k,\ n\ge 1,\ T_0=0,\ e_{n+1}=e_0,$$

there is a waiting time to recovery (duration of cycle) process $\omega(t)$, determined by its possible trajectories.

Under the cycle duration ξ we understand an ordered pair $\{\xi,z(t)\}$, where ξ – valid non-negative integer, and $z(t)$ – function is defined $0\le t<\xi$ when the value of n-dimensional euclidean space R_n. Suppose that the set of all possible cycles specified probability measure such that:

$$P\{\xi=0\}<1,\quad P\{\xi<\infty\}=1, \tag{1}$$

and for all $t\ge 0$ a certain probability:

$$P_A(t)=P\{z(t)\in A;\xi>t\},\ A\in R_n. \tag{2}$$

Suppose also that, in accordance with a given probabilistic measure is chosen an infinite set of mutually independent cycles $\{\xi_i,z_i(t)\}$ $(i=1,2,\dots)$. In this case, using the values $\xi_1, \xi_2, \ldots$ can create the recovery process such that:

$$F_\xi(t) = P\{\xi \le t\} = 1 - P\{z(t) \in R_n; \xi < t\}. \quad (3)$$

In the General case, the values $\xi_1, \xi_2, \ldots$ may be different from each other distributions. But the greatest practical importance is the case when the values ξ_i, $i = 1, 2, \ldots$ are equally distributed according to the law $F_\xi(t)$. Then the sequence $\{\xi_i\}, \forall\, i = 1, 2, 3, \ldots$ creates a recurrent stream (stream recovery), the time n of recovery is equal:

$$X_n = \xi_1 + \ldots + \xi_n. \quad (4)$$

In this case, random process $\xi(t)\,(t > 0)$ specifies the number of events in the stream restoration incurred prior to the date t. Given (1)...(3) determine if $t \ge 0$ random process:

$$Z(t) = z_{\xi(t)+1} \cdot \left(t - X_{\xi(t)}\right).$$

Process $Z(t)$ is a regenerative stochastic process and the moments $\{X_i\}_{i=0}^{\infty}$ – the point of the regeneration process. It is proved that the mathematical expectation $M(\xi_i)$ time to recovery (MTTR) makes sense for any finite interval $T = [t_1, t_2]$ the number of restore points X_n, which fall into T, finite with probability one and is a definite value N. It is proved that the random variable N at large t asymptotically normally distributed with mathematical expectation and variance, respectively:

$$M[N(t)] = 1 / M[\psi(t)],$$

$$\sigma[N(t)]^2 = t \cdot \sigma[\psi(t)]^2 / M[\psi(t)]^3.$$

Since the transition to exploitation $e_i \to e_0$, $i = l, l+1, \ldots, n$, are the moments of regeneration process $Z(t) \equiv \omega(t)$, and the random duration between the moments of recovery form the recovery process, to assess the effectiveness of the recovery system, it is sufficient to have only one cycle of recovery of a random process $\omega(t)$, we characterize the mathematical expectation of the regeneration $M(\xi_i)$ and the number of updates N during the study period of time T.

Для формального представлення процесу maintenance and repair a single object of IC, we define the following events:

Event of failure of the facility during a campaign (task) at a random point in the cycle of operation ξ, where ξ is counted from the moment $t = 0$ and a random amount of time, in which there was a failure of the object. Based on the fact that the monitored object, the IC operates continuously when passing between the ports and time in port are neglected, the random variable of an operating time of object before refusal θ will be equal to the random time of operation ξ.

The event of detection of failure in this or subsequent transitions random transitions between fields $\xi + \eta$, where η – random variable from the moment of occurrence of the failure until its detection (self-manifestation) while performing the task.

The recovery event coincides with the event identified during execution of the task or in the port due to the assumption of instantaneous restoration of an object of SK.

Event failure detection during the transition between the ports, in which it originated, will be interpreted in the following way: failure can be detected within a transition using on-Board controls (UPC) (readout of the crew) or a crew with direct (indirect) signs of failure (lack of communication, the disappearance of data with indicators of the object SK or their apparent inconsistency, etc.). These characteristics allow for control of the operation of the facility, the IC transitions to establish the fact of failure.

If control of the technical state of the object is not carried out, the random process of technical operation $\omega(t)$ at the time of operation of the machine t can you imagine how a sequence of random time intervals of operation of the machine with the object in a healthy state ξ_i and in a state of latent failure η_i.

Given the conditions (4), we consider the values ξ_i, $i = 1, 2, \ldots$ identically distributed according to the law $F_\xi(t)$, values $\eta_i, i = 1, 2, \ldots$ identically distributed according to the law $F_\eta(t)$.

If you select condition, which can be exploited during the process of technical maintenance during the operation of the machine as S_1, if at time t the property is situated in a healthy state and S_2, if at time t the object is in a state of latent failure, random process $\omega(t)$ state changes S_1 i S_2 alternative is a random process (Fig. 1).

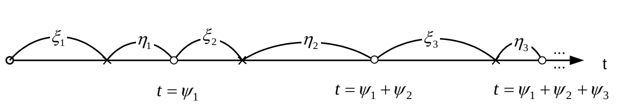

Fig. 1. Alternative random process

During the transition process from the state S_2 in the state S_1 is full of restoration (regeneration). Then the duration of the period of regeneration (between the two moments of recovery) is:

$$\psi_i = \xi_i + \eta_i.$$

In the general case, the residence time of the object SK in the transition to a state of latent failure (after failure until its detection) depends not only on how distributed random variable η_i, but from the moment of technical inspection of the facility operation.

Provided that the technical condition of the object of operation is controlled every x units of time at the time of operation of the machine, x = const, the failure that occurred at a random point in time ξ_i, distributed according to the law $F_{\xi}(t)$, is, or during the transition using a random time distributed according to the law $F_{\eta}(t)$, during the periodic monitoring of the technical condition (TC) of the object of operation. The event of detection of failure is determined by the perfection of the means of control applied at different stages of operation, and the allocation of time "the expression" failure $F_{\eta}(t)$ is a property of a complex technical object. Therefore, in the simulation process and R we assume that if the next control of the vehicle at the time $t_k = (k+1)\cdot x, k = 0,1,2,\ldots,N$ it is established that test object is in state e_i, $e_i \in A_1 \cup A_2, i = 0,1,2,\ldots,l-1$ (or is a test object in a state of full health, or a means of control is not able to detect the failure of a faulty but workable), the decision about any control action not taken until the next monitoring of performance after time *x*, if in e_i, $e_i \in A_2, i = l, l+1,\ldots,n-2, n-1$, or in e_n – work is being done on the recovery, which transferred the exploitation to the state e_0.

In this case, the time of finding the object in a state of latent failure prior to the first restore is:

$$\psi^{(1)} = \begin{cases} (k+1)\cdot x - \xi_1, & k\cdot x < \xi_1 \le (k+1)\cdot x; \\ & \eta_1 \ge (k+1)\cdot x - \xi_1;\ k = 0,1,\ldots,; \\ \eta_1, & 0 \le \eta_1 < (k+1)\cdot x - \xi_1. \end{cases}$$

We assume, as before, the quantities $\{\xi_i\}$ identically distributed according to the law $F_{\xi_i}(t) = F_{\xi}(t), \forall\, i = 1,2,3,\ldots$ and size $\{\eta_i\}$ identically distributed according to the law $F_{\eta_i}(t) = F_{\eta}(t), \forall\, i = 1,2,3,\ldots,$ the process lasts sufficiently long $t \to \infty \quad (i \to \infty)$, and the control period TC – X, does not change after 1, 2,..., *i* recovery.

The first assumption implies that in each state, operating rules, the object is the end time θ, then jump instantly into another state. In fact, the transition from one state to the other PTE takes some time. However, if this intermediate state is not used in the analysis, the transition time will include the time spent in the initial state of the PTE, and the transition is considered instantaneous.

The second assumption involves the random character of change of the States of the maintenance process and the randomness of time spent in these States. The assumption of stochasticity of the evolution of object SK in the process THAT does not exclude a certain set of deterministic transitions and deterministic durations of stay in States of PTE.

The third assumption assumes that in a nite time with probability one the process will end up in a state in which the entire background does not affect its further development.

In the above formalized description of the process and R are not taken into account the costs of calendar time to perform operations to control the vehicle and the object is restored, operation (instant on time of operation).

Meanwhile, a simple machine to work on the control of vehicle and Troubleshooting significantly affect the characteristics of the SK, in performance of assigned tasks. In this connection it is necessary to introduce a mathematical model that is developed, independent variable, calendar time of operation, and the set of possible States of the facility should include condition of the host facility for operations control, operations recovery failure.

In accordance with formalized description of PTE single object, SC as part of the Park the same type of vessels in the regenerating process with a discrete set of possible States of operation $E = \{e_0, e_1, \ldots, e_i, \ldots, e_n\}$, where *n* – the total number of States of PTE, imagine a process that explores geometric pattern – stochastic graph of States and transitions of PTE object of SK (Fig. 2).

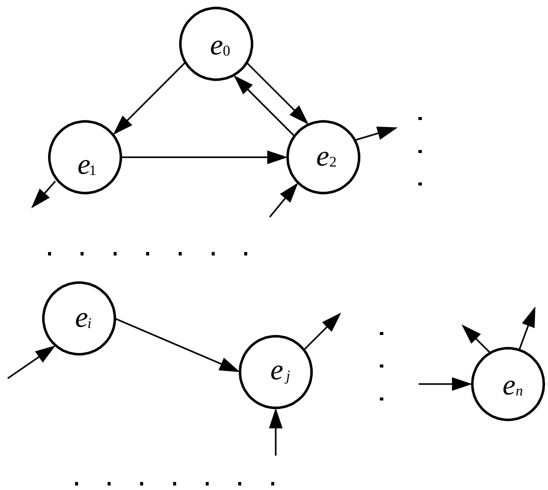

Fig. 2. Directed graph of states and transitions of PTE single object, SK

Thus the possible States of PTE will be in the form of circles and arrows the possible directions of transitions from one state to another. In this case, the graph of States and transitions displays a geometrically possible in the framework of the model taking into account the accepted assumptions the state of the PTE of the facility IC that is investigated (model state) and the possible transitions from state to state.

It is obvious that the study process of technical operation of objects of SK is convenient to consider as a random process with discrete States, that is, as a process, the possible States which can be counted. On the other hand, the real process of technical operation of STS of various types is characterized by the fact that the transition from one state to another PTE in the General case can happen at any random time. In this regard, the process is modeled, we will consider as a random process with continuous time. Thus, we describe the PTE single object of SK as a random process with discrete States and continuous time.

As shown the modern machines are complex technical systems consisting of a large number of systems, modules, assemblies, components (blocks) and individual elements that are sources of failures with different patterns of change in their intensity, their detection and removal during operation. In this regard, for an adequate description of the process of technical operation of the machine as a complex technical system will present it as a product consisting of many components, by which we understand objects that cannot be further detailed in the study. For example, a set of modules separate block in the functional system (FS) machines, the set of blocks of the FS machine, a set of functional systems of the machine, and the like.

Another feature that should be considered in the study of the effectiveness of the recovery system and its impact on the efficiency of the process and repair cars, is that in actual operation recovery efficiency of the constituent elements of the machine (the COA) is carried out upon detection of failure (peredove state) of object, despite its performance at the moment. For example, a failure is detected a backup element operable object SK (damage SK) leads to its replacement by a fully intact, with restoration to a healthy state. Therefore, in this study we assume that the failure of any core element (unit, unit, unit) puts the car to the disabled state.

Thus, when considering the machine as a set of functional systems will be presenting it in the form of the STS with elements, connected to the reliability (dependability) in series (Fig. 3).

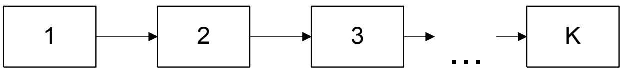

Fig. 3. The approved scheme of connection of functional systems of machine reliability (K is the number of functional systems of this type).

In this case, the probability of failure-free operation of the machine (assuming no or limited exchange of Fund units) is defined as:

$$P_C(t) = \prod_{k=1}^{K} P_k(t),$$

$$Q_C(t) = 1 - P_C(t),$$

$$N_{o\phi_k}(t) << n_k(t),$$

where: $P_C(t)$ – the probability of failure of the machine, $P_k(t)$ – the probability of failure of components of the product, $Q_C(t)$ – the probability of machine failure, $N_{o\phi_k}(t)$ – the number of objects k type in the exchange fund operator, $n_k(t)$ – the number of failures of an object k type during the study period.

Process $\omega(t)$ is determined by the vector of parameters of the recovery process, as managed $\Lambda_u = \{\Lambda_{u1}, \Lambda_{u2}, \ldots, \Lambda_{ul}\}$ so unmanageable $\Lambda_V = \{\Lambda_{V1}, \Lambda_{V2}, \ldots, \Lambda_{Vk}\}$, as well as the parameters characterizing the conditions of application of the machine $\Lambda_R = \{\Lambda_{R1}, \Lambda_{R2}, \ldots, \Lambda_{Rn}\}$. Typically, the separation parameters for managed and unmanaged conditional and depends on the type of problem that is being solved. In some problems part of the managed settings can be defined as (uncontrollable). In addition, the controlled parameters can cause the unmanageable. As a rule, at formation of system recovery on-Board equipment of the machine to the managed settings will include: types of control, means of control applied at different stages and R, the completeness and depth control, tool reliability raskladami means of control, frequency of control, completeness of recovery, the number and qualification of personnel, and the like.

Unmanaged parameters Λ_V Typically, the separation parameters for managed and unmanaged conditional and depends on the type of problem that is being solved. In the attitude – structural characteristics and reliability of the objects of the IC, the testing efforts and the search space of the failure using this monitoring tool.

Settings Λ_R related the intensity of flights, their duration, nature of tasks etc.

Change at least one component of the vector control u on the maintenance stages are considered, leads to the creation of a new version of the construction of the recovery process.

In reality, the number of possible variants is limited. On this basis, the task of choosing a rational variant of the process of recovery of SK machines are able to reduce to the problem in variational formulation, in which of the many alternative options to select the most favorable. Alternatives u_j are formed by changing the values of the components of the vector u,

$$u = (\lambda, \mu, x, P, q, Q, \eta, T),$$

where: λ – the failure rate of the object SK, μ – the intensity of the self-manifestation of the failure of the object SK, x – the frequency of the control, P – the probability of detection of failure of control, q – the likelihood of providing control information on the “about” denial, Q – completeness of recovery of the object SK in the operating organization, η – full control of failures (damages), T – the duration of operation of the IC.

Due to the fact that the attraction of objects of SK in different States of the real process of PTE is statistically repeated, and as the formal description of the selected scheme of the recycling process, to assess the effectiveness of this process will use performance indicators expected result:

$$\vec{W}(u) = M\left[Y^{\langle R \rangle}(u)\right],$$

$$W_r(u) = M[y_r(u)],$$

$$r = \overline{1, R},\ u \in U, \tag{5}$$

where: $W_r(u)$ – private utilization u the variant of the organization of the process of recovery of SK machine, reliability (dependability) economic and other types of effectiveness of PTE machines, $y_r(u)$ – partial characteristics of the result of the operating rules of the machine.

Figure (5) is a special case of the rate at which the feature is equal to the real result:

$$\rho\left\{Y^{\langle R\rangle}(u), Y_в^{\langle R\rangle}\right\} = Y^{\langle R\rangle}(u).$$

The average result (5) is widely used in studies of the effectiveness of complex technical systems. This is due to the property of additivity, which greatly simplifies their assessment lies in the fact that in case of the possibility to submit result $Y^{\langle R\rangle}(u)$ the operation of docum system as the sum of results of individual stages $Y^{\langle R\rangle}{}_i(u)$:

$$Y^{\langle R\rangle}(u) = \sum_i Y^{\langle R\rangle}{}_i(u),$$

the average result of the process is considered to present a medium amount of private results, despite their possible stochastic dependence:

$$M\left[\sum_i Y^{\langle R\rangle}{}_i(u)\right] = \sum_i M\left[Y^{\langle R\rangle}{}_i(u)\right].$$

Вибір та обґрунтування показників ефективності СК allows the machine to evaluate the different options (strategies or modes of recovery and to elect for the formulated criterion K the "best" option u^* under given operating conditions Λ. As is known, criterion of efficiency K there is a rule that allows you to compare the options $u \in U$, characterized by different degrees of goal achievement, and to implement a directed choice of options u from the set of the admissible U. When using the concept of optimization criteria major results in the form of: highest average score, the highest probabilistic guarantee of results, the largest guaranteed result.

Imagine in the mathematical form of the partial tasks which are given above and answer the two main decision-making processes in the study of efficiency of various variants of the organization of the process of recovery of SK machines and need to be addressed:

1) the process of obtaining results:

$$\Psi : \left\{ Y \,\middle|\, H : U \times \Lambda \xrightarrow{\Theta} Y(G) \right\} \xrightarrow{\Theta} W, \quad (6)$$

2) the process of analysis of the results:

$$\Im \xrightarrow{\Theta} K : U \xrightarrow{W} u^*.$$

The expression (6) means that the dependence of the vector efficiency index $\vec{W}(u)$ the organization of the recovery process $u \in U$ and other relevant factors Λ, defining the conditions of PTE of objects of SK that is set in the display view:

$$\Psi : \left\{ H : U \times \Lambda \to Y^{\langle R\rangle} \right\} \to W,$$

where: $H(\varphi) : U \times \Lambda \to Y^{\langle R\rangle}$ – a mathematical model of PTE STS that allows us to estimate the value of different characteristics of partial implementation $y_r(u)$ result $Y^{\langle R\rangle}(u)$ for each option $u \in U$, φ – the transition operator.

Formally, we represent the model of PTE of the facility, the IC developed, $\Psi : U \times \Lambda \to W$ in the form of a compound statement assessment of effectiveness, which is a superposition of operators:

$$\Psi = H \circ Q \circ M,$$

where: Q – the compliance statement,

M – the operator of averaging,

$\circ$ – character superposition.

That is, we assume that the operators Q і M display multiple values $Y^{\langle R\rangle}(u)$ results of PTE object SK in the set of values of the performance indicator $\vec{W}(u)$. In this case, the set of values $Y^{\langle R\rangle}(u)$ with the statement of compliance $Q : Y \times Y_в \to \rho$ appears in the set of values of the function of compliance ρ, and the operator of averaging $M : \rho \to W$ translates the value set of compliance features ρ in the set of values of the performance indicator $\vec{W}(u)$:

$$Q \circ M : Y \to W.$$

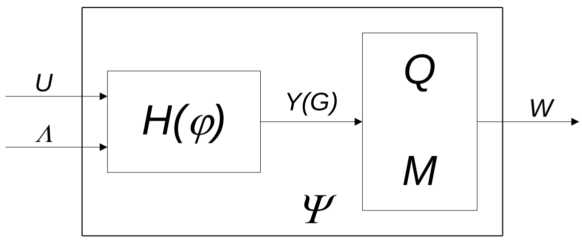

Fig. 4. The structural diagram model of the process of technical operation of complex technical systems

In accordance with the above formalized representation of the process object SC as a process changes its States in the plural, imagine normal operators , that is operators of transition and exit, respectively, in the form of correspondences:

$$\varphi : E \times U \times \Lambda \to E,$$

$$H : E \times U \times T \times \Lambda \to Y(G),$$

where: T – the duration of the operating period that is studied.

The necessity of use of mathematical model of investigated process in which interrelated parameters, indicators and criteria, based on the principle of system approach when evaluating the performance of complex systems.

The choice of the mathematical device of the analysis of the studied phenomenon, based on previous experience and data obtained as a result of studying the real objects. Considering, in General terms, any phenomenon is investigated, can be chosen as one of the two mathematical models – deterministic or stochastic . A deterministic model is chosen in those cases in which it is possible to accurately specify the reasons which influenced changes of the investigated process, and in the case of known input impacts with any degree of accuracy calculate the output.

Due to the fact that the process of maintenance and repair of objects of SK is categorized as stochastic, just take into account all the random factors that influence it is almost impossible, for an adequate description of the process and P must be a stochastic model.

1.5. The requirement of adaptability: allow for the rapid refinement of the model with the accumulation of current information on the progress of the real operation.

1.6. The requirement of verifiability of the results: provide a real opportunity to trace the causal relationships of the model parameters of process of technical exploitation in the course of the simulation.

1.7. The requirement of low complexity of the calculations: provide efficient algorithms for estimating the unknown indicators of technical and economic efficiency of the process of technical operation of objects of SK with the aim of obtaining foreseeable simulation results.

2. As can be seen from the developed requirements to the mathematical model of the process of technical operation, insurance car, requirements 1–3 are determined by the class of the selected stochastic model requirements 5–7 are determined by simulation, with the requirement of simplicity of the model 4 is. Based on the above requirements, the mathematical model will select the class of stochastic model and simulation method.

CONCLUSIONS

1. As is known, a mathematical model to quantitatively describe the process of functioning of objects of exploitation, based on a priori information about the possible states of the process of technical operation and the transition from one state to another, as well as on statistical data obtained during the operation of the same technical systems. In this regard, based on the analysis of features of process of technical exploitation of vessels and the purpose of the study, formulate the requirements of a mathematical model is developed:

1.1. The requirement of the model building process: the transition of the SK object from one state of the process of technical operation to the other occurs over time, so the mathematical model of process of technical exploitation of SK machine must be a model of the process with known statistical description.

1.2. The requirement for restrictions: to allow a comparative techno-economic evaluation of various options for the organization of the process of recovery of the UK and influence the process of technical operation of hardware and software systems for monitoring and diagnosing the technical condition of the IC on the results of simulation models should not be severe restrictions on the state space of the process of technical operation and functions of distribution of time of stay in the state of the process operation.

1.3. The requirement of simplicity: to be easy to describe the process of technical operation of SC in the model, which will allow you to solve the problem with sufficient accuracy, and to ensure the ease of creating the model itself. This requirement is based, on the one hand, the necessity of obtaining the desired result, and on the other practical limitations on the amount of information needed to determine the desired characteristics of the studied process.

1.4. The requirement of clarity: to provide visual expression of the process that is investigated, the restoration models developed for easy understanding.

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ВЫБОР КЛАССА МОДЕЛИ И МЕТОДА МОДЕЛИРОВАНИЯ СИСТЕМЫ ВОССТАНОВЛЕНИЯ РАБОТОСПОСОБНОСТИ СЕЛЬСКОХОЗЯЙСТВЕННЫХ МАШИН

Иван Роговский

Аннотация. В статье разработаны требования к математической модели процесса технической эксплуатации объектов сельскохозяйственных машин, выбран класс модели и метод моделирования. Это позволило разработать формализованное описание процесса восстановления работоспособности сельскохозяйственных машин, что исследуется, обосновать форму показателей эффективности и критерия оптимальности, осуществить математическую постановку частных задач исследования.

На основании формализованного описания рассматривается математическая модель процесса технической эксплуатации объекта сельскохозяйственных машин в виде регенерирующего процесса восстановления. Приведены аналитические зависимости показателей от параметров системы технического обслуживания для случая одноэтапного периодического контроля работоспособности. Получены выражения для расчета асимптотических оценок выбранных показателей эффективности при экспоненциальных распределениях времени безотказной работы объекта сельскохозяйственных машин и времени самостоятельного проявления отказа в эксплуатации.

Стохастические модели обычно классифицируются как случайные процессы и могут представлять собой процессы с дискретными состояниями (множество состояний конечная или подсчитывается) и с непрерывным множеством состояний (множество состояний ставится во взаимно-однозначное соответствие множеству точек числового интервала), с дискретным временем (случайные последовательности) и с непрерывным временем. В настоящее время разработано большое количество стохастических моделей, применяемых для описания функционирования сложных технических систем, основными классами которых являются: логические, линейные, гауссовские, автоматные, агрегатные, марковские, полумарковские, регенерирующие, многокомпонентные, модели в виде систем массового обслуживания.

Исследуется случай многоэтапного технического обслуживания с учетом полноты контроля технического состояния объектов сельскохозяйственных машин.

Ключевые слова: моделирование, технология, модель, метод, восстановление, сельскохозяйственная машина.