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MATHEMATICAL MODELING OF AGRICULTURAL MACHINERY TECHNICAL MAINTENANCE

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ABSTRACT

They developed the mathematical model of the maintenance system for the functional systems of machines and equipment the implementation of which will reduce the cost of the labor hour of maintenance and repair and justify the economically feasible level of the technical readiness coefficient. Modeling is the basis for automated system creation to improve the performance of agricultural machinery application.

Keywords: technological system, machinery and equipment, maintenance, mathematical model.

INTRODUCTION

An urgent task of an agricultural enterprise engineering service in the organizational and legal form of a commercial organization is to ensure the continuity of agricultural products manufacture processes and its processing by maintaining the technical readiness of machines and equipment at a sufficient level.

Due to the complexity increase of tractors, grain harvesters and other harvesters, agricultural machinery and processing equipment, the task of bringing the technical maintenance (TM) of this technology in accordance with its increased complexity and cost,

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It is necessary to improve the process ability of the maintenance, and use innovative solutions, respectively. The latter include the solutions based on information technology and the automation of maintenance operations, the creation of which requires mathematical models.

From the analysis of this issue state it follows that technical services are carried out without a system, during routine maintenance work the current failures are eliminated and their future manifestation is not prevented by the performance of routine maintenance work. The reason is that at present the economic activities of commercial organizations are aimed at financial indicator achievement. The functioning of the maintenance and repair system (MRS) developed in the USSR for managers aimed at obtaining current profits is a secondary task. An organization head often has no necessary information and technologies to ensure the functioning of MRS system. Thus, we have what we have: in practice, there is a "reactionary" approach according to the following principle: "one should not interfere in an operating mechanism". It is the most widespread and it actually replaced the system of maintenance and repairs, forcibly implanted in a planned economy. Such a system was developed by the researchers from GOSNITI (Moscow), VNIITiN (Tambov), VNIPTIMESH (Zernograd) and other research institutes. Currently the intensity of work on this subject is reduced significantly, since most scientific institutions of this profile ceased functioning or was reorganized, and a significant number of scientific workers was dismissed.

The scientific hypothesis is that the development of maintenance techniques based on information technologies grounded on mathematical models, will improve the performance indicators of agricultural machinery by modern technical tools provision for engineers and technicians.

The purpose of the work: the development of a refined methodology to increasing the efficiency of agricultural machinery maintenance on the basis of mathematical modeling.

The object of the research is the functioning of the engineering and technical service of an agricultural enterprise.

The object of research is a set of element system states (cars, tractors, agricultural machines, combines, maintenance and repair equipment, their components, aggregates, mechanisms, parts, processed material and labor resources) [1, p. 8].

The subject of the study is the dependencies and regularities that arise when the technical maintenance of machinery and equipment of an agricultural enterprise is performed.

Research methods in this industry are determined by the following factors. The system of machines and equipment operation in accordance with the standard [2] refers to technological systems, characterized by multiphase nature, the exchange by mass and energy with the environment. It consists of a set of probabilistic elements and its functioning goal is achieved in a probabilistic sense. For this reason, it should be regarded as an energy-entropic system, the physical essence of which is defined by the following laws: the conservation of energy; the increase of entropy (R. Clausius and V. Thompson); Nerst's theorem; limiting development, preferential development, which is applied to an object of research as the result of research [3]. The criteria for a studied system effectiveness were divided into three groups: characterizing the material basis (agricultural machinery and equipment); reflecting the structural and functional structure (the technology and the structure of the machine-tractor fleet and engineering service structure), labor resources, as well as internal and external impacts. The efficiency criterion should reflect the process of entropy level maintenance of the system and subsystems within given limits [4]. Maintenance is a significant subsystem that supports the readiness of technology and prevents the entropy uncontrolled growth of the system under study.

MRS system is considered in the works of the following academicians: V.M. Kryazhkov, V.I. Chernoivanov, A.I. Selivanov, M.S. Runchev, A.E. Severny, etc., and the features of man-machine agrarian systems were studied by the academician E.I. Lipkovich [4]. The study of maintenance issues was carried out using various methods, the most effective ones were the application of Markov's process theory and its applications, primarily the queuing theory. These methods were used by N.S. Khmelevoy, A.V. Lensky, N.I. Agafonov, N.I. Chuprinin, N.V. Valuev, A.P. Solomkin et al. The implementation of expert system possibilities is shown in the works by V.P. Dimitrov, S.M. Kharashakhyan, Yu.A. Tsarev et al. These methods allow to optimize the organization of maintenance on the basis of failure and recovery flow study, the identification of incoming flows, the identification of a functioning mechanism, which is shown in a number of recently published papers, in particular by E.N. Kushcheva, N.S. Poluyan, S.A. Nazarenko [5, pp. 47-49; 6, pp. 69-77, 7, pp. 18-23].

This article shows the application of the study previously unused in the subject area - the method of a functional system formal image development to analyze the process of its maintenance, which makes it possible to construct an appropriate mathematical model.

The study is based on the theory of images by U. Grenander, according to which a system image is a set of configurations developed from elements.

In accordance with the definition of a system as an emergent set of subsystems and elements, united by a system-forming factor and possessing the systemic properties of stability, adaptation, reliability of functioning, etc. An element is an object of the lower level of a hierarchy whose internal structure is not considered, that is, it is indivisible for this level. Let's denote it as s_i. Each element is associated with a label that identifies it as an object of the considered technical system. Thus, s_i = S - m_i = M for each element. A label can denote machine nodes and machine details. For example, the most complex machine is a harvester which has many elements (a piston, a cylinder, a fuel pump, an oil pipeline, a drum, a deck, a beater, a fuel pipe, a radiator, a cylinder unit, a valve, a rocker, a hydraulic cylinder, a fan, a casing, a belt, a chain, a sprocket, a gear, etc.), their sign is a purpose function, expressed in the transformation of a studied subsystem interdependent parameters (for example, in the change of fluid direction flow in a hydraulic system by moving a distributor plunger, and the amount of fuel injected into the cylinders when the position of an injection pump rack changes, etc.). $s_i s_o$ elements with their connections ξj are combined functionally and structurally in configuration C taking into account the limits. The latter differ in their composition Λ and structure Ψ

$$\Lambda = (s1,\ s2,\ s3, \dots\ ,\ si\ , \dots\ sn), \quad (1)$$

$$\Psi = (\psi 1, \psi 2, \dots\ , \psi i, \dots, \psi m). \quad (2)$$

According to U. Grenander's theory, the abovementioned relations make up a research object image and are specified by the set of its elements Λ and the configurations, developed from them according to certain engineering methods U of machine construction (in this example - grain harvesters).

A number of engineering design methods were designated as G(U). This set determines the image of the functional system under consideration. Its image will be represented as a set of structures (in terms of the theory under consideration - "regular configurations")

$$\Psi_1,\ \Psi_2\ \ \Psi_3, \dots\ \Psi_i,\ \ \dots,\ \Psi_n = G(U), \quad (3)$$

Where n is the number of configurations.

With the use of these designations, it is possible to construct a formal model (3) of the functional systems of machines (a tractor, a combine, an agricultural machine).

For example, it is possible to build the images of internal combustion engine systems: power, cooling, lubrication, as well as a hydraulic system, a pneumatic system, an electrical system (if available on this machine), etc. For this you can use a corresponding design diagram of this machine. In each specific case, constructive schemes can be used, they are available in the technical literature and are of engineering, not scientific interest, and therefore they are not given. Its mathematical model is constructed on the basis of the scheme, in the form of graph G (X, Y) and the necessary path on the graph is found.

It is recommended to use reachability functions whose matrix $R= [\psi_{i,j}, \lambda_{i,j}]$ is expressed by the following formula

$$ri,j = \begin{matrix} 1, \text{ если вершина } xi \text{ достижима из } xj \\ 0, \text{ если не достижима} \end{matrix} \quad (4)$$

the matrix of the unreachable function, $Q = [q_{i,j}]$ is expressed by the following formula:

$$qi,j = \frac{1, \text{ если из вершины } xi \text{ можно достигнуть вершину } xj}{0, \text{ в противоположной ситуации}}. \quad (5)$$

The above formulas (4, 5) allow us to obtain a set of vertices R(xi) ∩ Q(xj), each of which belongs to at least to one path going from the vertex xi to the vertex xj. The construction of "reachability" and "unattainability" matrices makes it possible to construct a mathematical model of strongly coupled structures of the system, the maintenance of which is performed. Based on the mathematical model, a conceptual model of an image is developed (table). Similarly, graphs and tables are developed for all the systems of a machine internal combustion engine, its controls and operating mechanisms (a threshing machine, the system of separation of grain from straw, chaff and other impurities, a bunker system for grain unloading from a bunker, etc.), a life support system of a mechanizer (the stabilization of the temperature regime, ventilation and air purification, etc.).

Table1. The conceptual mathematical model of an image (using the example of a diesel combine harvester fuel system)

«Strong» component	Graph vertex x_i	Forming element q_i	Forming element identifier
1	*2*	*3*	4
X1	x_1	q_1	Fuel tank
	x_2	q_2	fuel line
	x_3	q_3	valve
	x_4	q_4	filter
	x_5	q_5	Injection pump
	x_6	q_6	fuel feed rail
	x_7	q_7	nozzle

In the process of technical service, it is necessary to compare the conformity of an serviced system image with its actual state, which is ensured by the implementation of the identification algorithm on the computer. The algorithm is developed on the basis of the conceptual model "corresponds - does not correspond" (see Table 1). Thus, a technique is developed for the presentation of maintenance operations as space-time images of movement characterized by the change of a considered functional system element states in accordance with its technological operations specified by the technological map TO-1, TO-2, TO-3, seasonal maintenance and the maintenance during storage. It is interesting to note that for most agricultural machines the non-use period substantially exceeds the working period. For example, in a combine harvester it exceeds 12 times, in a seed drill it exceeds 26 times. Tractors are not used in field work for at least three months a year. Let us designate 3 levels - the seasonal one through the subsystem 1 of the TO-1 and TO-2, the second level of TO-3 and when we store and interpret the model of routine operation system content ("elementary" actions) graphically (Fig. 1).

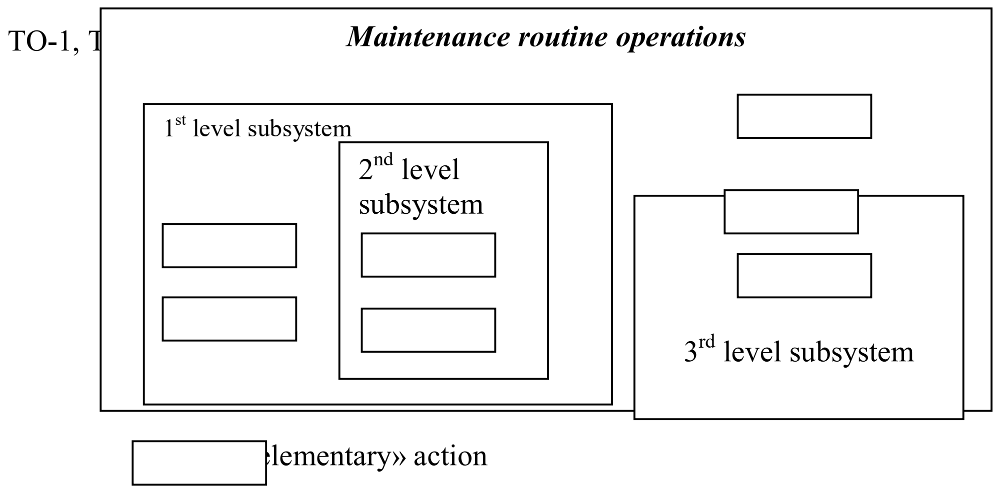


Fig.1. The model of routine maintenance operation composition system

During the creation of a spatial-temporal image, the technological process of maintenance (TO-1, TO-2, TO-3, seasonal maintenance and the maintenance during storage) was grouped into 4 classes of "generative actions", namely:

1. The operation of the maintenance procedure h_i with the duration T_i
2. The monitoring the state k_i with the duration T_k
3. The movement n_i with duration t_i
4. The delay z_i with the duration T_z

Thus, the maintenance operation is represented as a dynamic system with cause-effect relationships between the performance of maintenance and its technical state, as well as the technical availability factors and other reliability indicators. The correspondence between an image and a state is estimated according to the scheme (Fig. 2).

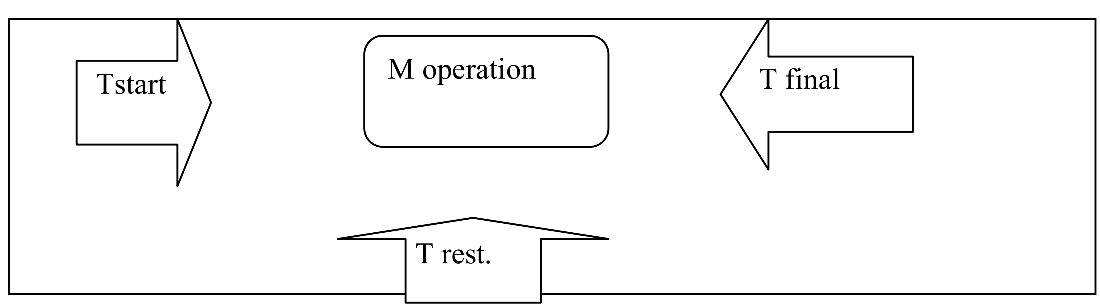


Fig.2. Spatial-temporal image of the generating maintenance procedure of the system element

The following notations were introduced (see Figure 2).

Let's denote the maintenance operation by A_i (g_i), the operation of the "generator" g_i serving

T_{start} - the recovery of an element restoration will be denoted as t_{sigi}

$T_{rest.}$ - the time of an element restoration start - as t^1_{sigi}

T_{finish} - an operation end time as t_{xigj}.

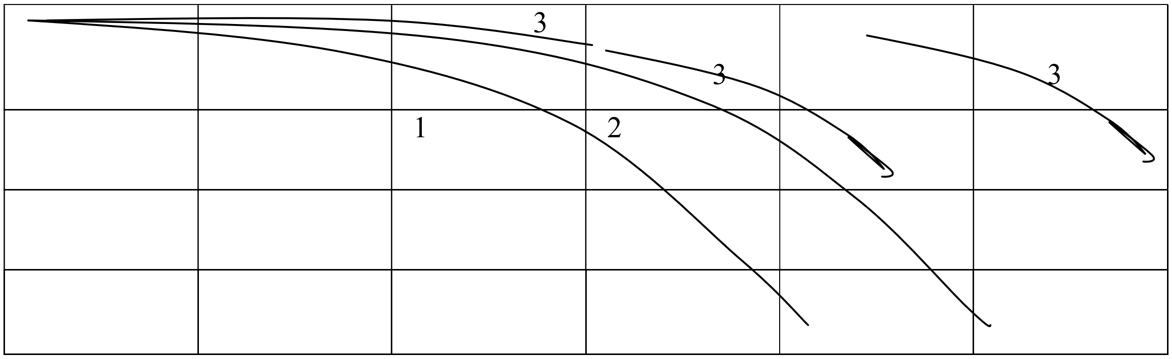
The developed formalized model allows to design the technological process to perform maintenance operations in the form of a diagram in which the signs A_i of the operation correspond to its duration T_i so that the coupling indicators satisfy the following condition

$$ti = tsi + \Delta ti, \tag{6}$$

Where t_i is the end of *Ai* operation,

t_{si} is the beginning of *Ai* operation.

The mathematical model provides for the following situations: the conformity of a unit (a node) to technical requirements or the inconsistency of its condition with these requirements, the detection of a failure and its restoration. The recovery of a detected failure is an unscheduled job. All these data are recorded by the computer program that can be developed using this mathematical model and the effectiveness of maintenance based on the results of an agricultural machine system or equipment under study monitoring and diagnosing system, which allows you to manage the operations of maintenance. The total effect of the implemented maintenance operations is estimated by the ratio of the planned time for the maintenance to its actual execution time. The practical significance of the presented mathematical model is that it can be used to create an algorithm and a computer program that allows to make decisions on a technological process adjustment of the maintenance process based on the calculation of functions (4.5) and the accumulated actual data on the process under study at a particular agricultural enterprise. Thus, the engineering service will be able to switch from reactive maintenance to proactive one, which will improve the level of technical preparedness of a serviced fleet of machines and equipment and extend the service life, which is illustrated by the graph (Figure 3).



1 - reactive maintenance, 2 - state maintenance, 3-proactive maintenance

Fig.3. Level of technical readiness of a fleet of vehicles depending on the time of operation at different types of maintenance

The developed mathematical model of a maintenance system identification for the functional systems of machines and equipment can be used to reduce the cost of the labor hour of maintenance and repair and to justify an economically feasible level of the technical readiness coefficient.

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