Reliability of technological systems: structure and modeling

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Abstract. The article is devoted to the analysis of the structure and methods of mathematical modeling of technological systems for the production of agricultural products. The article presents a study of technological subsystems of the use of machinery and equipment in the production and processing of agricultural products. Examples of elements of a technological system in an agro-industrial complex are a tractor, an agricultural machine, a combine harvester, a device or adapter, a working tool and equipment for maintenance. The structure of mathematical modeling of probabilistic processes of ensuring the reliability of technological systems, taking into account the modeling of the patterns of their functioning, has been developed. It is proposed to consider technological systems in the agro-industrial complex at four levels of the hierarchy: technological systems of operations of the crop, livestock and other agricultural and processing agricultural products of industries, technological systems of processes of crop production, animal husbandry, processing of raw materials of plant and animal origin, technological systems of production units and technological systems of production units of enterprises. A block diagram of the algorithm for modeling the implementation of the plan and an assessment of the achieved results of increasing reliability in the crop, livestock, processing industries of the agricultural enterprise is presented.

1. Introduction

Agricultural producers in the form of an organization, private peasant farms, are interested in the effective use of the machine and tractor fleet and equipment. For this task, it is necessary to pay due attention to its technical service, which ensures a decrease in unproductive downtime, an increase in the coefficient of technical utilization, and the reliability of technological processes for the production of agricultural products. In order to increase the reliability of the latter, various methods are used, the effectiveness of which can be found out in mathematical modeling.

The purpose of the work is to analyze the structure and methods of mathematical modeling of technological systems for the production of agricultural products.

The object of research is the technological subsystems of the use of machinery and equipment in the production and processing of agricultural products.

Research subject. Structures and mathematical modeling of probabilistic processes of ensuring the reliability of technical systems based on modeling the patterns of their functioning.
2. Materials and methods
The research is based on the monographic method of studying ideas about the reliability of systems for operating a machine and tractor fleet in agricultural enterprises. The efficiency of the operation of machines and equipment, including the machine and tractor fleet, significantly depends on the perfection of technological systems for their use. A large role belongs to the subsystem that ensures the maintenance and restoration of working capacity, safety during the period of non-use. The method of economic analysis made it possible to reveal the reserves for increasing the efficiency of the operation of the machine and tractor fleet - not only in improving the quality of manufacture, increasing maintainability but also in ensuring reliability during operation by methods of maintenance and storage. A monographic analysis of previous studies has shown that an increase in the power and productivity of agricultural machinery increases the importance of their operational reliability. At the next stage of research, the method of mathematical analysis was used.

3. Results and discussion
A.I. Selivanov [1], V.M. Kryazhkov [2], V.I. Chernoivanov [3], A.E. North [4] and other academicians noted the importance of scientific developments in the field of ensuring the reliability of the machine and tractor fleet and equipment during the operation. The development of a control system for the reliability of technology remains relevant, as it allows creating reliable technological systems from machines of insufficient reliability, thereby increasing the efficiency of agricultural production. The machine and tractor fleet of most agricultural organizations remains insufficiently reliable due to its high average age approaching the deadline for amortization.

Renewal of the machine and tractor fleet is a rather lengthy process due to the high cost of machinery and equipment. For example, an imported grain harvester or a powerful tractor with a train of agricultural machinery can be purchased for at least 20 million rubles. If an enterprise is large enough, for example, with a sown area of 12 thousand hectares, then its machine and tractor fleet will include about 60 tractors and combines worth over a billion rubles. For example, PJSC "Donskoye" of the Zernogradsky district of the Rostov region has 61 tractors, 55 combines, 291 agricultural machines to service 25,100 hectares of sown area. It is financially impracticable to update such a fleet of equipment urgently. An alternative to the urgent renewal of the technical park is to ensure the reliability of equipment during its operation by improving the organization of maintenance, modernizing the engineering service. State and international standards regulate the organization of the service for ensuring the reliability of machinery and equipment, technological systems for their use.

As a rule, in organizations, the machine and tractor fleet is used as part of technological systems, which GOST 27.004-85 interprets as "A set of functionally interconnected technological equipment, production items and performers for performing specified technological processes or operations under-regulated production conditions". In agricultural production, objects of production include material objects of crop production, animal husbandry, processing of agricultural products in the stages of storage, transportation, biological reproduction (vegetation), sowing, care (cultivation), protection from pests, diseases and weeds, maintenance and repair, control and testing (e.g. variety testing). The regulated conditions of agricultural production include compliance with agro-terms, agro-zoo-requirements, standards and technical conditions for the quality of products, production, parameters of material and technical supply and energy supply, environmental parameters, i.e. weather and climatic conditions and other conditions. It is proposed, following the standard [1], four levels of the hierarchy of technological systems in the agro-industrial complex: technological systems of operations of the crop, livestock and other agricultural and processing agricultural products of industries, technological systems of processes of crop production, animal husbandry, processing of raw materials of plant and animal origin, technological systems production units and technological systems of production units of enterprises (Figure 1).

For the production of agricultural products, not isolated machines are currently used, but technological complexes. Technological complexes have completely replaced manual labor and draft power, which can be interpreted in relation to the agro-industrial complex as follows. A technological
complex is a set of functionally interconnected means of technological equipment for performing specified technological processes or operations of crop, livestock and processing industries under regulated conditions of agricultural production”. An element of the marked technological system (Technological system Element) can be called a part, conventionally taken as indivisible at this stage of its analysis [5].

![Diagram](image)

**Figure 1.** The structure of the technological production system agricultural products in the agro-industrial complex

For the production of agricultural products, not isolated machines are currently used, but technological complexes that have entirely replaced manual labor and draft power, which can be interpreted with the agro-industrial complex as follows. A technological complex is a set of functionally interconnected means of technological equipment for performing specified technological processes or operations of crop, livestock and processing industries under regulated conditions of agricultural production. An element of the noted technological system can be called it is conditionally indivisible part in a specific study [5].

Examples of elements in an agro-technological system are as follows: a tractor, an agricultural machine, a combine harvester, a device or adapter, a working tool and equipment for technological support. The concept of the structure of ensuring the reliability of a technological system following the standard includes its operable and inoperative states (Figure 2). Performance parameters of the machine and tractor fleet are shift workings and threshing. The parameters of material and cost costs in the agro-industrial complex are – rates of sowing seeds and applying fertilizers, consumption of raw materials, materials, standards for fuel and fuel and lubricants, heat and electric energy for raising and fattening animals or processing agricultural products, a range of spare parts and tools, standards of maintenance and repair. An inactive state can be both in terms of product parameters and in terms of performance.
Concerning the engineering and technical service and the reliability service, the technological system of the machine and tractor fleet can be stated to be inoperative. When the system is inoperative, the value of at least one parameter of material and (or) cost costs does not meet the requirements established in the technical documentation. It is known from the state standard [5] that malfunctioning means a failure, which in the case of a technological system can be both functional and parametric and forced (Figure 3). The standard establishes such indicators as the percentage of operating time, the probability of failure-free operation of the system in terms of performance parameters, costs, assigned operating time before the adjustment; the probability of completing the task, including the volume of agricultural production.

The following factors are referred to the complex indicators of reliability: the use of the technological system; the output of finished agricultural products (excluding its losses); product yield when processing plant or animal raw materials; expenses of material costs by type or specific indicators of finance consumption, material consumption, capital intensity, capital supply and other ratios. The Research Center for Control and Diagnostics of Technical Systems has developed a standard according to which the reliability management system should be built. The purpose of the standard is "... to ensure the implementation of the risk management system ... the standard will help developers ... to more clearly articulate the goals, objectives and risk management program, ... defines the main processes of this system ... and the objectives of reliability at the stages of the product life cycle" [6]. It can be used as the basis for the structure of ensuring the reliability of the technological system in the agro-industrial complex and the algorithm for its modeling.
Figure 3. Structure of failures of the technological system of the agro-industrial complex following GOST

Following the standard, first, it is necessary to determine the goals and objectives of the subsystem for ensuring the reliability of the designed technological system and, perform their analysis, develop a strategy and action plan to ensure the specified reliability of the system, implement the reliability management subsystem and generalize the implementation results according to the following algorithm (Figure 4). “The algebra of stochastic processes is used for model technological systems, but it is not structured and does not have an apparatus for expressing the composition of subtasks,” summarize A.S. Sorokin [7]. “However, this problem can be solved by automatic generation of process algebra models from the structural description of applications,” which “allows compiling process algebra applications suitable for assessing the reliability of agricultural technological systems [7].
Figure 4. Block diagram of the algorithm for modeling the results of the implementation of the reliability management subsystem of the technological system of agricultural production

This algebra, known in Russia as the algebra of Markov processes, differs in that with each transition of the system, the defining sequential components (exponential distribution of a random measure of the duration of a process or recovery of out-of-service machines) are compared [8]. The model consists of components $\alpha$, interacting by action [9]

$$S ::= (\alpha, \mu). S + S \mid C,$$

(prefix, selection and component name), describes the equation

$$P ::= P \triangleright L \triangleleft P/\Delta \mid C$$

(cooperation, abstraction and the name of the component of the technological system in the agro-industrial complex), where $S$ – sequential, and $C$ – modeling components; $C$ – const, including $C_\alpha$ – const. “... defining sequential components”.

The prefix $(\alpha, \mu) S$ specifies the first action assigned to the component, this is the first action $\alpha$, and the duration of the elimination of a failure (Poisson distribution of time between failures, the distribution of the recovery time by exponential distribution with parameter $\mu$. In this case, $(\triangleright)$ is the
selection operator allows the actions of two operands" [9]. An action is a transition from the first operator to the second with probability p. The structure can be described by a model – a cooperator compiler (▷ i ◁). In the described case, to assess the reliability of systems, this model is borrowed from the CSP – parallel transition compilation, when the operations of the process of failures and restoration are synchronized according to the allowed by these components in the set of the cooperator L. This statement lead to conclusion about the expediency of using algebraic skeletons [10] (pipeline), distributor skeleton (Deal), farm skeleton (Farm). The reliability model from these constructions is formed in three stages: building a graph, describing the processes of the synthesis of the system.

The model was tested on the example of the technological system of hydraulic technology in the source [9]. This model made it possible to obtain a quantitative analysis of the system reliability, compare the reliability of various structures of the technological process. The studies performed are consistent with the results previously obtained by a team of authors on the efficiency of agricultural production [11] and the use of tractors [12], increasing the reliability of technological systems [13] and will improve the reliability of agricultural technological systems.

4. Conclusion

The cost and operation of the machine and tractor fleet and equipment in the agro-industrial complex are much more expensive in the absence of a technical service system. The technical service system makes it possible to increase the reliability of not only the machine and tractor fleet or equipment for the mechanization of animal husbandry and processing but also the reliability of the technological system of agricultural production in agricultural organizations as a whole. It is necessary to design a reliability management system, the methodological foundations of the construction of which are set out in the standard for the industry and adapted in this work to the field of agricultural production. Next, it is necessary to assess the reliability management system, for which the structure and mathematical apparatus have been developed and proposed for use. The implementation of these methodological developments develops research on the efficiency of agricultural production [11] and the use of tractors [12]. It will improve the reliability of agricultural technological systems, which is consistent with previously obtained results on managing the reliability of technological systems [13, 14].

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