Simulation modeling in the process of loading the machine and tractor fleet

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Abstract. The article describes the use of simulation modeling as a method to increase the efficiency of the formation of the machine and tractor fleet (MTF). The advantages of the use of simulation modeling in combination with traditional approaches to the formation of the MTF are presented. A model of verification of the production plan of an agricultural enterprise has been formed taking into account the use of simulation modeling. The place and role, conceptual requirements, an interaction overview diagram have been determined and basic parameters of the simulation model have been identified which satisfy the process under study. The simulation model can be used both as an independent program module and as part of software systems related to the management of the production resources of agricultural organizations.

1. Introduction
As a result of the economic reforms carried out in Russia, there is a change in the set of internal processes of the enterprise itself and its environment, which has become more dynamic and unpredictable. Under constantly changing conditions of activity, there is a need for continuous monitoring of production and making timely management decisions.

Improving the activities of an agricultural enterprise can be carried out on the basis of an analysis of the system of existing business processes. In this paper, we will focus on the business process of the formation of the machine and tractor fleet, which is key in the framework of the agricultural enterprise for the management of production resources.

Agricultural enterprises have significant differences in the characteristics of both the farms themselves and the machinery employed and used in them. Due to the individuality of the requirements, the effective management of the composition of the machine and tractor fleet requires the use of modern methods and techniques. In the case of determining the most appropriate composition of the machinery employed, it is necessary to take into account the basic features of this task: highly detailed input parameters, stochastic nature. In these cases simulation methods can be used.

For a more correct construction of the simulation model and its adequate integration into the business processes of the agricultural enterprise, the process of forming the composition of the machine and tractor fleet was analyzed. As a methodological basis for the description of this business process, a process approach was used, which allowed for the aggregation and refinement of existing flows, data and information.

2. Materials and methods
2.1. Related work

As part of the business process of forming a machine and tractor fleet, the following areas can be distinguished, on the basis of which decisions are made: based on the construction of peak load schedules for machines; based on economic and mathematical models. The basis of the first approach is cash-flow charts, after analyzing which the number of machines of a certain brand and type is selected for the relative agricultural period of time. This approach is simple, intuitive and affordable when used and allows you to solve most of the problems associated with the MTF; it can be used to justify the promising composition of technology, as well as help to improve the effectiveness of an existing composition of an agricultural enterprise. However, for a large number of types of work and technology, the construction of these maps is complicated.

When constructing and analyzing economic and mathematical models of the formation of the MTF composition, the main idea is to build a stochastic model, which should reduce to a linear programming problem. After that, should choose the most appropriate optimality criterion, which should have some quantitative measure of measurement. In 1962-1963 V.A. Bulavsky and L.V. Kantorovich developed a technique for calculating the needs of collective and state farms for technology, based on the application of linear programming methods and their implementation on the computer. To solve this problem, an interactive method was used, which allows solving linear programming problems when there are a large number of variables and limiting conditions. Economic and mathematical models more sufficiently reflect the real conditions in which it is necessary to make a choice of solutions. But, because of a large set of factors, both external and internal, optimization is much more complicated and the final solution does not always work effectively in practice.

In our opinion, within the framework of the process of forming the machine-tractor fleet, it is advisable to combine optimization and simulation fleet. However, among the works devoted to the problem of the formation of the MTF, it is possible to identify a general tendency - concentration on optimization of the composition of technology with a bias in economic and mathematical methods. For example, Danish scientists H.T. Sogaard and C.G. Sorensen have developed and described a model that supports the process of choosing the optimal size of the machine and tractor fleet, taking into account the inclusion of operational factors and a block of the labor system [1]. The approach to the formation of the MTF based on the efficiency of the use of fields, the performance of the technology was proposed by scientists from Sudan [2]. Chinese scientists used the linear programming method to determine optimal agricultural production, which allowed them to form models taking into account a significant number of variables and processed data [3]. Work based on simulation modeling can be divided into three areas: to select the most effective production strategy of the enterprise; assessment of possible profits and losses depending on weather and climatic conditions and the corresponding level of crop yields; for the formation of an economic strategy. Scientists from Vietnam have developed a model that describes the effect of land use on the economic behavior of small and medium-sized households. Such model, according to the authors, can be used as a means for explaining macro-economic events in the industry on the basis of experiments on farms-agents at the micro-economic level [4]. The impact of agricultural and environmental policies on agricultural systems in the EU has also been studied using simulation modeling. As a result, a model was built that allows modeling of arable and livestock farms in several regions In their work, it is proposed to use the model as a universal tool for the future analysis of farms depending on the policy being pursued [5]. Also, we would like to mention R. S. Parmar, R. W. McClendon, W. D. Potter, who developed a simulation model based on a genetic algorithm to maximize profits [6].

It should also be noted that in the majority of works in the process of construction, the stage of development of process models is missed. In our opinion, the modeling and optimization of the structure of the MTF should be preceded by the development of a process model. This will allow one to describe the set of necessary functions, to identify possible «bottlenecks» places in the business process under study, to identify the relationship between existing forms of organization of the technological process and the capabilities of the organization itself, to provide opportunities for targeted improvement, in particular the reduction of time and material costs. The basic approach to building suchlike model is
based on the process approach. As part of it, AS-IS and TO-BE models are being developed, which will give us the opportunity to aggregate and detail existing data and information flows. The main feature of the process approach is the mapping, through various models, of converting the input data stream (resources or events) into the outgoing data. It allows one to consider a set of ongoing actions in dynamics and provides a basis for determining the place of application of simulation methods.

There are various approaches to the definition of it. According to Anu M., the simulation modeling of a system is, first of all, a representation of the model operation of this system [7]. Later, Robert E. Shannon defines simulation modeling as the process of constructing a model and conducting experiments on it in order to either understand the behavior of the system under study, or assess the consequences of applying various system development strategies. In the future, quantitative computer analysis of the model and the resulting data became an important characterizing aspect of simulation [8]. Combining previous approaches, we may define simulation modeling as the principle of constructing existing or abstract systems using computer computing power to conduct experiments in real time and further analyze the output data.

Simulation modeling, according to Robert E. Shannon, is advisable to apply if any of the following conditions exist: there is no complete mathematical formulation of the problem under study, or there are no well-developed analytical methods for solving it; to solve the required mathematical procedures of high complexity and time-consuming; end users are not well prepared mathematically. Another advantage of simulation modeling is the ability to control and set the time of the process being studied, since the phenomenon can be slowed down or accelerated at will.

There are a number of common steps and rules for building a simulation model. In general, modeling can be presented as a cycle, the results of which should be compared with the conceptual and real model, which will allow making certain changes to them, for further study of the resulting alternative model. Accordingly, as a result of several iterations, the simulation model should become more close to the real system. At the same time, the main difficulty that the researcher faces is to determine the most appropriate number of such simulation iterations [9].

Simulation models, because of the inclusion of non-linear dependencies between variables and taking into account fluctuations of production factors with basic system parameters, allow us to assess the stability of these parameters and their adequacy to the functioning environment, which is a decisive factor in their use in the task of forming a machine and tractor fleet.

2.2. Simulation task
The statement of the problem has already been formulated by the authors [10]. Let, with a certain volume, there be a number of types of agricultural work. Different units with different performance and resource consumption can perform these jobs. The basic condition of the problem is connected with the terms of the work, which should not exceed certain limits. Each operation must be performed in a certain period of time and in a certain sequence. Additional restrictions on the sum of the intensities of using machines of a certain type—should be equal to the total number of this type of farm machines and is determined by a positive value. It was necessary to determine the intensity of use of the machine.

As a function that needs to be minimized, you can use:

$$L = \frac{P}{W}, (j = 1,2...Z; t = 1,2...T; s = 1,2...S)$$

(1)

where, \(L_{\text{its}}\) – the number of machine-tractor units, which, as a result of calculations, can be expressed as the completed load share; \(P_j\) – the amount of work \(j\) performed during period \(t\); \(W_{\text{its}}\) – the maximum possible output when performing work \(j\) with the same energy-engine of brand \(i\) in period \(t\). The objective function reflects the minimum number of machines required to perform all the volumes of agricultural work.

The authors applied the basic provisions of the method of end-to-end viewing of variants of annual work complexes for graphical display and analysis of annual work complexes and the use of power machines on them [11]. To determine the processing time of the unit operation, an approach was used.
based on the economically feasible duration of the field work. These terms are not normalized due to the delay in carrying out field work, leading to yield losses, as well as due to the costs caused by the technical support of these deadlines. It is considered that the ripening periods are different and may vary in some ranges. The existing function of total costs for agricultural enterprises, depending on the duration of the technological operation, allows you to determine the appropriate time frame for the field work [12].

We have identified the basic data required for the operation of the simulation model. Input variables include: machine aggregate class (power, performance, maximum possible hourly load); reliability factor of technical equipment; the readiness ratio of the machine and tractor fleet to perform work; the duration of the work shift; weather conditions being a probabilistic variable; type of agricultural operation; the volume of work in physical units; the duration of the agricultural year. Internal calculation variables: working time reserve for each energy machine of a given class; the duration of the periods of agricultural year; the volume of work; the productivity for the period of operation of the aggregates; minimum hourly output of the unit. Output variables: the share of production for a particular operation from the maximum possible performance of a given amount of work for the period; the minimum value of the execution time of the received annual work package; a set of technical tools for performing annual work complexes.

3. Simulation modeling as a verification tool
As part of the formation of the machine and tractor fleet, it is necessary to carry out a set of measures that would allow an assessment of the presence of errors in the generated plan for the use of equipment. In the practice of developing information systems in such cases, we should resort to verification, which is designed to determine how much the output results correspond to the solution requirements set for the object of study. There are two approaches to solving the problem of verification: the first is to apply simulation methods, hardware emulation and other types of modeling, the second approach is related to the methods of conducting verification procedures at different design stages. Most often, the optimal solution is to combine both of these approaches. In our case, verification refers to the process of checking the plan of using machinery, by means of running the simulation model, to carry out the volume of agricultural work stated in the plan of production, which will also reveal the existing shortcomings and form a set of necessary adjustments. For the process of forming the MTF composition, the simulation model may be the basis for carrying out the verification of the production plan of an agricultural enterprise and will allow to estimate the workload of the formed complex of technical means and form a number of adjustments and alternatives to the production plan of the agricultural enterprise (figure 1).
Figure 1. Verification of the machine and tractor fleet utilization plan

Accordingly, verification includes the following blocks: verification of the formed periods of the agricultural year; unit responsible for the ranked distribution of technical means between technological operations for specific cultivated areas; the block of loading of the machine and tractor fleet, which includes modeling the shares of the load by periods of the agricultural year for the formed complex of technical means and the block forming an alternative plan and adjustments, taking into account the performed verification. The simulation model conceptually should correspond to the first three blocks and provide an opportunity for analysis based on the data and graphs obtained during the run.

4. Formalization of requirements for simulation model

To identify and formalize the requirements for a simulation model, we will use a UML use case diagram. First of all, this type of diagram will allow one not only to explicitly reflect the goals of the projected model, but also to display the necessary functional connections between the projected system and external actors, and this can be either users, decision makers, and external data stores or other information systems.
Thus, external interaction with the simulation model takes place with a decision-maker and a database in which information necessary for work is stored (for the farm, for agricultural technology and technology, for the cultivation and harvesting of agricultural crops, for operational and economic indicators of machinery).

Thus, the implementation of verification, within the framework of the task of forming the MTF, will allow checking for compliance with the general requirements for a set of machines and, through the use of a simulation approach, will allow adjusting the production plan to achieve the desired result.

5. Software implementation
To build a simulation model, we selected the AnyLogic software system, thanks to the advantages: the possibility of combining all three paradigms of building simulation models (system-dynamic, discrete-event and agent) in one model; availability of simple tools and libraries for the introduction of probabilistic parameters. Due to the use of Java, the model in AnyLogic can be used as a separate application completely independently of the development environment and the platform on which it is launched; ability to control simulation runs; availability of tools for collecting, viewing and comparing simulation results.

The simulation model block diagram formed in AnyLogic combines system dynamics, agent-based and elements of discrete-event modeling. The base agent is the “Main”, which contains all the variables and parameters presented above, and an auxiliary class “Inquiry” was created to collect data on the application-model operations.

The experiment consists in the following: let the processing by the machine-tractor unit (tractor together with the sowing complex) receive some technological operations (these can be either shares in conditional hectares, or just applications for agricultural work). Operations must be carried out in accordance with the optimal duration of the field work. At the same time, until one operation-request is executed, the next one cannot be executed. Thus, on the basis of the model, it is possible to determine the amount of work performed by the unit, operation time, workload and the likelihood of the operation (taking into account the situation of the unit congestion). Days were chosen as the main model time. Since the operation on which the experiment was carried out was chosen as a direct seeding operation, taking into account resource-saving technology, the final model execution time is 30 days.

As a result of running the simulation model, the average time to perform the operation at 30% is 1.5 days and increase up to 2 days, which corresponds to analytical calculations with similar values of parameters. At the same time, the maximum possible number of processed operations is 38. However, only 35 are likely to be completed, which means that some of the operations were not completed due to the lack of power of the unit, which led to a violation of the deadlines, and additional units are required for further operations, calculations.

6. Conclusion
The use of a simulation approach allows on to improve the quality and flexibility of the process. For the process of forming the composition of the MTF, the simulation model can be the basis for carrying out the verification of the production plan of an agricultural enterprise. Analysis of the run of the simulation model will allow one: to decide in particular cases without the implementation of the optimization problem; to give recommendations on how to change the parameters of the objective function or restrictions imposed in the optimization problem; to assess the workload of the formed complex of technical means. It should be noted that, on the one hand, simulation modeling is an excellent addition to solving optimization problems and, on the other hand, it can be used separately, since in particular cases it will be enough for decision-making.

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