Planning of scientific and technological development of agricultural organizations

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Abstract. In context of realization of scientific and technological development scenarios in agro-industrial sector agricultural organizations should tackle the task of planning their production using various technologies, varying the number of workers and enhancing machine and tractor fleet. This task is solved through linear programming techniques. The authors suggest a computational method for identifying the structure of equipment needed to fulfill the scheduled work in the field. The operating costs for the implementation of all technologies within a certain period of time are the objective function. Our method can be applied in dedicated software to strategically plan the scientific and technological development of agricultural organizations

1. Introduction

Innovations facilitate scientific and technological progress but they are impossible without new technologies. At the present time scientific and technological development of agro-industrial sector is considered in two scenarios: the “Local growth” and the “Global breakthrough” [1].

The “Local growth” scenario is based on the model of catching-up development. It implies a speedy solution to the problem of food and biological security, preserving social stability. In the “Local growth” scenario there would be a steady positive dynamics in production of most agricultural crops, in particular grain. Wheat and maize offer the best prospects for increase in production due to an expansion in the area under cultivation as well as introduction of new effective technologies. The following innovations are foreseen for agricultural organizations: basic technologies of precision agriculture based on information and communication technologies and satellites, new fertilizers, new advanced agricultural machinery, etc.

The “Global breakthrough” scenario is based on advanced development model. Its priorities are providing food and biological security, social stability; increasing the share of agricultural exports; diversifying the agro-industrial complex; integrating agriculture, food and processing industry; increasing resource efficiency; building climate-resilient infrastructure. In this scenario the share of grain crops in agricultural production will be the same as in 2015, however the share of livestock will increase through the introduction of new technologies. For agricultural organizations the implementation of this scenario will bring forth the following innovations: complex technologies of precision agriculture; conservation agriculture, including organic farming; integrated pest management;
soil and water conservation; restoration of soil fertility, etc. [2-5].

Thus, one of promising strategies for crop production is precision farming. There are two views of the concept of precision agriculture. The first one defines it as the way to improve agricultural yields by responding to intra-field variability of crops, while the second one sees it as a management strategy which integrates information technologies for effective management of a farm. [6, 7]. Creation and implementation of these technologies face a lot of problems. In our view, they should be solved not only on a farm level but also on the national level involving a system approach. The challenge is to shift towards a new paradigm of production based on advanced technologies, transformation of the existing business models for management, involvement of the necessary expertise and skills.

The transition of agricultural organizations to these scenarios will require changes in technology, modeling the structure of the tractor fleet, developing a replacement schedule and a number of other activities. In practice, it becomes quite a complicated problem for departments of agricultural organizations to choose the required machinery among the wide range of equipment offered. This often leads to adoptions of subjective, economically unreasonable decisions on the modernization of production, therefore, it is necessary to develop effective tools for planning activities.

2. Materials and methods
Machine and tractor fleet (MTF) can be considered as an economic system which needs constant improvement of its technical condition and modes of operation. Optimization of an economic system is based on a certain strategy, by which an ordered set of rules is meant. By following this set of rules the best of all possible decisions is made. Nowadays it is necessary to develop new approaches to the content of optimization. It must be based on previous methods and production and operational practice as well as on modern requirements for mathematical modeling and forecasting.

There is already a developed software as well as mobile applications [8-10], but they only solve the specific tasks of operating expenses analysis and equipment cost estimation. However, the most promising solution is seen not just in the development of a mathematical model, similar to the existing ones, but in the creation of a computer programme which will be used for the enhancement of machine and tractor fleet and planning its effective operation in specific production conditions.

This requires a set of activities in the following main areas:
1) development of necessary databases with field information (cartographic information);
2) development of methodology to complete machine and tractor units (MTU) and estimate their performance indicators (productivity and fuel consumption);
3) development of an optimisation algorithm for machine and tractor fleet;
4) creation of an optimal field work schedule.

The basic principles of MTF optimisation, preparation of work plans and building a system of machines for crop production are presented in a number of publications [11-13].

3. Optimization of the machine and tractor fleet
We propose a method in which the acquisition of units needed for planned field work and calculation of their operational parameters are made automatically based on the data in administrative and user databases. This approach is preferable because there is a wide range of machines used and it is necessary to consider a lot of possible MTU combinations. Besides, there is often no reliable information about the performance of machines, especially imported ones, therefore the performance is determined by optimization of the speed mode of machine-tractor units. The assessment of completed units is based on technical and technological criteria taking into account the requirements of agricultural machines as well as rational loading of a power unit engine.

Another important feature of the proposed method is that the units are completed from existing machines.

This means that a large number of similar MTU can be created with different performance indicators due to different age of its constituents and variation of shift capacity depending on field configuration.

The next step is optimization of fleet composition and field work scheduling in accordance with user-
defined conditions. In practice, scheduling is quite a long and complex process, because it requires finding an optimal solution from a large number of feasible solutions, which makes it a combinatorial task. Since each element of the model is a machine and tractor unit with an individual set of characteristics or a technology with a complex structure of interrelated operations scheduling is also considered as a multi-criteria task. As the objective function, we use the operating costs for the implementation of all within a given period of time:

\[
A = \sum_{j=1}^{J} \sum_{n=1}^{N} A_{jn} = \sum_{j=1}^{J} \sum_{n=1}^{N} \left( F + L + D + RP + IA + IL + IS \right)_{jn} \rightarrow \text{min} \tag{1}
\]

where \( A \) is operating costs, \( i \in J, n \in N \) are numbers of technological operations and machine units to perform them; \( F \) is fuel and lubricant costs, \( L \) is labour costs, \( D \) is depreciation expense, \( R \); \( RP \) is repair and maintenance costs, \( S; \) \( IA \) is opportunity costs, \( IL \) is interest payment on loans, \( IS \) is insurance and storage costs, \( S \).

In order to give a correct description of optimization algorithm it is necessary to clearly specify the relationship among inputs:

- the number of the field \( (k) \rightarrow \) sequence of operations \( (j) \). All field numbers have their own sequence ordered uniquely according to the type of technology selected by the user.
- operation \( (j) \rightarrow \) a list of units \( (n) \). For each operation there is a list of units which can perform it. This list is formed automatically from a user-defined list of available equipment suitable for given operations.

The main calculation parameter during optimization is operation time. Operations, in turn, can be considered as sequential or parallel processes:

1. A sequential process implies that time periods for each operation in one field do not overlap. Then,

\[
TS = \sum_{k=1}^{K} \sum_{j=1}^{J} \left( TO_{kj} + TB_{kj} \right), \quad TB_{\text{min}(j)} \leq TB_{kj} \leq TB_{\text{max}(j)} \tag{2}
\]

where \( TS \) is the time taken to perform a sequence of operations, hrs; \( TO_{kj} \) is the time taken by all units to perform the \( j \)-th operation in the \( k \)-th field, hrs; \( TB_{kj} \) is a time break between operations \( j \) in the \( k \)-th field (the time break \( TB \) is only for the current and the previous operations in the sorted list of operations for a particular field), hrs.

This algorithm makes it possible to create a cultivation technology as a sequence of operations, based not only on calendar but also on the life cycle of a crop, which will fully reflect special features of growing a particular crop. The countdown begins with the time period of the first technological operation. The remaining operations will be determined taking in account \( TB_{\text{min}}-TB_{\text{max}} \) parameters, which can be changed if necessary.

2. A parallel process implies that time periods for similar operations in different fields overlap or several operations are performed simultaneously in one field. Then,

\[
TP = \max_{1 \leq k \leq K} \left( \sum_{j=1}^{J} \left( TO_{kj} + TB_{kj} \right) \right) \tag{3}
\]

where \( TP \) is time taken to perform parallel operations, hrs.

In this case the parameter \( TB \) acquires another meaning. It is the time required for moving a unit and solving organizational tasks. It can be applied for optimization of logistics. Then the total time to perform all work can be written as

\[
T = \max \left[ TS, \max \left( TP_0 + TP \right) \right], \quad 0 < T \leq T_{\text{max}} + \delta T \tag{4}
\]

where \( TP_0 \) is a technological break between operations in a parallel process (similar to \( TB \) in a sequential process), hrs; \( T_{\text{max}} \) is maximum completion time for all work (can be set by the user and limited by the budget for the salaries of workers (for the whole complex of works), or by the time planned on certain operations (for example, sowing or harvesting) which need to be done in the shortest possible time, hrs;
\( \delta T \) is additional time which can be added to the total time \( T \) and/or time for operations in order to reduce costs, hrs.

The performed operations are assembled into a matrix with the size of \( J \times J \), where on the main diagonal there is sequence of operations with indices. These operations are performed one by one sequentially. Non-diagonal elements are operations that can be performed concurrently. Each non-diagonal element can form its own diagonal branch. The time taken by units for performing the operations is determined by the formula:

\[
TO_{kj} = \sum_{n=1}^{N} \beta_{kn} \cdot \omega_{kjn} \cdot TA_{kjn}, \quad TO_{kj} \leq TO_{kj}^{max} + \delta TO_{kj}
\]  

(5)

where \( TO_{kj} \) is operating time of all possible units \( N \) to perform the \( j \)-operation in the \( k \)-field, hrs; \( \beta_{kn} \) is coefficient of availability of the \( n \)-unit in the \( k \)-field (valid values are from 0 to 1); \( \omega_{kjn} \) is indicator of operating cost of the \( n \)-unit performing the \( j \)-operation in the \( k \)-field in relation to the most expensive unit that can be used for this operation (valid values are from 0 to 1); \( TA_{kjn} \) is time required for the \( n \)-unit to perform the \( j \)-operation on the \( k \)-field, hrs; \( \delta TO_{kj} \) — operating time of all possible units performing the \( j \)-operation in \( k \)-field, which can be added to the total operating time of all units \( TO_{max} \) to reduce cost, hrs.

Parameter \( TA \) can be calculated by dividing field area by unit efficiency:

\[
TA_{kjn} = \frac{S_k}{E_{kjn}}
\]  

(6)

where \( S_k \) is the area of the \( k \)-field, hectares; \( E_{kjn} \) — efficiency of the \( n \)-unit performing the \( j \)-operation in the \( k \)-field per hour, ha/ h.

Based on the calculated values of the time spent on operations, a decision can be made on the availability of the unit (parameter \( \beta \)):

\[
\beta_{kn} = \begin{cases} 
0, & \text{the unit cannot be used} \\
\frac{TA_{kjn} - TA_{kn}}{TA_{kjn}}, & \text{the units available after } T \\
1, & \text{the unit is available at any time} 
\end{cases}
\]  

(7)

where \( TA_{kn} \) is time period after the start of the operation when the unit or machines it contains become available for operation, hrs.

The cost indicator \( \omega \) is calculated on the basis of the objective function for a specific unit performing a particular operation:

\[
\omega_{kjn} = \frac{A_{kjn}}{\max_{1 \leq n \leq N} A_{kjn}}
\]  

(8)

where \( A_{kjn} \) is operating costs of the \( n \)-unit performing the \( j \)-operation in the \( k \)-field, $.

The possibility of the solution will be determined by a set of restrictions that must be met.

1. Restriction on the amount of work:

According to this restriction each field must be fully processed and all operations must be completed. The formalized record represents the sum of all work done by units performing each technological operation:

\[
\forall j; \quad \sum_{k=1}^{K} \sum_{n=1}^{N} E_{kjn} \cdot TA_{kjn} = \sum_{k=1}^{K} S_k
\]  

(9)

2. Restriction on continuity of an operation:

According to this restriction there must be no interruptions in the operation of a unit during the period of the operation, that is:
\[ \forall n, j; \sum_{k=1}^{K} (TA_{k_{jn}} + TA_{0_{n}}) = \sum_{k=1}^{K} TO_{kj} \]  

(10)

3. Restriction on breaks between operations:
As it was mentioned earlier, there are minimum and maximum technological breaks, which are determined by the TB parameter. Therefore, the restrictions for sequential and parallel processes will be expressed by formulas (2) and (3).

4. Congruence between parallel processes:
This restriction is based on parameter TP0 which implies that a parallel process cannot be started until a sequential process with a higher priority is finished. This restriction is taken into account in formula (4) for calculation of the total time of work.

5. Restriction on the use of the machine:
The algorithm for each technical means is checked to ensure that its total operating time does not exceed the maximum value set by the user (this can be a shift time or other individual restrictions).

\[ \forall m; \sum_{k=1}^{K} \sum_{j=1}^{d} TA_{k_{jm}} \leq TM_{\text{max}} \]  

(11)

where \( m \) stands for machine; \( TM_{\text{max}} \) – the maximum daily operating time limit, hrs.

Thus, we propose a new method to solve the problem of optimal completion of machine fleet, give the general description of tasks to solve, mathematical description of processes and restrictions, which allows us to create software.

4. Conclusion
The proposed method can become the basis for the creation a software product. We see it as a computational and analytical system which will enable us to solve a number of tasks such as long-term production planning and forecasting with the development of necessary technological documentation, optimal distribution of equipment according to the type of work, acquisition planning and developing a strategy for fleet and equipment enhancement, maintaining up-to-date record of performed work, carrying out a comparative assessment of machinery and equipment efficiency, etc. Thus, it will be possible to solve one of the most important tasks which are to develop a successful acquisition strategy in order to enhance the effectiveness of agricultural production.

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