

Genetic Algorithm: Application in the Decision Support System for Selecting a Machine and Tractor Fleet

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Abstract – The considered problem is to select a machine and tractor fleet to perform an annual cycle of work in agribusiness. There are many criteria for selecting a machine-tractor fleet and mathematical models based on them to solve this task. The complexity of the problem lies in many numerous solutions. A specialist carries out the assessment and final choice of machine and tractor fleet, so the number of variants offered for consideration should not exceed a reasonable number. In this work, the task is to reduce the number of solutions for selecting a machine and tractor fleet. To solve this problem a combined application of two approaches is proposed. The first one is based on choosing the length of periods that make up the annual work cycle. The second is based on the application of a genetic algorithm based on John Holland's evolutionary algorithm and the selection hypothesis. We held the adaptation of the genetic algorithm and presented the result of its testing. It demonstrates the effectiveness of this approach. It is concluded that the application of the genetic algorithm to the task of reducing the number of solutions allows to do it as well as to cut the time spent on performing calculations for selecting a machine and tractor fleet for cultivation of grain crops.

Keywords—mathematical model, adaptation, evolutionary methods, genetic algorithm, machine and tractor fleet, optimization, agriculture, selection criteria

I. INTRODUCTION

The task of choosing a machines and tractor fleet (MTF) emerges from the beginning of field work to perform an annual cycle of work in agriculture. This task is difficult because it is needed to take into account many factors (market conditions in the future, expected weather conditions, physical and chemical characteristics, fertility of agricultural land, etc.) that are variable in time and space [1]. At the same time, the regularities of interaction between the tractor fleet, tillage, and human resources, the existing soil and climate potential and the level of agronomic culture, should be taken into account [2, 3]. Also, the task of accounting for emergency situations and analysing their consequences is among the tasks of planning agricultural work. It requires timely correction of the compiled work plans with the least losses [4].

There are many criteria for selecting MTF and mathematical models based on them for solving this task [5]. Optimization of the tractor fleet involves the use of linear or linear-integer mathematical models [6]. Most often, they use

cost criteria that are aimed at a minimum to reduce costs in the production of products. Thus, the task of optimizing the composition of MTF is a linear programming task.

II. PROBLEM STATEMENT

Choosing the appropriate method of solution is one of the main tasks of optimizing the MTF structure. The solution space of the problem is a set of selection variants (MTF structure) that satisfy the constraints of the optimization task. The complexity of the task lies in the large size of this set (the number of possible options for selecting equipment). However, the number of variants offered for consideration should not exceed a reasonable number, because the assessment and finally choosing the one of selected variants is carried out by a specialist.

A calendar schedule of planning mechanized works is built for their implementation. As can be seen from figure 1, several technological operations can be performed simultaneously (works r from 1 to R) using different aggregates (a form 1 to A_r).

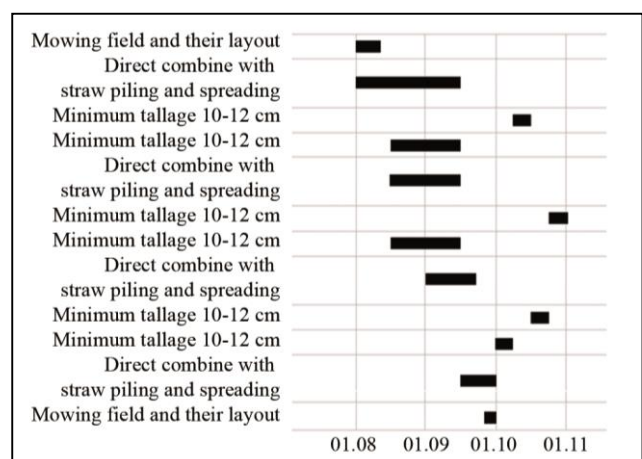


Fig. 1. Calendar schedule for the annual cycle of mechanized works

The entire annual work cycle is divided into periods p from 1 to P to solve the problem of distributing equipment for these operations. Because agricultural machinery is used simultaneously in several jobs, and there are several types of aggregation (connection of tractors and agricultural

machines), the number of possible options for selecting equipment for the annual cycle of work can be determined by the formula:

$$C = \prod_{p=1}^P \prod_{r=1}^R \prod_{a=1}^{A_r} (x_a + 1) \quad (1)$$

where C is the number of possible options for selecting equipment;

x_a – the number of aggregates a used to perform the work r .

The length of the period p is 1 day to get an exact solution in this formula.

The resulting amount can be reduced by increasing the duration of the period, for example, up to five days, then the formula (1) will take the following form:

$$C = \prod_{p=1}^{P/5} \prod_{r=1}^{R_p} \prod_{a=1}^{A_r} (x_a + 1) \quad (2)$$

But the duration of operations is not always a multiple of five days, and machines used on one operation (which ended during the period) can be used on another, therefore, the given solution to the task does not take this into account (the problem with the released technique).

The task is divided into subtasks and options with minimal costs are searched separately to reduce the number of solutions. The solutions obtained from the subtasks must be combined with the further search for solutions to the general problem, and then the resulting costs must be summed up. The sum of the minimum costs for each subproblem will give the minimum costs as a whole, thus we will simplify the search for a solution without reducing the accuracy.

Select the calculation groups to separate the problem (hereinafter referred to as groups). We will arrange all the works by start and end dates, divide them into several groups g from 1 to G . Looking at the works starting from the first and in order for each group, we will divide them into periods p_g from 1 to P_g (Fig. 2).

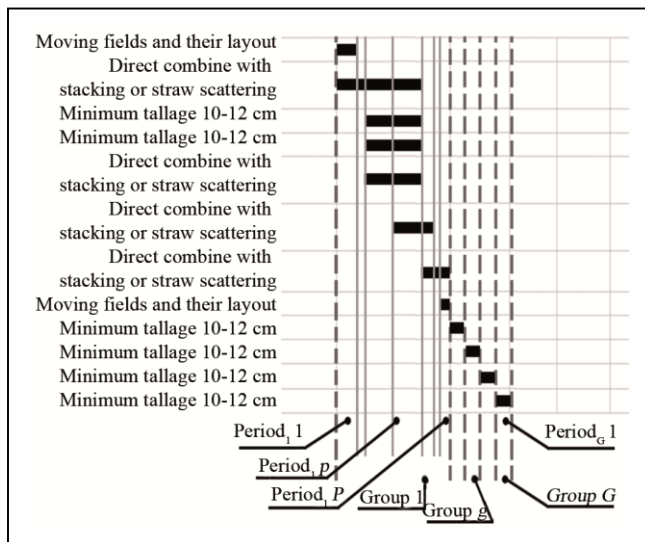


Fig. 2. Calendar schedule for the annual cycle of mechanized work divided into groups and periods

Thus, the task is reduced to finding a solution for each group separately, and the formula (2) for each group will take the following form:

$$C = \prod_{p=1}^{P_g} \prod_{r=1}^{R_{p_g}} \prod_{a=1}^{A_r} (x_a + 1) \quad (3)$$

This study used two optimization criteria: minimum direct costs and minimum qualified machine operators [7].

Limitations in finding a solution of the task have the following form:

- Implementation the given amount of works:

$$\sum_{p_g=1}^{P_g} \sum_{a=0}^{A_r} SR_{ar} \cdot x_{arp_g} = Sq_r \quad (4)$$

where r – the number of all agricultural works performed on a farm, piece;

a – the number of all possible aggregation options, piece;

A_r – the total number of aggregates performing work r , piece;

SR_{ar} – the performance of aggregate a on work r , ha/shift;

x_{arp_g} – the number of aggregates a required to perform the work r in period p of group g , piece;

SR_r – a volume of work r , ha;

- Non-surplus machines for performing work r :

$$\sum_{p_g=1}^{P_g} \sum_{a=0}^{A_r} SR_{ar} \cdot x_{arp_g} - \min_{a \in A_r} SR_{ar} < Sq_r \quad (5)$$

- The number of tractors and agricultural machines must not exceed the number available on the farm:

$$\sum_{r \in R_{p_g}} \sum_{a=0}^{A_r} b_{ar}^t \cdot x_{arp_g} < x_t, \quad \sum_{r \in R_{p_g}} \sum_{a=0}^{A_r} b_{ar}^s \cdot x_{arp_g} < x_s \quad (6)$$

where x_t, x_s – the total number of tractors and agricultural machines of the brand t and s , respectively, required for the farm, piece;

b_{ar}^t, b_{ar}^s – the number of tractors and agricultural machines of the brand t and s , included in aggregate a , performing the r work, piece;

- The number of machine operators should be lower than the number of them employed on the farm:

$$\sum_{r \in R_{p_g}} \sum_{a=0}^{A_r} b_{ar}^{m_n} \cdot x_{arp_g} < x_{m_n}, \quad \sum_{n=1}^N x_{m_n} < x_m \quad (7)$$

where x_m – the total number of machine operators required for this farm, people;

x_{m_n} – the total number of machine operators having category n , required for this farm, people;

$b_{ar}^{m_n}$ – the number of machine operators having category n and performing work r by aggregate a , people;

N – the highest category of machine operators.

- The category of performing work, n_r , should be lower than the category of machine operators:

$$n_r \leq n \quad (8)$$

- In addition:

$$x_t \geq 0, x_s \geq 0, x_{arp_g} \geq 0, x_{m_n} \geq 0, x_m \geq 0 \quad (9)$$

The number of possible solutions to the task will be less than the one calculated by the formula (1), but it may be more than the one calculated by the formula (2). This will solve the problem of the released equipment. Making the decision of MTF selection is carried out by accepting limitations (4) - (9) only during those periods in which one or more works are completed, as well as at the end of each group according to the task optimization criteria.

An example (Fig. 3) is given as an illustration of the effectiveness of the proposed method. We calculate the number of options for it. The initial data of works are presented in the table (table 1).

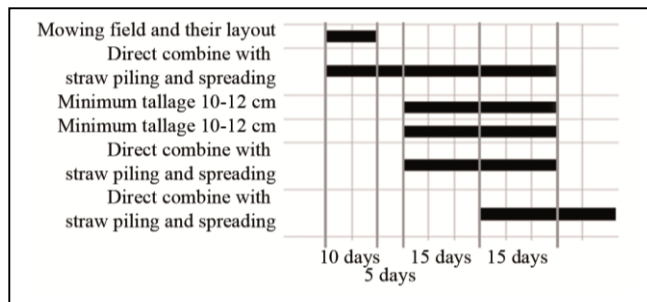


Fig. 3. An example of work execution with the duration of periods

TABLE 1. TABLE TYPE STYLES

Work number	Name of work	Aggregates			$\prod_{a=1}^{A_r} (x_a + 1)$
		Type	Number, piece	Performance, ha/day	
1	Moving field and their layout	1	2	14	3
2	Direct combine with straw piling and spreading	1	2	14	6
		2	1	19	
3	Minimum tillage 10-12 cm	3	2	85	9
		4	2	50	
4	Minimum tillage 10-12 cm	3	2	85	9
		4	2	50	
5	Direct combine with straw piling and spreading	1	2	14	6
		2	1	19	
6	Direct combine with straw piling and spreading	1	2	14	6
		2	1	19	

For further calculations, we calculate the number of options for all periods:

$$\prod_{r=1}^{R_{p_g}} \prod_{a=1}^{A_r} (x_a + 1) \quad (10)$$

A series of numbers, is calculated: 18, 6, 2916, 17 496. Then, if a period is 1 day, the number of variants received by the formula (1) is:

$$C = 18^{10} \cdot 6^5 \cdot 2916^{15} \cdot 17496^{15} \quad (11)$$

if a period is 5 days:

$$C = 18^2 \cdot 6 \cdot 2916^3 \cdot 17496^3 \quad (12)$$

and if periods are divided according to figure 2:

$$C = 18 \cdot 6 \cdot 2916 \cdot 17496 \quad (13)$$

In the first period, 6 variants remain after evaluating by limitations (4) - (9). In subsequent periods, it is not possible to evaluate variants by these limitations (there are no completed works), so the number of solutions increases, according to formula (3) at these stages and will be equal to 1,836,660,096 in the last period.

The considered example is very simplified. The number of works performed simultaneously reached 13 in real conditions on the farm, and the number of variants was much greater. A lot of time was spent on their processing and performing all calculations. The decision must be made by the specialist in a short time, for example, due to changed weather conditions or suddenly failed equipment. Thus, the goal of this study was to reduce the number of solutions in the selection of MTF.

III. REDUCING THE NUMBER OF SOLUTIONS USING A GENETIC ALGORITHM

It is necessary to reduce the number of decision options in the period for each work and develop an intelligent decision-making system that can process multiple decision options for a number of constraints simultaneously in a short time. A genetic algorithm (GA) is proposed for this purpose.

It was based on the evolutionary algorithm of John Holland in 1975 [8] and the selection hypothesis. It can be formulated as follows: the higher the suitability of an individual, the greater the chance signs determine suitability will be expressed even more strongly in the offspring obtained with its participation [9].

The main feature of GA is crossing and selection of strong individuals by sorting through variants and screening out obviously non-viable individuals. Therefore, the number of individuals participating in selection at each stage decreases. Thereby the amount of usable RAM the calculation time for finding optimal solutions are reduced [10]. GA has the potential to adapt the algorithm for finding optimal solutions to various tasks [11] and is successfully used in many areas of activity, including agriculture [12-14].

We consider the problem of selecting individuals from the point of view of evolution, applying GA to our task. Each solution is an individual, and the array of solutions is a population from which we choose parents from the selection. The resulting parents are crossed, and we get an array of solutions called descendants. We select a new population

based on the suitability criteria. And this cycle (Fig. 4) pass until the stop condition is met.

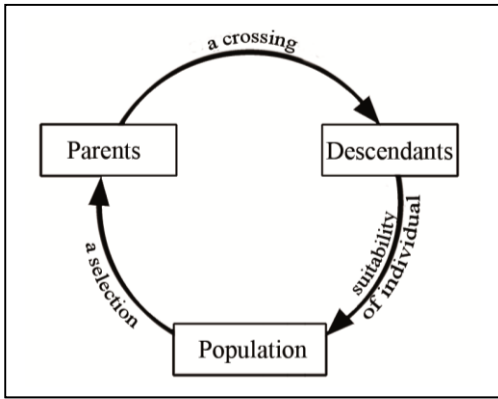


Fig. 4. Evolution cycle

It is needed to make several steps of GA [9]:

- To choose a solution representation (how to encode a phenotype into a genotype);
- To decide how to initialize a population;
- To define main genetic operators (to choose a suitable operator of the crossing);
- To choose a method for evaluating an individual's suitability;
- To decide how to manage population (choosing individual parents);
- To decide when algorithm is stopped.

To do this, determine the phenotype, genotype and perform the steps described above:

- A phenotype is the performance of aggregate, period number, group number, number of days in the period, work number;
- A genotype is a string consisting of integers from 0 to A_r , where A_r is the maximum number of aggregates of a certain brand, available in the farm that can perform this work r ;
- An individual is represented by discrete values (integers), where the genome is a sequence of k aggregates (the number of each aggregate varies from 0 to A_r) that perform the current work r ;
- A chromosome is the selected p_g period, which includes works from 1 to R_{p_g} (fig. 5);
- A parent is a set of chromosomes, where the number of its corresponds to the total number of periods in the group, all chromosomes consist of zeros, except for the one that corresponds to the period in question.

We define the concept of iteration to determine the main genetic operators. It is one pass through the cycle (fig. 4) at the end of each period p_g .

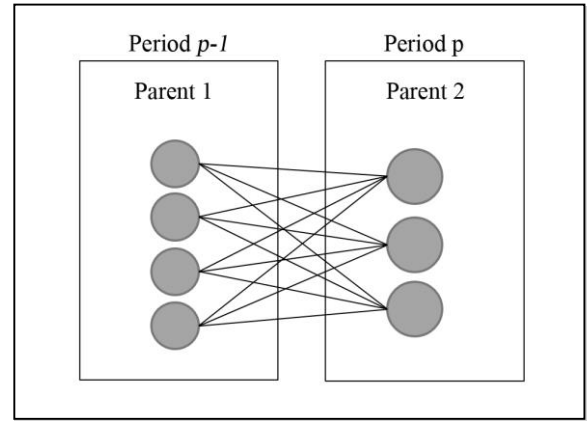


Fig. 5. An example of parents crossing from two periods

Parents from periods p_g-1 and p_g for p_g iteration are analyzed. And all are crossed with all (Fig. 6).

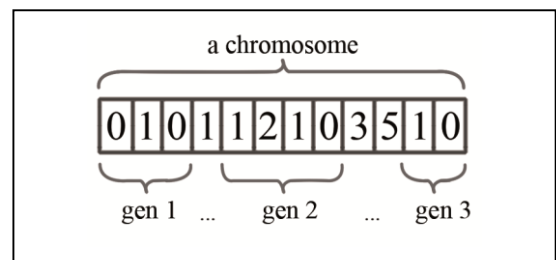


Fig. 6. Chromosome representation

The parent of the p_g-1 period contains zeros in chromosomes starting from the period p_g , and the parent of the period p_g contains zeros in all chromosomes except the period p_g . We choose a single-point crossing to solve our problem (Fig. 7), where the break point is the end of the current period (chromosome) in this group. The parent chromosomes break at this point and exchange parts. A child containing only zeros is considered unsuitable for further selection.

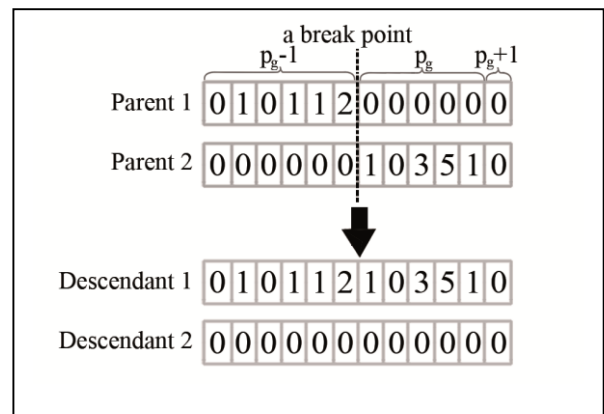


Fig. 7. Single-point crossing

The fulfilment of conditions (4) - (9) only for those genes that belong to the works ending in the period p_g is the criterion of individual suitability. After that, we get a population, from which it is necessary to conduct selection and identify the most adapted individuals for further crossing.

We consider the selection criteria to be the fulfilment of the conditions:

- Performing more than the specified amount of work (failure to comply with the condition (4)):

$$\sum_{p_g=1}^{p_g-1} \sum_{a=0}^{A_r} SR_{ar} \cdot x_{arp_g} \geq Sq_r \quad (14)$$

$$\sum_{a=1}^{A_r} SR_{ar} \cdot x_{arp_g} > 0 \quad (15)$$

- The specified amount of work has not yet been completed for the periods 1, ..., p_g-1 , and no work is performed in p_g :

$$\sum_{p_g=1}^{p_g-1} \sum_{a=0}^{A_r} SR_{ar} \cdot x_{arp_g} > Sq_r \quad (16)$$

$$\sum_{a=1}^{A_r} SR_{ar} \cdot x_{arp_g} = 0 \quad (17)$$

- A performance of the remaining amount of work does not meet the deadlines:

$$\frac{Sq_r - \sum_{p_g=1}^{P_g} \sum_{a=0}^{A_r} SR_{ar} \cdot x_{arp_g}}{\sum_{a=0}^{A_r} SR_{ar} \cdot x_{arp_g} / days_{p_g}} > \sum_{p_g=P_g+1}^{P_g} days_{p_g} \quad (18)$$

Iterations are repeated until the number of generations (cycles) reaches the pre-selected maximum, P_g . When the period P_g is reached, additional selection is performed based on the optimization criteria at the end of the group. Since the task is divided into several subtasks, after completing the review of the g group, we repeat all actions from $g+1$ to G group.

When populations in all groups are obtaining, another crossing is performed, and the resulting descendants are considered to be the solution of the task. The analysis of the received solutions is carried out by the specialist, choosing the best variants from his point of view.

IV. APPROBATION OF THE GENETIC ALGORITHM IN THE TASK OF MTF SELECTION

We apply GA to the example discussed earlier (Fig. 2) and consider the first period. There are 6 variants, that left out of 18 after applying the restrictions (4) - (9), and the second period with 6 variants. Since only one work is performed in the second period and it doesn't end, the number of solutions is 36 without GA. The processed area for this work is 400 ha. We get a certain population from the remaining variants of the first and second periods using GA. It is checked according to the selection criteria (Table 2). Of the 36 variants 16 of the fittest individuals were identified.

The obtained result allows concluding that applying the GA algorithm to the task reduces the number of variants for selecting MTF and significantly reduces time costs. Obviously non-viable variants of using machines are not formed during the calculation process. This is important for a specialist who makes a decision in a limited time. The results of this study

are used in the web-complex "PIKAT" [15], which is implemented in some farms in the Novosibirsk region.

TABLE 2. CHOOSING OF PARENTS BY SELECTION CRITERIA

Descendant	Evaluation criterion					
	Square of p_g-1 , ha	Square of p_g , ha	Remaining untreated area, ha	Performance, ha/day	Number of days, days	Suitability of the individual
10000...	0	400	0	0	-	-
10010...	70	330	14	23,6	-	-
10001...	95	305	19	16,1	-	-
10011...	165	235	33	7,2	-	+
10020...	140	360	28	9,3	-	+
10021...	235	165	47	3,6	-	+
11000...	0	260	0	-	-	-
11010...	70	190	14	13,6	-	+
11001...	95	165	19	8,7	-	+
11011...	165	95	33	2,9	-	+
11020...	140	120	28	4,3	-	+
11021...	235	25	47	0,6	-	+
12000...	0	120	0	-	-	-
12010...	70	50	14	3,6	-	+
12001...	95	25	19	1,4	-	+
12011...	165	55	33	1,7	-	+
12020...	140	-	28	-	-	-
12021...	235	-	47	-	-	-
10100...	0	210	0	-	-	-
10110...	70	140	14	10	-	+
10101...	95	115	19	6,1	-	+
10111...	165	45	33	1,4	-	+
10120...	140	70	28	2,5	-	+
10121...	235	-	47	-	-	-
11100...	0	70	0	-	-	-
11110...	70	0	14	0	-	+
11101...	95	-	19	-	-	-
11111...	165	-	33	-	-	-
11120...	140	-	28	-	-	-
11121...	235	-	47	-	-	-
12100...	0	-	0	-	-	-
12110...	70	-	14	-	-	-
12101...	95	-	19	-	-	-
12111...	165	-	33	-	-	-
12120...	140	-	28	-	-	-
12121...	235	-	47	-	-	-

V. CONCLUSION

This paper shows the effect of choosing the period length on the number of variants for solving the task of selecting MTF. The expediency of applying GA to the task is proved. The adaptation of GA is carried out in the article, and the result of testing in the task of selecting MTF is presented.

Thus, this study shows that the solution to the problem of reducing the number of variants for selecting MTF for the cultivation of grain crops was achieved using two different approaches. The first approach was to choose the length of the period. It allows to significantly reduce the number of solutions without losing accuracy, but the resulting set of solutions still is large. The second approach with the use of GA allows to solve this problem. This is achieved by selecting the most suitable variants for each iteration. Thereby obviously unsuitable solutions for further evaluation in subsequent iterations are excluded. Applying GA allows to reduce the number of solutions and reduce the time spent on performing calculations for selecting MTF by cultivation of grain crops.

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