The 9th IEEE International Conference on Dependable Systems, Services and Technologies, DESSERT'2018
24-27 May, 2018, Kyiv, Ukraine

# Application of the fish search algorithm for optimization plans of the full factor experiment

V.V. Muratov[1], N.D. Koshevoy[2], E.M. Kostenko[3]
[1] Kharkov, Chkalova, 17, 61070, vmuratov77@gmail.com
[2] Kharkov, Chkalova, 17, 61070, ndkoshevoy@rambler.ru
[3] Poltava, Skovoroda, 1/3, 36000, kostenko@pdaa.edu.ua

*Abstract* – **A method and program was developed to optimize the plans for a full factorial experiment using the search algorithm for fish. A comparative analysis of methods for the synthesis of optimal full-scale experiment experiments for cost and time costs has been carried out. The efficiency of the method was tested on a number of such technological objects: fuel consumption in the internal combustion engine, welding of thin plates, production of parts by hot stamping, and also the process of servicing machines with numerical control. The effectiveness of the method of searching for fish by the school is shown.**

***Keywords – method, algorithm, optimal plan, search by school of fish, optimization, experiment planning, cost, time, win.***

## I. Introduction

The most important part of scientific studies are experiments. This is one of the main ways to get new scientific knowledge. The basis of this method is an experiment, representing a scientifically delivered experience or observation of the phenomenon under precisely taken into account conditions, allowing to monitor its progress, to control it, to recreate it every time when these conditions are repeated. From ordinary, passive observation, the experiment is distinguished by the active influence of the researcher on the phenomenon being studied.

Planning an experiment is a section of mathematical statistics that studies methods for organizing a set of experiments with different conditions to obtain the most reliable information about the properties of the object under investigation in the presence of uncontrolled random perturbations. The use of experimental planning makes the experimenter's behavior purposeful and organized, significantly contributing to the increase of his labor productivity and the reliability of the results obtained. An important advantage of the method is its universality, suitability in the vast majority of areas of research. Experimental research methods are widely used to optimize production processes. One of the main objectives of the experiment is to obtain the maximum amount of information about the influence of the factors studied on the production process. Further, a mathematical model of the object under investigation is constructed. At the same time, it is necessary to obtain models with minimal cost and time costs. This is especially important in the study of long and costly processes. The task of optimizing plans at a cost (time) of the experiment is NP-complete, i.e. for its solution takes time and a large number of computations, rapidly growing with increasing dimension of the problem. Therefore, a complete search of all possible solutions is difficult. In this connection it is necessary to find solutions using approximate algorithms.

## II. Purpose of the Article

Development of a method and software for optimizing plans for a full factorial experiment using the search algorithm for fish.

## III. Analysis of Research and Publications

Combination optimization methods are known [1] - [3], but they are not used to construct optimal multi-factorial experiments in terms of cost and time costs. There are examples of constructing multi-factor experimental plans that are based on the use of the following optimization methods: analysis of permutations [4]; method of successive approximation [4]; method of branches and boundaries [4]; random search (permutation of the rows of the planning matrix) [4]; the simplex method [5]; ant algorithm [6]; genetic algorithms [7]; annealing method [8]; greedy algorithm [9], swarm of particles [10]. The effectiveness of the use of methods is also shown in the study of various objects - technological processes, instruments and systems [4], [11]-[14]. All these methods have both advantages and disadvantages. For example, with a large number of factors, a lot of time is required for a complete search of all the rows of the planning matrix, and other algorithms allow obtaining an optimal experiment plan for a limited number of factors k. With a large number of factors, the optimization results are approximated to the optimal experiment plan. In view of this, it is advisable to use the search algorithm for fish by a school to compare the results.

## IV. Materials of Research of the Proposed Method and Algorithms and Programs Realizing It

A method and software for optimizing the plans for a full factorial experiment on cost (time) costs using the search algorithm for a school of fish has been developed.

978-1-5386-5902-1

The essence of the application of the search algorithm for schools of fish is as follows:

Step 1. At the beginning of the algorithm, the number of factors k is entered.

Step 2. Enter the values of the transitions between the levels for each of the factors.

Step 3. Depending on the selected number of factors, the experiment planning matrix is constructed.

Step 4. Calculation of the initial cost of the experiment.

Step 5. Generate the matrix of the sum of the values of the transitions between the levels for each of the factors.

Step 6. Sort the indexes and generate an array of indexes for the sum of the values of the transitions between the levels for each of the factors.

Step 7. Permutation in the columns in accordance with the array of indices for the sum of the values of the transitions between the levels for each of the factors.

Step 8. Separation of the experiment planning matrix into blocks in accordance with the array of indices for the sums of the values of the transitions between the levels for each of the factors whose dimension is calculated by the formula

$N_{blocks} = 2N+1$, where N – index (0…3).

Step 9. Calculation of the local minimum cost of the experiment when the blocks are rearranged.

Step 10. For each column, the permutations of the local blocks of the experiment planning matrix are generated with the calculation of the minimum local sum of the values for each of the columns.

Step 11. Construction of the optimal experiment planning matrix.

Step 12. Calculation of the total cost of the experiment.

Step 13. Calculation of the value of winnings B as the ratio of the initial cost of carrying out the $C_{init}$ experiment to the cost of the experiment $C_{min}$.

Step 14. Calculation of the time t spent on optimizing the plan of the full factorial experiment using the search algorithm for fish schools.

The software is implemented in C++ programming language. The required amount of memory for the implementation of the program of the search method by the school of fish is 37 MB. Thus, the implementation of the method of searching for fish by a school requires a small amount of computer memory and has a high speed of solving the problem.

Verification of the efficiency of the developed method and software for optimizing the plans for a full factorial experiment was carried out on a number of practical problems. The system for determining fuel consumption in internal combustion engines was studied. At the same time, fuel consumption q in milliliters was considered as an optimization criterion. Factors that affect this indicator were selected: $X_1$ – number of revolutions n of the engine per minute, rpm; $X_2$ – engine temperature T, °C [4].

The cost of changing the values of the levels of factors are given in table 1 [4].

The initial plan of the full factorial experiment (k = 2) and the optimal experiment cost plan, developed using the method of searching for fish by the school, are given in table 2.

TABLE I. COSTS OF CHANGING VALUES OF FACTOR LEVELS

| Cost of changes levels of factors, cond. units | Notation factors | |
|---|---|---|
| | $X_1$ | $X_2$ |
| from «-1» to «+1» | 0,32 | 0,16 |
| from «+1» to «-1» | 0,22 | 0,48 |

TABLE II. The initial plan of the full factorial experiment and the optimal design of the experiment, developed using the method of searching for fish

| Initial plan | | | Optimal plan | | |
|---|---|---|---|---|---|
| Number of experience | Notation factors | | Number of experience | Notation factors | |
| | $X_1$ | $X_2$ | | $X_1$ | $X_2$ |
| 1 | -1 | -1 | 1 | -1 | -1 |
| 2 | +1 | -1 | 2 | +1 | -1 |
| 3 | -1 | +1 | 4 | +1 | +1 |
| 4 | +1 | +1 | 3 | -1 | +1 |

The cost of the optimal experiment plan obtained by the method of searching for fish by the school is 0.7 conv. units, and the cost of the plan, obtained by the method of full search, is also 0.7 conv. units [4].

The search for the optimal experimental plan (k = 2), obtained by the method of searching for fish by the school, was realized in 0.013 seconds.

The win in comparison with the initial planning matrix is 1.46 times, in the work [4] the gain is also 1.46 times.

A study was carried out of the technological process of welding plates of small thickness, in which an experiment was carried out to determine the optimal mode of spot welding of plates of small thickness. The factors considered were: $X_1$ – capacitor capacitance, μF; $X_2$ – coefficient of transformation, $X_3$ – force at the electrodes, N [11].

The cost of changing the values of the levels of the factor are given in table 3 [11].

The initial plan of the full factorial experiment (k = 3) and the optimal experiment cost plan, developed using the method of searching for fish by the school, are given in table 4.

TABLE III. Costs of changing values of factor levels

| Cost of changes levels of factors, conv. units | Notation factors | | |
|---|---|---|---|
| | $X_1$ | $X_2$ | $X_3$ |
| from «-1» to «+1» | 2,5 | 2,0 | 1,5 |
| from «+1» to «-1» | 3,0 | 2,5 | 2,0 |

TABLE IV. The initial plan of the full factorial experiment and the optimal design of the experiment, developed using the method of searching for fish

| Initial plan | | | | Optimal plan | | | |
|---|---|---|---|---|---|---|---|
| Number of experience | Notation factors | | | Number of experience | Notation factors | | |
| | $X_1$ | $X_2$ | $X_3$ | | $X_1$ | $X_2$ | $X_3$ |
| 1 | -1 | -1 | -1 | 1 | -1 | -1 | -1 |
| 2 | +1 | -1 | -1 | 5 | -1 | -1 | +1 |
| 3 | -1 | +1 | -1 | 7 | -1 | +1 | +1 |
| 4 | +1 | +1 | -1 | 3 | -1 | +1 | -1 |
| 5 | -1 | -1 | +1 | 4 | +1 | +1 | -1 |
| 6 | +1 | -1 | +1 | 8 | +1 | +1 | +1 |
| 7 | -1 | +1 | +1 | 6 | +1 | -1 | +1 |
| 8 | +1 | +1 | +1 | 2 | +1 | -1 | -1 |

The cost of the optimal experiment plan obtained by the method of searching for fish by the school is 14 conv. units, and the cost of the plan, obtained by the method of full enumeration, is also 14 conv. units [11].

The search for the optimal experimental design (k = 3) by the method of searching for fish was realized in 0.05 seconds.

The win in comparison with the initial planning matrix is 1.93 times, and in the work [11] the gain is also 1.93 times.

A study of the technological process for the production of parts by hot stamping was carried out. On the basis of a priory information, the thickness of the part was chosen as the criterion for optimizing the process $h_{det}$, and the following are the dominant factors: $X_1$ – billet heating temperature, °C; $X_2$ — billet heating time, min; $X_3$ — temperature of die heating, °C [4].

The time for changing the values of the factor levels is shown in table 5 [4].

The initial plan of the full factorial experiment (k = 3) and the experimentally optimal plan for the experiment, developed using the method of searching for fish by the school, are given in table 6.

TABLE V. Time for changing values of factor levels

| Time of change levels of factors, min | Notation factors | | |
|---|---|---|---|
| | $X_1$ | $X_2$ | $X_3$ |
| from «-1» to «+1» | 30 | 22 | 3,75 |
| from «+1» to «-1» | 25 | 5 | 7,5 |

TABLE VI. The initial plan of the full factorial experiment and the optimal experimental design, developed using the method of searching for fish

| Initial plan | | | | Optimal plan | | | |
|---|---|---|---|---|---|---|---|
| Number of experience | Notation factors | | | Number of experience | Notation factors | | |
| | $X_1$ | $X_2$ | $X_3$ | | $X_1$ | $X_2$ | $X_3$ |
| 1 | -1 | -1 | -1 | 2 | +1 | -1 | -1 |
| 2 | +1 | -1 | -1 | 6 | +1 | -1 | +1 |
| 3 | -1 | +1 | -1 | 8 | +1 | +1 | +1 |
| 4 | +1 | +1 | -1 | 4 | +1 | +1 | -1 |
| 5 | -1 | -1 | +1 | 3 | -1 | +1 | -1 |
| 6 | +1 | -1 | +1 | 7 | -1 | +1 | +1 |
| 7 | -1 | +1 | +1 | 5 | -1 | -1 | +1 |
| 8 | +1 | +1 | +1 | 1 | -1 | -1 | -1 |

The time of realization of the experiment, obtained by the method of searching for the fish by the school, is 74.5 minutes, and the time according to the plan obtained by the full-scan method is 72 minutes [4].

The search for the optimal experimental design (k = 3) by the method of searching for fish was realized in 0.051 seconds.

The gain in comparison with the initial planning matrix is 3.33 times, in the work [4] it is 3.37 times.

A study of a section of a machine tool shop with numerical program control was carried out. As a criterion for optimization, the total operating time of numerical program management machines was chosen. The dominant factors that affect this indicator were selected: $X_1$ – time of the prevention $t_n$, h; $X_2$ — number y, of machine tools with numerical program management; $X_3$ — machine hours during the day $t_c$, h; $X_4$ — periodicity of prevention $t_0$, h [4].

The time for changing the values of the factor levels is shown in table 7 [4].

The initial plan of the full factorial experiment (k = 4) and the experimentally optimal plan for the experiment, developed using the method of searching for fish by the school, are given in table 8.

TABLE VII. Time of changing values of factor levels

| Time of change levels of factors, h | Notation factors | | | |
|---|---|---|---|---|
| | $X_1$ | $X_2$ | $X_3$ | $X_4$ |
| from «-1» to «+1» | 7,0 | 6,0 | 16,0 | 100,0 |
| from «+1» to «-1» | 3,0 | 2,0 | 12,0 | 50,0 |

TABLE VIII. The initial plan of the full factorial experiment and the optimal design of the experiment, developed using the method of searching for fish

| Initial plan | | | | | Optimal plan | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Number of experience | Notation factors | | | | Number of experience | Notation factors | | | |
| | $X_1$ | $X_2$ | $X_3$ | $X_4$ | | $X_1$ | $X_2$ | $X_3$ | $X_4$ |
| 1 | -1 | -1 | -1 | -1 | 5 | -1 | -1 | +1 | -1 |
| 2 | +1 | -1 | -1 | -1 | 13 | -1 | -1 | +1 | +1 |
| 3 | -1 | +1 | -1 | -1 | 7 | -1 | +1 | +1 | -1 |
| 4 | +1 | +1 | -1 | -1 | 15 | -1 | +1 | +1 | +1 |
| 5 | -1 | -1 | +1 | -1 | 8 | +1 | +1 | +1 | -1 |
| 6 | +1 | -1 | +1 | -1 | 16 | +1 | +1 | +1 | +1 |
| 7 | -1 | +1 | +1 | -1 | 6 | +1 | -1 | +1 | -1 |
| 8 | +1 | +1 | +1 | -1 | 14 | +1 | -1 | +1 | +1 |
| 9 | -1 | -1 | -1 | +1 | 2 | +1 | -1 | -1 | -1 |
| 10 | +1 | -1 | -1 | +1 | 10 | +1 | -1 | -1 | +1 |
| 11 | -1 | +1 | -1 | +1 | 4 | +1 | +1 | -1 | -1 |
| 12 | +1 | +1 | -1 | +1 | 12 | +1 | +1 | -1 | +1 |
| 13 | -1 | -1 | +1 | +1 | 3 | -1 | +1 | -1 | -1 |
| 14 | +1 | -1 | +1 | +1 | 11 | -1 | +1 | -1 | +1 |
| 15 | -1 | +1 | +1 | +1 | 1 | -1 | -1 | -1 | -1 |
| 16 | +1 | +1 | +1 | +1 | 9 | -1 | -1 | -1 | +1 |

The time of realization of the optimal experiment obtained by the method of searching for fish by the school is 136 hours.

The search for the optimal experimental design (k = 4) by the method of searching for fish was realized in 0.14 seconds.

The gain in comparison with the initial planning matrix is 1.85 times, and in the work [4] the gain obtained by the limited search method is 1.17 times.

Thus, as a result of the study of the selected objects, it was shown that the method of searching for fish by the school gives results close to optimal or optimal, both in the method of full search, but in less time in view of the smaller number of necessary transformations.

## V. Conclusions

A method and a program have been developed for optimization of plans for a full factorial experiment using the search algorithm for schools of fish. Their operability and efficiency on some examples of research of systems and technological processes are proved. Also, the method of searching for fish can be effectively used to optimize experiment plans for the study of various objects.

The search for an optimal or close to the optimal plan, obtained by this method, is realized for a low counting time. It is shown that in order to optimize the plans for a full factorial experiment, it is advisable to use the method of searching for fish by researching objects with the number of factors $2 \leqslant k \leqslant 5$.

Scientific novelty is the proposed method of searching for fish by a school, optimal for cost (time) cost plans for a full factor experiment, and practical value - software for its implementation.

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