OPTIMAL PLANNING METHODS FOR MEASUREMENTS IN LIMITED MATERIAL RESOURCES CONDITIONS

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Abstract: Methods and programs for multifactorial experiment design optimization have been developed by means of the following algorithms: taboo search, random search and particle swarm. Efficiencies in comparison with other optimization methods of multifactor experimental plans while optimization of: portable dielectric moisture meters, moisture meter for bulk materials and process of printed circuit boards' metallization area measurement are estimated. The efficiency and effectiveness are proved by the coincidence or approximation of the optimal plans obtained by means of developed methods and the complete enumeration method.

Key words: optimization, experiment design, cost, time, taboo-search, particles swarm, random search.

1. Introduction

At the present stage of science and production development, experimental design methods are widely used in order to minimize the number of conducted tests and also help to in establishment of rational order and conditions for the studies' performance depending on their kind and required results' accuracy.

Usage of experimental planning methods makes it possible to reduce the cost of carrying out experiments and to shorten the time needed for its implementation by means of the rational experiments' arrangement. That is especially important during the study of expensive and long-term processes.

The task of obtaining the minimum cost of carrying out experiments is NP-difficult; as a result absolutely exact solution can be obtained only for a small number of factors. For the number of factors k>4 the number of permutations increases significantly and at the current stage of computer development it is not possible to find the exact solution.

2. Literary sources analysis and formulation of the problem

In order to construct optimal experiment plans methods of combinatorial optimization [1-3] can be used. Wide spreads have such optimization methods [4]: complete search, method of successive approximation, random search, branches and boundaries method. The effectiveness of those methods in the study of technological processes, devices and systems is proved. These methods have both advantages and disadvantages. Disadvantages of these methods are low speed, and possibility to find close to optimal solution.

It was decided to apply methods of taboo search, random search (permutation of the planning matrix's columns), and swarm of particles in order to compare obtained optimization results for multifactorial experiment plans.

3. Experiment plans optimization by means of taboo-search methods, random search (permutation of the planning matrix columns), swarm of particles.

Software for the following methods was developed: taboo-search [5], random search (permutation of the planning matrix's columns) [6], swarm of particles [7]. Initial data for calculations: factors, costs' matrices of changing factor levels, the initial experiment design and the optimization results of the initial plan by: complete search methods, permutations analysis (limited search), or branches and boundaries, serial sequences, successive approximations. Initial data given for calibration technological processes of: portable dielectric moisture meters, moisture meter for bulk materials and process of printed circuit boards' metallization are given in the monograph [4].

The experiment plans presented in Table 1 were obtained for study of portable dielectric metric moisture meters calibration technological process using methods of taboo-search, random search (permutation of the planning matrix's columns), particles swarm.

The cost of experiment implementation is the same as for the full-busting method – 110 units, while applying methods of taboo-search, random

search, swarm of particles. The initial cost of the full factorial experiment is 120 units. The maximum cost is 190 units. Gain in experiment implementation cost is 1.1 times in relation to initial plan and 1.7 times in relation to maximum cost plan.

Optimal plans for investigation of moisture meter for bulk materials [8] obtained by methods of taboo-search, random search, and swarm of particles are presented in Table 2.

Comparative characteristics of experiment carrying out cost and gains, which were obtained with the help of various optimization methods, are presented in Table 3.

During the study of printed circuit boards' metallization area measurement using developed optimization methods were obtained experiment plans presented in Table 4.

Cost of experiment, obtained using the taboo-search method, is 3.63 units. The gain is 1.6 times compared to initial plan and 3.27 times comparing to maximum cost plan. Program's counting time is 0.05 s.

Cost of experiment performance, obtained by means of random search method (permutation of

Table 1. Optimal experiment plans for optimization of the portable dielectric metric moisture meters calibration process

Optimal plan (taboo-search)			Optimal plan (permutation of the planning matrix's columns)			Optimal plan (particle swarm)		
Experiment number	Factor		Experiment number	Factor		Experiment number	Factor	
	X_1	X_2		X_1	X_2		X_1	X_2
2	+1	-1	2	+1	-1	2	+1	-1
1	-1	-1	1	-1	-1	1	-1	-1
3	-1	+1	3	-1	+1	3	-1	+1
4	+1	+1	4	+1	+1	4	+1	+1

Table 2. Optimum experiment plans for investigation of moisture meter for bulk materials

Optimal plan (taboo-search)				Optimal plan (permutation of the planning matrix's columns)				Optimal plan (particle swarm)			
Experiment number	Factor			Experiment number	Factor			Experiment number	Factor		
	X_1	X_2	X_3		X_1	X_2	X_3		X_1	X_2	X_3
1	-1	-1	+1	1	-1	-1	+1	1	-1	-1	+1
2	-1	+1	-1	3	+1	-1	-1	3	+1	-1	-1
6	-1	+1	+1	7	+1	-1	+1	7	+1	-1	+1
8	+1	+1	-1	5	-1	-1	-1	5	-1	-1	-1
4	+1	+1	+1	6	-1	+1	+1	6	-1	+1	+1
3	+1	-1	-1	8	+1	+1	-1	2	-1	+1	-1
7	+1	-1	+1	4	+1	+1	+1	4	+1	+1	+1
5	-1	-1	-1	2	-1	+1	-1	8	+1	+1	-1

Table 3. Comparative characteristics of metaheuristic optimization methods used in the investigation of moisture meters

Method	Cost of the experiment realization, units	Gain in relation to the original plan	Gain in relation to the maximum cost plan
Analyzing permutations	54	4,65	5,54
Taboo-search	50	5,02	5,98
Random search (permutation of the planning matrix's columns)	56	4,48	5,34
Particle swarm	48	5,23	6,23

Table 4. Optimal experiment plans for investigating the process of printed circuit boards' metallization area measurement

Optimum plan (taboo-search)					Optimal plan (permutation of the planning matrix's columns)					Optimal plan (particle swarm)				
Experiment number	Factor				Experiment number	Factor				Experiment number	Factor			
	X_1	X_2	X_3	X_4		X_1	X_2	X_3	X_4		X_1	X_2	X_3	X_4
1	+1	+1	+1	+1	1	+1	+1	+1	+1	2	-1	+1	+1	+1
3	+1	-1	+1	-1	4	-1	-1	+1	-1	3	+1	-1	+1	-1
5	+1	+1	-1	-1	5	+1	+1	-1	-1	1	+1	+1	+1	+1
4	-1	-1	+1	-1	2	-1	+1	+1	+1	4	-1	-1	+1	-1
6	-1	+1	-1	-1	6	-1	+1	-1	-1	7	+1	-1	-1	+1
7	+1	-1	-1	+1	8	-1	-1	-1	+1	5	+1	+1	-1	-1
2	-1	+1	+1	+1	3	+1	-1	+1	-1	8	-1	-1	-1	+1
8	-1	-1	-1	+1	7	+1	-1	-1	+1	6	-1	+1	-1	-1

the planning matrix's columns) is 4.75 units. The gains comparing to initial plan are 1.22 times and 2.5 times comparing to maximum cost plan. Program's counting time is 13.5 s.

Cost of experiment, obtained with the help of particle swarm method is 3.41 units. The gains are 1.7 times comparing to initial plan and 3.48 times comparing to maximum cost plan. Program's counting time is 0.03 s. Comparative characteristics of the obtained experiment's costs wich were gained using various optimization methods while studying the process of printed circuit boards' metallization area measurement are shown in Figure 1.

4. Conclusions

According to calibration process of moisture meters investigation results usage of: taboo-search, random search (permutation of the planning matrix's columns), particle swarm for objects with k = 2 factors give the same costs and gains of experiment implementation with the values obtained by the full search method.

During experimental plan optimization for moisture meters of bulk materials investigation (k=3) the biggest gains by experiment's realization cost gives implementation of swarm particle method.

According to Figure 1 during investigation of the process of printed circuit boards' metallization area measurement (k = 4) gives implementation of swarm particle method. Also, comparing to random search (permutation of the planning matrix's columns) and taboo-search, swarm particle method has best performance time.

The studies of optimization of plans for studying the calibration of portable dielectric metric moisture meters, a device for measuring the moisture content

of bulk materials and measuring the area of metallization of printed circuit boards have proved the efficiency and effectiveness of the developed methods of taboo search, random search (permutation of columns of the planning matrix) and a swarm of particles.

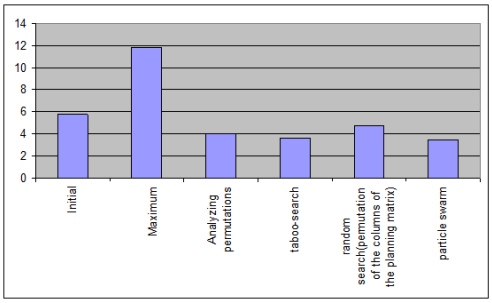

Figure 1. Comparative characteristics of the obtained experiment's costs using different optimization methods

Efficiency and working capacity of taboo-search, random search (permutation of the planning matrix's columns) and swarm particle method have been proved for experimental design optimization of: portable dielectric moisture meters calibration process, moisture meter for bulk materials calibration process and process of printed circuit boards' metallization area measurement

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