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METHODS FOR SOLVING THE PROBLEMS OF COMPLETING OPERATIONS IN COMPUTER AIDED DESIGN OF IN-LINE GARMENT PRODUCTION*

МЕТОДЫ РЕШЕНИЯ ЗАДАЧ КОМПЛЕКТОВАНИЯ ОПЕРАЦИЙ ПРИ КОМПЬЮТЕРНОМ МОДЕЛИРОВАНИИ ПОТОКА ШВЕЙНОГО ПРОИЗВОДСТВА

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The division of labor for the in-line production of garment at the modern level is developed in an automated production control systems. For example, in Russia automated production control systems such as "Stylon", "Julivi" are widely used. The division of labor scheme is formed in the system module of the same name by combining technologically indivisible operations into organizational ones that meet the set of requirements. Following a given route, one single solution is obtained for each production operation, without other options, and with characteristics predetermined by the technologist intuitively. The purpose of this publication is to identify scientific methods the most suitable for the development of an improved search algorithm of production operation characterized by optimum parameters. By presenting of the essence of integer programming methods and heuristics methods reveals the possibility of their application in the applied aspect, namely, for the development of the division of labor in the production line for the manufacture of garment model. The author has proposed an algorithm for finding the optimal structure of a production operation, which includes two stages of solving the problem. At the first stage, based on a combinatorial approach, the software application generates many variants of solutions for a production operation, acceptable in terms of the value of the quantitative attribute of time consumption. At the second stage, the user selects and makes the optimal decision of a production operation based on a set of qualitative indicators of an attributive nature with distributed priorities: connectivity of technological operations, specialty and complexity of execution.

Схему разделения труда для потока по изготовлению модели одежды на современном уровне разрабатывают в автоматизированной системе управления производством. Например, в России применяют АСУП «Julivi», «Стилон» и другие. Схему разделения труда формируют в одноименном модуле системы комплектованием технологически неделимых операций в организационные, отвечающие комплексу предъявляемых требований. Следуя по заданному маршруту, для каждой производственной операции получают одно единственное решение без иных вариантов, причем с характеристиками,

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предопределяемыми технологом интуитивным образом. Целью настоящей публикации является выявление научных методов, наиболее приемлемых для разработки усовершенствованного алгоритма поиска организационной операции, характеризуемой оптимальными параметрами. Изложением сущности методов целочисленного программирования и методов эвристики раскрыта возможность их применения в прикладном аспекте, а именно для разработки схемы разделения труда в потоке изготовления модели одежды. Автором предложен алгоритм поиска организационной операции оптимальной структуры, который включает в себя два этапа решения задачи. На первом этапе на основе комбинаторного подхода программное приложение генерирует множество вариантов решений производственной операции, допустимых по величине количественного признака затраты времени. На втором этапе пользователь выбирает и принимает оптимальное решение производственной операции по совокупности показателей, измеренных по атрибутивным признакам с распределенными приоритетами: связность технологических операций, специальность и сложность исполнения.

Ключевые слова: одежда, поточное производство, схема разделения труда, технологическая операция, производственная операция, метод, целочисленное программирование, эвристика.

Keywords: garment, in-line production, division of labor, technological operation, production operation, method, integer programming, heuristics.

Introduction

The problems of completing operations, solved for the division of labor in the in-line production of garments, contains a complex apparatus of search and decision-making.

Production operations are completed from technological operations for the manufacture of garment models. The number of variants of the formed production operation is very large. A technologist's decision on the composition of a production operation is associated with the choice of a particular combination of technological operations, satisfying a set of presented requirements. The division of labor is a more complex combination of technological operations grouped into production operations.

In this regard, the final result should be obtained by methods that consist in the use of search procedures in the space of all possible solutions of problems. Search procedures are implemented based on the application of both methods of applied mathematics and methods of heuristics.

Literature review

At enterprises, the in-line production of garments is organized on the principles of continuity, straightness, proportionality, parallelism, rhythmicity and synchronicity [1].

The functional model of the in-line production of garment is shown by the division of labor. This document is presented in the form of a table or graph. The division of labor is created by completing technological operations for the manufacture of garment model in the production operations of the production line.

When completing, a set of requirements is imposed for the construction of the production line as a whole, including the compatibility of technological operations in the structure of each production operation [2]. The essence of the formulated requirements is as follows.

1. In the division of labor, consistency is achieved in worker's actions according to the principles of proportionality, rhythmicity and synchronicity of the functioning of the production line

Currently, several approaches to the design processes of the in-line production of garments have been formed in Russia, characterized by the way of synchronizing the work: according to the production time, according to the production per worker and balancing of operations [3].

When designing production lines in which the execution of work is synchronized according to the production time, two fundamentally different representations are used:

– Professor V. E. Murygin substantiated the formation of the structure of the production line based on the commonality of design features in the models of one type of garments [4]. This view of the manufacture of a product implies a detailed specialization for groups of workers involved in the production line.

– In the view of Professor P. P. Koketkin, the structure of the manufacture of garments in the production line is formed on the basis of the generality of joining technology, used equipment and technological tooling [5]. This representation assumes operational specialization for workers othe production line.

Doctor of Economics N. V. Sokolov proposed to form the structure of the production line based on the allocation of the budget of the working shift time. Each employee is assigned to perform work of trivial composition, which minimizes internal connections in the production line. The production problem for the worker is formed as a priority from one technological operation repeated many times during the shift; further - from two or more compatible technological operations. The repeatability of each technological operation is determined by the calculated number of products, limited to the output per shift [6]. In this way, the output of workers for a production shift is equalized, which ensures the rhythmicity of output.

In the situation of manufacturing products in small series, they design flexible production lines for the making of different models from the assortment group of garments. Professor N. S. Mokeeva proposed to concentrate the equipment in the working areas, which provides flexibility in the functioning of the production line. Each worker is assigned up to three pieces of equipment for various purposes, which are included in the flexible production module. When changing the manufactured models, the compositions of the modules remain stable. The synchronized functioning of the production line is ensured by balancing operations taking into account the individual labor productivity of each performer [3].

2. Manufacture of the product in the expedient order of technological operations for the processing of parts with subsequent assembly into the finished product and its finishing. This requirement is based on the principles of continuity, straightness and parallelism of the organization of in-line production.

3. Minimization of internal connections in the production line. The fulfillment of this requirement contributes to the reduction of time spent on service actions and operations for moving labor items.

4. Compliance with the specialization of work (detailed, subject or operational) performed by both individuals and groups of performers.

5. Compliance of the worker's qualifications with the complexity of the work performed by him.

6. Minimization of the multiplicity of production operations, characterized by the number of performers [2].

Compliance with the listed requirements allows to reduce losses during the organization and functioning of in-line production and, as a result, to increase its efficiency.

When completing in a module the subsystems every time receive one single solution to a production operation. However, many other solutions, among which there may be the best, remain outside the operational field of attention of the technologist. At the same time, the priority ratio for the complex of characteristics of the formed production operation is not established in advance. In addition, the set of restrictions imposed on the initial set of technological operations significantly narrows the search area. As a result, the desired solution to the production operation with the specified characteristics is often not found. Then the search for a different solution to the production operation begins after the initial set of technological operations has been transformed.

Thus, the mentioned systems [7, 8] model the procedures for completing operations implemented in the traditional way.

Methodological framework

INTEGER PROGRAMMING METHODS

Mathematical programming is an area of applied mathematics, in which they study problems of finding the extremum of an objective function on a set with constraints, and develop methods for solving them. Problems with a conditional requirement for the integer value of variables are allocated to the section of integer programming.

Integer programming methods are used to develop the division of labor in the in-line production of garments. Scientists O. V. Apykhtin, V. A. Afanasyev in the book [9] presented the characteristics of two applied methods: random-walk search and directed search.

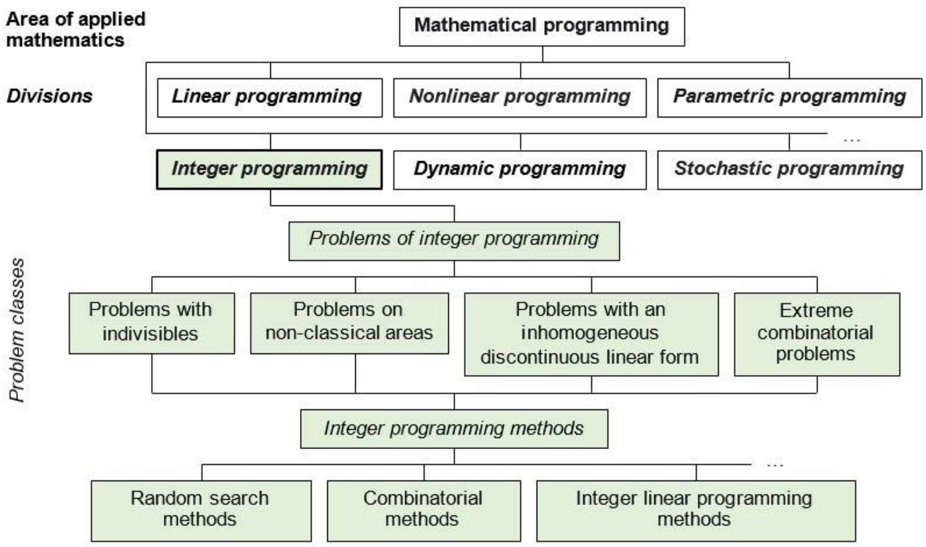


Fig. 1

The problem of completing can be formulated as partitioning the set of technological operations that make up the process of manufacturing a product model into disjoint subsets that are consistent in duration with the production time. The essence of the source problem is the sequential formation of production operations. Thus, the problem is reduced to solving simpler subproblems in terms of content, interrelated based on the initial data.

The characteristics of technological operations form a finite countable set of variables. First of all, these are the cost of time. The objective function of each subproblem is to achieve the minimum deviation of the time spent on the production operation from the production time. The requirements for the compatibility of technological operations as part of a production operation set limitations in the subproblem under consideration.

Then the posed problem has signs of belonging to one of the class's characteristic of integer programming - to the problems with indivisibles. The mentioned property points to the nature of the initial data represented as physically indivisible quantities.

Random-walk methods, which include the brute force method, are approximate. They are aimed at solving problems of integer programming of high dimension, because exact methods are inefficient.

The brute force method in the state space consists in finding a solution that corresponds to the objective function. The term "state" indicates a certain moment of solving the problem. Depending on the structural level of the formed information, this term means either a completed production operation, or a more complex combinatorial object - the division of labor in the designed production line.

The essence of this method is described on the basis of graph theory.

The initial vertex in a graph corresponds to the initial state. From a certain vertex, called the parent vertex, one or more child vertices are spawned. This action is called vertex disclosure, which is performed by the operator as a state transformation function. With each disclosure vertex, a new state is obtained. On the graph, the parent vertex is connected to the child vertices by arcs, which are pointers of the traversed path.

The vertices of the graph are disclosed in a given order. With the disclosure of child vertices, they are checked for their compliance with the objective function. If none of the child vertices satisfies the objective function, then the subsequent vertices continue to disclose. Having found the objective vertex, the solution path is revealed by the pointers in the opposite direction, from the objective to the beginning of the graph [10].

When solving the set problem, the state transformation function means the action of completing technological operations.

It is obvious that the graph of states, showing the completeness of a production operation, is finite. Thus, the position of the objective vertex will certainly be found on the graph, if it exists.

Random walk algorithms are distinguished by the completeness of the search in the state space. A brute-force search is exhaustive for finding a solution to a problem. In case of incomplete search, carried out in order to reduce the search time, they operate in a limited state space. However, an incomplete search can lead to a situation when the desired solution will not found, because initially the position of the objective vertex in the graph is unknown.

The number of vertices that can be disclosure on the graph of states in a brute-force search has an exponential dependence on the values of initial data. For high-dimensional problems, the implementation of computational procedures by combinatorial methods gives very low efficiency in finding a solution. Completing of operations in the development of division of labor for the in-line production of clothing model refers to this type of problems.

Another class is formed by problems on non-classical areas. The search area for extremum of linear function is defined, as usual, by linear inequalities, but it is supplemented by logical conditions "either/or". By additional conditions, the area of feasible solutions is transformed into a non-convex or disconnected one, which are called non-classical areas.

If a priori the areas in which the desired result does not exist are known, then the specified areas are ignored during the search. On the graph of states a certain subgraph is chosen according to the given constraints, on which the search procedures are implemented. Such methods of problem solving refer to directed search methods. In this group, the most significant are the cutting-plane method, the branch-and-bound method [11].

The next class unite combinatorial extremum problems. From the elements of a finite set, a combinatorial configuration is built, on which, in addition to the extremum of an integer linear function, a subset of elements corresponding to the found extremum is also found.

At certain stages of obtaining the division of labor, it is possible to use linear programming methods when the formulation of the objective function corresponds to the formulation of an extreme combinatorial problem.

Number	***Technological operation***	***Specialty***	***Level of work***	***Time, s***	***Equipment, tools, fixtures***

Fig. 2

For example, at the input, the manufacturing technology is set, described by the sequence of operations according to the product model, and the power of the production line expressed by the output per shift. It is required to find such a partition of the partially ordered set of technological operations into groups, according to which the minimum number of workers will be involved in the production line [10]. At the output, it is assumed to get a solution for organizing work with the highest labor productivity achieved by the conditioned technology of manufacturing products.

In a linear programming problem, it is required to find the optimum of an objective function with constraints imposed on the area of variable variation. The model of the problem is presented in general form:

– by the objective function

$$f(x) = \sum_{j=1}^{n} c_j x_j \rightarrow max(min), \quad (1)$$

– by a system of inequalities and equations limiting the solution

$$\sum_{j=1}^{n} a_{ij} x_j \{\leq, =, \geq\} b_i, \quad i = 1, 2, \dots, m, \quad (2)$$

– by the requirement of non-negativity of the variables

$$x_j \geq 0, \quad j = 1, 2, \dots, r, \quad (3)$$

where a_{ij}, b_i, c_j are notations of numbers.

Dependencies are expressed linearly with respect to the set of variables $\{x_1, x_2, \dots, x_n\}$ used as arguments of functions. For integer linear programming problems, in addition, a requirement is introduced for the integer value of n_1 variables on the entire set $(n_1 = n)$ or on its part $(n_1 < n)$,

$$x_j \in \mathbb{Z} \quad by \quad j = 1, 2, \dots, n_1; \quad n_1 \leq n. \quad (4)$$

In most real problems the number of subsets of elements forming the search area of the optimum is very large. Then the construction of a combinatorial configuration by iterating over elements is associated with insurmountable difficulties. But still, methods of integer linear programming are applicable to solving some problems, for example, in tasks to determine the optimal characteristics of production operations. In particular, an example is the solution of tasks to determine the minimum and maximum capacity of a production operation, considered as a subset of technological operations, when synchronizing work according to the production time.

Heuristic methods

The purpose of heuristics is to establish general patterns in human behavior when solving various kinds of problems, regardless of their content. The value is represented by those human thought operations that prove useful in the process of solving a problem [12].

Heuristic methods solve the problems of balancing work in production lines.

According to the method of ranked positional weights (authors W. Helgeson and D. Birnie) [13], a precedence matrix is preliminarily constructed. The order of the matrix $\|p_{xy}\|$, which is square, is set by the number of n technological operations $(x, y = 1, 2, \dots, n)$ with which the garment model is made. Row indexes, as well as column indexes, correspond to the ordinal numbers of technological operations from the sequence of manufacture of the product.

The precedence matrix is filled in the form of a triangle by elements located not below the main diagonal. Each of these elements carries one bit of information. The values of the alternatives are indicated depending on the locations and relationships of operations on the graph of the technological process for manufacturing the product model. In particular, the presence or absence of a connection between operations is established based on the definition of the term “simple chain” in graph theory. A chain represents a route composed of distinguishable edges. In a simple chain, there are no identical vertices on the graph [14].

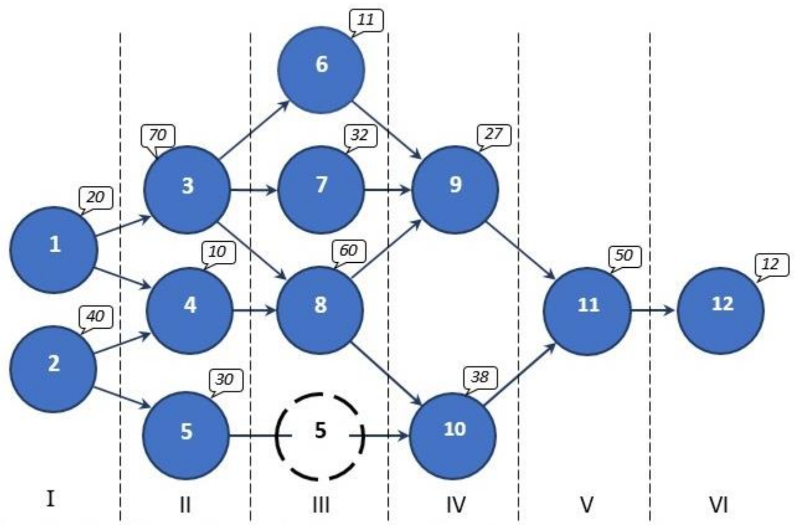


Fig. 3

Any (x-th) technological operation from the sequence has a certain positional weight. This fact is noted by the unit value of the element located on the main diagonal of the matrix. Each element p_{xy} located in the matrix to the right $(x < y)$ is assigned one if the x-th technological operation precedes the y-th operation on the path in the process graph. This unit value records the fact of increasing the positional weight of the x-th operation. Otherwise, as in the absence of a connection between a pair of operations, zero is shown in the current element of the matrix.

$$\begin{cases} y = x & \rightarrow \quad p_{xy} = 1; \\ y > x & \rightarrow \quad p_{xy} = \begin{cases} 1, & \text{if } x \rightarrow y; \\ 0, & \text{in other cases;} \end{cases} \\ y < x & \rightarrow \quad p_{xy} = \emptyset. \end{cases} \tag{5}$$

Then, following the rows of the precedence matrix, the positional weight of each technological operation is calculated using the formula

$$W_x = \sum_{y=x}^{n} p_{xy} t_y, \tag{6}$$

where t_y is the cost of time on performing the technological operation, which is identified by the index y by the number from the sequence.

According to the results of calculations, technological operations are ranked in the non-increasing order of positional weights /Figure 4, a)/.

The process elements are completed in the direction of increasing the rank on the condition that the duration of the production operation does not exceed the production time. It is possible to obtain an alternative option of completing when using inversion weights of technological operations.

	1	2	3	4	5	6	7	8	9	10	11	12
1	1	0	1	1	0	1	1	1	1	1	1	1
2		1	0	1	1	0	0	1	1	1	1	1
3			1	0	0	1	1	1	1	1	1	1
4				1	0	0	0	1	1	1	1	1
5					1	0	0	0	0	1	1	1
6						1	0	0	1	0	1	1
7							1	0	1	0	1	1
8								1	1	1	1	1
9									1	0	1	1
10										1	1	1
11											1	1
12												1

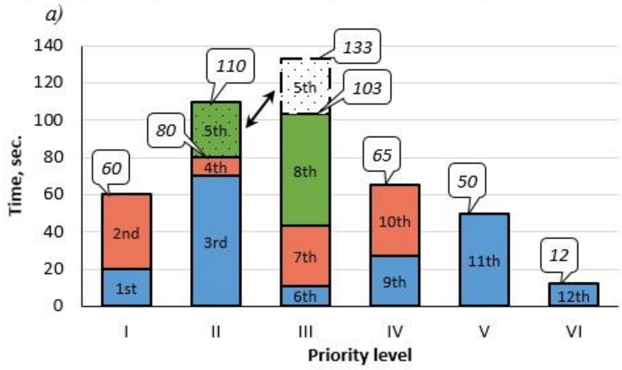
→

Operation number	Positional weight, sec.	Time, sec.	Immediate predecessors
1	330	20	-
3	300	70	1
2	267	40	-
4	197	10	1, 2
8	187	60	3, 4
5	130	30	2
7	121	32	3
6	100	11	3
10	100	38	5, 8
9	89	27	6, 7, 8
11	62	50	9, 10
12	12	12	11

a)

Operation number, sec.	Time, sec.	Immediate predecessors
3	70	1
8	60	3, 4
11	50	9, 10
2	40	-
10	38	5, 8
7	32	3
5	30	2
9	27	6, 7, 8
1	20	-
12	12	11
6	11	3
4	10	1, 2

b)



c)

Fig. 4

Another, although close in essence, is the heuristic method, which is implemented by the largest candidate rule (authors C. Moody and H. Young) [15]. Preliminarily, the operations that make up the technological sequence are listed in a list in the direction of decreasing parameters of the time cost. For each operation, with the exception of the initial ones, the immediate predecessors are additionally indicated /Figure 4, b)/. Then, from the most time-consuming elements in the ordered list, an operation is selected that is acceptable for combining according to the priority of execution in the technological process. When selecting a candidate for inclusion in a production operation, the following restriction is also observed. The sum of time cost $\mathfrak{T}_i$ on operations assigned to the i-th workstation should not exceed the value τ of the production time. The production operation is considered completed according to the condition $(\tau - \mathfrak{T}_i) \rightarrow min$.

However, in some situations, the appointment of a specific candidate seems to be a difficult decision. Difficulties arise when the most time-consuming operation, considered as the largest candidate at the current stage, by the logic of the flow of the technological process should be performed much later. In such situations, selection and decision making may contradict the fundamental rule of the method.

The heuristic method of M. Kilbridge and L. Wester [16] does not cause such difficulties in solving the problem. According to the information from the graph of the technological process of manufacturing the product model, a priority diagram is constructed. Each column, as an element of a diagram with accumulated data, displays the amount of time spent on technological operations located in the graph at the same level of the hierarchy. The alternation of columns is set strictly according to the priority of performing operations in the technological process /Figure 4, c)/.

The completing of operations is carried out sequentially, according to the priority diagram. At each level, starting from the first, the ratio of the amount of time spent (by column) with the production time is considered. When comparing, the goal is to combine this group of technological operations, in full or in part, into one production operation. By moving of one or more process operations, which, according to the process graph, can be performed on two or more levels of the hierarchy, it is possible to redistribute the data between the corresponding columns of the diagram. For example, the 5-th operation can be performed at both the II and III levels /see Figures 3 and 4, d)/. Similarly to the previous heuristic methods, the time spent on performing a production operation is brought closer to the production time, but without exceeding its value.

Heuristic methods are often considered in opposition to formal methods of solving problems. Unlike algorithmic prescriptions, heuristic prescriptions form the strategy and tactics of finding a solution. In a situation of uncertainty, unclear, randomness, ambiguity of the phenomenon, researchers bring new information to the search for a solution to the problem. Thus, heuristic methods purposefully limit the range of solutions to the problem.

Main results

To improve the mathematical, methodological and software subsystem in the development of the division of labor, the author proposed a different, two-stage algorithm for the formation of production operations of the production line.

The completion of operations should be carried out in separate parts of the technological process, each of which is aimed at manufacturing a certain section of the product design (the requirement of item 2 in section 2). The partition of the technological process into parts ensures the continuity of the production line structure when changing of the manufacturing object. As a consequence, this action contributes to the stability of the detailed specialization for groups of performers [17]. Partitioning also leads to a very significant reduction in the dimension of the combinatorial problem being solved.

At the first stage, according to the selected part of the technological process, the computer will automatically generate a subset of acceptable solutions for the production operation. The subset is formed by combinatorial objects are combinations of technological operations, initially partially ordered by the indicator of time spent. The acceptability of the obtained solutions is justified by quantitative indicators: consistency of time spent with the production time of the production line, as well as compliance with the criterion of minimizing the multiplicity of execution (according to the requirements outlined in items 1, 6). Based on the dichotomy method using the cut-plane method [11], the search for acceptable solutions is carried out here on the set of all combinations of technological operations in the selected part of the process.

The algorithm for solving the search problem is described in the article [18], and the possibility of processing information by means of a personal computer is confirmed by the certificate [19].

Acceptable solutions are displayed in lists consisting of records of combined technological operations. It is recommended to split a subset of acceptable solutions into blocks of up to six (or up to eight) combinations for symmetrical arrangement of information on the user interface. The specified number corresponds to the "magic number seven plus or minus two" [20].

Thus, the technologist has an opportunity to choose the production operation of the optimal structure.

At the second stage of solving the problem, it is proposed to use an analytic hierarchy process [21] on the decision-making theory. Qualitative indicators for attributive features are subject to consideration: the connectivity of technological operations in combination [22], specialty and complexity of execution (requirements of items 3-5), between which priority relations are established. The selection is carried out sequentially according to a hierarchical scheme. In each block, the best solution is selected by paired comparisons of acceptable solutions of the production operation, sending it to the next level of the hierarchy. At the last level of the hierarchy of the selection procedure, the optimal solution of the production operation being formed will be located. The quality of the decision being made at the same time increases explicitly.

Conclusion

A finite countable set of technological operations forms the process of manufacturing of a garment model. The implementation of the procedure of completing technological operations is presented as solving the problem of searching for a production operation that meets the specified requirements.

By revealing the essence of various integer programming methods and heuristics methods, the possibility of their application in the applied aspect is set forth, namely, in the development of the division of labor for the in-line production of garments.

Based on the presented material, an algorithm for searching a production operation of the optimal structure is proposed. The two-stage implementation of the search algorithm consists in the application of a combinatorial approach from the area of applied mathematics and decision-making theory.

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