Arrangement of equipment at production site of multi-product production using heuristic algorithm

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Abstract. This article considers the task finding of the optimum equipment arrangement on the production site. Naturally, even earlier, before the development of the concept of lean manufacturing, the designers of machine-building enterprises faced the task of minimizing transportation costs. However, the techniques used in the past are usually focused on mass production, not lean, and therefore cannot be correctly used in the design of modern production systems. In addition, such methods, often developed several decades ago, are based on a broad regulatory framework and accumulated experience in designing enterprises. Still, they are not designed to use computer technology to find solutions to optimization problems typical for production design. As a result, today, the task of creating methods for designing enterprises, taking into account the specifics of lean production and involving the use of computers to solve optimization problems of designing machine-building production, is relevant. Flexible and rigid settlement models of the solution of a task are described, and the shortcomings and advantages of both models are specified. The algorithm of the solution of a task when using a flexible model is offered. This algorithm is constructed on a synthesis of a heuristic algorithm of imitation of annealing with linear programming methods.

1 Introduction

Currently, one of the most important tasks of machine-building production is to ensure the required quality of products with a minimum cost of manufacture. However, when organizing production, not enough attention is paid to issues that are not directly related to quality assurance but seriously affect such an indicator as the cost of production of products. An example of such a question is the problem of placing equipment at production sites. Two enterprises can produce the same products using identical equipment and technology; however, due to the rational arrangement of machines at one of the enterprises, the costs of transporting blanks and parts may be significantly lower. This will affect the cost of production and will allow you to set a lower price for the products, ultimately making it more competitive compared to the products of another enterprise. However, it seems that the production technology is the same at both enterprises [1-4].

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Often, when solving the problem of equipment placement, it is assumed that there are already fixed positions for equipment placement, and it is only necessary to indicate which position which machine needs to be placed. Thus, estimating a finite number of arrangements and choosing the best one is necessary [5-7]. The evaluation criterion is usually the value of the capacity of the cargo flow, calculated by the formula:

$$C = \sum_{i=1}^{n} \sum_{ab=1}^{w} Q_i l_{abi} \text{ , } t \cdot m/year \qquad (1)$$

where n is the number of items moved per year (or to another unit of time); w is the number of operations in the i production process of manufacturing the product; Q_i is the value of cargo traffic $t/year$; l_{abi} is distance between a and b the working positions to which the movement takes place i name of the product, m.

To determine the capacity of the cargo flow, it is necessary to know the route of movement of workpieces between machines.

Fig. 1. Numbering order of items in production area

When arranging the equipment, it is assumed that special positions are already provided at the production site (Figure 1), on which the equipment should be located [8]. The location of these positions depends on the requirements of safety and ergonomics, on the ability to ensure the connection of the machine at each position to the power grid, pneumatic network, etc. Usually, one-sided and two-sided standard schemes of equipment placement with separate or combined input and output from the production site are used. Thus, it is necessary to specify which position to put which machine, that is, to find the optimal arrangement of technological equipment at the production site [9-11].

2 Methods

Currently, the so-called rigid calculation model is usually used for calculations. It assumes that initially, in the directive technological routes for manufacturing parts in multi-nomenclature production, the models of technological equipment on which operations should be performed are indicated. This means that by choosing a specific equipment layout, we can unambiguously determine which production routes the workpieces will move on the site. Knowing these routes, as well as the mass of workpieces and the production volume of parts, it is possible to calculate the capacity of the cargo flow corresponding to this arrangement.

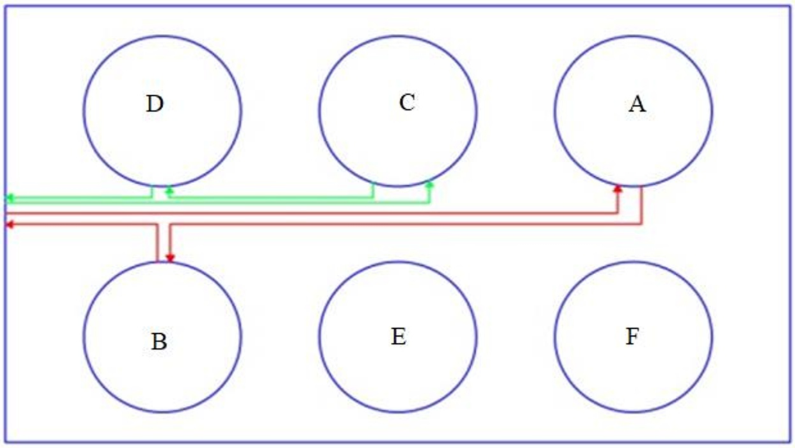

Fig. 2. Rigid computational model of problem of equipment placement

An example of such a model with 6 machines is shown in Figure 2. Initially, two technological routes (routes between machines) were set:

1) input – machine A – machine B – output
2) input – machine C – machine D – output.

Knowing them, for the arrangement shown in Figure 2, it is possible to uniquely determine the corresponding production routes (routes between positions):

1) input - position 5 - position 2 – output
2) input - position 3 - position 1 – output

When using a rigid computational model, the assignment problem turns out to be essentially identical to the quadratic assignment problem. Methods for solving the quadratic assignment problem have been developed and represent various heuristic algorithms (the particle swarm method, genetic algorithms, etc.).

The advantage of the rigid model is that it is relatively simple, and it is possible to use already developed heuristic algorithms to solve it. However, it also has significant drawbacks. In reality, when placing a large number of machines, usually many of them have similar technological capabilities. It is difficult to imagine that with the arrangement of 20 machines among them, there will be only one lathe, only one milling, etc. However, the rigid model assumes exactly this. She puts each technological operation into one machine model on which it can be performed, but in reality, the same operation can usually be performed on different equipment. Thus, the rigid model does not allow the interchangeability of machines. Finally, it should be noted that the rigid model assumes that the level of equipment loading is predetermined in advance since it is impossible to "transfer" the operation to another machine. This loading may turn out to be uneven, leading to a significant increase in costs. Due to the presence of such shortcomings, a different, flexible calculation model is proposed for the problem of equipment placement. Its fundamental difference is that for each operation, not one machine is specified, but a certain set of machines on which it can be performed. An example of such a model is shown in Figure 3:

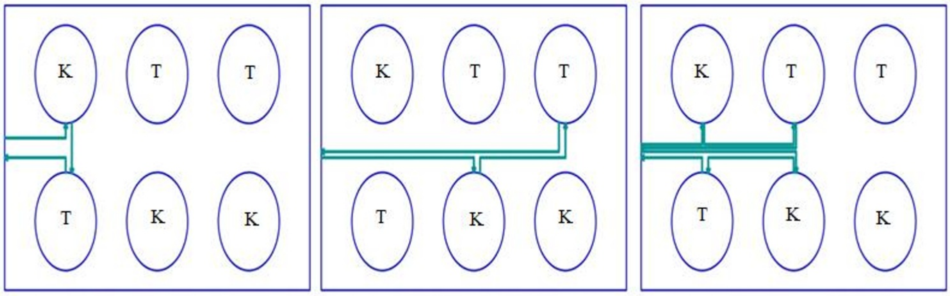

Fig. 3. Flexible calculation model of equipment placement problem

Here the machines are divided into groups K, T, and M. The technological route looks like this: Input - machine model K- machine model T – output

It is no longer possible to specify the production route unambiguously. It can be either a short left part in Figure 3 or a long one in the center in Figure 3; moreover, several production routes are possible for one technological one in Figure 3.

This model has many advantages. Firstly, it is closer to reality, that is, more adequate than a rigid model, since, in reality, the same operation can be performed on different equipment. In general, it can be noted that a rigid model is essentially just a special case of a flexible one. Secondly, since production routes are not rigidly defined in a flexible model, they can be controlled; that is, they can also be varied to ensure the best value of the objective function. This means moving from one-dimensional optimization to two-dimensional optimization. At the same time, you can set such a restriction as the uniformity of equipment loading.

However, the flexible model has an obvious drawback. Since it is impossible to calculate the capacity of cargo traffic for a specific arrangement (due to the uncertainty of production routes), then it is impossible to apply the usual heuristic algorithms used to solve the quadratic assignment problem "head-on", other, more complex and time-consuming calculation methods are needed. It should be noted, however, that this is a general rule – the more adequate a mathematical model is and the better it describes a real-life object, the more complex the mathematical apparatus it uses.

3 Results and Discussions

Nevertheless, an algorithm for solving it was developed for a flexible model. As mentioned above, we are dealing with a two-dimensional optimization problem in this case. To begin with, let's consider the case when the arrangement is unchanged and only the production routes vary (Figure 4). In this case, you can represent the production system as a graph. In the figure for the technological route Input - T - K- M - Output, the following graph is constructed: the graph's vertices are machines, and the arcs are possible routes for moving workpieces between them. Each arc can be matched with the number a, meaning how many blanks pass through it. To find the values of all these numbers a and means to determine all production routes.

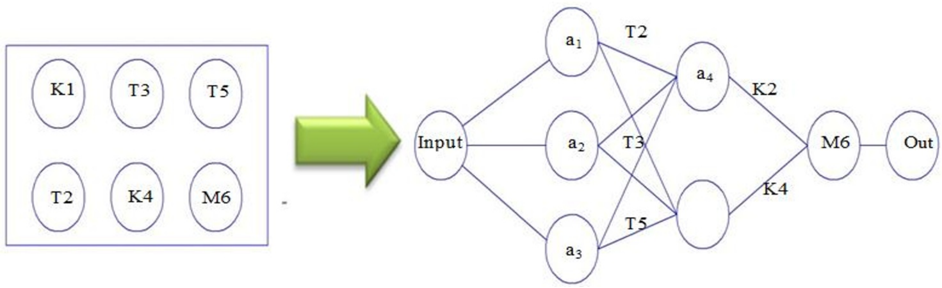

Fig. 4. Transformation of arrangement into graph

In graph theory, there are optimization methods based on linear programming. It can be proved that the problem of finding such numbers a that minimize the capacity of the cargo flow is just a linear programming problem. There are many algorithms for solving it, particularly the simplex method.

Applying the simplex method to the constructed graph, finding the minimum value of the cargo flow capacity for a specific arrangement is possible, thereby solving the problem of one-dimensional optimization. To move to two-dimensional optimization, one of the heuristic algorithms used to solve the quadratic assignment problem can already be applied. In this case, the annealing method was chosen.

Figure 5 shows a general algorithm for solving the problem of equipment placement using a flexible calculation model.

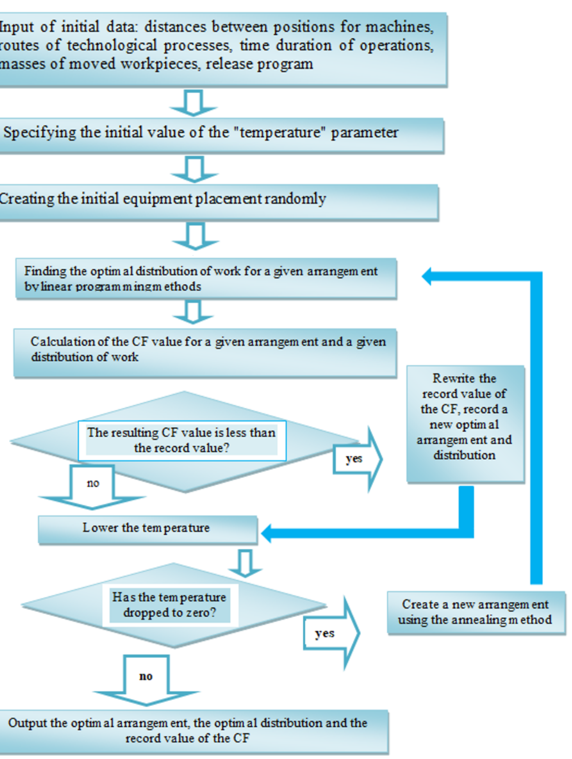

Fig. 5. General algorithm for finding optimal arrangement

As a result of solving the problem of equipment placement with a flexible model, it is possible to obtain the actual arrangement and production routes that ensure both uniform loading of equipment and a minimum value of cargo flow capacity. Thus, applying the proposed methodology for developing the optimal layout of machines at the machining site will reduce production costs and the cost of products.

4 Conclusions

As a result, it is impossible to unambiguously calculate the power of material flows in a flexible calculation model since they significantly depend on the distribution of operations between equipment. As a result, for the same arrangement of equipment, the capacity of the cargo flow, as well as the total mileage of the transport, can take on different values.

For each arrangement of equipment in a flexible calculation model, it is possible to compose two linear programming problems, solving which you can find the upper and lower estimates of the value of the load flow capacity in the production system. The lower estimate is recommended to be used as an optimization criterion when choosing a variant of equipment placement.

To enumerate options for equipment arrangements, it is proposed to use such a heuristic algorithm as the annealing method. At each iteration, it creates a new equipment arrangement, using the simplex method, calculates the value of the objective function for it, and then compares the arrangement with each other by this parameter.

To formulate a linear programming problem, a special graph called the graph of the technological process is used. On its basis, three types of constraints can be written, two of which are linear equalities, and one more, related to the need for uniform loading of equipment, is linear inequalities. In this case, the so-called flows along the edges of the graph act as variables, which means how many workpieces of one type or another are moved between the specified pair of machines.

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