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Scientific and methodological principles of restructuring the production process

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Batch production is typical for engineering enterprises connected with aeronautical engineering manufacturing. One of its main problems is the need to periodically change the production pattern which arises as a result of the instability of the products range, changes in volume of series, moral and physical wear of technological equipment. Such a change is carried out in the course of reconstruction and technical re-equipment in order to improve the efficiency of material flows.

The main characteristics of material flows are determined by a spatial component of a flexible manufacturing system pattern, set by the machine tools laying according to the organization of batch process. The bulk of the cost of final product manufacturing is associated with the arrangement of material flows. In order to reduce the total costs it is necessary to improve the pattern of production by establishing a technology-oriented machine tools laying. In this case, there is a need to develop scientific and methodological basis of restructuring the manufacturing process.

One of the most effective approaches to the design of machine building plants with a batch type of manufacturing is the use of program-target method based on the methodology of choosing the best technological solutions.

Modern methodology of batch technologies design is based on the system approach to the analysis and synthesis of the basic structure of the manufacturing processes, which allows to apply mathematical simulation.

The orientation of each of the sites on the end result leads to a substantial reduction of manufacturing costs, which significantly simplifies solving problems of division and coordination of labor on the principles of self-organization and self-regulation.

The proposed mathematical model of manufacturing costs optimization is designed in accordance with all the aforementioned principles. The problem being solved is multiobjective. That is why the mathematical model has several goal functions them requiring finding peak values and some of them requiring finding the bottom values.

The model can be applied in organizing the aeronautical engineering manufacturing, which requires effective remounting during the change of product range thus ensuring the required flexibility of manufacturing.

Keywords: production process, mass production, material flow, flexible manufacturing system, tentative placement, planning concept.

Introduction

Batch production is typical for engineering enterprises connected with aeronautical engineering manufacturing. The characteristic feature of aeronautical engineering manufacturing is the need to periodically change the production pattern due to the instability of products range, changes in volume of series, moral and physical wear of technological equipment.

Such a change is usually carried out in the course of reconstruction and technical re-equipment in order to raise the flexibility of production systems by optimizing material flows.

These changes in the organization of production level up the demands for flexibility both of production itself and of manufacturing sites. In this regard designing the sites is a quite independent task of an utmost importance. It should be considered that each site has specific characteristics, peculiar for it only. Hereby the success of solving production tasks considerably depends on the ability to minimize losses, organize a new production department, and optimize traffic flows.

1. Analysis of recent research and publications

As shown in the work [1], main characteristics of material flows are determined by spatial component of the flexible production system pattern, set by machine tools arrangement according to the group technological process. The bulk of the cost of final product manufacturing is associated with the arrangement of material flows. In order to reduce manufacturing costs it is necessary to improve the production pattern by applying technologically oriented equipment arrangement [2]. In this case, there arises a need to develop scientific and methodological basis of restructuring the production process.

One of the most effective approaches to the design of machine building plants with a batch type of production is the use of program-target method [3] based on the methodology of choosing the best technological solutions. There exist three principles of manufacturing sites and departments forming, which determine form of organization of production:

- linear. It is characterized by strictly determined sequence of performing technological process operations in every moment of time. This principle is most often implemented in the form of automatic transfer lines;
- subject. It is applied when there are significant product ranges, units with duplicate parts with raised demands regarding reliability, quality and operability;
- technological. It is characterized by performing homogenous operations of technological process with application of modular machines.

This is why when designing a new manufacturing site as well as when carrying out technical retooling and reconstruction of existing sites one of the main stages is creation of an optimal structure, which involves scientifically determined selection of its sites components

Modern methodology of batch technologies design is based on the system approach to the analysis and synthesis of the basic structure of the production processes, which allows to apply mathematical simulation.

2. Purpose of the study

The aim of the present work is to search the ways to reduce manufacturing costs when producing aeronautical engineering by optimizing material flows based on the developed mathematical models.

3. Experimental part

Mathematical simulation of the production process entails the need to solve a big amount of logistic problems, including optimization of the machinery composition for each of the manufacturing sites, optimization of details production start-up, calculating the production lead time during machining the batch of details, optimizing batch size, organization of just-in-time flow of cargo.

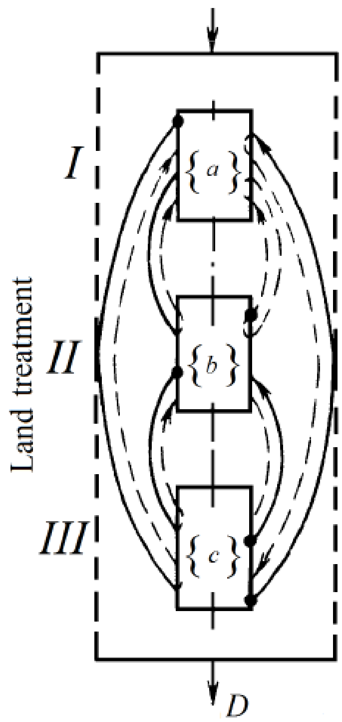
When using the system approach to analyse production systems and their components, the following subsystems can be distinguished: functional, organizational and element. They cannot be separated, since they represent three sides of a unified whole: relationship, unity and interaction.

The functional aspect of the flexible production system (workshop) and its subsystems (manufacturing sites) is determined by their technological purpose.

The element aspect is defined by the equipment in these sites.

The organizational aspect of the system establishes system pattern and objectives for each of its components and provides their achievement in accordance with the functional purpose.

When applying the traditional approach for determining the pattern and workshop and manufacturing sites management type, special emphasis is placed on breaking down the total volume of works into individual production operations on different parts and joints. The operations mentioned, especially under batch production conditions, are concentrated in the corresponding manufacturing sites formed on the functional principle. In this case the recommendations for the structure are made primarily on the basis of the production process bulk analysis and do not interfere with the interaction of operations. The structural scheme of the production process and the relations entailed is shown in Fig. 1.



I, *II*, *III* –manufacturing sites

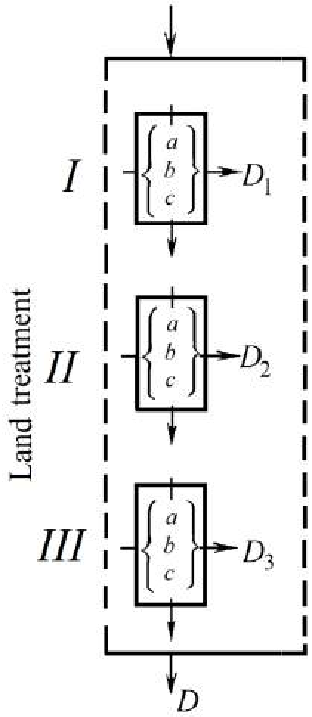
a, *b*, *c* -a group of machines of the same technological purpose

Fig. 1. Schematic structure of the production process, under the traditional approach

The diagram shows three manufacturing sites, each formed out of the machines of the same technological purpose. The machine tools mentioned can belong to the same technological group, but to different size groups. Such structure entails numerous direct and inverse external relations between sites intended for production the set *D* of parts.

Interrelationship, unity and efficiency of work of different manufacturing sites (subsystems) as well as of manufacturing workshop(system) as a whole are most crucial under the system approach. The choice of the manufacturing pattern as an integrated objet with qualitatively new characteristics is made in accordance with the results of the analysis and synthesis of its components.

Therefore, under the system approach the structure of production process is based on the use of detailed or subject specialization of the manufacturing sites and workshops. Fig. 2 shows the structural scheme of the production process under the system approach.



I, *II*, *I* manufacturing sites

a, *b*, *c* -a group of machines of the same technological purpose

Fig. 2. Structural scheme of the production process under the system approach

In this case, the site consists of three sections, built on the principle of detailed specialization, external vertical and internal horizontal relations being crossed. Here, the ultimate goals of the production system (site) are composed of the private goals of separate divisions (manufacturing sites), producing the finished parts subsets $\{D_1, D_2, D_3\} \subset D$.

The orientation of each of the sites on the end result leads to a substantial reduction of manufacturing costs, which significantly simplifies solving problems of division and coordination of lab or on the principles of self-organization and self-regulation.

Three basic structure-forming principles are realized when applying manufacturing management method based on the system approach:

- specialization of manufacturing workshops and their sites according to our goals entailing spatial concentration of production of homogeneous parts or assembly units;
- standardization of technological processes of homogeneous parts or assembly units manufacturing entailing a certain specialization and completeness of equipment and tools required;

– centralization of target program distribution among workshops and sites by operation administration for manufacturing of parts, necessary to reduce the manufacturing cycle and costs.

Selection of the way of manufacturing sites organization forming is carried out on the principle of cooperation. The index of cooperation is determined according to the formula:

$$X = \sum k_i / N, \tag{1}$$

where k_i– is the number of material connections which connect the *i* equipment with the rest of the equipment;

N – is the quantity of technological equipment in the organization department.

The areas of implementation of different ways of manufacturing sites organization forming are shown in the Fig. 3. Lines, limiting each area are built based on the relations presented in [3, 4].

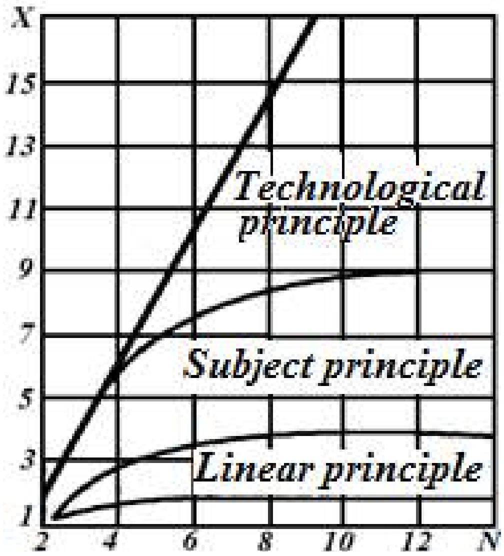


Fig. 3: Areas of implementation of different ways of manufacturing sites organization forming

The proposed mathematical model of manufacturing costs optimization is designed in accordance with all the aforementioned principles. The problem being solved is multi-objective, thus the mathematical model has several target functions.

Let's consider two goal functions

$$\begin{cases} S_1 = \sum_{j=1}^{n} k_j x_j \to \max, \\ S_2 = \sum_{j=1}^{n} m_j x_j \to \min, \end{cases} \tag{2}$$

with the following constraints

$$\sum_{j=1}^{n} \sum_{i=1}^{m} p_{ij} x_j \le q_i, \quad x_j \ge 0. \tag{3}$$

The problem is solved separately for each value, and the criteria S_{1max} (machine work load) иS_{2min} (cargo flow capacity) are determined. Then the constraints are formulated as following

$$\begin{cases} \sum_{j=1}^{n} k_j x_j + S_{1_{\max}} x_{n+1} \geq S_{1_{\max}} \\ \sum_{j=1}^{n} m_j x_j - S_{2_{\min}} x_{n+1} \geq S_{2_{\min}} \\ \sum_{j=1}^{n} p_{ij} x_j \leq q_i x_j \geq 0, \quad i = \overline{1,m} \quad j = \overline{1,n} \end{cases} \tag{4}$$

and the new goal function (manufacturing costs) is written as:

$$W = x_{n+1} \to \min. \tag{5}$$

The model can be applied in organizing the aeronautical engineering production, which requires effective remounting during the change of product range thus ensuring the required flexibility of production.

Away of selection of manufacturing sites forming is provided as an example. The main initial data are technological processes of details (articles) production shown in the Table 1.

Table 1

Manufacturing routes of details processing

Article (code)	Manufacturing route (machine №)	Traffic, t
A	3-6-1-4-5	4
Б	4-2-6-5	2
В	2-5-4	6
Г	1-3-2	3

Manufacturing routes of *A*, *B*, *C*, *D* details (articles) manufacturing are viewed consequently in order to determine material connections with each machine. This overview allows to determine that the № 1 machine has the following connections: in the manufacturing route of the A detail production – with the № 4 и № 6 machines, in the manufacturing route of the D detail production – with the № 3 machine. The connections determined this way are tabulated to the table 2. Duplicated connections are considered once.

Table 2

Results of calculations for selecting the manufacturing site forming principle according to the index of cooperation

Machine №	Material connection with other machines	Number of connections $-\sum k_i$	Number of machines – N, p.
1	6, 4, 3	3	1
2	4, 6, 5, 3	4	1
3	6, 1, 2	3	1
4	1, 5, 2	3	1
5	4, 6, 2	3	1
6	3, 1, 2, 5	4	1
Total		20	6

After having calculated the number of connections for each machine and summing them up for all the equipment items, we determine the index of cooperation according to the formula (1):

X = 20 / 6 = 3,33. According to the Fig. 3 according to the value of X and the number of machines N we determine the manufacturing site forming principle (in the example considered it is the subject principle).

For the achieved principle of manufacturing site structure we build the graph of material bonds between the material equipment (Fig. 4). Graph ribs reflect the value of traffic between the separate items of equipment. The construction of the matrix is considered when manufacturing site enter and exit coincide. In this case the number of interplant transport dead runs is reduced.

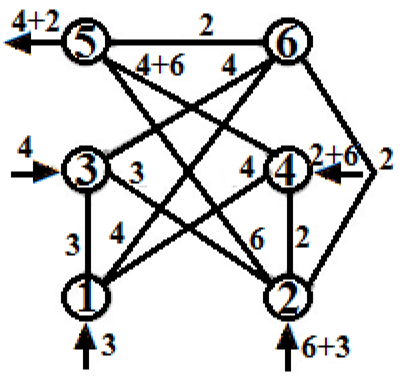


Fig. 4: Graph of material connections between technological equipment

Concentration of the machine groups processing similar list of details, carried out by optimizing the options of machines location according to the criteria of the traffic power minimum (S_{2min}). on the given stage the technique is applied – all the machines are nominally placed in one line. Total traffic power is calculated as the sum of products of raw stocks (m) on their relocations according to the following scheme. The raw stock is transferred to the first machine given it this sequence, involved in any operation of the technological process of the given detail production and follows through all the machines up to the last similar one. Geometrical sizes of the manufacturing equipment are not considered hereby and it is supposed that that the distance between the neighboring equipment items equals to the unit length. Thus optimization of the linear machine sequence leads to approximation of those of them on which the technologically similar details are manufactured. Moreover, machine groups form in the linear sequence, which are intended to manufacture the details of the defined assortment.

In order to solve the given problem Ant algorithms were selected, which are based on using the manifold of potential solutions and developed to solve the combinational organization problems, first and foremost of searching different ways on graphs. Algorithm operation time is in direct ratio to the number of equipment items. During its operation the following is carried out for each detail: the first and the last machine tool, involved in raw stock processing are determined, the last machine tool switched with the machine tools located between the end machines, but not the ones processing the given raw stock, the target function for achieved options is calculated, the options are compared with each other and with the initial linear sequence, the best option is selected and accepted as the initial for the following iteration.

The result of Ant algorithm solution is an optimal linear sequence of the machine tools arrangement and the traffic power corresponding to it.

Results and discussion

The form of the assembly-line production, type and functional capabilities of the transportation system, technological peculiarities of product manufacturing, also define the organizational structure of the warehouse system.

A prerequisite for creating a warehouse is the need to transform the parameters of inbound and outbound cargo flows. If the cargo flow in terms of assortment and intensity remains unchanged, then a warehouse is not necessary.

We propose synchronizing the production cycle to eliminate the need for warehousing. As a result, we will have minimal overhead costs and complete synchronization of the product manufacturing cycle.

Conclusions

The Ant algorithm body of mathematics is capable of satisfying all the demands, set by the modern manufacturing, since it represents the behavior of actual ants, whose ability to adapt to any conditions has been sharpened by the nature for centuries. Due to their simplicity, scalability and vibrancy Ant algorithms are reasonable to be implicated to solve the problems of forming technologically oriented structures of the serial manufacturing departments and optimizing the options of planning concepts.

Development of production processes optimization methods, conducted in our department of Theoretical Mechanics, Engineering and Robotic Systems at the National Aerospace University "Kharkiv Aviation Institute" is carried out to design flexible manufacturing systems for aeronautical industry.

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Науково-методичні засади реструктуризації виробничого процесу

Серійне виробництво є типовим для інженерних підприємств, що займаються виробництвом авіаційної техніки. Однією з його основних проблем є необхідність періодично змінювати схему виробництва, що виникає внаслідок нестабільності асортименту продукції, змін обсягів серій, морального та

фізичного зносу технологічного обладнання. Така зміна проводиться в ході реконструкції та технічного переоснащення з метою покращення ефективності матеріальних потоків.

Основні характеристики матеріальних потоків визначаються просторовою складовою схеми гнучких виробничих систем, встановленою за допомогою розміщення верстатів згідно з організацією серійного процесу. Більшість витрат на виготовлення кінцевої продукції пов'язана з організацією матеріальних потоків. Для зменшення загальних витрат необхідно покращити схему виробництва, встановивши технологічно орієнтоване розміщення верстатів. У цьому випадку є необхідність розробки науково-методологічних засад реструктуризації виробничого процесу.

Одним з найефективніших підходів до проектування машинобудівних заводів з серійним типом виробництва є використання програмно-цільового методу на основі методології вибору найкращих технологічних рішень.

Сучасна методологія проектування серійних технологій базується на системному підході до аналізу та синтезу основної структури виробничих процесів, що дозволяє застосовувати математичне моделювання.

Орієнтація кожного зі споруд на кінцевий результат призводить до значного зменшення витрат на виробництво, що значно спрощує вирішення проблем розділу та координації праці на принципах самоорганізації та саморегуляції. Запропонована математична модель оптимізації витрат на виробництво розроблена відповідно до всіх зазначених принципів. Вирішувана проблема має багатоцільовий характер. Тому математична модель має декілька цільових функцій, які потребують знаходження максимальних значень, і деякі з них потребують знаходження мінімальних значень.

Модель може бути застосована при організації виробництва авіаційної техніки, яке потребує ефективного переоснащення під час зміни асортименту продукції, забезпечуючи необхідну гнучкість виробництва.

Ключові слова: виробничий процес, серійне виробництво, матеріальний потік, гнучка виробнича система, орієнтовне розміщення, концепція планування.

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