Testing models of organizational and technological processes for machining based on the method of ant colonies

O V Chengar, V I Shevchenko and T A Kokodey
Sevastopol State University, St. Universitetskaya 33, Sevastopol, Russia
E-mail: tanya.kokodey@gmail.com

Abstract. This article presents testing results for the model of organizational and technological processes in a flexible production system using the instrumental capabilities of ant algorithms for operational production scheduling. As a result of computer experiments, we have determined that implementing the proposed model allows for increasing the average load coefficient for flexible production modules that results into transport unload, thereby solving the problem of equipment idle time. Also, based on the testing data of the proposed model using the ant colonies method applied during machining tools, such as solids of revolution, for a set production plan, the possibility of reducing the number of flexible manufacturing modules at a production site without reduction of output was considered.

1. Introduction

The process of improving the organizational structure of enterprise management enhances the value and expands the scope of information technology. The widespread introduction of computer technology has led to a new stage in the development of production management, characterized by a transition to decentralized management and the solution at the production site level of tasks such as operational planning and accounting [1].

The specifics of the organization of modern production is the use of flexible production systems (FPS), which allow you to switch from one type of product to another with minimal time and labor. The use of such systems is primarily associated with the use of multi-purpose complexes of technological means - flexible production modules (FPMs) equipped with numerically controlled machines (NCM), as well as automatic tool and workpiece change mechanisms. Such manufactures provide the production of a wide range of different types of products and have a high degree of flexibility. However, they are characterized by a complication of the management and planning process, especially when it concerns small-scale and medium-series multi-item production. The high cost of FPM and other automation equipment, combined with a constantly changing current production situation, make special demands on the process of FPM operations. Therefore, the tasks of optimizing the production schedule are put to the forefront in the process of managing FPS with the aim of reducing production costs and improving performance indicators of FPS with given restrictions on resources of various types.

The problems of developing methods and models of information technology for planning the loading of technological equipment in the machine-building industry have been investigated for a long time and do not lose their relevance at the present time [2]. Such information technologies allow you to build the most profitable (according to given criteria) work plans and optimal technological routes...
for processing parts of various types, as well as provide the ability to adjust the schedule taking into account the influence of various external and internal factors on the execution of the plan.

To date, considerable experience has been gained in solving discrete-type production planning problems [3], however, in general terms, this problem has not been solved.

The main tool for ensuring high efficiency of FPS work is modeling and optimal control. Creation of software systems for modeling and controlling the operation of FPS based on advanced computer technologies is an urgent scientific and technical task.

2. Modelling of the organizational and technological process in FPS based on the method of ant colonies

At the first stage, the main parameters were determined that characterize the object under study, performance criteria and task limitations for representing the model of the organizational and technological process in the form of a directed graph: \( G=(V,D,P) \), where \( V \) – many vertices (part processing positions); \( D \) – many graph arcs representing the transition time from one technological operation to another; \( P \) – matrix of transition rules, where each arc \((i,j)\in D\) is assigned a weight \( P_{ij} \). After that, a graphic-analytical model of the organizational and technological process for loading flexible production modules of the machining section was developed (Fig. 1) with the aim of further using the tool capabilities of ant algorithms to optimize operational-scheduling.

![Graphical model of the organizational and technological process](image)

**Figure 1.** Generalized graphical analytical model of the organizational and technological process of loading technological equipment of FPS.

The presented graphical analytical model provides for the distribution of equipment according to technological operations according to the parts production plan, and also allows you to vary its quantity, depending on its serviceability and planned preventive maintenance.

The initial vertex of the graph determines the beginning of the implementation of the production plan (according to the production program and production flow sheets of parts) is the starting point.
The remaining vertices of the graph are divided into levels, each of which corresponds to a separate technological operation \( O_{mn} \) (according to the technological map). Taking into account the warehouse and transport subsystems, the vertices corresponding to the warehouse operations for issuing blanks, receiving finished products and providing tools are also included in the graph-analytical model.

An array of ants is placed at the starting point of the graph-analytical model, the number of elements of which is equal to the number of technological machines involved in production, including transport units ("elite ants"). It should be noted that the population capacity of the ant colony directly depends on the current production situation (equipment breakdown, preventive maintenance, etc.) and, therefore, can be adjusted at any time. After that, the probability of transition of each of the ants to the peaks of level I is calculated by the formula (1).

\[
P_{ij} = \frac{K_{ij}}{\sum K_{ij}}, \quad \sum P_{ij} = 1
\]  
(1)

where \( K_{ij} \) – coefficient of transition factor (2)

\[
K_{ij} = \frac{T_{oij} + kf}{T_{sij}}
\]  
(2)

where \( T_{oij} \) – execution time for operation \( O_{ij} \) over a batch of i-type parts; 
\( kf \) – coefficient for possibility of transition (\( kf = 1 \));
\( T_{sij} \) – production time for a batch of i-type parts (4);

\[
T_{oij} = \sum_{j=1}^{n} T_{nij} + T_{vij} \ast n_{ij},
\]  
(3)

where \( T_{nij} \) – FPM setup time for operation \( O_{ij} \);
\( T_{vij} \) – operation time \( O_{ij} \) over i-type part;
\( n_{ij} \) – the number of di parts launched into processing (start-up lot)

\[
T_{sij} = k_{i} \ast dl
\]  
(4)

where \( k_{i} \) – number of working days to complete an order;
\( dl \) – the duration of the work shift, in hours

The time of the release of the FPM from the vertex is calculated taking into account the value of the maximum launch batch and the time parameters of the technological operations (5).

\[
T_{svij} = L_{ij} \ast T_{vij} + T_{nij} + T_{prij},
\]  
(5)

where \( L_{ij} \) – maximum allowable part start-up batch \( d_{i} \);
\( T_{prij} \) – Idle time of the FPM before executing the technological operation \( j \) on a batch of parts \( d_{i} \).

If transitions from the starting point are possible only to the vertices of the first level, then further transitions involve the connection of vertices of the same level and the presence of loops, which means the continuation of this technological operation with the next batch of launching parts without reconfiguring the FPM. The rules for further transitions are calculated taking into account the already completed part of the production plan for each FPM processing unit separately, and the loop transition has the highest priority (\( kf > 1 \)).

The possibility of transition between vertices of different levels is zero if there are no parts that have passed the previous operation (\( kf = 0 \)). After the passage of all FPMs, the initial and subsequent transition rules are adjusted in accordance with the time parameters of the production plan.

3. Characteristics of the object of experimental research

For conducting experimental studies and testing the developed methods and models for planning the loading of technological equipment, the organizational and technological process of the technological sites for machining parts, such as solids of rotation, was chosen as an object. This production site is designed for processing couplings, washers, discs, nipples of locks, and rings. It is of a medium-sized
production type. On this site, for each product, an average of 3 to 5 operations is performed depending on its type and up to 12 items can be processed.

In fig. 2 is a structural diagram of a machining section. It consists of: six FPM processing units, a transport module, and an automated warehouse.

A machine room with a control computer complex provides operational management of a flexible production system. Computers perform direct numerical control of machine groups; management of systems that provide each workplace with blanks, tools, equipment, production planning and scheduling.

FPS has a linear single-row layout, i.e. it is built on the basis of NCM machines of the same model and the same technological purpose, placed in one row. With this layout of the site, all flexible production modules interact with the automated warehouse through a transport module located in parallel.

![Figure 2. The structural diagram of the production site of machining parts such as solids of revolution.](image)

Six FPMs are located along the span of the workshop building in one row. Each such module is equipped with a NCM system and is serviced by an outboard robot. In the capture range of parts, a machine-mounted robotic arm allows loading and unloading in automatic mode. An industrial robot is installed on the machine, forming a complex with it (the machine is an industrial robot), which is a flexible production module designed for continuous operation without operator intervention. The robot and the machine are controlled by an autonomous control system. Processing of parts on the FPM is carried out mainly by a cutting tool equipped with carbide non-grindable inserts.

The automated transport and storage system is portrayed on the diagram in the form of a line located along the site. It is designed for multi-operation storage, transportation and distribution of workpieces, finished parts, tools and accessories during parallel work with FPM and includes: automated transport and automated warehouse. Automated transport consists of a vehicle and a transport robot. The speed of movement of such a transport module is 0.5 m / s. An automated warehouse consists of areas for receiving and issuing objects, a section for their placement in transport and storage containers, and a storage area in the form of two cage racks with cantilevered supports for
goods. It is served by a stacker bridge crane with a lifting capacity of up to 1 ton with a horizontal speed of 15 m / min and a vertical speed of 13.5 m / min.

Billets and finished products come in a special container in the acceptance section. Near the automated warehouse there is a tool preparation section from which the sets in a special container are loaded into the transport module. The production process at this site usually employs 10 people.

Taking into account the data on the technological process of processing parts, the structure and technical characteristics of the considered FPS, as well as the production program for a month, a series of experiments was conducted to determine the adequacy of the developed methods and models. The purpose of the research is to obtain estimates of the temporal parameters of technological processes for processing parts and equipment maintenance in FPS, characteristics of device loading, etc. for the synthesis of the production schedule. The simulation results are significantly influenced by the values of a number of variable technological and organizational parameters and various strategies for intra-workshop production planning.

4. Testing the model of organizational and technological processes of machining

4.1. Checking the adequacy of the process equipment loading process model

To assess the adequacy of the model in production, information about the work performed in the previous months of planning was selected in order to compare the schedules obtained experimentally on the basis of the developed object model. The comparison was carried out for several months, while the following factors were evaluated:

- compliance with the model of cause-effect relationships of work and technological operations;
- obtaining the planned indicators of the compiled schedule (loading, downtime and readjustment of equipment; meeting the deadlines).

Since the production site under consideration was built on the basis of NCM machines of the same technological purpose, the analysis confirmed the relative uniformity of loading and downtime of the FPM. The readjustment losses are quite small and make up about 3.5%, and downtimes make up about 25% of the total simulation time.

The main reasons for the downtime of the FPM:

- lack of blanks (7%);
- lack of tool (5%);
- waiting for service by the transport module (10%);
- equipment breakdown (2%);
- other reasons (1%).

Thus, the main possibility of “consolidating” the schedule is to reduce the downtime of technological equipment for the first three of the above reasons. Also, an analysis of the functioning of automated transport showed that its load factor, close to 1, significantly exceeds the load of the FPM, because FPS is served by one transport, which moves the workpieces and tools in two directions. Therefore, the transport system has always been the “bottleneck” of the FPS and the urgent question is to unload the transport, thereby increasing the load factor of the FPS.

Using the developed software and tools, the proposed model was tuned for the FPS parameters described above. Evaluation of the results showed compliance with cause and effect relationships in all experiments and a significant improvement in key parameters of the production schedule.

In table 5.5. the averaged values of the performance indicators of the production program of both the FPM and the automated transport are placed before and after the process of loading the technological equipment.
Table 1. The average values of the parameters of the production program before and after the introduction of the model of the process of loading equipment

| Processing type | Before model implementation | After the implementation of the model |
|-----------------|-----------------------------|----------------------------------------|
| Mean Value      |                             |                                        |
| Proportion of adjustments | 0,040                      | 0,028                                  |
| Proportion of idle time      | 0,283                      | 0,186                                  |
| Coefficient of loading       | 0,690                      | 0,801                                  |

Thus, a comparison of the actual data on the implementation of the production program collected at the enterprise with that obtained during the implementation of the model of the equipment loading process allows us to conclude that it is adequate (the discrepancy between the results does not exceed 5%).

It was experimentally established that due to the introduction of the proposed model of the loading process, the average loading factors of the FPS equipment change as follows: the FPM will increase to 0.801, and the transport will decrease to 0.940. Fig. 3 shows a comparative diagram of the loading of technological equipment, which confirms the effectiveness of the proposed model of the process of loading equipment.

Figure 3. Diagram of averaged values of loading parameters, idle time and adjustments of technological equipment before and after the introduction of a model of the process of loading technological equipment.

4.2. Experimental studies of the model based on the ant colony method

It is rational to consider the following as criteria for the effectiveness of the functioning of FPS:

- average load factor of technological equipment (Kzsr→max), as this criterion includes two others: the duration of the production cycle (Tc→min) and the idle time of technological equipment (Tn→min);
- "just in time" – avoiding violation of the deadlines for the manufacture of the order (Ts → \min), because this criterion is the most relevant in a real production environment.

By setting recommended modeling parameters for various performance criteria (Kzsr → \max и Ts → \min) it is necessary to study the number of iterations (populations of ants) n_t to obtain a suboptimal schedule for loading technological equipment. Moreover, experimental studies were carried out taking into account various values n_k for a different amount of process equipment ready for work (taking into account breakdowns of the FPM, scheduled preventive repairs and simply reducing the number of process equipment in order to save resources). We have considered the situation with the failure of one (n_k = 6), and then two FPMs (n_k = 5).

The results of the experiments are shown in figures 4 and 5, respectively.

![Figure 4](image1.png)

**Figure 4.** The dependence of the average load factor of technological equipment (Kzsr) by the number of ants in the population n_t with a different number of artificial ants n_k.

It is obvious that the maximum value of the average load factor of technological equipment should strive to Kz_{\max}=1, and the minimum value for the violation of the deadlines of the order - to Kz_{sr_{\min}}=0. Therefore, to verify the effectiveness of the obtained solutions, it is necessary to compare the obtained results with the optimal values.

![Figure 5](image2.png)

**Figure 5.** Dependence of the time of violation of the deadlines of the order (Ts) on the number of ants n_t with a different number of artificial ants n_k.

An analysis of the dependence of the average coefficient of loading the technological equipment (Kzsr) from the quantity of the population of ants the quantity of iterations for the “directioned” ant algorithm (Kzsr → \max) showed that, for a different number of iterations and the number of technological equipment, an approximation to the optimal value occurs (Kz_{\max}=1).
So for \( n_t = 7 \), when the number of \( n_t \) populations grows above 100, the value of \( K_{zsr} \) takes its best value (\( K_{zsr} = 0.9 \)) and practically does not change. Similarly, for \( n_t = 6 \), when the number of \( n_t \) populations grows above 80, the value of \( K_{zsr} \) also assumes its best value (\( K_{zsr} = 0.91 \)) and practically does not change.

Based on this, it can be concluded that it is possible to reduce the number of FPMs at the production site by one unit without losing the volume of output, which also meets one of the efficiency criteria: minimizing the amount of FPMs used (\( L \rightarrow \min \)).

An analysis of the results showed that there is a relationship between the number of populations and the number of ants in each population. So, with an increase in the number of ants, the number of iterations increases, and, accordingly, the time for finding a solution, which is critical in real production conditions. Therefore, for this example, it is recommended to choose as rational parameters for \( n_k = 7 \) \( n_t = 110 \), and during \( n_k = 6 \) \( n_t = 80 \).

5. Conclusion
This article presents the results of testing the model of the organizational and technological process in FPS using the tool capabilities of ant algorithms for operational calendar planning.

The presented model provides for the distribution of equipment according to technological operations in accordance with the production plan, and also allows you to vary the number of FPMs, depending on their serviceability and planned preventive maintenance. Also, the developed algorithm simulates the functioning of transport equipment taking into account warehouse operations, which is especially important in a real production situation, because, as a rule, transport is the “busiest” link in the production process.

As a result of a computer experiment, it was found that due to the introduction of the proposed model, the average FPM load factors increase to 0.801, and transport decreased to 0.940.

Comparison of actual data on the implementation of the production program collected at the enterprise with that obtained using the process equipment loading model allows us to conclude that it is adequate (the discrepancy between the results does not exceed 5%).

By setting the recommended parameters of the control coefficients \( r_0, \alpha \) and \( \beta \), for various criterions of efficiency (\( K_{zsr} \rightarrow \max \) and \( T_{sr} \rightarrow \min \)) we studied such important parameters of the model as the number of iterations (populations of ants) \( n_t \) to obtain a suboptimal schedule for loading technological equipment.

Based on the data obtained during testing in the conditions of the machine shop, such as solids of revolution, for the proposed production program, it was proposed to consider the possibility of reducing the number of FPMs at the production site by one unit without losing any production volume.

Analyzing the results obtained, it can be argued that a computer experiment confirmed the possibility of using the proposed method of ant colonies for simulation of the organizational and technological process in FPS.

References
[1] Sachko N S 2005 Organization and Operational Management of Engineering Production (Minsk: New Knowledge) p 635
[2] Malyarenko I 2006 Planning and Optimization Vol 27 (Corporate systems) pp 29-32.
[3] Chengan O V, Skobtsov Yu O and Secirin O I 2010 Analysis of methods, models, algorithms for operational planning of the robot for virobnic dilyanka, Science and practice of the Donetsk National Technical University, Series: “The numeral technology and automation” 18 (169) 133-40
[4] Chengan O V and Savkova E O 2011 Graph-analytical model of loading flexible production modules of an automated technological section of a machine-building enterprise, Bulletin of the East Ukrainian National University named after Vladimir Dahl, Scientific journal 13 (167) 239-45
[5] Chengan O V 2012 The object model of the production process for compiling a suboptimal
schedule of the automated technological section Science and Technology of Donetsk National Technical University, Series: “The numeral technology and automation” 22 (200) 56-62

[6] Dorigo M 2001 Swarm Intelligence, Ant Algorithms and Ant Colony Optimization Reader for CEU Summer University Course «Complex System» (Budapest: Central European University) pp 1–38

[7] Chengar O V 2013 Development of a “directed” ant algorithm for optimizing the production schedule Bulletin of the Kherson National Technical University 1(46) 212-7

[8] Chengar O V 2013 Simulation algorithm for modeling organizational and technological processes in a flexible production system Bulletin of the Southern Federal University. Technical Sciences Publisher: Technological Institute of the Federal State Educational Establishment of Higher Professional Education "Southern Federal University" 4 128-34

[9] Skobtsov Yu A and Speransky D V 2015 Evolutionary Computing: A Training Manual (Moscow: National Open University "INTUIT") p 331

[10] Skobtsov Yu A, Sekirin A I, Zemlyanskaya S Yu, Chengar O V and Skobtsov V Yu 2015 Object-oriented modeling and evolutionary algorithms Proceedings of the 7th All-Russian Scientific and Practical Conference “Simulation Modeling” (IMMOD-2015) Vol 2 (Moscow: IPU RAS) pp 338-43