Synthesis Production Schedules Based on Ant Colony Optimization Method

Yuriy Skobtsov[1], Olga Chengar[2], Vadim Skobtsov[3](✉),
and Alexander N. Pavlov[4,5]

[1] St. Petersburg State National Research Polytechnic University,
St. Petersburg, Russia
ya_skobtsov@list.ru
[2] Federal Public Autonomous Educational Institution of the Higher Education
Sevastopol State University, Sevastopol, Russian Federation
OVChengar@sevsu.ru
[3] United Institute of Informatics Problems of National Academy
of Sciences of Belarus, Minsk, Belarus
vasko_vasko@mail.ru
[4] Saint Petersburg National Research University of Information Technologies,
Mechanics and Optics (ITMO), St. Petersburg, Russia
Pavlov62@list.ru
[5] Mozhaisky Military Space Academy, St. Petersburg, Russia

Abstract. It is proposed to use ant algorithms together with the object-oriented simulation models. To optimize the functioning of the automated technological complex machining together with a modified ant algorithm it is designed object model, which allows to calculate the fitness function and evaluate potential solutions. The transition and calculation of the concentration for synthetic pheromone rules are determined for supposed directed ant algorithms.

Keywords: Natural computing · Ant colony algorithm · Production schedules component · Flexible manufacturing systems

1 Introduction

The process of improving the organizational structure of company management strengthens and extends the value of the scope of information technology. The feature of the organization of modern production is the using of flexible manufacturing systems (FMS), allowing to switch from one product to another with minimal time and labor. The use of such systems involves the complex multi-technology tools - flexible production modules (FPM) [1]. They are characterized by complication management and planning process, especially in the small-scale and medium series of multiproduct manufacturing. Therefore, the problem of optimizing production schedules in order to improve performance FMS works always come to the fore in the FMS control process.

To date, we have considerable experience in discrete production planning, which is represented in papers [1, 2]. However, with increasing degree of automation of the industrial enterprises is increasing the need for more powerful systems, short-term

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production planning, especially intra shop planning to compile a detailed schedule download process equipment in a real production environment. This complicates the application of well-known classical methods that explicitly or implicitly assume a variety of facilitation in setting planning problems. An effective means for solving such problems is to use the methods of «Natural computing», which allows to design sub-optimal solutions to problems of real work situations in a short time. Ant algorithms are prominent representative of "natural computing" because are based on behavioral patterns ants as a population of potential solutions and solutions adapted for combinatorial optimization problems, primarily to search optimal paths at graphs [2]. Thus, it can be argued that the ant colony optimization (ACO) method, performing well for solving combinatorial optimization problems, is one of most perspective for planning process of FMS equipment.

2 Statement of the Research Problem

The problem of synthesis for FMS schedules is to allow for an industrial workshop with a given technological equipment to make the procedure for processing details, given the limitations of real work situations in a short time. The model of this process is conveniently represented as a graph, the construction of which is equivalent to the definition of the numbers t_{ij} – time moments of start process for technological operation O_{ij}. The set of numbers $\{t_{ij}\}$ $(i = 1, 2, \ldots n; j = 1, 2, \ldots, m_i)$, that satisfies the formulated conditions, called the schedule of FMS operation, or a graph model $G(i)$.

In addition to the corresponding representation in the form of a graph of the boot process of technological equipment, we must follow the following sequence of actions FMS for the adaptation of ACO method to solve this problem.

1. Design of graph representation for the potential solutions.
2. Determination correction rules for the pheromone concentration that define a positive feedback process.
3. Development of heuristics to determine the arc selection during path design in the graph.
4. Definition of the heuristic ant behavior in the construction solutions in the form of the transition probabilities.
5. Determination of the feasibility of a potential solutions by means of verification procedures, taking into account the problem of limitations.
6. Check the adequacy of the model.

In [3] the problem of the development and construction of graphical-analytical model is investigated in accordance with the selected optimization criterion (1).

$$G = (V, D, P), \tag{1}$$

where V - the set of vertices, each of which represents the position of the processing components; D - set of arcs representing the transition from one process step to another; P – matrix of transfer rules where each arc $(i, j) \in D$ attributed weight P_{ij}.

Based on the developed graphic-analytical model it is proposed the algorithm of ant population evolution for the simulation of the production process in the FMS [3]. This algorithm takes into account the various external influences, such as breaking FMP, planned maintenance works, commissioning of equipment, delays in the supply of materials, etc., as well as the availability of GPS vehicle and warehouse equipment. So when scheduling simulated start and end for each technological operation of the selected type for process equipment.

3 Development of “Directional” Ant Algorithm

The paper goal is design of the “directional” ant algorithm for optimizing production schedules in FMS, which can easily be adapted to the given limitations, taking into account additional problem conditions.

The analysis of existing research in the field of «Natural computing» [4] found that a promising method of solving for complex combinatorial optimization problems is to use ACO method. The advantage of this algorithm for this problem is that this method does not require the construction of a structural model of the production workshop itself, and allows simple modifications that can solve optimization problems of this class with high effectiveness.

Based on the developed graphic-analytical model representations for boot process of the technological equipment FMS [1] the new modification of ant algorithm was developed - “directional” ant algorithm [4, 5]. This modification differs from its analogues by the following features:

1. The proposed method of calculating the probabilities for artificial ant transition at node of the graphical-analytical model based on the analysis of the current situation of production;
2. It is uniquely determined the necessary number of artificial ants in each population, including “elite” individuals, which depends on the repair and readiness for operation of process equipment in the production area;
3. It is defined the available node set for artificial ants to visit next nodes, which contains the top list nodes - the candidates for their visit, and for all ants, besides “elite” ants, the list of forbidden transitions (tabu list) is generated;
4. It is suggested a global rule changes for pheromone concentration on the graph arcs, taking into account not “best”, as is commonly believed, [5] but the “worst” paths in the population of artificial ants with a view to improve its during the next iteration;
5. Heuristic information is based on “direct proportional” rule for the transition between nodes.

Let us consider the main features of the proposed method.

1. As previously mentioned for artificial ant the next node selection is not random and made taking into account the current production situation and dynamically changing environment and heuristic information collected to this moment.
   The transition probability of the k-th ant to node O_{ij} determined by the relation (2).

$$\begin{cases} P_{ij,k}(t) = \frac{[\tau_{ij}(t)]^{\alpha}\cdot[\eta_{ij}(t)]^{\beta}}{\sum_{k=1}^{l}[\tau_{ij}]^{\alpha}[\eta_{ij}(t)]^{\beta}}, & O_{ij} \in N_{ij}^{k} \\ P_{ij,k}(t) = 0, & O_{ij} \notin N_{ij}^{k} \end{cases} \tag{2}$$

where α - significance factor of pheromone concentration;
β - coefficient of importance for heuristic information;
τ_{ij}-the concentration of the pheromone on the arc of the graph;
η_{ij} - heuristic information;
N_{ij}^{k} - list of vertices O_{ij} available for the k-th ant.

2. The preferred choice of next node for the graphical-analytical model based on a “direct proportional” rule of the transition between the nodes, unlike some of the known modifications of ant algorithm [5], when the ant determines the next node, first at random, and then focusing on the amount of pheromone.
   “Direct-proportional” transition rule based on heuristic information, which is defined as the ratio (3) of the execution time $T\mathrm{o}_{ij}$ of technological operations to the planned time $T_{S_{ij}}$, which in turn is corrected after each process step of the detail party s, according to the formula (4).

$$\eta_{ij} = \frac{To_{ij}}{Ts_{i}} \tag{3}$$

   where $T\mathrm{o}_{ij}$ - the execution time of technological operations of the details party O_{ij} of i-type;
   $T_{S_{ij}}$ - term production of a details party of i-type.

$$Ts_{i} = Ts_{i} - Tos_{ij} \tag{4}$$

   Selected heuristic calculation formula (3) is determined enough well because, even using the features of the ant algorithm, ant elect not the node, in which he had free after the next manufacturing operation, but the node where the party details will soon end processing. This significantly expands the space search and allows to find a suboptimal solution [4].
3. At each iteration of “directed” ant algorithm all artificial ants incrementally build the paths from beginning to end nodes of the graphical-analytical model. Wherein at each node the artificial ant must select the next node of graph path. If k-th ant is in node O_{ij}, it selects the next node on the basis of the transition probabilities (2).
   To calculate the concentration of pheromone in the transition to the next node in the graph ant use “global” rules that promote directed search. These rules make ants move towards the found “worst” solutions with a view to “improving”.
   This strategy favors exploitation of the search space and is used after the solution is built, that is, after path generation by all ants. Moreover, the pheromone concentration allowed to change only the “worst” (in global sense) ants that built a none optimal path $x(t)$. Thus, for each arc graph pheromone concentration is determined according to the following rule (5 and 6)

$$\tau_{ij}(t+1) = \tau_{ij}(t) + \Delta\tau_{ij}(t), \tag{5}$$

where

$$\Delta\tau_{ij}(t) = \sum_{k=1}^{n_k} \Delta\tau_{ij}^{k}(t). \tag{6}$$

The pheromone concentration, for each artificial ant is computed depending on the desired optimality criterion and calculated by one of the following rules (7–9):

- for maximizing the average load factor of equipment:

$$\Delta\tau_{\mathrm{ij}}^{\mathrm{k}}(\mathrm{t}) = \frac{1}{\sum\limits_{i,j} Tpr_{ij}^{k}}; \tag{7}$$

  where Tpr_{ij}^{k} - downtime of the k-th equipment before carrying out process step O_{ij}.
- for the problem of minimizing the changeover time of the equipment:

$$\Delta\tau_{\mathrm{ij}}^{\mathrm{k}}(\mathrm{t}) = \frac{1}{\sum\limits_{\mathrm{i,j}} Tnr_{ij}^{k}}; \tag{8}$$

  where Tnr_{ij}^{k} - setup time to perform FMS manufacturing operation O_{ij}.
- for the problem of minimizing the cycle time manufacturing detail parts:

$$\Delta\tau_{\mathrm{ij}}^{\mathrm{k}}(\mathrm{t}) = \frac{1}{\sum\limits_{\mathrm{i,j}} Tpr_{ij}^{k} + \mathrm{To}_{\mathrm{ij}}^{\mathrm{k}}}; \tag{9}$$

In (7–9) pheromone deposited is inversely proportional to the quality of the full path to the arcs built ant. When this global information is used to change the concentration of pheromone.

Fumes pheromone will not occur. This is because the need to find more paths which together would provide the best result of the algorithm. On the basis of this feature it is not acceptable that an artificial ant passed the entire path from the first to the last operation. Because when looking for solutions from beginning to end, without taking into account the existence of other ants (production machines), we obtain as a result of the imposition of routes on each other, which is contrary to the mathematical formulation of the synthesis problem schedule. So after selecting the next node artificial ant with a minimum release time will select the arc with a maximum concentration of pheromones. Then pheromone matrix is updated, and the search will begin anew for other ants, until they all move to a new height. This will continue until all the artificial ants (equipment) will not process operations according to the technological production of the map. The method of calculating the amount of pheromone $\Delta\tau_{ij}^{k}$ laid by every ant, prevents premature stagnation.

4. The population of artificial ants always uniquely defined array $K(l)$ (where $l \in [1; nk])]$) and corresponds to the composition of technological equipment used in the production of (FMS and transport units). Thus, the problem of search rational number nk of ants in each population is solved. It should be noted that transport unit is regarded as "elite ant", for which there is no forbidden vertex (tabu list), and which has priority over the other ants in the transition from node to node. This is due to the fact that usually the production workshop it is the busiest transportation process equipment. Thus, a small number of ants convergence algorithm to the shortest path is good enough, while a large number of ants may cause that the search process is not convergent.
5. For all the ants predetermined set of available nodes for visiting vertices that contains the top of the list - the candidates for their visit. And for all the ants, but "elite" it is generated the list of forbidden (tabu list) nodes. The set defines the set of valid nodes for the k-th ant (10). This set may include those vertices Oij transition probability that is not equal to zero, regardless of whether they were visited ant k-m or less (including a shift around the loop). To this end, each ant is created and tracked taboo list. The nodes are removed from the list of N_{ij}^{k} according

$$N_{ij}^{k}(t) = V - \gamma_{ij}^{k}(t), \tag{10}$$

where V - the array of all possible graph nodes,
$v_{ij}^{k}(t)$ the taboo list for the k-th ant.
So for all of artificial ants, except for the "elite" the list of forbidden vertices includes nodes of the graphic analytical model indicating the storage operations for the issuance of blanks, tool and receive the finished product, because they are available to visit only the "elite" ants, i.e., transport equipment.

$$\gamma_{ij}^{k}(t) = \sum_{i=1}^{3}\sum_{j=1}^{n} O_{ij} + \sum_{i=1}^{m}\sum_{j=1}^{n} O_{ij}^{P=0} \tag{11}$$

It should be noted that the list of forbidden nodes (tabu list) for the k-th ant is dynamically updated after each artificial ant transition to a new node, but remains unchanged, only the part of the list that corresponds to the warehouse operations. This modification of the ant colony method includes a local search using the tabu-search for better solutions obtained at each iteration of "directional" ant algorithm.
6. The proposed algorithm uses one of the following convergence criteria [5]:

- end in excess of a user predetermined number of iterations;
- at the end found an acceptable solution;
- end when all the ants follow the same path.

In addition, some improvements have been used from modified ant algorithm of paper [4].

4 Experimental Study of the Parameters

The effectiveness of the ant algorithm depends on a number of control parameters, which include: n_k - number of artificial ants; n_{it} - the maximum number of iterations, τ_0 - the initial concentration of the pheromone, α - the intensification of the pheromone, β - intensification heuristics.

For experimental studies and testing of developed methods and models it is used the technological equipment as the object selected organizational and process technology area of machining parts, such as bodies of rotation.

The criteria of efficiency of functioning of the FMS were investigated as follows:

- Average load factor of technological equipment ($Kzsr \rightarrow max$), because this criterion includes two others: the duration of the production cycle ($T_y \rightarrow min$) and the downtime of production equipment ($T_n \rightarrow min$);
- "just in time" - extreme violation of the terms of manufacturing orders ($T_{av} \rightarrow min$), as this criterion is most relevant in a real production environment.

Values of positive constant α, which determines the effect of the concentration of pheromone, varied in the range of (0.3, 0.5), and factor β, which determines the influence of the heuristic information, varied in the range of (0.5, 0.8). In the tests executed for the selected production section considered different values of the coefficients α and β and their combinations for the two tasks of the proposed performance criteria alone. Figures 1 and 2 shows the production characteristics dependence on the value of positive constant β a value of α equal to 0.3; 0.35 and 0.4 respectively.

Thus, setting the recommended parameters τ_0 control coefficients, α and β, for a variety of performance criteria investigated another important parameter is "directed" the ant algorithm, namely the number of iterations (ant populations) n_t for suboptimal schedules download process equipment. Moreover, experimental studies were carried out taking into account the different number of technological equipment ready for operation (FMS accounted for breakage, scheduled preventive maintenance and a reduction in the number of process equipment in order to save resources).

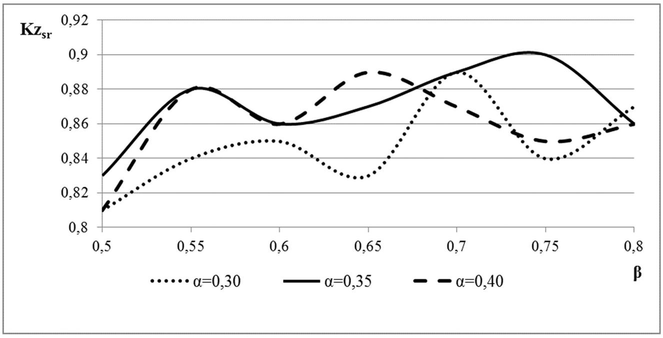

Fig. 1. The dependence of the average load factor of technological equipment from the values of the control coefficients α and β

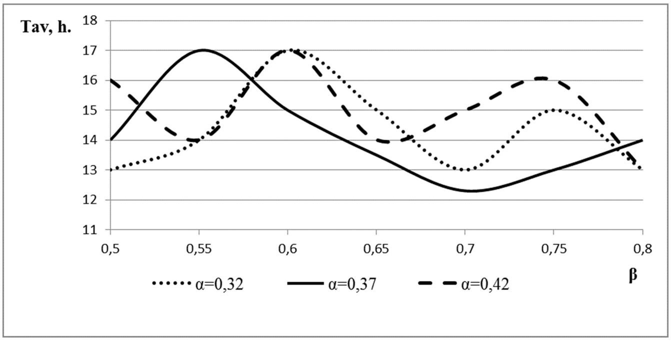

Fig. 2. The dependence of the violation of the order deadlines from the values of the control coefficients α and β

So the situation is viewed from the breakdown of first one ($nk = 6$), and then two FMS ($nk = 5$). The results of these experiments are shown in Figs. 3 and 4, respectively.

Based on the obtained results for the control example, it is possible to conclude that the possibility of reducing the number FMS workshop per unit volume without loss of output, which also corresponds to one of the performance criteria: minimizing the amount used FMS.

Also during the tests "directed" ant algorithm has been found that for the best results of its operation, the coefficients of the algorithm must be experimentally selected for each specific task. Different production sites have their technological features can vary the size of the detail parties and their number, composition and type of equipment - all this affects the result of the algorithm.

Thus, given the specifics of the problem, one can conclude that a single adjustment algorithm parameters (α, β and the number of iterations nt) is not the best option. Also, experiment received several combinations of parameters at the end of the algorithm, it

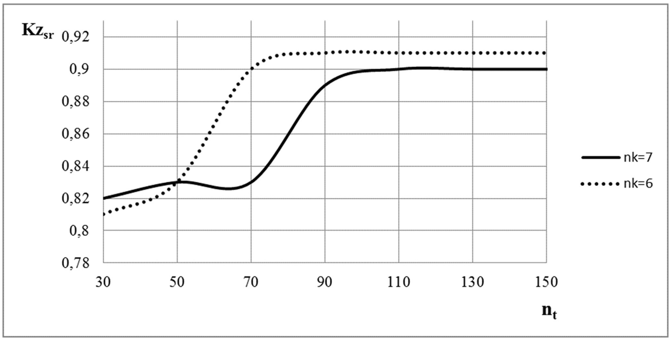

Fig. 3. The dependence of the average load factor of technological equipment (Kzsr) on the number n_t ant populations at varying number of artificial ants

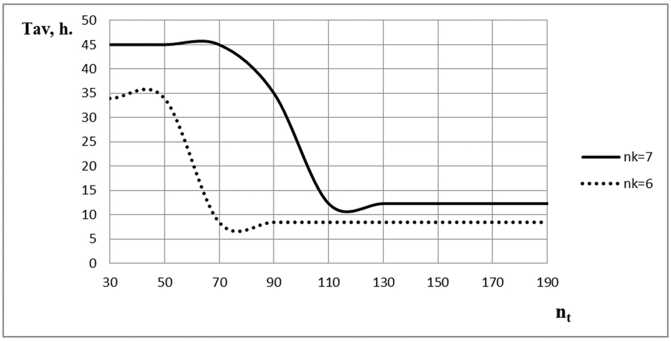

Fig. 4. The dependence of the violation of the order deadlines (Tav) of the number nt ant populations with different numbers nk artificial ants

is necessary to choose the values of the coefficients that allow to find the "best" decision on the selected optimization criterion.

This means that the experimental value of the output parameter data in one production site, can lead to poor results when applying the proposed algorithm to another location. Besides the fact that the optimal values of the "direction" of the coefficients must be obtained experimentally ant algorithm, you must also be able to automatically adjust the settings. In this connection, it was decided to implement a dynamic change in the basic parameters of the algorithm, i.e., after finding the route for all types of processing equipment, to change the coefficients by which it is possible to influence the simulation.

5 Conclusion

In this paper, we propose a modification of the method of ant colonies in order to optimize production schedules in FMS.

1. The proposed method is researched and specified the rules of choice of next node of the graphical-analytical model based on a "directionally proportional to the" rule of the transition between nodes.
2. The "global rules" are proposed for the calculation of the pheromone concentration in the transition ant to the next node in the graph to facilitate search direction.
3. Established and justified the size of the population of artificial ants, the appropriate number of process equipment used in the production of (FMS and transport). Transport unit is regarded as "elite ant.
4. For all the ants predetermined set of available for visiting nodes that contains the list node - the candidates for their visit. And for all the ants, but "elite" defined list of forbidden nodes (tabu list).
5. It is performed numerous computer experiments on test case showed that the effectiveness of the directional ant algorithm increases with the dimension of the problem. It was also found that for the best results of its operation, the coefficients of the algorithm must be experimentally selected for each specific task.

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