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OPTIMAL SHAPE NESTING OF SHEET MATERIALS WITH TECHNOLOGICAL LIMITATION

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Abstract. *The article deals with the problem of constructing an optimal shape nesting of sheet materials. An algorithm for solving the problem nesting sheet materials, taking into account technological restrictions. Demonstrate the use of ant colony algorithm for solving the proposed task.*

Keywords: ant colony algorithm; cutting-stockpiling production; technological limitations; true shape nesting.

I. INTRODUCTION

Improving the design and technological preparation of modern stockpiling manufacture of products depends on optimization of various quantitative and qualitative factors. Among them are five main characteristics that influence the effectiveness of process nesting material:

1. Material flow quantity upon receipt of items of known shape and size.
2. Terms of designing process of cutting and cutting material.
3. While cutting machines with Computer Numerical Control (CNC).
4. The cost cutting on machines with CNC.
5. Quality design solutions in terms of compliance with the requirements of cutting technology.

Application of computer technology to optimize these characteristics is the only way to ensure the company's competitiveness in need in the production of sheet metal items. In general, it should be noted that, despite some progress achieved in the field of CAD/CAM systems design cutting sheet material and preparation for Numerical Control machines, CNC currently remain two major problems increase the efficiency of stockpiling production stage. This is the problem of developing an, easily adaptable to various, tools for designing rational cutting of sheet material and the associated problem of optimization of technological processes of cutting material at a particular process equipment.

The problem of optimizing material consumption per unit production is characterized by constant change of nomenclature and the need to obtain items rational cutting cards with different geometric dimensions on the, which may include as rectangular items and the items more complex geometry (shape nesting).

Cutting of industrial materials – one of the most important in the production of a harvesting operation. It will reveal the management can increase material efficiency, as other technological operations tend to have well predicted rates of raw materials. To date, there are many technological methods that allow for cutting industrial materials: mechanical, thermal and others. Each of the methods of cutting industrial materials applicable in a range of thicknesses and type (species) of the material being cut, and has a number of advantages and disadvantages over other methods. Analysis of their technological characteristics will highlight both common and individual technological limitations that must be considered when sizing an industrial material. Therefore, in solving optimization problems cutting of industrial materials should be considered technological limitations encountered in actual production.

II. THE PROBLEM STATEMENT

From the point of view of geometric optimization problems related to cutting cutting-packing problems for which no known algorithms for solving polynomial complexity. One of the most difficult problem in the S & P is the problem of Nesting. In general, a task Nesting understood optimal placement of geometric objects with complex shapes in specified areas.

Let $A_1, A_2, ..., A_n$ are two-dimensional geometric objects (point sets), which are simply connected or multiply connected domains bounded by one or more closed curves (boundary contours). These objects are geometric models items. Suppose also specified $B_1, B_2, ..., B_m$ are the placing of objects (in the general case and various multiply). The location of each items A_i $(i = 1, 2, ..., n)$ in accommodation which is defined by three parameters x_i, y_i, α_i where x_i, y_i

are the abscissa and ordinate of the fixed point (pole) in some coordinate system; α_i is the option specifies the orientation (angle) of the object in the plane. Thus, it is necessary to define the parameters of $3n$ organize billets in which some objective function $F = F(x_1, y_1, \alpha_1, x_2, y_2, \alpha_2, ..., x_n, y_n, \alpha_n)$ reaches its extremum, and the conditions are not mutually crossing facilities, conditions of placement of objects within one of the areas of accommodation B_j $(j = 1, 2, ..., m)$ as well as a number of additional conditions determined by the properties of the material being cut, the normal production and characteristics of the technological equipment used for cutting, that is

$$F = F(x_1, y_1, \alpha_1, x_2, y_2, \alpha_2, ..., x_n, y_n, \alpha_n) \to extr; \quad (1)$$

$$f_{ij}^1 = (x_i, y_i, \alpha_i, x_j, y_j, \alpha_j) \geq 0, i \neq j, ij = 1, 2, ..., n; \quad (2)$$

$$f_i^2 = (x_i, y_i, \alpha_i) \geq 0, \ i = 1, 2, ..., n; \quad (3)$$

$$f_l^3 (x_1, y_1, \alpha_1, x_2, y_2, \alpha_2, ..., x_n, y_n, \alpha_n) \geq 0; \quad l = 1, 2, ..., L, \quad (4)$$

where (1) – the condition is not mutually crossing objects; (3) – conditions of accommodation in area of placement; (4) – other conditions which, together with; (2) and (3) determine the area of feasible solutions *G* satisfying additional geometric and technological constraints. In practice, as the objective function is most often used function whose value is equal to the so-called cutting coefficient (or cutting material utilization – CMU).

$$k = \frac{\sum_{i=1}^{n} s_i}{P},$$

where s_i is square of *i*th object; *P* is the total square of the occupied part of the placing (the material used).

Since the properties of material for cutting is most often not depend on the side from which cutting is performed for optimizing the placement generally should provide specular reflection path of the preform. This means that the task of cutting vppe formulated to determine the location of an object is necessary to introduce a fourth parameter (sign mirroring). Unlike other placement options blank, this parameter can take only two values, such as “0” – initial position items contour, “1” – mirroring circuit. Thus, the optimization problem Nesting will be to identify placement options items in which the objective function (cutting quality) $F = F(x_1, y_1, \alpha_1, p_1, x_2, y_2, \alpha_2, p_2, ..., x_n, y_n, \alpha_n, p_n)$, reaches its extremum. Accordingly, the conditions (2) – (4) can be written in a generalized form, that is

$$F = F(x_1, y_1, \alpha_1, p_1, x_2, y_2, \alpha_2, p_2, ..., x_n, y_n, \alpha_n, p_n) \to extr; \quad (5)$$

$$f_{ij}^1 = (x_i, y_i, \alpha_i, p_i, x_j, y_j, \alpha_j, p_j) \geq 0, \quad i \neq j, ij = 1, 2, ..., n; \quad (6)$$

$$f_i^2 = (x_i, y_i, \alpha_i, p_i) \geq 0, \quad i = 1, 2, ..., n; \quad (7)$$

$$f_l^3 = (x_1, y_1, \alpha_1, p_1, x_2, y_2, \alpha_2, p_2, ..., x_n, y_n, \alpha_n, p_n) \geq 0, \quad l = 1, 2, ..., L. \quad (8)$$

III. ANALYSIS OF THE LAST RESEARCHES AND PUBLICATIONS

Formulated problem (5) – (8) belongs to a class of mathematical programming problems, for which there are no analytical methods solutions (primarily due to the fact that the form of constraint functions (6) – (8) in an analytical form is unknown, as well as due to the large dimension of practical problems). Given the fact that the geometric shape of the objects in the general case is different, and their location can be arbitrary, this type of cutting is called irregular shaped. The basic approach to solving the problem of irregular shape nesting is to decompose the problem into a number of sub-tasks, among which are the geometric and optimization problems, chief among which are the problems of forming the set of feasible solutions *G*.

As can be seen from the statement of the problem, the set *G* is a set of elements of a vector space of dimension $4n$, which satisfy the constraints (6) – (8). Most subtasks that arise during decomposition nesting problems belong to the class nondeterministic polynomial time – hard problems for which solutions are not known algorithms of polynomial complexity, and their decisions will apply common approaches: exact methods, simple heuristics and metaheuristics.

Currently, the exact methods to ensure receipt of a global extremum, designed only for tasks with very strong constraints on the geometric shape of the objects [1], [2]. Therefore (and because nonpolynomial complexity of exact algorithms and large dimensionality of real-world problems), many developers matches algorithms and rectangular Nesting pay considerable attention to the approximate methods and heuristics [3].

Developed and accurate methods for obtaining local extrema [4]. Most of the automated methods rectangular cutting-packing and Nesting based on the decomposition scheme known solutions of the problem (5) – (8), providing for the formation of such a set of feasible solutions *G*, each element of which is uniquely determined by some “code” (for example, the order (sequence) placing pieces on the material $I = i_1, i_2, ..., i_n$). Numerical algorithms forming cutting options for a given code in the scientific school cutting-packing E. A. Mukhacheva called decoders. Some decoders rectangular packaging described, inter alia, in [5]. Decomposition model reduces the problem of cutting to search the optimal code of a finite set of admissible. The dimension $O(G)$ is usually not less than $n!$.

IV. Analysis of approximation method for Nesting

In solving the problem of designing nesting problem use approximation approach based on the approximation of geometric objects with complex shapes rectangles is the most common way. The main effect of the rectangular nesting software for solving problems of "nesting" is a much higher speed of the algorithm of formation of feasible solutions in comparison with similar algorithms Nesting that allows you to view a much larger number of options in the cutting area of feasible solutions.

As is natural to choose the approximating rectangle circumscribing the outer contour of the object rectangle minimum area. If the conditions of the problem (5) – (8) rotation of objects on the material being cut is disabled, the task of constructing minimum area rectangle coincides with the task of building a single described (dimensional) rectangle and is simple enough, no matter what form of representation of the geometric information about the object used, vector or raster.

If the orientation of objects no restrictions, then the desired rectangle is sought among the entire set of rectangles described. Known following simple algorithm for constructing exact rectangle Smaller objects that have a polygonal shape [6]:

1. Constructed convex hull polygon.
2. Construct a finite set of rectangles described such that one side of the rectangle contains one side of the convex hull of the polygon.
3. Among this finite set is sought rectangle minimum area.

Obviously, the optimization problem of finding the optimal dimension of the rectangle will have $O(s)$, where s - number of sides of the polygon. Study of the approximation method for solving the Nesting problem engaged A. A. Petunin. The study question the advisability approximation rectangles complex objects to solve the problem Nesting computational experiment was conducted.

To describe the experiment were introduced two concepts:

1. Squareness ratio K_p two-dimensional object – a quantity equal to the ratio of the area blank area of a rectangle of minimal area containing object.

$$K_p = \frac{S}{p},$$

where S is a square of the object; p is a square containing a rectangle object.

2. Squareness ratio K_{rect} cutting task – a quantity equal to the average value of the shape factor of individual objects in the job.

$$K_{rect} = \frac{\sum_{i=1}^{n} K_p^i}{n},$$

where n is a number of objects in the cutting task.

The results of this experiment are shown in Fig. 1.

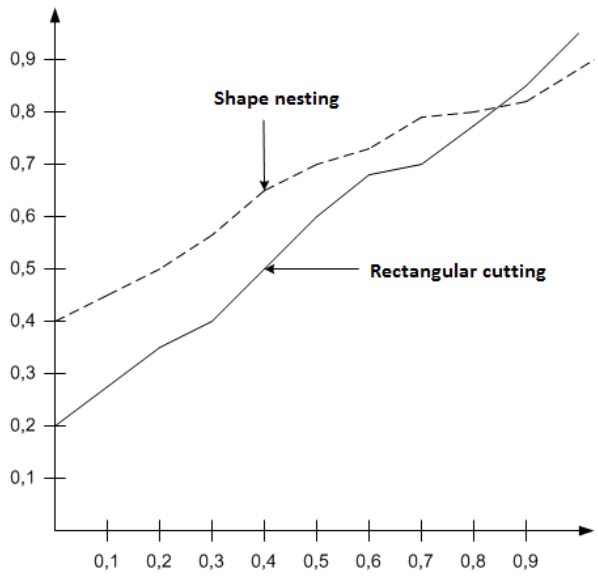

Fig. 1. Cutting material utilization dependence of the coefficient of squareness cutting task

As can be seen from the graph, the algorithm rectangular cutting-packing algorithm outperforms irregular shape nesting when the values of squareness 0.85 more. Given the experimental results, we can conclude that the solution of "nesting" can be reduced to the solution of the rectangular cutting tasks it if $K_{rect} \geq 0.85$. This simplification allows to significantly reduce the time required for the formation of the cutting chart that is very important for small-scale or unit production.

V. Technological restrictions for a rectangular cutting

Nesting reducing the problem to a rectangular formulation of the problem is necessary to make a rectangular cutting taking into account technological restrictions.

Analysis of the process and existing technologies stockpiling production showed that today there are many technological methods that allow for cutting industrial materials: mechanical, thermal, and others. Each of the methods of cutting industrial materials applicable in a range of thicknesses and type (species) of the material being cut, and has a number of advantages and disadvantages over other methods. Analysis of their technological characteristics possible to identify both common and individual technological limitations that must be considered when sizing an industrial material.

Therefore, in solving optimization problems cutting of industrial materials subject to the following technological limitations:

– allowances for edging sheet material;

– machining allowance – zones of thermal effects, non-perpendicularity cutting roughness;

– allowances to perform cuts;

– allowances between the items for fixing material;

– account of defective material areas;

– condition of the guillotine;

– direction of the fibers of the material.

We introduce the notation common technological limitations:

1. Allowances for edging material sheet:

a) η is an allowance edging top and bottom sides of an industrial material;

b) μ is an allowance edging sides industrial material.

2. λ is a machining allowance (zones of thermal effects, non-perpendicularity cutting, roughness).

3. ρ is allowance to perform cuts.

4. τ is allowance between the items for fixing material.

Let Δ is required total allowance between the items, then variable Δ defined by the formula

$$\Delta = \begin{cases} 2(\rho + \lambda) + \tau, & \forall \tau > 0; \\ \rho + 2\lambda, & \forall \tau = 0. \end{cases}$$

Let σ is required total allowance between upper/lower side of the industry and the items material, then the variable σ, determined by the formula

$$\sigma = \eta + \lambda + \rho.$$

Let φ is required total allowance between the sides of an industrial material and the items while the variable φ, defined by the formula

$$\varphi = \mu + \lambda + \rho.$$

The problem of cutting the sheet into rectangular items. When this preform either fixed or can be rotated by 90° (Fig. 2).

Initial information of the problem can be represented as follows:

$$< W; L; n_r; W_r; L_r; \varepsilon; \gamma; \Delta; \sigma; \varphi >,$$

where, W, L are length and width of the sheet material; n_r is a number of rectangular items; $W_r = \left(w_{1r}, w_{2r}, ..., w_{jr}, ..., w_{n_r r}\right)$, $L_r = \left(l_{1r}, l_{2r}, ..., l_{jr}, ..., l_{n_r r}\right)$ are vector widths and lengths of rectangular items; w_{jr} and l_{jr} are width and length jth of the rectangular blank respectively $j \in J_r = (1, 2, ..., n_r)$); ε is sign turns rectangular items; γ is sign guillotine; Δ is required total allowance between the items; σ is required total allowance between upper/lower side of the industry and the items material; φ is required total allowance between the sides of an industrial material and the items.

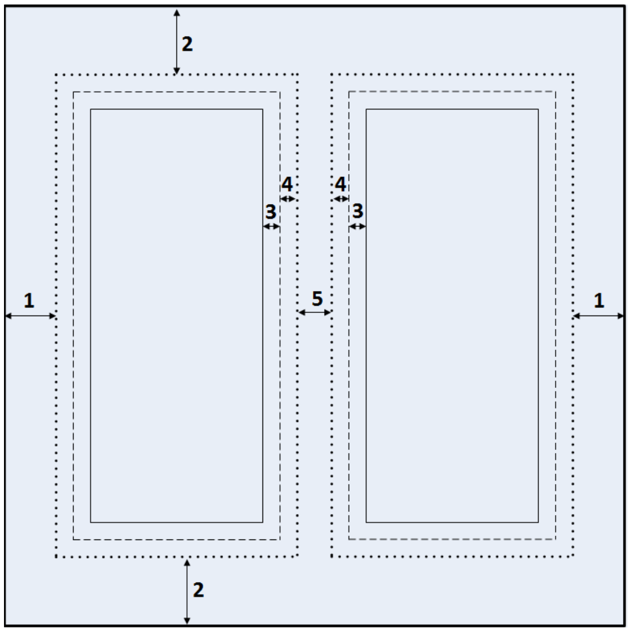

Fig. 2. Technological limitations: *1* are allowances on the sides of the ending material; *2* are allowances on the top and bottom ending material; *3* are allowances for machining the item; 4 is allowance to perform cutting; 5 are allowances between the items

Introduce the rectangular coordinate system *XOY*, whose axes *OX* and *OY* coincide respectively with the top and left side of the sheet material. Solution of the problem is represented as a set of elements:

$< X_r, Y_r, K_r >$ is a problem for cutting sheet material where, $X_r = \left(x_{1r}, x_{2r}, ..., x_{jr}, ..., x_{n_r r}\right)$, $y_r = \left(y_{1r}, y_{2r}, ..., y_{jr}, ..., y_{n_r r}\right)$ are coordinate vectors rectangular items; x_{jr}, y_{jr} are coordinates of the upper left corner jth rectangular blank along the X axis and Y, respectively. In the case of the cutting sheet material jth position of the rectangular blank is determined by a set of elements $\left(k_{jr}, x_{jr}, y_{jr}\right)$ where $k_{jr} \in K_r = \left(k_{1r}, k_{2r}, ..., k_{jr}, ..., k_{n_r r}\right)$ is a number of the sheet on which the jth placed rectangular blank. Set of elements $< X_r, Y_r, K_r >$ is called is admissible reveal if the following conditions are met:

1. Hand rectangular items are parallel to the sheet or web material. Let $\left(x_{jr}, y_{jr}\right)$ coordinates of l th vertex of the jth rectangular blank, then the orthogonality condition can be written according to the next formula

$$\left(\left(x_{j_l r} = x_{jr}\right) \cup \left(x_{j_l r} = x_{jr} + l_{jr}\right)\right) \cap \left(\left(y_{j_l r} = y_{jr}\right) \cup \left(y_{j_l r} = y_{jr} + w_{jr}\right)\right).$$

2. Rectangular items $j, s \in J_r \left(\forall s \neq j\right)$ not overlap

$$\left(x_{sr} \geq x_{jr} + l_{jr} + \Delta\right) \cup \left(x_{jr} \geq x_{sr} + l_{sr} + \Delta\right) \cup \left(y_{sr} \geq y_{jr} + w_{jr} + \Delta\right) \cup \left(y_{jr} \geq y_{sr} + w_{sr} + \Delta\right).$$

3. Rectangular items $j \in J_r$ not go beyond the boundaries of the material being cut

$$\left(x_{jr} \geq \varphi\right) \cup \left(y_{jr} \geq \sigma\right) \cap \left(\left(x_{jr} + l_{jr} + \varphi\right) \leq L\right) \cap \left(\left(y_{jr} + w_{jr} + \sigma\right) \leq W\right).$$

In the problem of cutting sheet material is required to find cutting into rectangular billets, minimizing the length L of the sheet used.

V. RATIONALE FOR USE ANT COLONY ALGORITHM

Ant colony algorithms were first proposed by Dorigo, Maniezzo, Colomi [7] as a method of solving difficult combinatorial optimization problems such as traveling salesman problem and the quadratic assignment problem. Over time, the ant colony algorithms actively developed and have been applied to other problems of discrete optimization. Have developed algorithms for routing problems on graph coloring, cutting and packing problems, the simplest location problem, the problem of the p-median and a number of other tasks.

Ant colony algorithms are the result of analyzing the behavior of real ant colony. Ants are social insects, live in colonies, and their behavior is directed to the survival of the colony and not the survival of an individual unit. Attracted the attention of scientists the high level of social insect colonies and the relative simplicity of the members of the colony. Of particular interest is the behavior of ants in search of food, namely, finding the shortest path from their nest to a food source. Ants crawl from the nest in random directions throughout.

Each ant choosing a path leaves on the ground a substance called pheromone. Pheromone trail allows the ant back to the nest in the same way, and is also used by other ants in search of food. Faced with a pheromone trail, ant with a certain probability (the stronger trace, the more likely that the ant will follow this path) followed by him, causing his next over pheromone by increasing the concentration of the pheromone.

To study the behavior of ants foraging in the two experiments were delivered using a so called binary bridge. The first experiment [8] is as follows: a source of food and ant colony species “Linepithema humile” are double bridge, and the two branches of the bridge are the same length, in which ants can move freely. They were given the freedom to choose the route between the anthill and the source of food, and explore their percentage they choose one of the two bridges. The experiment revealed – despite the fact that the pheromone originally was not on one of the branches, eventually all the ants sought select the same path. This is explained by the fact that in the beginning most of the ants randomly chose the same branch of the bridge, causing a large number of her pheromone. As a result, this is the way possessed more likely to select the ants. On this basis it is clear that in this experiment path selection ants strongly depended on the experiment.

In a second experiment, the length of the branches of the bridge was varied binary. In this experiment, it was found out that after a while the shorter leg of the bridge has become increasingly chosen. This is because as ants move at approximately the same speed, so the ants have chosen the shorter path will spend less time to achieve food and return to the nest. Since the beginning of the experiment the choice of each path is equally likely ants, the concentration of the pheromone on the short path to grow faster than the long end. Consequently, the ants are more and more likely to choose the shortest branch. Unlike the previous case in this experiment, the influence of the initial phase of the experiment are much smaller, and the greatest value for that branch in which members of the colony pick up is the path length.

The experiments showed that in the first case - the entire colony seeks to choosing one out of the way, although not that the same bridge leg length and direction of movement is determined according to the concentration of the pheromone; in the second case - that such an exchange of information between ants allows you to find the shortest path. On the basis of all the above mechanism in the organization of ants are the following features:

– lack of direct information exchange between ants;

– by physical changes in the environment, ants record information about your visit to this place.

We describe the general scheme of the ant colony algorithm. Suppose that the problem of combinatorial optimization is given a pair of $P = (S, f)$, where S is a set of feasible solutions (пространство поиска); f is a target function to be minimized (maximized) [9]. Solution of the problem P is an element $s \in S$, that provides the optimal (minimum / maximum) value of the objective function f.

At each iteration of the ant colony algorithm finite number of artificial ants (agents) are looking for feasible solutions to the optimization problem [9]. Solution is the minimum or maximum of the objective function. Ant builds a solution, starting from some initial state, depending on the specific task at hand. After each of artificial ants (agents) constructed a solution, they get some information about the problem, which is processed and used by them in the future. This information is an analogue of the pheromone.

Each agent moves over the states of the problem according to some probabilistic rule, builds decision. After constructing solutions agents evaluate their decisions and change the value of the pheromone on the components used in this solution. It follows that each agent – some greedy algorithm that builds step by step solution of the problem (iteratively). At each step of the j-th ant defines a set of future directions of the current state and selects one of them with a certain probability. For the j th ant probability p_{ij}^{k} of transition from one state to another depends on the combination of values of the transition and the attractiveness of the pheromone level:

1. Attractiveness transition (heuristic information) n_{ij} from state i to state j is a number calculated according to some rule (depending on the task) and does not depend on what solutions have been found in previous iterations.

2. Pheromone level τ_{ij} is a positive number indicating how often a transition from one state to another was a member of the best solutions found by the algorithm.

Pheromone level is overridden after when all the artificial ants have finished the construction of solutions to a given iteration. Increasing or decreasing the pheromone for the corresponding transitions between states depends on the decisions of what quality they are.

Ant colony algorithms have shown good results in solving combinatorial optimization problems, and some problems were found new record solutions.

The main advantages of these algorithms is: positive feedback, allows you to quickly find good solutions; distributed computation, preventing early convergence of the algorithm; use greedy heuristic for finding good solutions in the early stages of the search process.

VII. Conclusions

At this point the solution Nesting true for single and small batch production, where a wide variety range of items. The basic approach to solving the problem Nesting is to decompose the problem into a number of subtasks. In this article, the first phase is proposed to make a rectangular approximation of items to reduce the problem of “nesting” to the problem of the rectangular cutting. In the future, the resulting task rectangular cutting are improving technological constraints derived from the analysis of equipment and types of cutting-blank production. A brief description of the ant colony algorithm and the urgency of its application to the task.

References

[1] Buhvalova, V. V. Problem rectangular cutting: method of zones and other algorithms. St. Petersburg: St. Petersburg State University, 2001. 96 p. (in Russian).

[2] Lipovetsky, A. I. Properties of rectangular packings. Preprint. Ural Branch of the USSR, Institute of Engineering. Sverdlovsk, 1988. 48 p. (in Russian).

[3] Beasley, J. E. 2004. “A population heuristic for constrained two dimensional non-guillotine cutting” *European Journal of Operational Research 156*. 2004. pp. 601–627.

[4] Stoyan, Y. G.; Yakovlev S. V. Mathematical models and optimization methods of geometric design. Kyiv: Naukova Dumka, 1986. 286 p. (in Russian).

[5] Filippova, A. S. “Modeling evolutionary algorithms solving rectangular packing technology-based block structure“ *Information Technology*. 2006, no. 6. 36 p. (in Russian).

[6] Freeman, H.; Shapira, R. “Determining the Minimum-Area Encasing Rectangle for an Arbitrary Closed Curve,” *Communications. ACM 18*: pp. 409–413, 1975.

[7] Dorigo M. “Optimization, Learning and Natural Algorithms II” *PhD thesis, Dipartimento di Electronica*, Politecnico di Milano, IT. 1992. (in Italian).

[8] Dorigo, M.; Di Caro G.; Gambardella, L. M. “Ant Algorithms for Discrete Optimization II” *Artificial Life*, 1999. vol. 5(2). pp. 137–172.

[9] Blum, C.; Roli A. “Metaheuristics in combinatorial optimization: Overview and conceptual comparison” *ACM Computing Surveys*. 35(3). 2003. pp. 268–308.

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В. М. Синєглазов, О. В. Осадчий, А. Ю. Бурдак. Оптимальний фігурний розкрій листових матеріалів з урахуванням технологічних обмежень

Статтю присвячено проблемі фігурного розкрою промислових матеріалів в одиничному або дрібносерійному виробництві. Запропоновано алгоритм вирішення поставленого завдання шляхом зведення до прямокутного розкрою. Запропоновано основні технологічні обмеження, які накладаються на постановку завдання. Обгрунтовано застосування алгоритму мурашиної колонії для вирішення завдання прямокутного розкрою.
Ключові слова: алгоритм мурашиної колонії; технологічні обмеження; фігурний розкрій.

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В. М. Синеглазов, А. В. Осадчий, А. Ю. Бурдак. Оптимальный фигурный раскрой листовых материалов с учётом технологических ограничений

Статья посвящена проблеме фигурного раскроя промышленных материалов в единичном или мелкосерийном производстве. Предложен алгоритм решения поставленной задачи путём сведения к прямоугольному раскрою. Предложены основные технологические ограничения, которые накладываются на постановку задачи. Обосновано применение алгоритма муравьиной колонии для решения задачи прямоугольного раскроя.
Ключевые слова: алгоритм муравьиной колонии; технологические ограничения; фигурный раскрой.

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