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DEVELOPMENT OF AN ALGORITHM FOR THE REASONED SELECTION OF MACHINES FOR LEATHER GARMENTS MANUFACTURING

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The technology of processing clothing elements is very mobile and changes with the appearance of new materials and equipment. The selected design and technological solutions that ensure the conformity of aesthetic properties and requirements can be satisfied through continuous improvement of sewing production technologies. This study aims to develop an algorithm for choosing the optimal equipment, taking into account the material parameters and the permissible requirements for the technological process of manufacturing sewing products from artificial leather. As a result of the analysis of the range of sewing machines and manufacturing companies, Juki sewing machines were chosen to build a complex matrix of machine equipment. A morphological scheme of the selection process and a mathematical description of the two-dimensional matrix of elements have been developed. That has made it possible to reflect the simultaneous consideration of all process components and their influence on the technological parameters of the machine. The database of the parameters of the equipment selection system was built in the form of matrix elements: a matrix of the type of operations, a matrix of material coatings, a matrix of the base of materials, a matrix of machine assignments, and a matrix of qualifications. Each matrix is a production rule for making a decision at a separate selection stage. The operation matrix was constructed using the TechLab mobile application, which includes 50 processing schemes for artificial leather products. The analysis of the schemes has made it possible to determine the frequency of occurrence of types of seams for processing artificial leather products: 1.01.01 (28.75 %), 2.01.01 (16.75 %), 1.06.02 (11.00 %), 2.02.01 (15.50 %), 5.01.01 (24.25 %), 6.02.01 (3.75 %). The mathematical notation of the algorithm for choosing the optimal machine equipment has made it possible to visualize the structure of the process using a graph. The graph was built using Gephi. Such a notation takes into account the qualification of the worker, the type of technological operation, and the material's properties, including the material's thickness, coating, and base

***Keywords:** sewing machine, machine selection, machine operation, artificial leather, process graph*

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1. Introduction

The sewing industry is characterized by a fairly high level of sewing production equipment and large specialized enterprises. The technology of processing clothing elements is very mobile and changes with the appearance of new materials and various machinery. Therefore, when creating clothes, it is necessary to use the latest achievements of science, technology, and applied art. The selected structural solutions corresponding to the creation of high aesthetic properties and requirements can be satisfied through continuous improvement of sewing production technologies.

The technology of clothing production requires the mandatory use of seams. In general, the quality of seams has a significant impact on the quality of clothing. The types of seams and stitches affect the quality and appearance of clothes. Seams on clothes should be strong and smooth. The appearance and performance of the seams depend on the type of stitch and seam, stitch and seam parameters, defects and damage to the seams. All these factors directly depend on the type and parameters of the machine equipment that is used to directly produce this or that seam.

A sewing machine is an indispensable production tool widely used in the garment industry. Thus, the choice of sewing machine is an important decision for the productivity of sewing enterprises. Choosing the wrong sewing machine reduces productivity, while choosing the right one increases productivity. The performance of sewing machines depends mostly on the workers but to a greater or lesser extent on the characteristics of the machine. Appropriate machinery must be purchased to improve worker efficiency and production performance. Buying these machines requires information or rating criteria to choose the most suitable one.

The rapid change of technologies, their fast development, and the globalization of the technology market cause an excess of choices and the risk of increasing the number of errors associated with incorrect or insufficiently justified selection of sewing machines for a specific production. At the same time, sewing production, by default, is associated with fabric products. However, according to research [1], the market for biogenic and synthetic alternatives to natural leather is constantly growing. Artificial leather offers a wide range of applications, including in the field of clothing; therefore, demand increases over time. Along with the demand, the need for technological solutions related to the production of artificial leather products is growing.

Thus, the task of reasoned intelligent choice of machine equipment for the production of sewing products from artificial leather is relevant as solving it could make it possible to ensure high quality of clothing production.

2. Literature review and problem statement

Interest in intelligent manufacturing is growing in all industries. However, there is limited research into this topic in the garment industry. Paper [2] outlines the expediency and main considerations regarding the implementation of intelligent production in the garment industry. It was revealed that although the direction of research in garment production is aimed at intelligent production, direct studies of such production are still in their infancy.

Smart manufacturing usually means the use of high-tech equipment in all technological processes: from designing the structure to the stitching of parts and the finishing treatment of end products. Some of the possibilities of using elements of smart production are considered in [3, 4]. At the same time, the quality of clothing manufacturing is considered primarily dependent on the quality and accuracy of the construction of clothing details and the means by which it is developed. Technological studies into the direct production of clothes are rare and locally concentrated. In addition, there are technological gaps compared to other industries. Additional data are needed to resolve the issue of the application of critical technologies, in particular sewing equipment, in the production of clothing.

Machine selection in textile plants is a multi-criteria decision-making problem in which many conflicting criteria are considered. At the same time, various methods of solving the choice problem are used: the integrated gray model of the multi-criteria decision-making method (MCDM). This model includes a gray distribution scale (Grey AHP and ROV-G) [5]. Paper [6] demonstrates the application of Kano's fuzzy model, the method of importance of criteria through intercriteria correlation (CRITIC), and multiattribute utility theory (MAUT) [4].

Work [5] shows that the problem of choosing a sewing machine is a typical problem of choosing a machine. Enterprises must choose the most suitable machine to reduce costs and produce products quickly. For this reason, machine selection is also vital for textile and garment industries. However, in the cited work, the problem of choosing machines was considered in the context of the main goal of the enterprise – to make a profit and ensure it continuously.

Thus, in [5], the following criteria are considered: cost, energy consumption, company image, maintenance and service, productivity, safety, warranty conditions, ergonomics. The extended list includes:

– power (servo motor: power of the servo motor, ability to work at high speed: maximum working speed);

– performance (thread tension regulator: tension accuracy, measured by the number of thread separations from the needle; presser foot lever: smoothness and ergonomics of the presser foot lever; durability: average service life in years);

– quality (automatic and permanent lubrication system: the quality of the lubrication system present in this machine, whether it is automated or not; noise and vibration level: motor frequency; desk lamp: lamp position and light flow);

– price (without added value: market price);

– warranty (warranty period).

In this context, the choice of machines used by enterprises in production is an important issue, but this approach does not correlate with the features of the chosen technology of product treatment. The approach requires clarification regarding the direct model of the selected machine, not just the manufacturer.

Study [6] explored the application of Kano's fuzzy model and the analytic hierarchy process to transform consumer expectations and design quality products. The research focuses on prioritizing those characteristics that meet the requirements of employees (users) and contribute to overall industry revenue. At the same time, customer needs and technical characteristics were assessed and prioritized using the Hierarchy Analysis (HAA) method. Additional characteristics were then prioritized using the Kano model. Ready-to-wear businesses and purchasing departments can use the results of the cited study to help select a sewing machine. However, the technological aspects of equipment selection were not taken into account, which does not make it possible to ensure an increase in the quality of production while satisfying the user's requirements.

The price, type of stitch, access to the pattern programmer, availability of spare parts, serviceability, and energy consumption are discussed in [7]. The selection of machines for a textile company was performed using criteria importance through intercriteria correlation (CRITIC) and multiattribute utility theory (MAUT) methods. In the above study, the CRITIC method determined the weighting factors of the decision criteria, which are effective in making decisions. A machine selection was then made by evaluating the alternatives using the MAUT method. According to the results of the research, the CRITIC and MAUT methods are integrally applied to machine selection.

As you can see, the factors considered in [5–7] do not include any criteria regarding the manufacturing technology used to make clothes.

Works [8, 9] consider the task of machine selection and related issues. In study [8], factors affecting needle damage during sewing were determined. In this context, three types of knitted material, stitch direction, needle tip shape, needle number, and sewing speed were selected as variables. The influence of sewing threads was excluded from consideration. Regarding the obtained data, it was found that needle number was the most important factor that caused needle damage during sewing. The cited study also shows the influence of parameters to consider when choosing a needle, such as the type of material, the structure of the knitting, and the density of loops of the knitted fabric.

The effect of fabric properties on manufacturing technology and seam quality is important; therefore, it is extremely important to understand the influence of various parameters on the properties of fabrics during sewing. Study [9] aimed to evaluate the seam quality of traditional silk, cotton, linen fabrics, and their blends in terms of seam strength, seam appearance, and fabric stitchability. Based on the results, the authors came to the conclusion that sewing threads and the type of fabric significantly affect the strength and appearance of the seam.

Thus, in the works discussed above, it is concluded that the quality of technological treatment of clothes depends on the material and parameters of the machine, as well as the parameters of the seam. However, all of those studies describe different aspects of fabric tailoring, and none deal with specific materials such as leather, fur, faux leather, etc.

It should be noted that leather products are generally attractive to consumers. However, despite the fact that the number of artificial leather products has recently increased, the impression of their appearance is different from products made of fabrics or genuine leather. Accordingly, a number of papers report the peculiarities of the manufacture of artificial leather products [1, 10, 11].

Study [1] examined shoe upper leather, synthetic leather, and nine alternative materials. Comparison of the structure of materials and technical characteristics made it possible to assess the possible areas of their application. The variant of the product and the variant of its purpose require different properties, which the manufacturer can achieve by using different coatings. Works [10, 11] consider the issues of perception and influence of artificial leather coating on the mechanical properties of the material. Clothes made of artificial leather should have qualities different from fabric. At the same time, the quality of synthetic leather clothing should meet the requirements for ordinary clothing and genuine leather clothing. Study [11] analyzed the impression made by leather and proposed a model for evaluating people's feelings about its authenticity. However, none of the studies [1, 10, 11] paid attention to the relationship between the coating and properties of artificial leather materials and the parameters of sewing equipment.

Thus, the lack of scientifically based dependences between the parameters of the materials and the parameters of the sewing equipment, which affect the quality of the technological processing of the products, was revealed. This allows us to argue that it is appropriate to conduct a study aimed at developing an algorithm for justifying the choice of sewing equipment for the manufacture of artificial leather products.

3. The aim and objectives of the study

The purpose of this study is to develop an algorithm for choosing the optimal equipment, taking into account the material parameters and permissible requirements for the technological process of manufacturing sewing products from artificial leather. This will make it possible to ensure the quality of technological treatment of artificial leather products and ex clude the influence of the human factor on the choice of machine equipment.

To achieve the goal, the following tasks were set:

– to analyze the sewing equipment available in the market from various supplier firms according to its purpose;

– to form input data for the selection of sewing equipment;

– to build a matrix structure of the database of sewing equipment selection parameters;

– to justify the mathematical notation of the algorithm for selecting machinery for a specific technological operation.

4. The study materials and methods

The object of our research is the process of selecting sewing equipment for the production of sewing products from artificial leather.

The working hypothesis of this study is a set of the following assumptions.

Assumption 1. The choice of machinery for a specific technological operation of manufacturing sewing products from artificial leather is ensured by the unambiguous structure of the database of its selection parameters.

Assumption 2. The parameters for the selection of equipment for a specific technological operation are the parameters of the technological purpose of the sewing equipment.

When choosing the appropriate type of machine, it is necessary to have initial information about the types of seams and other features of sewing product processing. The mobile application TechLab (Ukraine) was used as the source data [12, 13]. The app contains a description of techniques for joining leather and fur clothing elements and features of the technology for processing products made of natural and artificial fur and leather.

The mobile application contains six laboratory works for studying the peculiarities of manufacturing clothes from leather and fur when studying the course «Fundamentals of sewing technology» at institutions of higher education. Three of them investigate the manufacture of clothes from natural and artificial leather. The other three laboratory works are related to the production of appropriate elements of clothing from natural and artificial fur. So, the mobile application «TechLab» includes 50 diagrams showing the processing of sewing products made of artificial leather. Among them are initial processing of parts (17 possible options), pocket processing technology (10 possible options), collar and edge processing technology (13 options), sleeve bottom and cuff processing technology (10 options) [12].

To analyze and simplify the information during the study of parameters for the selection of sewing equipment, a mathematical tool for constructing graphs was used. A graph is a method of constructing data and relationships between them [14]. It is widely used for various cases of representing hierarchical trees in the modeling of technological processes in the garment industry. For example, to visualize the productivity of the appearance of piles during the formation of peeling on textile materials [15].

Graphs are built to represent different types of complex data for their adequate description in the algorithm. Objects are denoted as vertices or nodes of a graph, and connections are denoted as branches. Graph types may differ in orientation, restrictions on the number of connections, and additional data about vertices or branches depending on the field of use. The Gephi software environment (France) was used to visualize the graph using the UMAP (Uniform Manifold Approximation and Projection) technique. This algorithm is based on Riemannian geometry and topological algebra. UMAP preserves most of the global structure with high performance during its execution. Algorithm parameters: number of neighbors, minimum distance, distance metric, dimensionality of finite space.

The formation of the initial information for the construction of the graph is performed using rectangular incidence matrices.

5. The results of investigating the database of sewing equipment selection parameters

5. 1. Analysis of sewing machines and sewing machine manufacturers

Sewing machines produced by companies have their classification; each company assigns its conditional number to both basic machines and their modifications. The assignment of basic machines and modifications makes it possible to represent these machines in structurally unified series. Modified machines differ from basic machines in the presence of additional mechanisms:

– thread cutting mechanism;

– for trimming the edge of seams of stitched parts;

– to stop the needle in the upper position;

– for automatic lifting of the needle;

– a differential mechanism of movement that ensures the gathering or stretching of seams.

In addition to the classification of companies, there is a technological classification of machines, according to which sewing machines are categorized as follows:

– by type of stitch (shuttle and chain stitch machines, combined);

– by the number of needles participating in execution (single-threaded and multi-threaded);

– according to the technological purpose (stitching, hemming, sewing-hemming, for sewing on buttons, for hemming loops, for making fasteners, for hemming the bottom of products, quilting);

– by the nature of the operation performed on the sewing machine (universal, special, specialized, semi-automatic).

Five parameters of the technological purpose of sewing equipment were proposed, according to which it can be characterized and appropriately selected. In accordance with this, the range of sewing equipment offered by supplier companies was analyzed (Table 1) [16–20]. In Table 1 mark «–» means that the equipment of this brand of sewing machine is currently «not available» (requires shipment from another country), and the mark «+» means «availability» (available on the site).

It is advisable to choose one company-supplier of sewing equipment that meets the maximum number of parameters according to the technological purpose to ensure stable operating conditions in various production situations and equipment repair. According to the results of the analysis given in Table 1, Pfaff and Juki sewing machines comply with the full list of proposed technological parameters.

Juki sewing machines were chosen to form a complex matrix of machine equipment. The choice is based on the results of comparing the cost of the equipment of the mentioned manufacturing companies, which revealed a significant advantage of the price policy of the Juki company (price range USD 330–4500) compared to the Pfaff company (USD 1000–20000). In addition, the analysis of the diversity of the range of sewing equipment available in the market showed that the Juki company presented a wider range of equipment for the production of artificial leather sewing products.

5. 2. Input for the selection of sewing equipment

The selection of each type of equipment is carried out according to equipment catalogs and handbooks. At the same time, the following is taken into account:

– type and purpose of the product;

– raw material composition and properties of the package of materials from which the product is made;

– model features of the product;

– technological characteristics (stitch type, stitch length, speed; movement mechanism; availability of automation mechanisms, etc.).

It is advisable to choose a sewing machine according to the generalized scheme shown in Fig. 1. This method makes it possible to represent the simultaneous consideration of all components.

Clear conditions are necessary for the practical implementation of such a process. They unambiguously describe the possibility of imitating structural elements and variant features in the totality of the subject list. To build the graph, we shall construct a database of the investigated parameters of the equipment selection system in the form of matrices of elements: matrix of the type of operations, matrix of material coatings, matrix of the basis of materials, matrix of machine designations by material thickness, matrix of qualifications.

The matrix of types of operations is a two-dimensional matrix of size $i \times j$ (Fig. 2), which contains information about a specific list of types of machinery and types of technological operations used for the manufacture of leather products. Each cell of the two-dimensional matrix $i \times j$ represents the characteristics of the i-th type of equipment (serial number in the matrix horizontally) for the performance of the j-th type of technological operation (serial number in the matrix vertically) and includes the following parameters:

– C_{ij} – the name of the machine model, the purpose of which is to perform the j-th type of technological operation;

– Th_{ij} is the i-th type of technological operation performed on the j-th type of sewing machine.

Table 1

Analysis of the available sewing equipment of different suppliers by purpose

Company name	Purpose of sewing equipment				
	Universal (for all products and fabrics)	Specialized (zigzag stitches, two-needle, multi-needle)	Special (flat-seam, overcast, for sewing sleeves into the armhole)	Semi-automatic (buttonhole, button)	Semi-automatic action for nodal machining (for processing welt pockets, darts, etc.)
Pfaff	+	+	+	+	+
Durkopp-Adler	+	+	–	+	+
Juki	+	+	+	+	+
Brother	+	–	+	+	+
Yamata	–	–	+	–	–
Pegas	–	–	+	–	–
Reece	+	+	–	+	+
Union-special	–	–	+	–	–
Rimoldi	+	+	+	–	–
Siruba	+	+	+	–	–
Sunstar	+	+	+	+	–

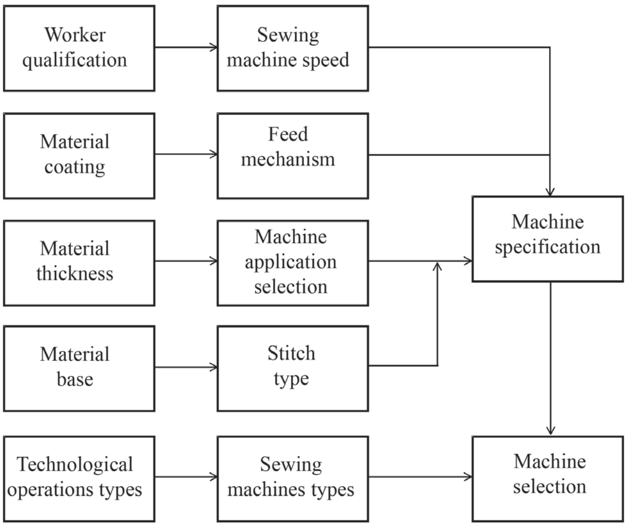


Fig. 1. Morphological diagram of the machinery selection process

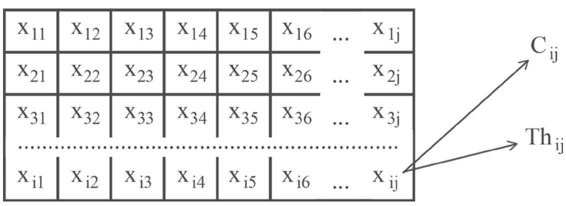


Fig. 2. Matrix of operations

The formulation of a finite list of individual machine operations used for the manufacture of leather products is necessary for the formation of a matrix of operations.

The structure and mathematical description of other elements that form the database of sewing equipment selection parameters are similar to the structure and description of the matrix of operations.

5. 3. Construction of the matrix structure for the database of parameters for the selection of sewing equipment

After analyzing the sketches of processing parts of sewing products given in the «TechLab» application, the most common types of seams were determined. Each seam has a digital designation according to «DSTU ISO 4916:2005 Textiles – Types of seams – Classification and terminology» [21], as shown in Fig. 3.

Six different types of seams were identified, which should be taken into account when choosing a sewing machine for a specific operation (Table 2).

Therefore, the analysis of the frequency of occurrence of different types of seams used for processing parts of sewing products made of artificial leather has made it possible to form the initial data for the matrix of operations performed on different types of machine equipment (Table 3).

In Table 3, «1» denotes yes; «0» – no.

Using the same approach, a matrix of material coatings (Table 4), a matrix of material thicknesses (Table 5), a matrix of the base of materials (Table 6), and a matrix of employee qualifications (Table 7) were built.

These matrices include several parameters, for example: P_j – material coating properties; F_i – material movement mechanism; A_i – machine assignment; MThj – material thickness; Mbasej – properties of the base of materials; MTh_j – types of seams; EQ_j – qualification of employees; $Mspeed_i$ – machine speed parameters.

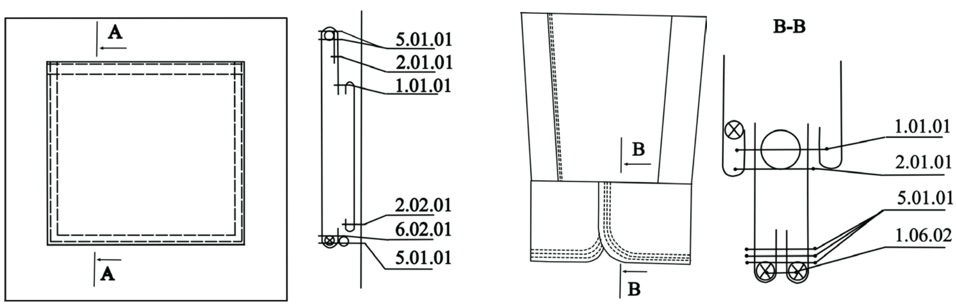


Fig. 3. Examples of numerical designations of types of seams

Table 2

Frequency of individual operations in the production of leather clothing

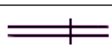
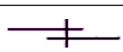
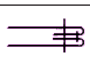
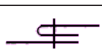
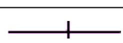
Seam		Garment part/ technique				Frequency of occurrence, %
Sketch	Designation	Shaping	Pockets	Collar and lapels	Cuffs and sleeve hem	
	1.01.01	45.00	7.00	22.00	41.00	28.75
	2.01.01	2.00	31.00	13.00	21.00	16.75
	1.06.02	0.00	14.00	23.00	7.00	11.00
	2.02.01	24.00	24.00	10.00	4.00	15.50
	5.01.01	24.00	24.00	22.00	27.00	24.25
	6.02.01	5.00	0.00	10.00	0.00	3.75

Table 3

Matrix of operations

Seam designation	Sewing machines types				
	Universal	Specialized	Special	Semi-automatic	Semi-automatic sewing systems
1.01.01	1	0	0	0	0
2.01.01	1	0	0	0	0
1.06.02	1	0	0	0	0
2.02.01	1	0	0	0	0
5.01.01	1	1	0	0	0
6.02.01	1	0	0	0	0

Table 4

Material coating matrix

Material coating	Feed Mechanism	
	Differential feed	Needle feed
Polyvinylchloride	1	0
Polycaprolactam (Capron)	0	1
Caproacetate fibers	0	1

Table 5

Material thickness matrix

Material thickness, mm	Application		
	Light-weight	Light-weight	Light-weight
0.3–1.0	1	0	0
1.0–3.0	0	1	0
>3.0	0	0	1

Table 6

Material base matrix

Material base	Stitch type	
	Lockstitch	Lockstitch
Knitted fabric	1	0
Fabric	0	1
Non-woven fabric	1	1
Faux fur	1	1

Table 7

Worker qualification matrix

Worker qualification	Machine speed	
	Low	High
High level	0	1
Low level	1	0

The matrices of elements given in Tables 3–7 form the database structure of sewing equipment selection parameters.

5. 4. Mathematical notation of the machine equipment selection algorithm

The final stage of determining the necessary conditions is the construction of a complex matrix of machine equipment that could be used for the manufacture of sewing products from artificial leather (Table 8).

In Table 8, each specific sewing machine is described by a specific set of sewing equipment characteristics. The set of characteristics (elements) of groups *Fi* (material movement mechanism), *Aj* (purpose of the machine), *Stypei* (types of stitches), *Mspeedi* (machine speed parameters) is formed on the basis of matrices (Tables 3–7). The choice of the material movement mechanism is determined from the matrix of material coatings (Table 4). The selection of the purpose of the machine according to the thickness of the materials to be stitched is determined using the material thickness matrix (Table 5). Matrices of the basis of materials (Table 6) and qualifications of workers (Table 7) determine the type of stitch and the speed of the machine, respectively.

The next step will be to choose a machine model from Table 8. At the same time, the choice of sewing machine type is clearly indicated in the symbolic form C_{ij}; Th_{ij}. In this form, C_{ij} is the selection of the model name, and Th_{ij} is the selection of the characteristics of the sewing equipment.

Given the number of items in each group, many combinations of critical characteristics and equipment choices can be expected. As an initial step, the basic rules for grouping objects should be defined. It is advisable to use the laws of mathematical logic to outline general approaches to the formation of the theory of machine selection and the construction of statements using logical relationships. In this case, the practicality of choosing a sewing machine consists of elements of the graph of morphological features. In its formalized form, each type of schema will be a complex statement that is composed of simple components by means of actions that can be meaningfully expressed as «and» which is a logical conjunction, or «or», which is a logical disjunction. The thickness of the sewn material, the basis and coating of artificial leather, the qualification of the worker, and the type of technological operation performed are analyzed to match the specific version of the sewing machine (model name). In the language of mathematical logic, this means that it is necessary to take into account the values of these components at the same time. To this end, the logical operation «and» ($\wedge$) is used, as shown below:

$$\begin{bmatrix} \left(\left(C_{ij} \wedge Th_{ij}\right)\right) \wedge \\ \left(\begin{matrix} \left(Material:\left(P_j \wedge F_i \wedge A_m\right)\right) \wedge MTh_j \wedge \\ \wedge Mbase_j \wedge Stype_i \wedge Mspeed_i \wedge EQ_{extr} \end{matrix}\right) \\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots \\ \left(\begin{matrix} C_{ij} \wedge Th_{ij} \wedge Material_p \wedge \\ \wedge MTh_j \wedge EQ_{extr} \end{matrix}\right) \rightarrow P\_roduct \end{bmatrix}, \tag{1}$$

where $i, j, k, l, m, n, p, h=1, 2, 3, \ldots$

For example, for the technological operation «Sewing parts of the front of a sewing product»:

$$\left[\left(\left(\left(C_{11} \wedge Th_{11}\right) \wedge Material_3\right) \wedge EQ_{extr} \rightarrow P\_roduct\right)\right].$$

The mathematical notation of the machine equipment selection algorithm represents gradual transformations between its components. It is advisable to represent such connections in the form of a graph, which makes it possible to display the simultaneous transformation of one element into several others with the help of the corresponding number of branches of the graph coming from one vertex. The order of displaying the vertices of the graph must be unambiguous to ensure the sequence of changes of both constant and variable elements (Fig. 4).

Table 8

Sewing machines and systems

Model name	Speed	Feed mechanism	Stitch type	Application	Sewing machine type
DDL 900-BSNBN-BB/AK85 «Juki»	low	needle	chainstitch	light-weight	universal
DDL-5550 «Juki»	low	needle	chainstitch	heavy-weight	universal
AEC-112 «Juki»	low	needle	lockstitch	heavy-weight	universal
ECS-154-470/ES-31/ET-5 «Juki»	low	needle	lockstitch	light-weight	universal
DNU-140 «Juki»	low	differential	chainstitch	heavy-weight	universal
DU-141H «Juki»	low	differential	chainstitch	medium-weight	universal
MH-484U «Juki»	low	differential	chainstitch	medium-weight	universal
LZ-228N-7WB «Juki»	low	differential	lockstitch	light-weight	universal
DDL-8100eH «Juki»	low	differential	lockstitch	heavy-weight	universal
DDL-8700L»Juki»	low	differential	lockstitch	medium-weight	universal
DDL-5600-NL-7 «Juki»	low	differential	lockstitch	heavy-weight	universal
MH-380 FU «Juki»	high	needle	lockstitch	light-weight	universal
DDL-7000A «Juki»	high	needle	lockstitch	heavy-weight	universal
MS-1261 «Juki»	high	differential	chainstitch	light-weight	universal
MS-1190 «Juki»	high	differential	chainstitch	heavy-weight	universal
DDL-900-BSNBN Juki	high	differential	lockstitch	light-weight	universal
LH-3568ASF «Juki»	high	differential	lockstitch	medium-weight	universal
DU-1181 N «Juki»	high	differential	lockstitch	heavy-weight	universal

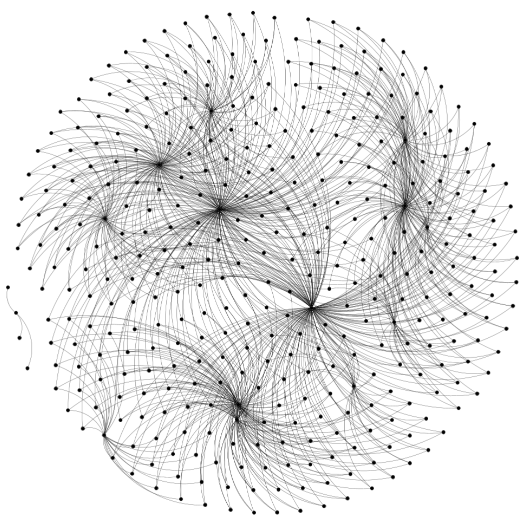


Fig. 4. A graph representing the hierarchical structure of machine selection

Thus, with the help of the algebra of statements, the sequence and simulation of the operation of the algorithmic program for selecting optimal machine equipment for a specific technological operation have been formulated.

6. Discussion of results of investigating the database of parameters for the selection of sewing equipment

The analysis of sewing equipment by various supplier companies according to its purpose allowed us to build input data for the selection of sewing equipment in the form of a database of selection parameters. The matrix structure of the database of sewing equipment selection parameters is based on the morphological scheme of the machine equipment selection process (Fig. 1). This scheme makes it possible to simultaneously take into account the components that were not taken into account in the solutions known in the field [2–4], namely: the properties of the material base, its coating, and the qualifications of workers. Each of the components affects one of the technological parameters of the equipment, and therefore, as a result of their combination, the solution to the task of forming the technological characteristics of the optimal sewing equipment is uniquely determined.

Previous solutions to the task of choosing machinery focus on choosing a supplier based on the factors of ensuring optimal logistics, price, capacity, and energy costs. In contrast to them, our solution involves the selection for specific technological operations of specific machines from a finite set of proposals of already selected supplier firms (in particular, using the methods proposed in [2–4]).

On the other hand, the developed algorithm allows for a more comprehensive analysis of equipment parameters and its selection in relation to known solutions [7, 8], which can be applied to configure the selected sewing machine for a specific technological operation.

The choice of a line of machine equipment from Juki's offers, as the basis for a database of parameters for the selection of sewing equipment, is confirmed by the results of the analysis of the range of sewing machines and sewing equipment suppliers (Table 1). The Juki company offers all types of equipment that are necessary for performing the types of seams most often used in the manufacture of leather and fur clothing (Table 2).

Our matrix structure of the database of sewing equipment selection parameters (Tables 3–8) in combination with the mathematical notation of the selection algorithm (2) could be used as a basis for building an expert system for selecting sewing equipment for the needs of a specific sewing industry.

The morphological scheme of the process of selecting machine equipment (Fig. 1) could be applied to any assortment of sewing products and does not depend on the selected line of sewing equipment. Therefore, our results of investigating the database of parameters for the selection of sewing equipment, after appropriate research and corrections to element matrices, could be adapted for manufacturing processes of other types of products.

When a researched enterprise has sewing equipment from any other company (different from the one described in this study), only the data in Table 8 are subject to change. The direct algorithm for selecting machinery for specific operations will remain unchanged.

The development of sewing equipment technologies leads to an increase in the number of possible options for mechanisms, in particular mechanisms for moving materials. At the same time, the rapid development of the fields of textile materials science predetermines the emergence of new technologies for the production of artificial leather. The combination of these factors causes a change in the dimensionality of the matrix of material coatings (Table 4). In turn, changing the dimensionality of the matrix requires the addition of input data for the proper functioning of the developed algorithm.

It should be noted that any changes in the dimensionalities of matrices and their filling do not affect the mathematical notation of the algorithm, which is an advantage of the proposed solution. However, at present, the algorithm cannot be used in the practical work of a technologist. This is explained by the fact that there is currently no customized software implementation, an interface for entering input data, and a description of individual optimization tasks at each of the decision-making stages.

It is advisable to further advance our research towards a fragmentary representation of the equipment selection process. In this case, it is expedient to divide control task into several problems of different levels, each of which refers to a certain fragment, is independent, has its optimality criteria and implementation algorithms.

The development of a user interface for working with a database of the investigated parameters of equipment selection will allow for the experimental verification of our data. Empirical confirmation of the optimality of the choice of this or that equipment may face the difficulty of assessing the heuristic experience and level of expertise of specialists responsible for the selection of equipment in real project situations.

7. Conclusions

1. As a result of the analysis of the sewing equipment available in the market from various supplier companies according to its purpose, it was found that the full list of proposed parameters of the technological purpose matched the sewing machines by the Pfaff and Juki companies. A comparison of the cost of the equipment of these manufacturers revealed a significant advantage of the price policy of the Juki company (price range USD 330–4500) compared to the Pfaff company (USD 1000–20000). Therefore, Juki sewing machines were chosen to construct a complex matrix of machine equipment that could be used for the production of artificial leather sewing products. The choice of a line of sewing equipment of one company is justified by the need to ensure stable operating conditions in various production situations and equipment repair.

2. A morphological scheme of the selection process and a mathematical description of the matrix of elements were developed to be used as input data for the sewing equipment selection algorithm. This has made it possible to reflect the simultaneous consideration of all process components and their influence on the technological parameters of the sewing machine.

3. The database of the studied parameters of the equipment selection system was built in the form of matrices of elements: a matrix of the type of operations, a matrix of material coatings, a matrix of the base of materials, a matrix of machine designations by material thickness, a matrix of qualifications. Each of the matrices is a production decision-making rule at a separate stage of equipment selection.

The construction of the operation matrix was performed using the TechLab mobile application, which includes 50 processing schemes for artificial leather products. The analysis of the schemes has made it possible to determine the frequency of occurrence of types of seams for processing artificial leather products: 1.01.01 (28.75 %), 2.01.01 (16.75 %), 1.06.02 (11.00 %), 2.02.01 (15.50 %), 5.01.01 (24.25 %), 6.02.01 (3.75 %).

4. The mathematical recording of the algorithm for selecting the optimal machine equipment for a specific technological operation has made it possible to visualize the hierarchical structure of the machine selection process using graphs. Such a notation takes into account the qualification of the worker, the type of technological operation, the physical and mechanical properties of the material, including the thickness, coating, and base of the material.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

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