INTRODUCTION

A modern machine-building enterprise, based on mechanical machining of materials, is a complex multi-component system, containing a large number of connections, a great deal of material resources and dataflows. Additionally, as a general rule, such an enterprise is a corporation – a large union of subdivisions. This requires a corporate enterprise control system for timely problem-solving in management. Creating a control system for such an enterprise is a complicated task and each case has its’ own aspects. The development of modern information technologies provides many opportunities for the perfection of control processes, and the most effective are decision support systems (DSS), developed based on the approach of Artificial Intelligence (AI) – multiagent systems (MAS), which have proven their working capacity and efficiency in real time and consist of groups of various types of agents, and can take upon themselves specific roles in an organizational structure. The unique feature of implementing MAS is the absence of a global control system, data decentralization, calculations are carried out locally, and MAS have demonstrated their effectiveness and efficiency in real-time control processes.

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out in asynchronous mode. The individual optimization of each agent’s actions leads to the global optimal system state. This effect appears as a result of agents working together, which is based on the auction principle, with which the optimal solution in the specified situation is identified. Thus, the agent technology is scalable for a wide circle of planning and modeling tasks both for small as well as large enterprises with hundreds of connected devices. The development of such a system is shown in section 1. The MAS system is suggested for planning the capacity load of a machine workshop and takes into consideration the unique features of the machining technological process, including the accumulated tool deterioration and in conditions of the imitation model of manufacturing with the aid of combinational auctions, providing minimal time for manufacturing a product batch.

To ensure the work of the MAS, data on technological processes of cutting materials are necessary and section 2 contains a description method of solving the problem of structural optimization of the technological process of cutting.

One of the important stages of building an effective TP control system is the of the machining process operations’ optimization parameters, thanks to which, using the data obtained on the stage of the TP structural synthesis, the optimal mode of operation of the chosen equipment from chosen criteria’s. Section 3 shows the solution to this problem.

### 1. Multiagent system for machine workshop work control

A multiagent system of a machine workshop has the following structure $MAS = \langle \{A^1, \ldots, A^i\}, \{K_1, \ldots, K_k\}, \{KB_1, \ldots, KB_m\} \rangle$, where $\{A^1, \ldots, A^i\}$ is a set of agents; $\{K_1, \ldots, K_k\}$ is a set formed at the specific moment of coalition; $\{KB_1, \ldots, KB_m\}$ is the MAS knowledge base. A coalition is regarded as the temporary union of a certain number of agents with the purpose of achieving a common goal, and their resources remain common. A coalition gives the agents the opportunity to come to an agreement together and create a common plan of action of how to use the common resources and means to coordinate complete all the orders. An agent coalition has the following structure $K = \langle Name, \{A^1, \ldots, A^n\}, G, \{St_1, \ldots, St_l\}, KB \rangle$, where Name is the coalition’s name; $\{A^1, \ldots, A^n\}$ is the set of agents, which are part of the coalition; $G$ is the coalition’s goal; $\{St_1, \ldots, St_l\}$ is a set of supposed strategies for the coalition’s behavior; $KB$ is the coalition’s knowledge base. Execution of the order plan $PZ = \{PZ_1, \ldots, PZ_m, \ldots, PZ_r\}$ is formed by coalitions $\{K_1, \ldots, K_m, \ldots, K_q\}$ and their goals are $\{G_1, \ldots, G_m, \ldots, G_q\}$ and consist of actions in a certain prioritized
sequence \{DK_1, \ldots, DK_m, \ldots, DK_P\}. Plan \( PZ_m \) is the structure 
\[ PZ_m = \langle \{DK_1, \ldots, DK_m, \ldots, DK_P\}, G_m, \{AD_1, \ldots, AD_n\}, KB_m, \{ZK_1, \ldots, ZK_m\} \rangle \]
where \{DK_1, \ldots, DK_m, \ldots, DK_P\} are the plan’s actions; \( G_m \) is the plan’s goal; 
\{AD_1, \ldots, AD_n\} are a set of agents carrying out the plan; \{ZK_1, \ldots, ZK_m\} are the system’s resources. The process of obtaining parts with the help of TP’s based on machine operations with the aid of machining, can be presented in the form of the following stages: 1) forming an application for parts’ production in the form of an order set \{Z_1, \ldots, Z_j\}, sorted by order of their production priority, where \( Z_j \) is the number of ordered \( j \)-type parts; 2) choice of an optimal template for the \( j \)-type part; 3) search for the basic TP manufacturer of \( j \)-type products in the database, in the form of a set of operations \( TII^j = O_1, O_2, \ldots, O_j \), where \( j_o \) is the number of operations in the basic TP for the \( j \)-type product; 4) identifying the machine which will carry out the operation in minimal time, considering all the technological limits on the quality of the as-machined service, and considering the part and instrument transportation time; 5) setting and visualizing the schedule of the workshop’s machine inventory.

The workshop’s MAS work (fig.1) can be pictured as cooperation of many agents of orders \( A^{ord}_{\text{ord}}, i = 1, \ldots, I \), where \( I \) is the number of submitted orders. \( A^i_{\text{ord}} \), which initiate the creation of parts’ agents \( A^j_{\text{dt}}, j = 1, \ldots, J \), where \( J \) is the number of required \( j \)-type parts. \( A^j_{\text{dt}} \) send queries to templates’ agents \( A^n_{\text{wp}}, n = 1, \ldots, N_{\text{wp}} \), where \( N_{\text{wp}} \) is the number of types of template for identifying the optimal templates for parts and based on TP database information, identify the basic TP of parts’ production.

Then \( A^j_{\text{dt}} \) sequentially send queries to carry out operations from the set of the basic TP to agents of the equipment (machines) \( A^m_{\text{mac}}, m = 1, \ldots, M \), where \( M \) is the number of machines, participating in the auction to carry out one TP operation. Every \( A^m_{\text{mac}} \) analyzes the query for the operation from \( A^j_{\text{dt}} \) and if the machine can execute it and is available (or will be available after a certain amount of time), then agents \( A^m_{\text{mac}} \) identify the time for operation execution on the machine. To identify the part, instrument and appliance’s delivery time \( A^n_{\text{mac}} \) send their queries for delivery to the transport robots’ agent coalition \( A^r_{\text{lr}}, r = 1, \ldots, R \), where \( R \) is the number of robots, participating in the coalitions, and which through the auction for delivery time identify the serviced machine, instrument
and machine for every robot. Each delivery time is calculated as \( A_{tr}^r \), which answers for the robot control, and the control rules depend on the robot’s brand, its’ work load, displacement speed, presence of manipulators etc.

The data received from the \( A_{mac}^m \) coalition is used during the auction for optimal allocation of all TP operations for all \( A_{dt}^j \). At the end of TP, the part’s agent makes the decisions about transporting parts to the warehouse or etc.

The objective function of the machines’ agent coalition \( A_{mac}^m \) for executing operations for producing a \( j \)-detail, for instance, can be presented as the total time for the production of a part in the form of \( G_{mac} = \sum_{m \in M} t_{mj} \Rightarrow \min \), where \( t_{mj} \) is the time for operation completion by the equipment \( m \)-agent, considering the part, instrument and appliance delivery time; \( M \) is the set of machine agents, which make up the coalition and offer to execute the operation for the \( j \)-part.

The objective function of template agent coalitions, formed for the production of \( j \)-type parts’ batch is given by \( G_{wp} = \sum_{n \in N_{wp}} d_n^j f_j \Rightarrow \min \), \( 0 \leq d_n^j \leq Z_j \), where \( d_n^j \) is the number of templates, offered by the \( A_{wp}^n \) agent; \( f_j \) is the minimal index of economic effectiveness of the \( j \)-template, defined as the difference between the production costs of \( j \)-type template batches; \( N_{wp} \) is a set of template agents, which make up the coalition and offer production from the \( j \)-template. An auction, carrying out the greedy algorithm, is implemented to find the optimal template (the auction is marked as \( \leftrightarrow \) on fig. 1).

To find the optimal machine capacity, a combinatorial auction, based on the PAUSE auction, is planned, which uses the distributed algorithm for problem solving; it’s executed in several stages and finds the quasi optimal solution (the auction is marked as \( \leftrightarrow \) on fig.1). These questions will be analyzed in the next publications.

The solution to a transport problem for a transport robot coalition, available in the current moment of time and making up the temporary coalition is shown in 9 and is executed through solving a multicritical problem of transport robots’ work optimization through forming situational robot coalitions and having these coalitions hold auctions in real time. The auction is marked as \( \leftrightarrow \) on fig.1. The choice of an optimal instrument for operation is likewise carried out based on an auction (\( \leftrightarrow \)).
The system’s simulation, which was created with the Protégé editor, the Java programming language and Jade application, showed flexibility as it dynamically reacted to changes, improves decisions in real time. The decisions made are characterized by a high reaction speed to events, short time of finding solutions and problem solving are presented in.
2. Method of solving the problem of structural optimization of the technological process of cutting

The tasks of synthesis of the technological process are solved in two stages. Stage I – structural optimization of the technological process in the form of an optimal sequence of operations of the technological process. Stage II – parametric optimization of the technological process where the search of optimal modes of operation of TP operations takes into account all the limiting factors.

When developing the technological process of cutting, technical and technological parameters of the equipment and tools, the cost of their operation, the wage costs during the operation of this equipment, the efficiency of its use for obtaining the final product with the given properties and characteristics, methods of processing, constraints on the technological opportunity take into account - transition between equipment and operations, etc. The scheme of possible optimization of the technological process shown in fig. 2.

To synthesize the optimal technological process of mechanical processing and to further efficiently manage it, it is necessary to obtain the following sequences and operating modes in which the equipment will be used with maximum efficiency and minimum processing cost.

In general, the statement of the problem of synthesis of the optimal technological process is as follows. The choice criteria for optimization for the technological process of machining \( K \) usually used either the co-cost of the product \( C_B \), or the efficiency of the \( P \). The optimal technological process of the \( T_O \) is the following \( C_B(T_O) = \min C_B(K) \), \( P(T_O) = \max P(K) \), \( T_O \in M \), where \( M \) – the set of possible variants of the technological process. The essence of search engine optimization in finding the best of the technological process, which holds inequalities:

\[
C_B(K_i) > C_B(K_{i+1}), \quad P(K_i) < P(K_{i+1}),
\]

where \( i \) – number of variants of technological processes.

Tasks of stage I – definition of structural optimization TP are often solved by three basic methods: the method of analogies, the method of analysis and the method of synthesis. The method of synthesis is based on the consistent hierarchical synthesis of the technological process, consisting of the synthesis of a series of technological operations and their distribution in time. For this, the item is divided into elementary surfaces, the intermediate states for determining the intermediate states are determined, and the methods of their processing are


selected. In this case, the dimensional bonds of the elements of the component are taken into account and the synthesis of the bases and operations structures is performed. The method is devoid of the disadvantages of the previous two methods, because: for its work it is not necessary to have knowledge bases of similar technological processes; the synthesis of TP turns out to be a completely new technological process, which is based on synthesized precisely for it operations, and not on unified standard solutions that by default assume averaging; the synthesis is performed taking into account the optimization goals relevant for this TP. In the work for the solution a method artificial intelligence methods, namely, production rules, implemented using the language of logical programming, was used. In fig. 3 shows a tree of synthesis of optimal TP production of products by mechanical cutting, consisting of 7 levels.

![Diagram of optimization process](attachment:image.png)

**Fig. 2. Scheme of optimization of the technological process of machining**
Fig. 3. Tree of synthesis of optimum TP making of products by means of mechanized cutting
Level from fig. 3: 1 – selection of workpiece; 2 – selection of technological transitions; 3 – equipment selection; 4 – selection of tools; 5 – selection of adaptations and methods of installation of the workpiece; 6 – selection of lubricating and cooling technological environment; 7 – formation of technological map. At 1, 5, 6 levels one solution is obtained, and at 2, 3, 4 levels – several alternative solutions.

On the other hand, the structural component of the TP can be represented as a set of time component of the $T_C$, which determines the composition and sequence of the elements of the technological process at each stage of product manufacturing, the functional component of $F_C$, which determines the order of transformation of the workpiece from one state into another and the spatial component of the $P_C$, which determines the dimensional and precise relationships between the base and the working surfaces $S_{sp} = \{T_C, F_C, P_C\}$. Technological information about the product (geometric dimensions, weight, material of the forging, etc.) and the structural scheme of the process $S_{sp}$ are input data for the structural synthesis of TP.

In this case, the $S_{sp}$ represents a sequence of steps $P_{i1}, P_{i2}, \ldots, P_{ij}$ for the processing of the workpiece surfaces, where $i$ is the number of stages of processing, for obtaining the part, $j$ is the surface number to be processed, $i = 1, I, \ j = 1, J \ S_{sp} = \{P_{i1}, P_{i2}, \ldots, P_{ij}\}$. Each $P_{ij}$ processing stage is a set of operations that transforms the workpiece from the state $Z_i$ to the next $Z_{i+1}$ until the end result $Z_f$ is reached $P_y = \{O_{i1}, \ldots, O_{ij}, O_{ij} \ldots, O_{ij} \}$. Each of the $Z_i$ states is described by the set of treated surfaces $G = \{G_1, G_2, \ldots, G_n\}$, where $n$ – is the surface number, $n = 1, N$, $N$ is the quantity of surfaces $Z = \{Z_1(G_1, G_2, \ldots, G_n), Z_i(G_1, G_2, \ldots, G_n), Z_j(G_1, G_2, \ldots, G_n)\}$, where $n1, n2, nI$ – numbers of internal surfaces.

The structure of the technological process $S_{sp}$ can be represented as a combination of the temporal component of the $T_C$, functional component $F_C$ and the spatial component $P_C$. 
where \( T_C \), determines the sequence of \( O_{ij} \) operations in time at each stage of the workpiece processing \( T_C = \{ P_{11}(O_{11}, O_{12}, ..., O_{1j}), P_{21}(O_{21}, O_{22}, ..., O_{2j}), ... \} \), where \( P_{ij} \) – sequence of stages of workpiece surface processing, \( i \) – the number of stages of processing the part, \( j \) – surface number to be treated, \( i = 1, I, j = 1, J \); the functional component of \( F_C \) defines the order of transformation of the workpiece from the initial state \( Z_1 \) in the final state \( Z_1 \) with a sequence of operations \( O_{ij}, O_{ij} : Z_{i-1} \to Z_i \); the spatial component \( P_C \) determines the dimensional and precise relationships between the base and the working surfaces, that is, defines the scheme of installation of the part in the tool or machine; \( K \) – number alternatives to TP.

In this case, the chosen structure of the TP variant provides the total minimum cost of the TP – \( A_k \) operation, and the minimum total specific energy costs of the operation TP – \( E_k \) and the maximum total capacity of TP operations – \( Q_k \) and is determined definitively at the second stage – the stage of finding the optimal parameters for the operations. Determining optimal operating parameters will be provided in the following works.

In the work on the first level (fig. 3), the selection \( M_{hr} \) of the workpiece is carried out according to the criterion of the minimum difference in volume, the size of the workpiece and the size of the part with consideration of the allowances for processing, and has the form

\[
M_{hr} = \min_{q_i} \left\{ M_{hrq_i} \left| \begin{array}{l}
V_{p_{q_i}} = a 
\geq 0, b \geq 0, c \geq 0, \\
|R| 
\end{array} \right\}, \phi^*_i = 1, \Phi^*_i, \phi^*_i = 1, \Phi^*_i, 
\right. 
\]

\[
a = X_{hrq_i} - (X_d + P_{proc}), b = Y_{hrq_i} - (Y_d + P_{proc}), c = Z_{hrq_i} - (Z_d + P_{proc}),
\]

where \( M_{hrq_i} \) – set of enterprise size \( \Phi_1 \); \( V_{p_{q_i}} = V_{hrq_i} - V_d \) – amount of material to be removed during processing; \( V_{hrq_i} \) – amount of workpiece; \( V_d = V_1 + V_2 + ... + V_m \) – the amount of detail that is calculated as the amount
of volumes $V_m$ shaping elements of the details; $a, b, c$ – the difference between the actual size of the workpiece and the size of the part with the addition of the feed to the processing $x, y, z$, mm; $X_{hr\phi_1}, Y_{hr\phi_1}, Z_{hr\phi_1}$ – the size $\phi_1$ harvesting, mm; $X_d, Y_d, Z_d$ – overall size of the part, mm; $P_{proc}$ – allowance for processing, mm; $R1$ – the rule determines conformity of the size of the workpiece and the part, taking into account the application to the processing, and the conformity of the steel grade of the workpiece, after which the choice is based on the minimum volume of the removed material

$$\text{If} \ (M_{hr\phi_1}(a) > 0, M_{hr\phi_1}(b) > 0, M_{hr\phi_1}(c) > 0 \land H_{st} = H_{st1}) \text{ to } M_{hr} = \{M_{hr\phi_1}\},$$

where $H_{st}$ – mark of the material of the workpiece; $H_{st1}$ – brand material details; $\Phi_1^*$ – number of elements of the set of blanks that correspond to the rule $R1$.

According to fig. 3 on the second level, the choice of a set of possible operations $M_{pp}$ for surface treatment is $M_{pp} = \{M_{pp\phi_2}[R2], \phi_2 = \overline{1, \Phi_2}\}$, where $\Phi_2$ – number of options for operations; $R2$ – the rule that takes into account the shape of the shaped surface to be treated, taking into account the possibility of substitution for an alternative kind of operation, that is, the possibility of replacing the towing by milling, milling by rolling, drilling by freeze-drawing or rolling and grinding by superfinishing turning or milling. Moreover, the choice of an alternative type of operation depends on the technical feasibility of such a substitution and type of the previous operation.

At the third level (fig. 3) the choice of a set of permissible type of equipment operation $M_{eq} = \{M_{eq\phi_3}[R3], \phi_3 = \overline{1, \Phi_3}\}$, where $\Phi_3$ – quantity of equipment; $R3$ – a rule that describes the choice of equipment by the type of operations that can be performed on the equipment, the size of the working area, the adaptations used on it, and the size and type of tool holders.

On the fourth level (fig. 3) selection of a set of permissible tool operations $M_{toh} = \{M_{toh\phi_4}[R4], \phi_4 = \overline{1, ..., \Phi_4}\}$, where $\Phi_4$ – number of types of tool; $R4$ – a rule that describes the choice of tool according to the criterion of compatibility between the size of the tool and the holder, the type of operation, the size of the material of the workpiece and the required qualification of the processing of the part.

On the fifth level (fig. 3) the definition of fitting is based on the criterion of rigidity of fastening, and has the form $M_{fit} = \max_{\phi_5} \left(\{M_{fit\phi_5}(k)[R5]\}\right)$,

$$\phi_5 = \overline{1, \Phi_5}, \overline{\Phi_5 = \overline{1, \Phi_5}}$$

where $\Phi_5^*$ – number of adaptations corresponding to the rule $R5$; $k$ – the coefficient depends on the method of fastening the part in the
cartridge; \( R5 \) – a rule that defines the fitting according to the rigidity of the fixing and the linear dimension of the part that can be fitted to it; \( \Phi_5 \) – number of possible variants of fitting.

On the sixth level (fig. 3) the definition of ICTE is based on the criterion of minimum value \( M_{ICTE} = \min \left( \left\{ M_{ICTE}(P_{ICTE}) | R6 \right\} \right), \Phi_6^* = 1, \Phi_6 = 1, \Phi_6^*, \Phi_6 = 1, \Phi_6^* \), where \( \Phi_6^* \) – the number of ICTE elements that match the rule R6; \( \Phi_6 \) – number of possible options ICTE; \( P_{ICTE} \) – cost ICTE; \( R6 \) – a rule that defines ICTE's choice for the minimum cost criterion, the possible use on the equipment chosen for the operation and with the required material for the workpiece.

At the seventh level (fig. 3) several variants of the route map of the technological process of making the product from the metal are made by cutting operations.

With this approach, the task has a multivariate solution, so the final decision on determining the necessary equipment \( M_{equipment} \) and instrument \( M_{tool} \) will be obtained after determining the optimal operating parameters, according to the criteria

\[
M_{equipment} \Rightarrow \begin{cases} 
\min(A_r(M_{eqr})), r = 1, R, \\
\min(E_r(M_{eqr})), r = 1, R, \\
\max(Q_r(M_{eqr})), r = 1, R,
\end{cases} \quad M_{tool} \Rightarrow \begin{cases} 
\min(A_p(M_{top})), p = 1, P, \\
\min(E_p(M_{top})), p = 1, P, \\
\max(Q_p(M_{top})), p = 1, P,
\end{cases}
\]

where \( A_r \) – cost of operation on \( r \)-th equipment; \( R \) – quantity of equipment; \( E_r \) – specific energy consumption on \( r \)-th equipment; \( Q_r \) – performance of operation on \( r \)-th equipment; \( A_p \) – cost of operation on \( p \)-th instrument; \( P \) – amount of tool; \( \mathcal{E}_p \) – specific power consumption on \( p \)-th instrument; \( Q_p \) – performance of the \( p \)-th instrument operation.

This allowed to determine the composition and sequence of elements of the TP at each stage of product manufacturing, the order of transformation of the workpiece from one state to another and the determined dimensional and precise relationships between the base and working surfaces were determined.

For the functioning of the system, with the production rules, a knowledge base was created that includes data on equipment parameters, workpieces, tools, IOTS, accumulated knowledge of cutting theory, experience of expert technicians, regulatory requirements, etc., using logical programming methods. For realization of the system the Visual Prolog was used.
3. Operational parameters optimization of TP machining considering accumulated wear

One of the important stages of building an effective TP control system is the II stage of the machining process operations’ optimization, thanks to which, using the data obtained on the stage of the TP structural synthesis, the mode of operation of the chosen equipment, which provides its’ optimal work from the position of the chosen criteria. The task of parametrical optimization of the machining process is a multicriterial multiparametrical optimization problem (MOP). This is due to the fact that criteria of TP optimization are often various contradictory criteria such as performance \( Q \), prime cost \( A \), quality of the finished surface etc.

Different approaches and methods are applied in solving MOP: the generalized criteria method (additive criteria, multiplicative criteria); the “convolution” method (method of stepwise concession, main criteria method); the special method of solving multicriterial problems (lexicographical method, search of a Pareto optimal solution).

To obtain numerous MOP TP solutions, algorithms in which Pareto’s domination concept is explicitly used, for example, VEGA, FFGA, NPGA, SPEA.

The value of the instrument’s accumulated wear \( h_z \) has the biggest effect on the change of the machining process’ output parameters. This is because with the same input operational parameters, the level of machining force, the finish of the processed surface, the temperature in the machining zone, dimensional accuracy of the acquired part, etc., all depend on the level of wear. The innovation in this approach is the consideration of the value of the instrument’s present accumulated wear, which allows receiving a more adequate mathematical model physically, and thus, a physically more realistic optimal MOP solution.

When posing problems of machining processes’ parametrical optimization, 4 objective functions are examined, based on the example of the clean machining.


\footnote{Албагачев А.Ю., Султан-Заде Н.М. Теоретические основы металлообработки в машиностроении. Старый Оскол, ТНТ, 2014. 552 с.}

operation: operation prime cost $A$, energy demands $E_z$, dimensional accuracy $\Delta_{\Sigma}$, activity throughput $Q$ and 10 limitations: in the electric motor power of the main motion drive machine $N_{dv}$; in the minimal and maximum machining speed $V$; in the minimal and maximum feed rate $S$; in the durability of the machining instrument (by maximum strain $\sigma_{\text{max}}$); in the stability of the machining instrument (deflection $f_i$); in the template stability (deflection $f_z$); in the stability of the longitudinal feed mechanism of the machine (maximum force $F_{xd}$); in the finish of the completed surface $R_a$.

The optimal solution is identified through the process of minimization (maximization) of the respective objective functions or their combinations through the search of an optimal combination of variate parameters of feedrate $S$ and machining speed $V$ within the margins of the operation of processing every consecutive part.

The objective functions examined in the paper are as follows\(^6\):

$$A = \frac{l_z}{S} \left( a_{rab} + a_{\exp} + \frac{e}{T_{ef}} + \frac{q_e F_z V}{6 \cdot 10^4 \eta_{st}} \right) \Rightarrow \min, E_z = \frac{F_V}{6 \cdot 10^4 \eta_{st}} \Rightarrow \min,$$

$$\Delta_{\Sigma} = \frac{F_y l_z^3}{k_z E_z I_z} \Rightarrow \min, Q = \frac{St}{l_z \Delta} \Rightarrow \max,$$

where $l_z$ is the template length, mm; $a_{rab}$ is the employee’s salary per minute, UAH/min; $a_{\exp}$ is the expenses on machine service, UAH/min; $e$ is the instrument cost, UAH; $T_{ef}$ – is the time of effective instrument service (effective durability period), min; $q_e$ is the cost of one kWatt/hour electricity, UAH; $F_z$ is the tangential machining force, $N$; $\eta_{st}$ is the machine’s efficiency; $F_y$ is the machine’s radial force, $N$; $k_z$ is the coefficient, which depends on the method of template securing; $E_z$ is the template’s Young’s modulus, MPa; $I_z$ is the moment of inertia of the template’s cross section, mm\(^4\); $t$ is the machining depth, mm; $\Delta$ is the allowance, mm.

The limits in solving MOP are presented in the functions:

$$N_{dv} = \frac{F_V}{60 \cdot 10^4 \eta_{st}} \leq N_{dp}, V_{\min} \leq V \leq V_{\max}, S_{\min} \leq S \leq S_{\max}, \sigma_{\text{max}} = \frac{F_i}{k_{\exp} W_i} \leq [\sigma_i].$$

$$f_i = \frac{F y l_z^3}{3 E_i I_i} \leq f_{id}, f_z = \frac{F y l_z^3}{k E z I_z} \leq f_{zd}, F_x \leq F_{xd}, R_a(V, S, t, h_z) \leq R_{a_{\text{max}}},$$

where: $N_{dp}$ is the machine electric motor’s documented maximum consumption capacity, kWatt; $V_{\text{min}}$ is the minimal allowed machining velocity, m/min; $V_{\text{max}}$ is the maximum allowed machining velocity, m/min; $S_{\text{min}}$ is the minimum allowed machine feed rate, mm/min; $S_{\text{max}}$ is the maximum allowed machine feed rate, mm/min; $k_z$ is the assurance factor; $W_i$ is the Z-modulus of the tool rest holder, mm$^3$; $[\sigma_i]$ is the working pressure of the tool rest holder, MPa; $l_i$ is the tool rest holder’s length, mm; $E_i$ is the elasticity of the tool rest holder material, N/mm$^2$; $I_i$ is the second area moment of the tool rest holder, mm$^4$; $f_{zd}$ is the allowed flexibility of the tool rest holder, mm; $f_{zd}$ is the allowed flexibility for the template, mm; $F_x$ is the axial force, N; $R_{a_{\text{max}}}$ is the maximum allowed finish of the processed surface, mkm.

It’s important to note that the working (output) parameters of the processing process, such as the time of effective service of the instrument $T_{ef}$, cutting force $F_z$, $F_y$, finish of the processed surface $R_a$ etc. depend on variate parameters $S$ and $V$ and the accumulated wear of the back surface of the machining instrument $h_Z$. In its’ turn, the change of wear $\Delta h_Z$ for the time of processing one template is defined by the level of the wear accumulated earlier and operational parameters $S$ and $V$. Separate functional dependencies for output parameters are described analytically, and in most practical cases, experimental-analytical or simply experimental functions are used$^7$.

The obtained model of the sharpening process has the 41 input parameters, 80 process parameters are calculated. As mentioned earlier, one of the problems, which appear when solving the given problem, is that for several parameters in the mathematical model, the function, which describes them with a high level of accuracy, is hard to formalize, or the applied functions contain empirical coefficients, obtained through a large number of experiments. Thus, to obtain a set of functions, an ANN perceptron with back propagation of error was employed. Data from was approximated with the help of ANN to define $h_Z$ and $R_a$.

The calculation of the optimal mode for a clean sharpening operation is given as an example for “Filter housing”. As an example, fig. 4–5 uses the approximation results using ANN experimental data from to obtain formulas $h_Z = h_Z(S, V, t)$ and $R_a = R_a(S, V)$ with a fixed machining depth. When approximating data with the help of ANN, it was possible to obtain a maximum operational margin of 2–3%.


Song W. Development of predictive force models for classical orthogonal and oblique cutting and turning operations incorporating tool flank wear effects. PhD, Queensland University of Technology, 2006. 208 p.
In this paper, as a practical example, the calculation of the optimal mode for processing of thin sharpening \((A = t)\) with input process parameters: template material – steel 52100; machining velocity \(V = 1–400\) m/min; machine feed velocity \(S = 0,1–0,24\) mm/revolution; machining depth \(t = 0,1\) mm; template length \(l_z = 70\) mm, diameter \(D = 100\) mm; maximum allowed finish of processed surface \(R_{amax} = 64\) µm; employee’s salary per minute \(a_{rab} = 0,83\) UAH/min; expenses on machine service \(a_{exp} = 8,5\) UAH/min; instrument cost \(e = 1250\) UAH; cost of one kW/h of electricity \(q_e = 1,56\) UAH; template’s Young’s modulus \(E_z = 2 \cdot 10^5\) MPa; coefficient, depending on the method of template securing \(k_z = 2\); the elasticity of the tool rest holder material the elasticity of the tool rest holder material \(E_i = 2 \cdot 10^5\) MPa; instrument – TR20 nose radius 0,8 mm; machine – Picomax 60-M.

The technical specification for the machine and instrument is taken from the respective technical documentation. The maximum value \(V\) is limited to 400 m/min as at a higher speed, the temperature which appears as a result of machining, leads to irreversible changes in the party’s top layer. The time of effective instrument service \(T_{ef}\) was calculated as the time of the instrument’s working capacity (upon reaching terminal wear) or upon reaching maximum allowed operation prime cost.

To find a Pareto-optimal solution in a combination of all objective functions, one of the AI methods – Fonseca and Fleming’s Multiobjective Genetic Algorithm (FFGA), was implemented\(^8\). MAP was solved, taking into consideration all 4

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objective functions with their equal relevance (each function’s weight is equal to 1). The table shows the solution for the case of a sharp instrument \( h_Z = 0 \) mm and an instrument with significant wear \( h_Z = 0.2 \) mm; 0.4 mm).

Table 1

<table>
<thead>
<tr>
<th>Instrument parameters</th>
<th>Operation prime cost ( A ), UAH</th>
<th>Energy consumption ( E_Z ), kW</th>
<th>Activity throughput ( Q ), ( \text{min}^{-1} )</th>
<th>Machine feed velocity ( S ), mm/rev</th>
<th>Machining speed ( V ), m/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sharp instrument ( h_Z = 0 ) mm</td>
<td>2.42</td>
<td>3.337</td>
<td>7.05</td>
<td>0.17</td>
<td>200</td>
</tr>
<tr>
<td>Instrument with wear ( h_Z = 0.2 ) mm</td>
<td>2.15</td>
<td>3.82</td>
<td>6.77</td>
<td>0.155</td>
<td>275</td>
</tr>
<tr>
<td>Instrument with wear ( h_Z = 0.4 ) mm</td>
<td>2.29</td>
<td>4.268</td>
<td>5.4</td>
<td>0.141</td>
<td>315</td>
</tr>
<tr>
<td>Stability of the tool ( T_{EF} ), min</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>416</td>
</tr>
<tr>
<td>Number of parts processed for ( T_{EF} ), pieces</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2672</td>
</tr>
</tbody>
</table>

The results that were obtained at this stage allow us to conclude on the effectiveness of the proposed approaches and methods. Comparison of the obtained results with similar ones for the basic technological process used at the enterprise showed a decrease in the cost of production of products from 613 to 527 UAH. (14%) and the time spent on the production of one part – from 66 to 62 minutes (6%).

CONCLUSIONS

This paper examined planning optimal workload of a machine workshop and suggested a DSS, based on a multiagent approach, considering the aspects of TP machining. The objective functions of a coalition, which execute the production plan and agents’ objective functions, were identified. Methods for solving problems of searching for optimal solutions on all stages of manufacturing production batches were found.

A multi-criteria parametric optimization problem for machining processes was presented and solved, taking into account the current accumulated wear of the tool on the example of surface treatment of the “Filter housing” product.

SUMMARY

The proposed methods and approaches, despite the complexity of their implementation, have shown good results for this task and the promise of their application in other areas of science and technology. In the future, it is planned to conduct a study to simulate the work of intelligent agents in emergency situations.
In the future, it is planned to conduct a study to simulate the work of intelligent agents in emergency situations.

REFERENCES


17. Song W. Development of predictive force models for classical orthogonal and oblique cutting and turning operations incorporating tool flank wear effects. PhD, Queensland University of Technology, 2006. 208 p.


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