Methods for modernization of processing equipment

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Abstract. Industry dynamics determines the improvement of manufacturing processes and necessarily implies the development and evolution of technological equipment for machining, assembling and controlling. The modern technological concept requires multicriteria optimization of the technological system, emphasizing its ability to adapt precisely, quickly and efficiently to the variation of production tasks. This paper proposes a combined method of optimization of technological processes capable of overcoming the difficulties caused by the complexity, diversity and dynamic character of the processing equipment in order to make objective technical and economic decisions. The in-depth analysis of optimization problems for technological processes and equipment is required by the need to respect the multitude of conditions and their interdependence and has as main objective the establishment of rational solutions in the field of manufacturing engineering. For a technological process, in the first stage, based on a technological chart, several processing procedures are analyzed depending on the complexity of the semi-finished products and the type of machine-tool used, and with the mathematical model associated determine the number and optimal sequence of operations. In the second stage, an optimal variant of the process, presented as a combination of processing procedures, is analyzed with the global utility method, especially in the nodes with several operations, as special or modular structures and the optimal solution for the construction of the devices and machines-tools, technological equipment in general.

1. Introduction
The modernization of the manufacturing processes is certainly conditioned by the increase in the performance of the technological equipment for processing, assembling and control. Achieving this goal is possible if new solutions are also promoted in the field of technological devices, but also through the development of special or modular components for the modernization of machine-tools.

This paper proposes a combined method of optimization of technological processes and equipment, able to overcome the general difficulties of their complexity, diversity and dynamic character, in order to make objective technical and economic decisions.

2. Methods for optimization of technological processes and modernization of manufacturing equipment
The multitude of devices, machinery and manufacturing systems, and technological processes, are creating major challenges in establishing rational solutions for technological equipment, which can only be overcome with the help of optimization methods [1 - 5]. For these reasons, it is proposed to optimize the technological process with the technological chart method, to optimize the development of new structures with innovative methods and techniques [4, 6], but also to optimize the construction and configuration of complex equipment with the global utility method.
2.1. The general design-optimization algorithm for process and technological equipment

For an in-depth analysis of the technical-economic problems in the field of manufacturing technologies and the establishment of rational solutions, is proposed the general design-optimization algorithm for the processing, assembling or control processes and equipment presented in figure 1.

The notations have the following meaning:

**N<sub>01</sub>- Process optimization level (POL)**

- **E<sub>01</sub>- Analysis of the technical documentation of the workpiece;**
- **E<sub>02</sub>- Identification of the required technological operations;**
- **E<sub>03</sub>- Determining the optimal succession of operations with the technological chart method;**
- **E<sub>04</sub>- Preparation of the technological documentation for the analyzed piece;**
- **E<sub>05</sub>- Characteristics of tools, devices and machines that equip the technological process;**

**N<sub>02</sub>- Structure optimization level (SOL)**

- **E<sub>06</sub>- Analysis of existing structures for the construction of devices, tools and machinery;**
- **E<sub>07</sub>- Developing new structures with features and performance superior to existing ones;**

**N<sub>03</sub>- Optimization of complex technological equipment level (OTEL)**

- **E<sub>08</sub>- Defining the characteristics and performance of the technological equipment;**
- **E<sub>09</sub>- Encoding the structures of the technological equipment;**
- **E<sub>10</sub>- Setting optimization criteria;**
- **E<sub>11</sub>- Choosing the optimization method;**
- **E<sub>12</sub>- Defining the centralized table of the analyzed variants;**
- **E<sub>13</sub>- Selecting construction options;**
- **E<sub>14</sub>- Establishing the optimal version of the construction of the technological equipment.**

2.2. Determining the optimal succession of operations and types of structures that equip the technological process

In the paper [1,4], the complex optimization of technological processes and equipment is the rational solution to these problems.

For this purpose, we present the design-optimization algorithm, customized in the case of a process and technological equipment for machining by cutting.

**N<sub>01</sub>- Process optimization level (POL)**

The optimal number and sequence of technological operations and the need for tools, devices, systems, machine-tools or other manufacturing equipment are analyzed and determined.

- **E<sub>01</sub>- Analysis of the technical documentation.** It analyzes the execution drawing of the workpiece, its assembly drawing, the required production volume and the technological conditions (devices, equipment, machinery).
- **E<sub>02</sub>- Identification of the required operations.** The numbering of the workpiece surface and the identification of the technological operations are done for their realization.
- **E<sub>03</sub>- Determining the optimal succession of operations**
  - The optimal sequence of the number of operations required to achieve the surfaces of the piece is determined using the technology chart method [1].
Column vector $X$ is expressed in relation 2.1, which describes the set of processing procedures initially specified:

$$X = [x_1, x_2, x_3, \ldots, x_n]^T$$  \hspace{1cm} (2.1)

The components of vector $X$ are bivalent variables associated with processing and have the value:

$$x_j = 1 \text{ or } 0, \ j \in \{1, 2, 3, \ldots, n\}$$  \hspace{1cm} (2.2)

Is considered $x_j = 1$, when the process is optimal and $x_j = 0$, when it is not.

Note with $C$ the vector line whose components represent the processing costs from relation 2.3 for the processes encoded with $x_1, x_2, x_3, \ldots, x_n$.

$$C = [c_1, c_2, c_3, \ldots, c_n]^T$$  \hspace{1cm} (2.3)

The mathematical model associated with the problem is expressed with the relation 2.4:

$$\begin{cases} \min(C \cdot X) = \min \left( \sum_{j=1}^{n} c_j x_j \right), j \in \{1,2,3,\ldots,n\} \\ F_i(X) \ \text{Rel} \ O, \ i \in \{1,2,3,\ldots,l\}; x_j = 1 \text{ or } 0 \end{cases}$$  \hspace{1cm} (2.4)

where: $CX$ is the objective function of the problem; $F_i(X)$ represent the conditions (restrictions) of the problem; Rel O is the relational form operator $<, =, >, \leq, \geq$.

For a technological process, the set of processing (operations) variants, expressed by the encoded processes initially specified by matrix $X$, can be expressed by the technological graph in figure 2.

The graph nodes represent the moments of transformation of the geometry of the piece, $M = \{1,2,3,4,\ldots,m\}$, and the operations, encoded with $x_j$, are the arcs of the graph shaped $(x_1, x_2, x_3, \ldots, x_n)$.

To formulate the mathematical model, insert the matrix $A$ of the applied methods, with $m$ lines and $n$ columns, the positive part of which is $A^+$, and square matrices $T_c, R_c$ of the capable tolerances and roughness, line matrices $T_p, R_p$ of the prescribed tolerances and roughness, then write the system of inequalities as in relation 2.5 and resolve, respecting the conditions $\sum x_j = 1, \ x_j = 1 \text{ or } 0$.

$$\begin{cases} \min(C \cdot X) \\ A^+ \cdot X = U \\ A^+ \cdot (T_c \cdot X) \leq T_p \\ A^+ \cdot (R_c \cdot X) \leq R_p \\ x_j = 1 \text{ or } 0 \end{cases}$$  \hspace{1cm} (2.5)

The optimal variant of the technological processes is a combination of procedures (operations) of the form presented in relation 2.6.

$$VO_{pt} = [x_a, x_j, x_4, \ldots, x_{n+1}]$$  \hspace{1cm} (2.6)

$E04$ Preparation of the technological documentation. An operating plan or a simplified technological sheet is being prepared.

$E05$ Characteristics of tools, devices and machines. Establishing the main features and the need for tools, devices and equipment that equip the technological process.
\textbf{N02- Structure optimization level (SOL)}

Existing structures are being analyzed and used or new structures are being developed for construction of technological equipment.

\textbf{E06- Analysis of existing structures}, for the construction of the necessary devices, tools and systems, which can assure the conditions required for performing operations on a particular machine type.

\textbf{E07- Developing new structures} with features and performance superior to existing ones, for making devices, tools and processing systems using inventive design methods and techniques [4,6].

\textbf{N03- Optimization of complex technological equipment level (OTEL)}

New structures are being developed and machine-tools and complex processing equipment are configured.

\textbf{E08- Characteristics of the technological equipment}. The type, structure, functions, characteristics and performance of the complex technological equipment required for the analyzed operations are defined.

Depending on these requirements, the Presentation Sheets are evaluated with the features of known structures described in some papers [7, 8], or new structures [9, 10, 11] with features, functions and performance superior to existing structures will be developed to configure the technological equipment.

\textbf{E09- Encoding the structures}. Coding variants of structures for the construction and configuration of specific technological equipment (devices, systems, machine tools, complex machines).

If we propose the construction of a complex machine tool on the minimal structure of a normal lathe, knowing the method of processing established in the optimized technological process, coding the variants of structures to be attached to the machine-tool in the areas that ensure, from the point of view cinematic and technological, the realization of the processing phases of the analyzed operation.

Possible variants of structures that can compose this complex machine tool are marked with $x_{ij}$, where $i = 1, 2, ..., m$; $j = 1, 2, ..., n$. In which: $m$ is the number of the type of structures that will be attached to the machine tool $(S_1, ..., S_m)$; $n$ is the number of constructive variants associated with each type of structure $S_1, ..., S_m$, in form of $x_{1n}, ..., x_{mn}$.

For this type of machine tool, coding structural variants is:

- $S_1$: Spindle
- $S_2$: The lathe
- $S_3$: Guides, instead
- $S_m$: The lathe trolley,

$trolley$, top, front of mobile doll \ldots top, back

$x_{11}, x_{12}, ..., x_{1n};$ $x_{21}, x_{22}, ..., x_{2n};$ $x_{31}, x_{32}, ..., x_{3n};$ \ldots $x_{m1}, x_{m2}, ..., x_{mn};$

\textbf{E10- Optimization criteria}. The criteria for technical and economic optimization specific to the equipment analyzed are established. The most important and relevant criteria chosen for the optimization and upgrading of technological equipment are related to precision ($\varepsilon$), productivity (p), flexibility (f), the manufacturing preparation time (t), behaviour in service ($e$) and the cost of structures (c), which have values established with the calculations presented in the papers [2, 8].

The precision is an important and eliminatory criterion, quantified as error of structure construction ($\varepsilon$), which must comply with the condition:

$$\varepsilon^{sp}_{i} < \varepsilon^{sp}_{ad}$$

where: $\varepsilon^{sp}_{i}$ - orientation-positioning error of construction structure; $\varepsilon^{sp}_{ad}$ - orientation-positioning error of admissible structure.

\textbf{E11- Choosing the optimization method}. In order to determine the optimal solutions of the variants of structures designed for the construction of this equipment, we have customized the method of global utility to the case analyzed with the following route:

- a range of variation is chosen $\{0 \ldots 1\}$ of the coefficients of importance, denoted by $u(vi)$;
- the value 1 of the most favourable decision consequence, denoted by $u(vi)=1$, and the most unfavourable consequence, the value 0, $u(vi)=0$;
- the other utilities are calculated by interpolation.
**E12- Centralized table.** Build and complete the centralizing table 1 of optimization variants and criteria with the variants of coded structures \(x_{ij}\) of the types of structures \(S_1, \ldots, S_m\), optimization criteria (\(e, p, f, t, c\) and \(c\)), with their actual and permissible values, but also of the coefficients of importance (\(CI\)), depending on how a variant is related to the criterion analyzed.

If we are interested in the decision criteria differently, for each criterion we introduce a correction coefficient (hierarchy) \(k_c\), depending on their importance.

To simplify the presentation, in table 1, three optimization criteria are completed (precision- \(C_{pr}\), flexibility- \(C_f\), cost- \(C_e\)).

When complex equipment is intended to upgrade a machine tool, it is introduced in the centralizing table 1, an additional optimization criterion specific to machine tools, \((C_{s^5}^{M-U})\), which appreciates the variety of operations that can be performed on that machine.

**Table 1. Centralizing table of constructive variants and optimization criteria**

| Nb. | Structure variants \(x_{ij}\) for \(S_1, \ldots, S_m\) | Precision criteria \(C_{pr}\) | Technical- economic criteria | Specific criteria \(c_{M-U}\) | Decision |
|-----|---------------------------------|-----------------|-----------------|------------------|----------|
|     | \(e_{op}^{c_{pr}}, e_{ad}^{p}\) | \(k_e^{c_{pr}}\) | \(k_e^{p}\) | \(k_e^{c}\) | \(k_e^{c_{pr}}\) | Max V |
|     | Actual values | \(Cl_{pr}\) | \(k_e^{c_{pr}}\) | \(Cl_{pr}\) | \(k_e^{p}\) | \(Cl_{pr}\) | \(k_e^{c}\) | \(Cl_{pr}\) | \(k_e^{c_{pr}}\) | \(Cl_{M-U}\) | \(k_e^{M-U}\) | Optimum |
| 1.  | \(x_{11}\) | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 2.  | \(x_{21}\) | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 3.  | \(x_{m1}\) | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| n.  | \(x_{mn}\) | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

**E13- Selecting options.** In order to establish the optimal solution for the construction of the technological equipment, the relations 2.8, 2.9, 2.10 are proposed for the selection of structures.

\[
\text{MaxVS}^{c_{pr}}[\text{CI}_{pr}^{1j} \cdot k_e^{c_{pr}}(\text{CI}_{pr}^{1j} \cdot k_e^{c_{pr}} + \text{CI}_{pr}^{1j} \cdot k_e^{c}) \ldots ; \text{CI}_{pr}^{mj} \cdot k_e^{c_{pr}}(\text{CI}_{pr}^{mj} \cdot k_e^{c_{pr}} + \text{CI}_{pr}^{mj} \cdot k_e^{c}) ; \ldots ; \text{CI}_{pr}^{in} \cdot k_e^{c_{pr}}(\text{CI}_{pr}^{in} \cdot k_e^{c_{pr}} + \text{CI}_{pr}^{in} \cdot k_e^{c})] \tag{2.8}
\]

\[
\text{MaxVS}^{c_{pr}}[\text{CI}_{pr}^{2j} \cdot k_e^{c_{pr}}(\text{CI}_{pr}^{2j} \cdot k_e^{c_{pr}} + \text{CI}_{pr}^{2j} \cdot k_e^{c}) \ldots ; \text{CI}_{pr}^{mj} \cdot k_e^{c_{pr}}(\text{CI}_{pr}^{mj} \cdot k_e^{c_{pr}} + \text{CI}_{pr}^{mj} \cdot k_e^{c}) ; \ldots ; \text{CI}_{pr}^{in} \cdot k_e^{c_{pr}}(\text{CI}_{pr}^{in} \cdot k_e^{c_{pr}} + \text{CI}_{pr}^{in} \cdot k_e^{c})] \tag{2.9}
\]

If the variants of structures are to be attached to a machine-tools relations, for \(S_2\), are:

\[
\text{MaxVS}^{MU}_{2j}[\text{CI}_{pr}^{2j} \cdot k_e^{c_{pr}}(\text{CI}_{pr}^{2j} \cdot k_e^{c_{pr}} + \text{CI}_{pr}^{2j} \cdot k_e^{c}) \ldots ; \text{CI}_{pr}^{mj} \cdot k_e^{c_{pr}}(\text{CI}_{pr}^{mj} \cdot k_e^{c_{pr}} + \text{CI}_{pr}^{mj} \cdot k_e^{c}) ; \ldots ; \text{CI}_{pr}^{in} \cdot k_e^{c_{pr}}(\text{CI}_{pr}^{in} \cdot k_e^{c_{pr}} + \text{CI}_{pr}^{in} \cdot k_e^{c}) + \text{CI}_{MU}^{2j} \cdot k_e^{c_{pr}}] \tag{2.10}
\]

Similarly, computational relations are written for other types of structures \(S_3, S_4, \ldots, S_m\), where: \(\text{MaxVS}_{3j}, \text{MaxVS}_{4j}, \ldots, \text{MaxVS}_{mj}\) - the maximum value of the coefficients of importance for the variants \(x_{ij}\) of the types of structures; \(\text{CI}_{pr}^{3j}, \ldots, \text{CI}_{pr}^{mj}, \ldots, \text{CI}_{pr}^{inj}\) - the importance coefficients for variants of structures specific to the optimization criteria; \(k_e^{c_{pr}}, k_e^{c_{pr}}, k_e^{c}\) - correction coefficients.

**E14- Establishing the optimal version of the construction of the technological equipment.** The optimal variant is a combination of structures that meet the maximum condition of the calculated coefficients with the relation 2.8, 2.9, 2.10:
\[
\text{VOC}_{\text{ET}} = \text{MaxVS}_1 + \text{MaxVS}_2 + \ldots + \text{MaxVS}_m + \text{MaxVS}_{\text{MU}}
\]  
(2.11)

3. Construction of technological equipment
A structure developed on the basis of these methods for the modernization of normal lathes is the multifunctional drive device [12] of figure 3 placed on the support 5 instead of the movable doll, which from an electric motor 2, the transmission through the belts 4, the main spindle in the body 3, rotating movement at various tool groups 1. The pieces oriented and fixed on the devices positioned on the lathe carriage alternately move for machining to this drive and on the opposite side to the tool groups of the main spindle.

4. Conclusions
The evolution of manufacturing processes is related to modernization of technological equipment for processing, assembling and control. The design-optimization methods and algorithm presented in this paper are an original approach that enables the development of new structures for the construction of complex tools, devices, systems and equipment with better characteristics and performances, even at the design stage of the technological process. A case study for an industrial application is completed and will be published in the next paper at a conference of scientific communications.

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