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Synergy Related Issues In Multi-Criterial Designing Of Technological Processes

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Abstract. A technological process may be realised according to various criteria, with the use of various methods and with the help of various technical measures, i.e. multi-alternatively. The objective of the paper is to determine the relations between the number of the assumed criteria and the optimal number of the assumed alternatives at defined synergy and coherency coefficients.

1. Introduction

The contemporary designing and planning of the production process should take into account all elements of the planned technology that affect the quality of the finished product, the speed of realization of the production process, and consequently, the delivery time. Evaluation of the effectiveness of a technological process is a complex task, involving analyses of criteria according to which it is possible to realise any arbitrary technological processes. Basically, two criteria, i.e. costs and time, are taken into account, and sometimes also the criterion of energy efficiency. Designing and planning of the production process should also take into account all the problems concerning the design of machine components, also in terms of multi-criterial and multi-variant designing.

Technological preparation of production should be preceded by a full analysis of the technological documentation from the point of view of standardization, unification, rational selection and material savings as well as optimal development of semi-finished products with the use of various types of treatment technologies [1]. The analysis should take into account the impact of the applied technology on the environment where the production process is to be implemented. Optimizing the designing process, in turn, should be based on the analysis of the criteria according to which the planned production will be realized.

It is necessary, therefore, to optimize and systematize the production process yet at its conceptual stage playing a significant role in reducing the quantity of media involved in the production process. Thus, such an analysis should take into account three fundamental criteria, i.e. costs, time and energy efficiency.

The analysis should also take into account the relationship between the number of adopted criteria and the optimal number of accepted technological alternatives at defined ratios of synergy and coherency between the parameters for the implemented technology and its optimization.

2. The analysis of basic concepts [2,3,4]

Synergy – means a collaboration of various factors, which add up more to the whole than the sum of individual separate activities. The term is a general concept and applied in various fields.

Technical synergy, on the other hand, is a mutual interaction between more than two technical factors (parameters).

In terms of organization, synergy means that separate departments of an organization cooperate, and through the mutual influence they become more efficient than if they worked separately. For instance, if each department of a small company collaborates with one financial department, their efficiency would be greater than if each department had their own financial section.

In technology, synergy is advantageous due to the positive difference between the result obtained thanks to cooperation on the one hand and a total result of occurrence of separated and isolated parameters on the other hand. When the difference is negative, then dis-synergy occurs.

Synergism – means a collaboration of two or more factors e.g. components, substances, manufacturing processes [2,3,4].

Prof. Burakowski singled out three basic types of synergies, namely [1,5]:

- *Total synergism*, when :

$a > (a_1+a_2)$ (i.e. when „2+2=>4") (1)

where: a- a factor of a process (e.g. process parameter) – global (general) effect
a_1 – process parameter (factor No. 1)
a_2 – process parameter (factor No. 2)

- *Additive synergism***,** when:

$a = (a_1+a_2)$ (i.e. when „2+2=4") (2)

- *Subtractive synergism*, when:

$a < (a_1+a_2)$ (i.e. when „2+2=<4") (3)

Thus, total synergism occurs when at least two factors interact positively with a result greater than the sum of their separate interactions. Subtractive synergism occurs when at least two factors interact positively with a result lesser than the sum of their separate interactions but greater than a separate interaction of each of the factors apart.

A situation when the factors (parameters) do not affect each other's performance may be referred to as a neutralism, i.e. when [5]:

„2+2=4" (4)

whilst the situation when the factors reduce the effect of each other's performance may be referred to as antagonism, i.e. when [5]:

„2+2<2" (5)

Obviously, antagonism is the opposite of synergism.

It should be noted, however, that synergism involves the occurrence of at least two factors (at least two constraints, two parameters). In the case when two factors occur, synergism is referred to as double-factor synergism [2÷5]. Assuming one factor (parameter) a_1, and the other a_2, and their synergistic effect a, it is possible to determine the synergy ratio as follows [2÷5]:

$$k_{a_1} = \frac{a}{a_1} \tag{6}$$

$$k_{a_2} = \frac{a}{a_2} \tag{7}$$

when synergism is the effect of interaction of more than two factors, then the respective synergy ratios may take the form :

$$k_{a_1} = \frac{a}{a_1},\ k_{a_2} = \frac{a}{a_2},\ ....,\ k_{a_x} = \frac{a}{a_x} \tag{8}$$

In technology, the effect of, at least, two factors on a given system may alter one or more features of this system, in other words may alter its characteristic.

2.1. Types and measurements of synergism [2]

Synergism results in a better efficiency (increased mechanical properties) than the sum of their separate performance. It is equal to the sum of their separate performances and sometimes may be less efficient but always greater than separate performance of single factors. In all the cases, new properties may be obtained (properties which do not occur at operation of a single factor). Thus, it is possible to differentiate (e.g. for a determined property a**)** Hence it stands out (for example, for a specific property a) [2]:

- *synergism total (full), the so-called „effect 2+2 = 5" for a > (a1 + a2),*
- *synergistic additive (additive), the so-called „effect 2+2 = 4" for a =(a1 + a2),*
- *synergism incomplete (incomplete), the so-called "effect 2+2 = 3" for a < (a1 + a2).*

Fig. 1 presents a graphical interpretation of synergism in engineering.

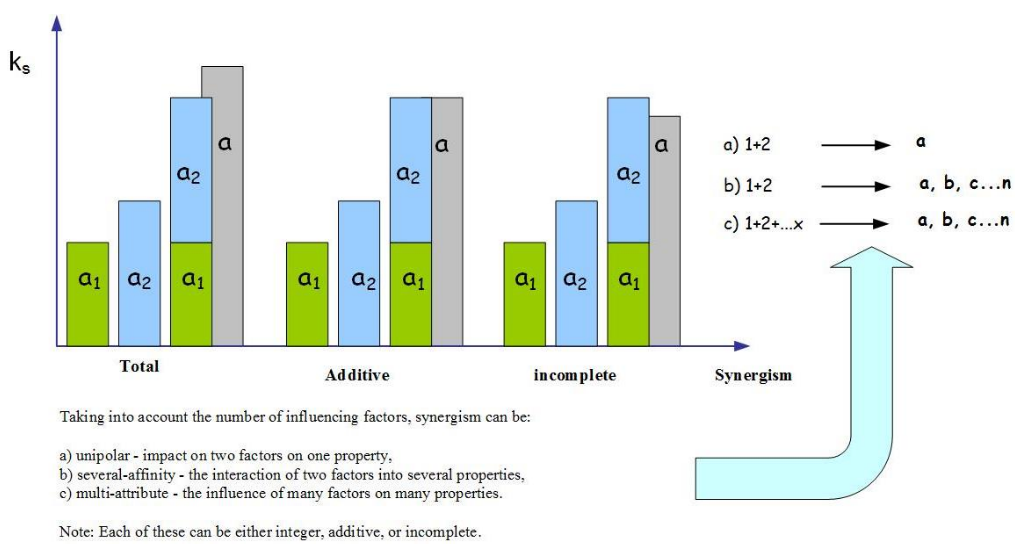

Fig. 1. Graphical representation of synergism in engineering [2]

2.2. Synergism in engineering

Considerations of technical synergism may be presented on the example of the determination of properties of a surface layer (WW).

The properties of non-modified surface layers may turn out to be insufficient for their exploitation and so they are subject to modification with the use of various technologies [2, 4, 6÷7].

A technological process of manufacturing a product includes a range of technologies (operations, treatments and transitions), applied in a certain order which results in alterations in a whole object or in a part of its volume. Thus, a given technological system describes synergism of a manufacturing technology (Fig. 2) [2].

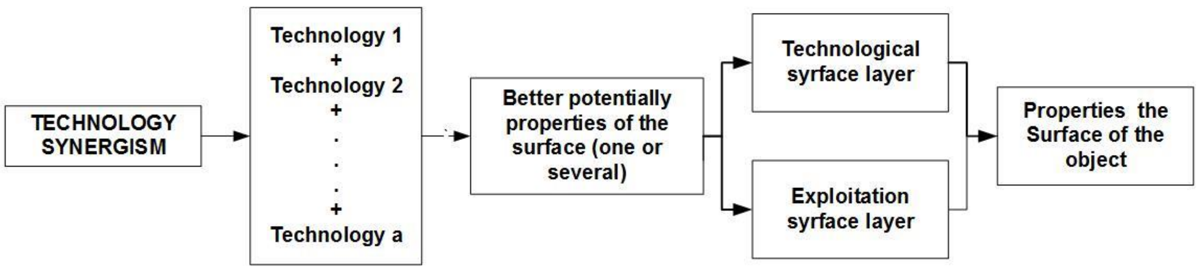

Fig. 2. A structure of synergism of manufacturing [2]

A required state of surface subjected to exploitation (at a given external constraints) requires proper selection of the number of technologies and the order of their application (1,2.3. ...n) to obtain the effect of synergy.

Synergism in engineering is, thus, the effect of interactions of the subsequent technologies of the manufacturing process on the properties of the resultant object.

All methods of technological manufacturing of a surface layer, depending on the phenomena prevailing or the type of physical or chemical effect on the core or surface, can be divided into 6 groups [2,3,4]:

1. *mechanical* — uses the pressure of a tool (machining) or the pressure and kinetic energy (shot peening) in order to cold strengthen the metal surface layer,
2. *thermal* — uses phenomena related to thermal operations such as: laser, electron, plasma or arc heating,
3. thermal-*chemical* — uses joined interaction of heat and chemical medium active for the processed material, e.g. nitriding, galvanising,
4. *electrochemical* — it uses electrochemical reduction (electrolytic coating),
5. *chemical* — uses chemical reactions (paint coatings),
6. *physical* — uses various physical phenomena taking place under atmospheric pressure or reduced contribution of ions or metallic or non-metallic element.

It is impossible to apply a single method to manufacture an object of required properties. It is always necessary to apply a number of technologies, and the order of the applied technologies (operations, treatments, and transitions) can not be arbitrary (tab. 2.1.) [3,4].

Table 1 presents values of ratios of synergy of hardness for a selected surface of an object made of 30HGSA alloy, whose surface layer was modified.

It should be emphasized that the correctly elaborated production process, starting with the correctly designed structure of a product, through manufacturing, and finally – correctly elaborated exploitation process – determines the type of synergism (total, additive or subtractive) that occurs between the considered technologies.

Further example of the considered task – synergism related to resistance to wear of friction surfaces (Tab. 2).

Tab. 1. Examples of synergy ratios obtained through the application of various treatment technologies [2,4]

Type of steel	**Method of modification of the surface layer**	**Surface hardness [HV]**	**Ratio of synergy of hardness [k_H]**
30HGSA	normalizing	236	1,00
	normalizing+shot peening	394	1,67
	normalizing+induction hardening	620	2,63
	normalizing+induction hardening+shot peening	723	3,10
	Thermal improvement	342	1,00
	Thermal improvement+shot peening	442	1,29
	Thermal improvement+induction hardening+shot peening	810	2,37

Tab. 2. Synergy ratios in a technical application for various treatment technologies [2,4]

Treatment		**Synergy ratio k_{zm}**
Mechanical treatment	Rolling	1,1÷1,4
	Shot peening	1,1÷1,3
Thermal – chemical treatment	Carburizing and hardening	1,1÷2,2
	Nitriding	1,1÷1,25
	Nitrocarburizing	1,3
	Cyaniding	1,8
Thermal treatment	Induction hardening	1,2÷1,6
Galvanic treatment	Chroming	0,66÷0,9 (-)
	Nickeling	1÷0,66 (-)

To analyse the complexity of the process of defining the values of the synergism ratio for a given manufacturing technology, the notion of *technical synergism* should be defined.

Synergism of a technological process can be divided into:

- *synergism of a design*:
  e.g. synergism resulting from technical preparation of production,
- *synergism of a process:*
  e.g. synergism of metallurgical processes,
  e.g. synergism of removal machining,
  e.g. synergism of forming machining,
  e.g. synergism of finishing machining,
  synergism of removal-free machining,
  e.g. synergism of thermal treatment,
  e.g. synergism of thermal-chemical treatment.

- *synergism of technological assembly*:

  e.g. synergism of a technological process of assembling mounting units,

  e.g. synergism of a technological process of assembling mounting systems.

The division depends on the technologies applied and the number of operations used in the manufacturing process.

Coherence **-** cohesion, connectivity, compactness, is an attempt to formulate opinions and to make decisions which comply with the former ones. In management, it is important to maintain coherence between the company's objectives, objectives of individual employers, company's economical needs on the one hand and the environmental needs, marketing needs and the needs of research and development – on the other hand [15].

Thus, considering the issue only in terms of synergism determination seems to be insufficient. Without the evaluation of the coherence of processes carried, it is difficult to state univocally whether the selected technology is the best and optimal option.

3. Research

The carried out research included the analysis of achievable structures of technical design. On the basis of the review of bibliography [10÷25], a new complex structure of technical designing of technological processes was elaborated. The proposed structure of technical design introduces, inter alia, the analysis of mutual influence of the used technologies yet at the design stage as an indispensable component in the structure of technical design (Fig. 3.). The proposed structure became a starting point for the subsequent analysis of synergy ratios as well as for the determination of the coherency coefficients.

Experience has shown that "it is not advisable to apply all the criteria simultaneously". For instance, for high-quality products, irrespective application of the time criterion may not lead to satisfactory results. Faster does not always mean better. The same applies to products which are costly to manufacture.

Thus, designing technological processes should be based on "healthy" multi-criterial and multi-alternative designing which takes into consideration full synergism and coherency between all the technologies applied in the production process. Multi-criterial approach should be critical in the search for optimal solutions.

Optimization of manufacturing processes leads to the formation of mathematical models whose components, i.e. sets of possible solutions and optimization criteria, should reflect leading ideas of the company's policy. Optimization depends on the existence of alternative solutions and may be related to all the components of the production process (Fig. 4.).

The implemented optimization should also consider synergism and coherency at each step of their implementation.

The need for the multi-alternative and multi-criterial approach to process design is presented in Manufacturing Interfaces Annals of the CIRP [10]. The paper emphasises the necessity to present the sets of solutions for possible manufacturing processes in a comprehensive manner. The set of evaluation criteria (optimization criteria) constitutes one element of a mathematical model which enables taking into account factors dominating in the company's policy.

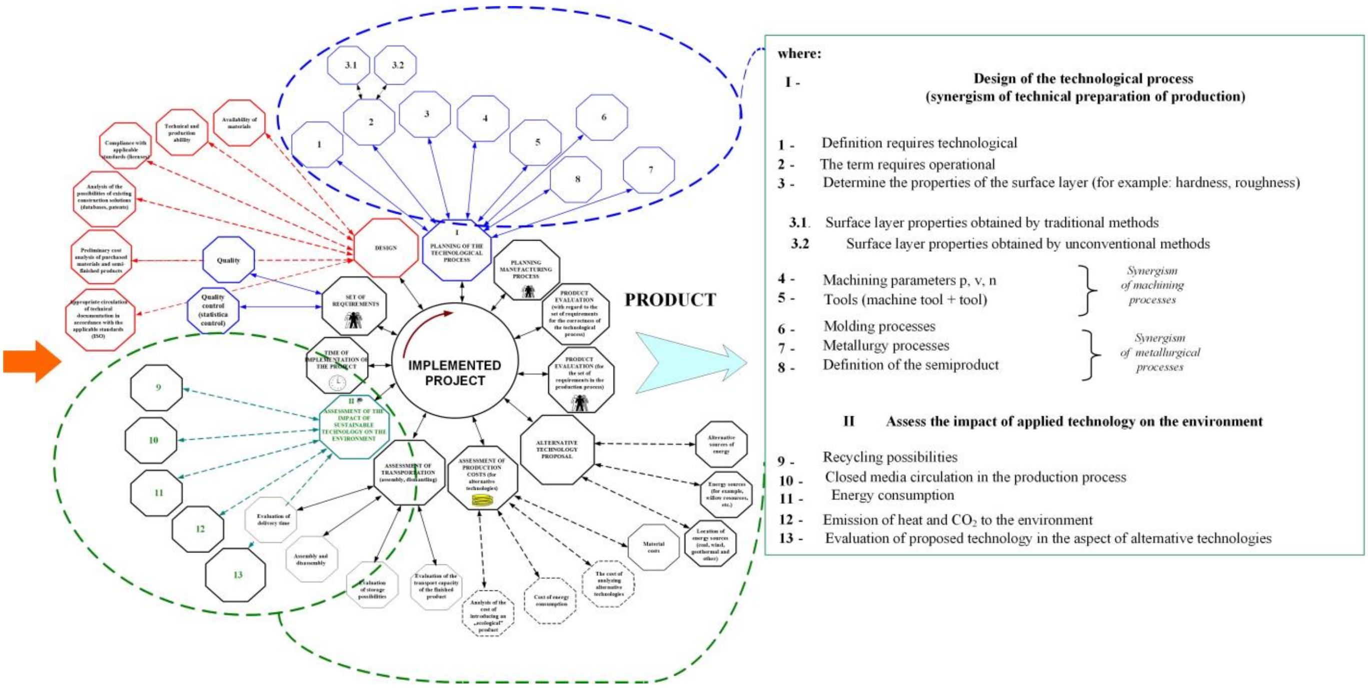

Fig. 3. Multi-criterial structure of technical design [8÷9]

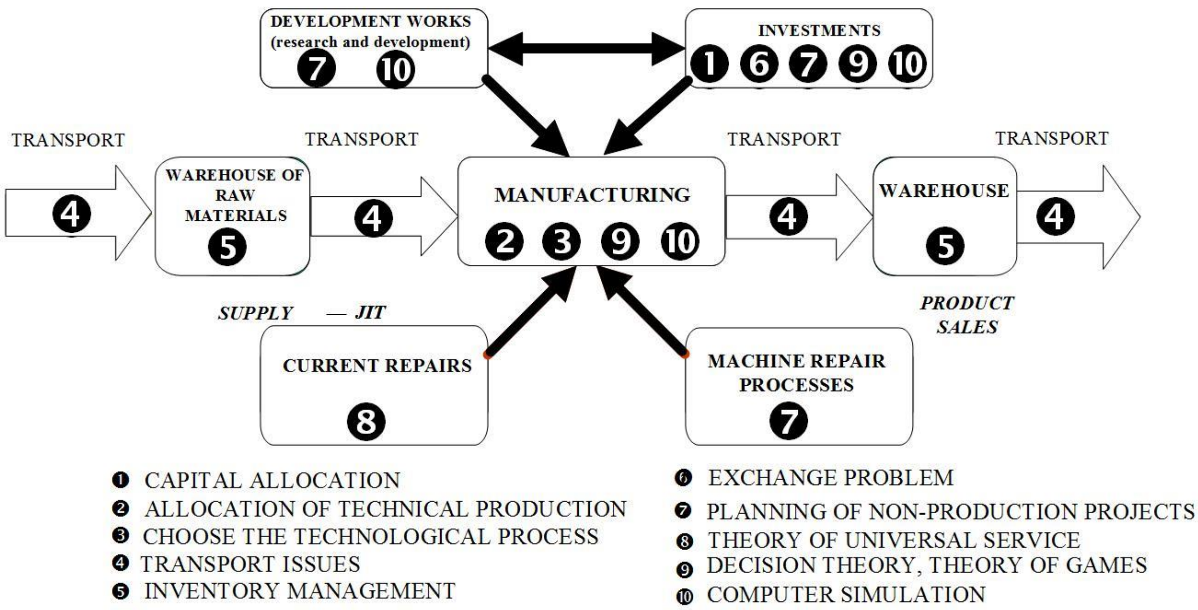

Fig. 4. Optimization applications in a production process [11]

While optimizing the company's activities, it is especially important to optimize manufacturing processes. The idea refers to both optimization of machining processes (referred to as parametric optimization taking into account the synergy of technical preparation of the production process) and the structure of the processes (structural optimization). The optimization of the conditions (parameters) of machining is complementary to the optimization of the structure. These two issues are closely related. The optimization of the structure requires a prior determination of process parameters (values of which should be as close as possible to the optimal ones), whereas the optimization of parameters requires prior optimization of the structure. To solve the arising contradiction, iterative procedure should be followed. First, the structure of the process is selected (the structure should be as close as possible to the optimal one) with typical values of the parameters. Next, the optimization of the parameters should be carried out which may be followed by the subsequent optimization of the structure, etc. [12÷13].

The analysis of the possibilities of optimization to be carried out in manufacturing processes requires the knowledge of a number of sciences such as mathematics, chemistry or strength of materials (Fig. 5).

The objective of parametric optimization (taking into account the process synergy) is the adoption of such values of parameters (out of the available ones in given conditions – within the range of solutions permissible by the determined restrictions [14]) which ensure extreme value of the assumed optimization criterion.

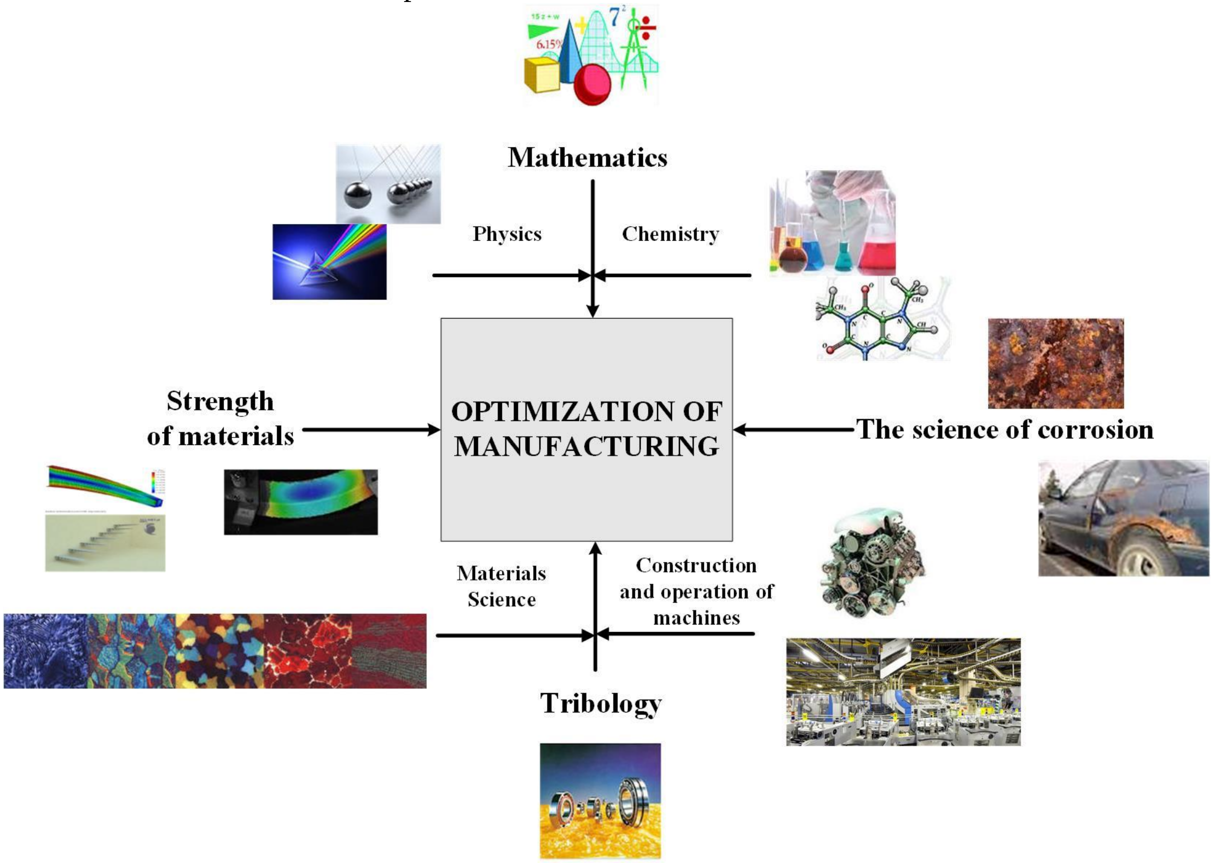

Fig. 5. The importance of basic sciences in the optimization of manufacturing [43]

3.1. Criteria for multi-criterial optimization

Each manufacturing process should compromise between the product quality (increasing its reliability) and the strive to reduce its manufacturing and exploitation costs (cost of raw materials including). Finding the best solution for the manufacturing process involves a properly prepared optimization analysis and the selection of criteria according to which the optimization is possible (Fig. 6).

The result of optimization largely depends on the task formulation, and particularly on the selection of criteria against which the alternative solutions of the process are evaluated, taking into account both the process synergy and coherency. In the optimization of manufacturing processes, the following criteria are most frequently adopted [41]:

- performance criteria (functional, aesthetic);
- technical criteria (general technical criteria, material and manufacturing criteria);
- economic criteria (production costs, exploitation costs).

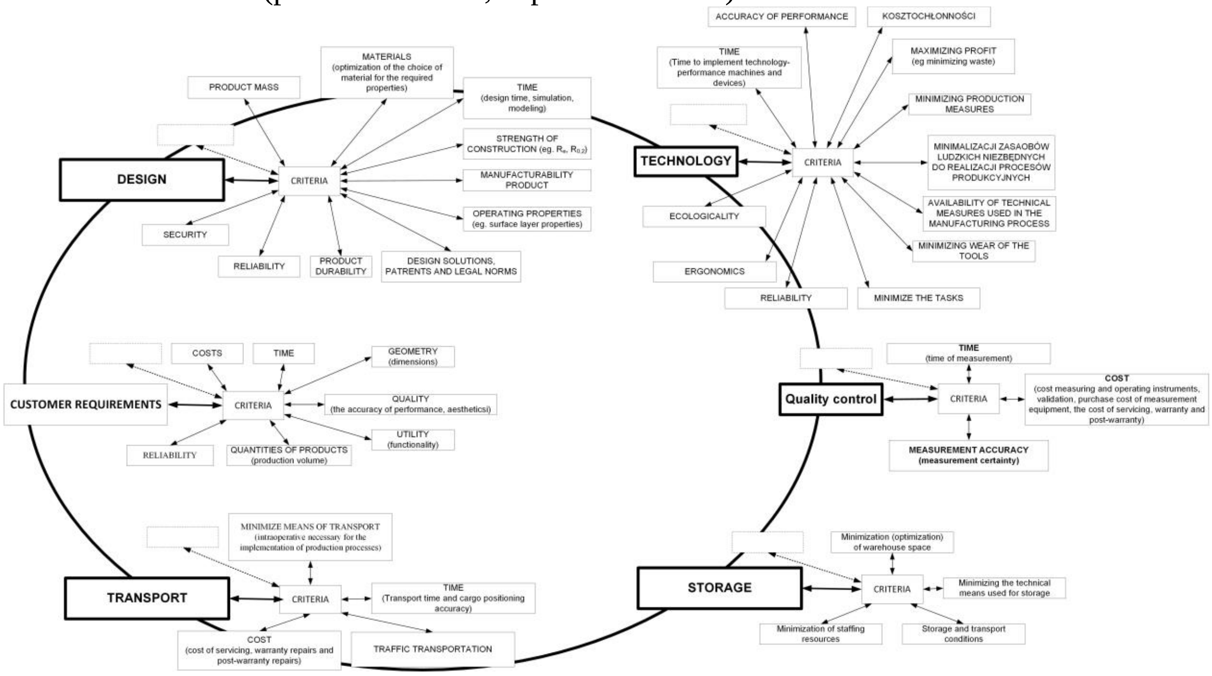

Fig. 6. Diagram of an optimization analysis and the optimization criteria [43]

The selected technology determines essentially the functionality and aesthetic of the product. It influences the quality of product properties such as: the accuracy of the shape and dimensions, stereometric structure of the surface, friction coefficient, mechanical properties, thermal conductivity, electrical conductivity, external appearance, mass. Providing the required quality of the product is the basic condition to be met while deciding on an option of the manufacturing process. *General-technical criteria* should take into account the production volume, i.e. the total number of products to be manufactured throughout the whole period of the product production, the production season (i.e. the expected number of years the product is to be manufactured without its sound modernization, the date for the production completion, etc.). *Manufacturing criteria* include the company's equipment (manufacturing devices and appliances), accessories, research and development backgrounds and staff. *Material criterion* should include the selection of the type of a semi-finished product, the accuracy of its dimensions and shape, its mechanical properties and material deficiency. *Economical criteria* include, first of all, production costs which in majority of cases are sufficient for the comparison and selection of the alternatives of the manufacturing process. When the considered options of the manufacturing process vary by just a single cost component, e.g. material consumption or labour costs, then in order to select the suitable option it is sufficient to determine and compare this particular cost component, irrespectively to it being a direct or indirect cost.

A number of technical-economic indicators may be used to compare and select the best (optimal) option of a manufacturing process, such as: an indicator of cost per unit, workload, the use of material, machines and their exploitation efficiency. Theoretically, the selection of a manufacturing option is not difficult. It is sufficient to determine the cost of the product, being the sum of manufacturing costs and exploitation costs, and the optimization problem is reduced to a single criterion task. However, a question arises how to put it in practice, at the stage of planning the production process, particularly while launching the production of a new product, i.e. when a precise determination of manufacturing costs, and particularly exploitation costs, is very difficult, and sometimes even impossible, due to the fact that it might require information available only after a trial sample has been manufactured and time consuming exploitation analyses have been carried out. Therefore, the evaluation of the options was based not on a single criterion, i.e. the product manufacturing costs, but on two or more criteria which are available yet at the planning stage, and the optimisation problem becomes thus a multi-criterial task. The evaluation criteria should be mutually independent, to allow the determination of their influences irrespectively of each other. However, this condition is difficult to be met in practice, therefore the literature describes it as a condition of "required independence" [28].

In the most general case, the evaluation of manufacturing processes may be based not only on criteria of deterministic (precise and sharp) and probabilistic nature (which in [39] were referred to as probabilistic-statistic criteria), but also criteria of a fuzzy nature (blurred) [28÷34], and additionally the effectiveness of mutual interaction of the assumed technical parameters (synergy and coherency) should be measured. At the stage of planning a process of manufacturing machine parts, the precise determination of the values of the deterministic criteria are impossible to be assessed. In such cases, subjective, score-based criteria should be used for the evaluation of the options of manufacturing processes [35÷39].

Generally, optimisation may be divided into [26]:

- a single-criterion based evaluation, when only a single criterion is required to achieve the ideal state,
- a multi-criterial based evaluation (vector, poly-optimisation), when a number of criteria condition achieving the ideal state.

Optimisation is a field of science which deals with methods of selecting optimal actions connected with human activities in the field of technology, economy, etc. [27].

Structure optimisation deals with the issues referring the selection of shape parameters and physical parameters of widely understood structures [27].

The shape of a structure is determined on the bases of the structure parameters. The structure parameters include: structure topology (the number and type of the structure elements), cross-section shapes, cross-section dimensions, the kind of material used, weight, physical, chemical and mechanical parameters of the material, structure vibrations, power supply, energy consumption, efficiency, functionality, exploitation parameters, colour, ergonomic parameters and many more [27].

The structure parameters include all the features characterising its shape, dimensions, power, rotations, etc., i.e. measurable parameters which can be presented with mathematical notions.

Apart from that, a structure is described with the help of non-measurable parameters, such as: aesthetics, appearance, etc., described with the blurred notions. Parameters may be determined before the planning stage, or may be determined with the use of optimisation procedures, and then they are referred to as *decision-making factors* (project factors).

Optimisation criterion is a basic optimisation notion. It is used for comparing particular solutions. In mathematical terms, a criterion is called an *objective function*. The optimisation criterion is selected at the initial planning stage, and has to meet the requirements for optimal planning and designing, may be selected out of a number of structure parameters or may be a combination of a number of parameters. A universal yard stick for measuring the quality of structural solutions is its cost. The decision-making problem is to express costs with the use of parameters [27].

An exemplary structure of criteria for the selection of a technological process is presented in Fig. 7.

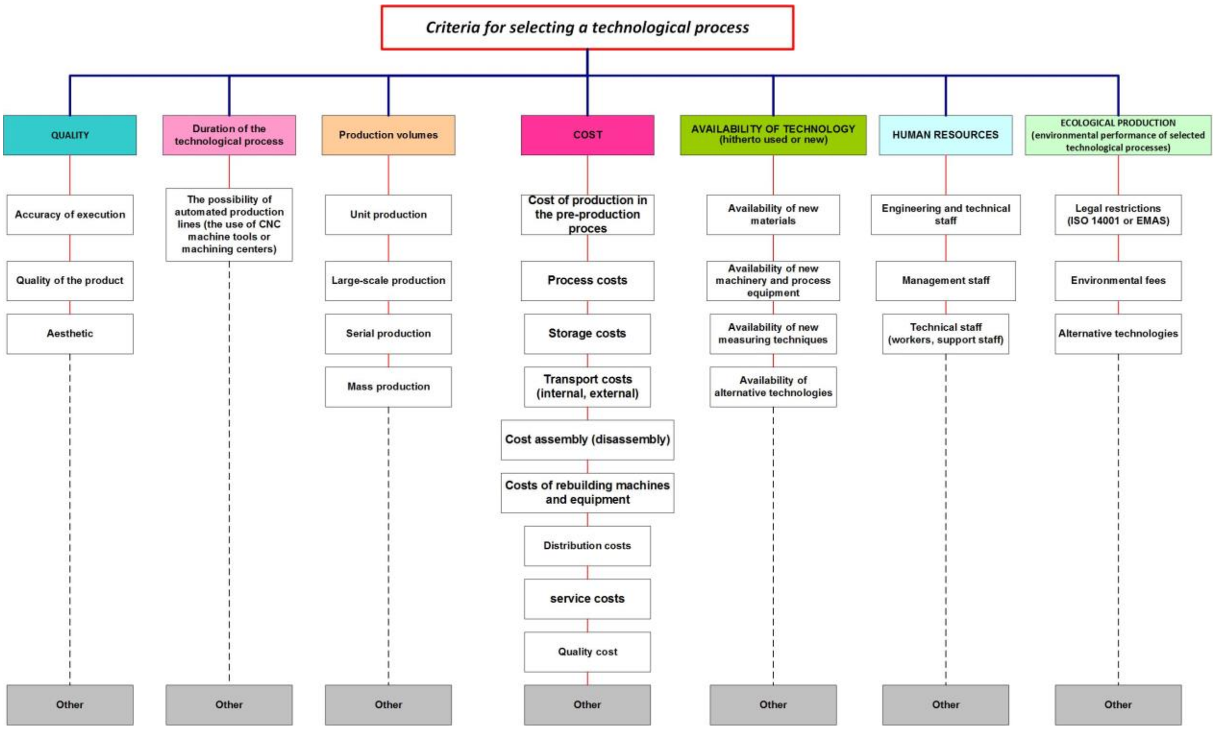

Fig. 7. A structure of criteria for the selection of a technological process [8÷9, 43, 122]

One of the most important stages of optimal designing of each manufacturing process is the selection of an optimisation procedure as a tool for solving an engineering problem. The selection is not an easy issue since there is no single universal method, equally efficient for all engineering problems. There is a kind of a psychological barrier connected with the abundance of procedures to choose from, which hinders the decision making process of solving the optimisation task. It is thus an example of optimisation in an optimal designing.

The concept of technical designing which takes into account design and process synergism consists in development and implementation activities in the fields of planning, designing and the elaboration of technology and manufacturing.

In the technical design, each new project is elaborated by an interdisciplinary team e.g. an SE team (simultaneous engineering) consisting in: designers-constructors, technologists salespeople, and representatives of procurement and finance departments as well as suppliers of manufacturing equipment and subsuppliers of basic parts of the planned product. The operation of the interdisciplinary SE team allows introducing any necessary changes in the product design and the manufacturing technology yet at the early stages of the product formation and the production planning. Thanks to it, the costs of the alterations are definitely lower and the new product may be launched faster [26].

Therefore, there is a need to combine the available methods of designing technological processes (taking into account synergy and coherency coefficients) with concurrent engineering as the most efficient and universal method of the realisation of a product which takes into account all stages of the manufacturing enterprise implementation. Tight collaboration of constructors, assembly workers, managers, planners service people and other specialists engaged in the product manufacturing process will allow to develop algorithms for methods of structure designing and planning of technological processes, and thus - typisation of elements of machine parts in the whole designing process.

It needs to be also stated that all works connected with the new product designing should be carried out concurrently taking into account design and process synergism. Also the environmental impact of the planned technology should be determined. The paper systematises the notion of the design of technological processes through the formation of a unified structure which takes into account the most essential aspects of the design and implementation of a new product to be launched onto the modern market. The proposed structure, as mentioned before, includes most essential issues from the point of view of the manufacturing technology in terms of technical design. It should be stressed that all "components" of designing of a technological process may be developed or simplified depending on the complexity of the designed product. It is also possible to determine the environmental impact for each component, with taking into account the synergy and coherency between the components of the manufacturing process. The final effect of the research implementation will be typisation of elements of the parts of machines in the whole process of technical design and the elaboration of a computer program solving the problem of a complete design of elements of machines from the stage of concept formation to the stage of a ready-made product (taking into account the basic criteria).

3.2. The selected methods of multi-criterial optimisation taking into account deterministic criteria

Among the multiplied methods of multi-criterial optimisation which exploit criteria of a deterministic nature, the most useful ones for solving engineering problems are the following [40; 42]:

- method of weights,
- method of weights with a normalized criterion,
- method of a global criterion,
- minimax method,
- minimax method with weights,
- utility function method,
- method of limited criteria,
- lexicographic method,
- method of objective planning.

Method of weights – the problem of multi-criterial optimisation is reduced to single-criterial optimisation thanks to the formation of a substitutive criterion. The method allows obtaining a certain representation of a set of alterations optimal in Pareto sense. The values of weights are almost always determined arbitrarily, and most frequently according to the decisive body, with taking into account subjective factors which is a drawback of this method. A method useful for solving engineering tasks is also a *method of a global criterion* which assumes finding the ideal solution which satisfies the condition of the minimum of each criterion being considered irrespectively of the others. Next, a global criterion is formulated by determining "distances" between the points: optimal and ideal (illustrating the optimal variant and most frequently a fictitious ideal variant) [41].

In the global criterion method [40], the best variant (optimal) is determined by vector, which minimizes the assumed form of the local global criterion.

Another method is the *minimax method*. It is close to the global criterion method as it assumes the minimisation of maximal deviations from ideal solutions. The deviations are assigned weights [40]. The weights represent directly the "importance" of particular criteria. The values of the weight coefficients are determined in a similar way to the one used in the weight method or in the normalised criterion weight method. The next method utilised in the multi-criterial optimisation is the *utility function method*. The method requires finding the extreme value of the utility function [41]. The utility function must be determined on the basis of the analysis of objectives which the solution is to be suited for. However, the determination of the function may be difficult in certain instances. The solution to the problem is the intersection of the set of compromises and the set of the curves of the utility function. The weight coefficients are determined as for the weight method, the weight with a normalised criterion method as well as in the minimax method completed with weights, i.e. arbitrarily in accordance to the decision-making person's knowledge and other subjective factors. The subsequent method is the *limited criteria method* [41]. The method is applied when it is possible to determine the maximum values for the particular criteria. The basic disadvantage of the application of the method is the necessity of determining restrictions which would allow satisfying particular criteria as well as the existence of a non-empty set of solutions. Moreover, it is necessary to decide which criterion will be minimised while solving the task. The next method is the *lexicographic method* [41] which consists in ordering the components of the criterion according their importance. The best variant is the one which minimises the criterion starting with the most important component to the least important one. The procedure finishes after an unambiguous variant has been obtained. The next method is the *objective planning method* [41]. The application of this method involves the determination of values of criteria which should be obtained. Detailed characteristics for the above mentioned methods are discussed in [40; 42].

4. Conclusions

Multi-criterial planning of manufacturing processes, particularly for new products, is implemented with incomplete information. Lack of information and limited measures necessary to acquire it, make the optimal option of a process structure easier to be determined basing on roughly assessed criteria. In a number of cases, they may be determined by experts in selected fields. Subjective score-based criteria may be very helpful in these cases. The selection of the optimal variant based on the mentioned above criteria may be realised on the ground of Yager's method. The method enables ranking of the evaluated options from the best to the worst in terms of the assumed weights. The weights of the criteria are evaluated by specialists by comparing subsequent pairs of criteria with the use of matrices.

In a multi-criterial planning of manufacturing processes for products similar to the ones that have already been manufactured, it is generally possible to determine (with sufficient accuracy) the values of criteria assumed for assessment. In these cases, a method with the optimum in the sense of Pareto is most frequently used. The weights of the assessment criteria are equal. In most cases, the method involves two stages. The first stage involves the determination of the set of non-dominated variants (the set of Pareto-optimal variants). The second stage involves the selection of the best variant out of this set. It usually entails introducing an additional (most frequently - new) criterion. The elimination of the least preferable variants, which is performed with the use of the method "optimum in the Pareto sense", is inefficient when two or more criteria are considered. Therefore Yager method has been modified in terms of its practical application for the assessment of variants of criteria obtained from calculations or measurements (the so called deterministic criteria).

For example, for machining purposes, at the stage of planning the processes of manufacturing of machine parts, the parameters of machining are selected from a catalogue of cutting tools, which is usually guided by the criterion of a unit cost of manufacturing. The selection of optimal parameters of machining, in terms of two (or more) criteria and also in terms of the value of coefficients of synergy and coherency between the used technologies is generally rare and used only in specific cases, e.g. for finishing of high quality surfaces.

Applying the multi-criterial optimisation of the structure of manufacturing processes, parameters for manufacturing of selected parts of machines as well as synergy of technological processes enable formulation general, informative conclusions:

- multi-criterial approach to the evaluation of the variants of manufacturing processes has become a basic means of considering the complex diversity of requirements that are to be met by machining processes,

- computer support for designing of optimal manufacturing processes must enable multi-criterial optimisation which takes into account various criteria, most often subjective score-based criteria or relative – used in the case of new products, as well as deterministic criteria for products which are similar to the ones that have been manufactured before,
- optimisation criteria, treated as deterministic criteria in conventional models (e.g. as costs) must be repeatedly treated as non-deterministic (e.g. subjective score-based criteria or subjective relative assessments). This is caused by lack of information at the early stages of planning a process of manufacturing of new machines parts. manufacturing design,
- optimisation criteria applied to the evaluation should be independent, and their number, for the determination of the set of non-dominated solutions (Pareto-optimal), should not exceed three, which is beneficial due to the possibility of obtaining an inconsiderable size of Pareto set,
- multi-crterial optimisation of the structure of a manufacturing process is the best when it is a single-stage procedure, e.g Yager's method or its modifications,
- mutli-criterial optimisation of parameters of operations and treatments usually brings good results if it consists of two stages: the determination of a set of non-dominated solutions (Pareto-optimal), and then (for a Pareto set with two or more elements) the selection of the best solution out of this set in terms of an additional (most often new) criterion,
- practical effects resulting from the application of multi-criterial optimisation depend mainly on skilful selection of the evaluation criteria (optimisation criteria) at particular stages of optimisation procedure,
- synergy and coherency between particular technologies (process parameters) need to be taken into account at each stage of implementation of a technological process (from planning to the manufacturing of a final product),
- taking into account synergy and coherency in multi-criterial and multi-variant planning of technological processes brings much better results in terms of efficiency and effectiveness of each manufacturing process.

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