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# Improvement of technological processes by the use of technological efficiency analysis

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**ABSTRACT**

**Purpose:** Technological process is a basic determinant of correctness of industrial company's functioning on the market. In this connection they should treat with the priority all activities connected with technology, technology management and controlling, that is with their continuous improvement.

**Design/methodology/approach:** The basis for preparing the process analysis model are the indicators of fragmentary and technological efficiency, as well as standardized parameters of the technological process depending on the applied treatment.

**Findings:** Thanks to the appropriate indicators it is possible to identify operations which need to be verified. Although interdisciplinary process control is very complex, it offers objective assessment. The assessment should include the influence of individual parameters on the process and enable good choice of the optimisation type.

**Practical implications:** The process analysis with the use of immaterial parameters based on different types of processing and the design of the technological process involved assessment of technological process efficiency with the use of indicators of operational efficiency.

**Originality/value:** Creating computer applications for calculating individual indicators, as well as final efficiency assessment used for planning optimisation of individual operations

**Keywords: Industrial mangement and organisation; Production planning and control; Technological efficiency; Optimization; Neural networks**

**MATERIALS MANUFACTURING AND PROCESSING**

## 1. Introduction

In view of optimisation based on a search for the best solutions, analysis is the primary tool for understanding and shaping reality. The current trends and principles of optimisation are decisive in the choice of goals and criteria of the conducted analyses. It would be ideal to create a model of a multi-criteria analysis aimed at optimisation of the existing problem with the use of all the possible criteria influencing the problem [5-8].

The creation of an ideal model of a multi-criteria analysis may be initiated by introduction of a number of partial models reflecting a certain aspect of a given problem, and thus offering a partial solution, which is the first step in solving the problem.

Rapid advances in science make optimisation crucial. For this reason, complex actions need to be taken on the ongoing basis in order to ensure constant quality improvement, as well as new solutions in the fields of technology, economy and ecology. Such innovations contribute to an increase in efficiency [5-14].

Industrial companies should perceive all the activities related to technologies, management and control as priorities. Efficiency analysis, which is a part of multi-criteria optimisation covers both global and specific aspects. It is affected by various financial and developmental factors. Technology may be classified on the basis of different criteria. The most accurate division from the point of view of process efficiency and analysis is one into material and immaterial technologies. Material technology refers to machines, products, and financial outlays; in other words, all the tangibles affecting the process. On the other hand, immaterial technology refers to scientific resources related to parameters of the technological process which contribute to product quality [6-14].

Corporate efficiency depends on the optimal use of production resources available in a given company, as well as its ability to adjust to external conditions, market needs, competition, the ability to forecast future production levels and make optimal decisions accordingly. Due to these facts. The majority of efficiency analysis models concentrates on financial aspects, i.e. Profit and loss account analysis [1-7].

The nature of efficiency is closely related to the production and technological processes which are the basis of operations of every production company. Having said that, one might conclude that technological efficiency depends on a number of technological parameters, as well as the technological process itself with its different stages – this efficiency is, to a large extent, dependent on immaterial technology [2-7].

The process analysis with the use of immaterial parameters based on different types of processing and the design of the technological process involved assessment of technological process efficiency with the use of indicators of operational efficiency. These indicators allowed detection of weak points in technological processes of toothed elements. These processes consisted of the choice of the semi-finished product and heat treatment and machining[2-7].

The analysis of technological efficiency conducted in the work place covered [5-7]:

– methodology of calculating the efficiency of chosen technological processes and creation of a model efficiency based on: specification of different types of treatment, division of each type of treatment into individual operations, calculating the technological efficiency indicator ($K_{iX}$) (systematisation of individual operations according to their significance in the technological process on the basis of the significance matrix, calculating operational efficiency indicators according to the following diagram of the process efficiency analysis: $W_{EM}$, $W_{EPM}$, WEPC, analysis of parameters of the appropriate operation which will be included in the calculation of the efficiency indicator of a given treatment operation ($W_{EX}$), calculating the indicator of the appropriate material choice WPD, calculating the indicator of the appropriate semi-finished material choice $W_{PÓŁ}$), calculating efficiency according to the type of treatment, efficiency of the entire technological process as well as process assessment by pinpointing low-efficiency operations which are important for the process,

– choice of facility and appropriate technological process,

– efficiency analysis of the chosen process according to the process efficiency analysis model,

– calculation of the operational efficiency coefficient $K_{iX}$ with the use of artificial neural networks on the basis of actual data related to the chosen processes,

– creating computer applications for calculating individual indicators, as well as final efficiency assessment used for planning optimisation of individual operations.

## 2. Methodology of research

The following analysis is based on optimisation of the chosen technological processes with an emphasis on efficiency:
The basis for preparing the process analysis model are the indicators of fragmentary and technological efficiency, as well as standardized parameters of the technological process depending on the applied treatment. This enabled description of the technological process and its individual operations, and the matrix allowed a certain operation systemization at the final stage of classification (Table 1) [5-7].

The process efficiency scale ($E_{PT}$) was created on the with the use of the rule based on the assessment of the technological process efficiency; namely: if $E_{PT} = 1$, the process is efficient, if $E_{PT} < 1$, the process is inefficient, if $E_{PT} > 1$, the process is inefficient, (nevertheless, the implementation of the process is sometimes necessary due to specific technological requirements. That is why it is important to consider these requirements while analysing efficiency levels) [5-7].

The following efficiency rating has been prepared for the $E_t = 1$ equation; $E_t$ stands for technological efficiency [5-7]:

$E_{PT}$ = 1 – ideal efficiency level,
$E_{PT}$ = 0,99 – 0,90 – very good efficiency level,
$E_{PT}$ = 0,89– 0,75 – good efficiency level,
$E_{PT}$ = 0,74 - 0,65 – sufficient efficiency level,
$E_{PT}$ = 0,64 – unacceptable efficiency level.

Considering the prepared model of technological efficiency analysis (Fig.1) a computer-aided system has been created. It is an application which facilitates the calculations of technological process efficiency; namely the TPEA (Technological Process Efficiency Analysis, Fig.2) [5-7].

Artificial intelligence tools, namely neural networks, have been used for the automation of the process of calculating the technological efficiency for a given operation $K_{iX}$, and the possibility of its optimisation [5-7].

The neural network-based model allows calculation of the efficiency indicator $K_{iX}$ with the mean error of 0.02, which shows a high level of accuracy in calculating the $K_{iX}$ efficiency indicator with the use of neural networks. While assessing the accuracy of the efficiency calculations it is important to note that the mean error while verifying the network was not greater than 3.89% of the operation efficiency indicator within the range of 0 to 1. The calculations of network quality for the test and verification sets are close to one another, which shows the model is accurate and that the proposed neural network may be used for calculating the operation efficiency indicator [5-7].

## 3. Example

The object of analysis was a toothed element – the toothed gear, which is an indispensable element of most machines and other mechanical devices.

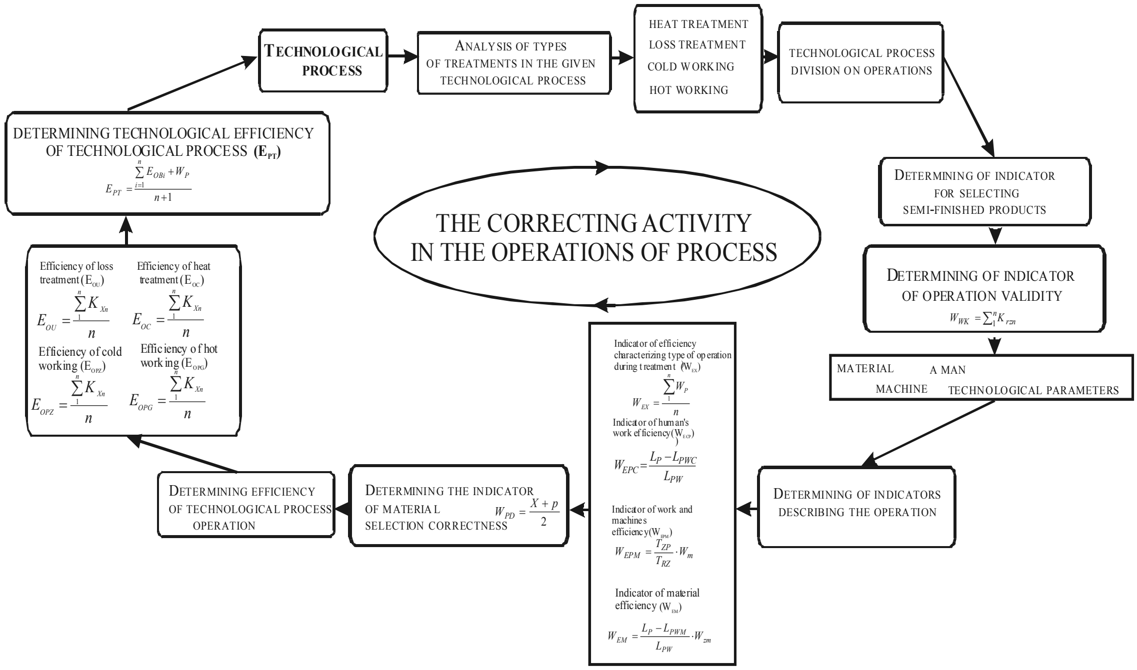


Fig. 1. The model of efficiency analysis [5-7]

Table 1.
Partial efficiency indicators for technological processes [5-7]

| Efficiency indicators | Indicator equation | |
|---|---|---|
| $K_{iX}$ - technological efficiency indicator | $K_{iX}=\dfrac{W_{EM}+W_{EPM}+W_{EPC}+W_{EX}+W_{PD}}{5}$ | |
| $W_{EM}$ – material efficiency indicator | $W_{EM}=\dfrac{L_P-L_{PWM}}{L_{PW}}\cdot W_{zm}$ | $L_{PWM}$ – number of dismissed products, $L_p$ – number of produced products, $L_{PW}$ – put number of products, $W_{zm}$ – indicator of material consumption |
| $W_{EPM}$ – machine efficiency indicator | $W_{EPM}=\dfrac{T_{ZP}}{T_{RZ}}\cdot W_m$ | $T_{ZP}$ – planned working time of the machine, $T_{RZ}$ – real working time of the machine, $W_m$ – indicator of technology correctness |
| $W_{EPC}$ – human labour efficiency indicator | $W_{EPC}=\dfrac{L_P-L_{PWC}}{L_{PW}}$ | $L_p$ – number of products, $L_{PW}$ – number of produced products, $L_{PWC}$ – faulty products because of human's mistake |
| $W_{EX}$ – operation type efficiency indicator | $W_{EX}=\dfrac{\sum_1^n W_P}{n}$ | $W_P$ – indicator evaluating correctness of parameters typical for a given type of operation (determined in standards), n- number of parameters |
| $E_{PT}$ - technological efficiency | $E_{PT}=\dfrac{\sum_{i=1}^{n} E_{OBi}+W_{POL}}{n+1}$ | |

Toothed gears are one of most technologically complex parts of typical machines. This analysis deals with a cylindrical gear with straight teeth. The technology of its production is complex due to the necessity to cut the teeth, which requires the use of specialised machine tools, state-of-the-art measuring devices, precision instruments, and more importantly, highly-qualified staff operating these machines, tools and instruments. The processing of toothed gears can be divided into three stages: before the tooth cutting, after the tooth cutting, and the tooth cutting itself.

The most common technology in the processing of toothed gears used for very heavy loads and working under very high pressure is carburising. Thanks to this process, the gears have a hard external surface which is resistant to material wear and fatigue, and at the same time, the core with little carbon content maintains its high impact resistance and ductility. The choice of

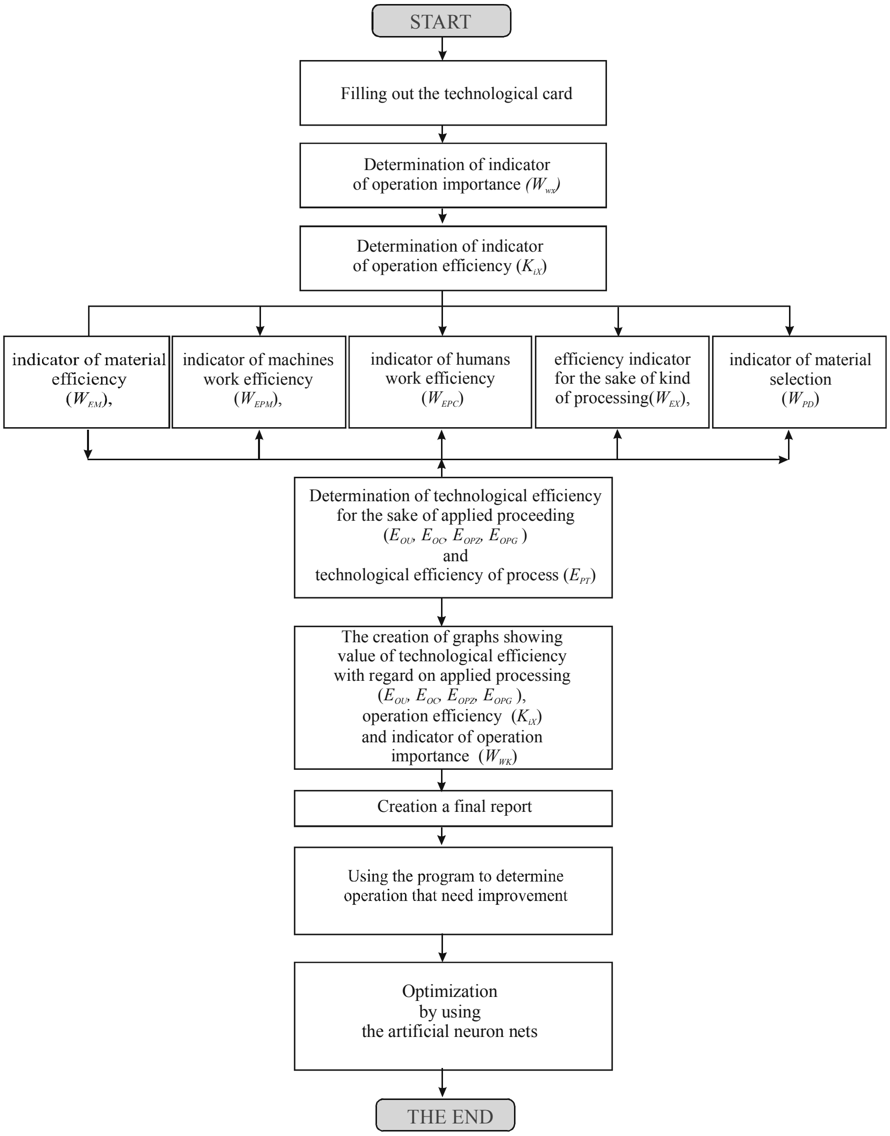


Fig. 2. Algorithm of proceedings by conducting the analysis of technological process efficiency by the use of computer application (TPEA) [5-7]

steel in the gears depends not only on the size of the cross-section and module of the gear, but also on the technology of its production. It is also worth remembering that if the heat treatment is followed by sanding, it is recommended to use steel with added Cr, Mn, Mo. Thus, the carburised and tempered gear uses the 18CrMo4 (PN-EN 10084:2002) for carburising (Table 2).

The results from the partial efficiency indicators of the analysed technological process showed that the maximum value of these indicators is one. This means that the operation was planned in accordance with the requirements of one of the criteria of the technological efficiency analysis model. The value of one is characteristic mainly of indicators based on defect analysis within one of the criteria. If the indicator shows the relationship between different technological parameters, then it is impossible to achieve the value of one. In this case, the value of one would mean that the operation is perfect and there is no need for further improvement (Table 3).

Table 2.
Data concerning the analysed toothed gear process

| Part | Productio n series | Semi-finished product | Material | Heat treatment |
|---|---|---|---|---|
| Cylindrical gear with straight teeth | Serial production, 100 pieces | Cylindrical rod | 18CrMo4 belonging to the group of alloy construction steels for . | carburising + tempering |

Table 3.
Total value of partial indicators for technological operations in the analysed processes

| Indicator reference depending on operation number | WEM1 | WEPM | WEPC | WEX |
|---|---|---|---|---|
| Material | 18CrMo4 | | | |
| 1 | 0,8160 | 0,7983 | 0,9900 | 0,8000 |
| 2 | 0,8160 | 0,9209 | 1,0000 | 0,8000 |
| 3 | 0,8075 | 0,9477 | 0,9900 | 0,8100 |
| 4 | 0,8160 | 0,9700 | 1,0000 | 0,8000 |
| 5 | 0,8160 | 0,9800 | 1,0000 | 0,9000 |
| 6 | 0,8245 | 0,6517 | 1,0000 | 0,8000 |
| 7 | 0,8245 | 0,9018 | 1,0000 | 0,8950 |
| 8 | 0,8245 | 0,9250 | 1,0000 | 0,8900 |
| 9 | 0,8160 | 0,9288 | 1,0000 | 0,8900 |
| 10 | 0,8245 | 0,9700 | 1,0000 | 0,9000 |
| 11 | 0,8245 | 0,6587 | 1,0000 | 0,8000 |
| 12 | 0,8245 | 0,9548 | 1,0000 | 0,8900 |
| 13 | 0,8245 | 0,9561 | 1,0000 | 0,8900 |
| 14 | 0,8245 | 0,8788 | 1,0000 | 0,8450 |
| 15 | 0,8245 | 0,9324 | 1,0000 | 0,8000 |

For the majority of operations the value of partial indicators approaches one. The value of partial indicators was $W_{EPM6}$ = 0,6517, $W_{EPM11}$ = 0,6587 (machine efficiency indicators for operations 6 and 11). According to the universal table of relative states, it is a convenient level. However, it is recommended to improve these operations in order to obtain better efficiency indicators for these operations.

The results of a detailed analysis of all the indicators ($W_{EM}$, $W_{EPM}$, $W_{EPC}$, $W_{EX}$, $W_{PD}$) (Table 3). The operations shown in the chart are based on the operation validity indicator $W_{WK}$ calculated according to the operation validity matrix. This indicator is used for assessing significance of a given operation in the analysed technological process.

While processing the gear, the heat treatment operations, according to the relevant states table and technological efficiency levels ($E_t$) was done at a very satisfactory level. The maximum efficiency level for operation involving a cylindrical gear with straight teeth in which the heat treatment (carbonising and tempering) values are as follows: operation 10 (tempering) $K_{10X}$=0,9089 $W_{WK}$=0,6607 and operation 5 $K_{5X}$=0,9092 (carbonising) $W_{WK}$=0,5536.

Thus, it is clear that the heat treatment operations for the analysed technological process were characterized by very high efficiency levels (indicators) (Kix), and consequently, by values which are decisive for the efficiency of the entire process.

The analysis of process operations significance ($W_{WK}$), which was conducted in accordance with the significance matrix prepared especially for this purpose, allowed pinpointing crucial operations which in the case of toothed gears are heat treatment operations (Table 3).
The next stage of the analysis was to calculate the technological efficiency on the basis of the treatment which was used ($E_{OC}$, $E_{OU}$, $E_{OPZ}$, $E_{OPG}$), and the technological efficiency of the analysed process EPT (Table 4).

Table 4.
Efficiency indicators for technological processes

| Efficiency indicators | |
|---|---|
| $E_{OU}$ – efficiency of loss treatment | 0,909 |
| $E_{OC}$ – efficiency of heat treatment | 0,884 |
| $E_{PT}$ – efficiency of technological process | 0,883 |

The program allow also to copy the content of matrix to other computer applications, besides in “matrix of operation importance menu” exist such a possibility to edit the basic matrix of operation importance, what follows changing of operation names and also change of weight importance.

## 4. Conclusions

The assessment of efficiency of technological processes is, in fact, a complicated and problematic activity. Difficulties in assessing efficiency stem from lack of any clearly defined methods of calculation and defining efficiency indicators. In order to assess technological efficiency it is necessary to analyse efficiency for individual operations of the technological process. The first stage of this analysis is defining technological efficiency indicators and collection of all the output data necessary for the calculations. Efficiency assessment for a technological process should be based on partial efficiencies referring to lead time, material consumption and the use of machines.

Thanks to the appropriate indicators it is possible to identify operations which need to be verified. Although interdisciplinary process control is very complex, it offers objective assessment. The assessment should include the influence of individual parameters on the process and enable good choice of the optimisation type.

State-of-the-art information tools, including artificial intelligence are becoming ever more common in different areas of science. The growth of interest in these methods can be explained by a wide choice of application. Neural networks are more and more popular in material as well as quality engineering.

The use of computer applications as a tool supporting optimisation also allows improvement of efficiency. It is also worth a while to mention some specialized programs which use artificial intelligence methods, such as neural networks, genetic algorithms and counselling systems. They allow automatic correction which facilitates the complicated optimisation and verification procedures. These and other advantages of neural networks make them ever more popular; especially if the information about the analysed event is incomplete. They can also assist us in the process of operation control and help make complex decisions.

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