Optimal management of production processes using the function of losses in the production processes

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Abstract. In today's modern world the manufacturing processes are designed in such a way as to ensure the desired quality of the end product. In this article are considered some aspects of desired quality in performance. The described quality management tools are based on Taguchi's theory Quality Engineering and Robust Engineering. In relation to this in the paper are presented a new application for assessing the losses of society from the irrational use of resources or their harmful impact in the transformation into a production process, the possibilities of Taguchi's theory in assessing the losses of the stakeholders in the functioning of the enterprise - in case of ineffective or inefficient use of the production process and proposal of the possibility for a complex assessment of the losses of the society and the stakeholders from the production of products and operation of production processes at quality indicators different from the desired nominal values

1. Introduction
Global competition in industry and especially in mechanical engineering requires the introduction of modern strategies in the management of production processes [1]. Knowledge of the technologies used have reached their limit and the production processes based on them allow to achieve the desired results, on the quality of the product without difficulty.

In the recent past and present one of the main concepts for the assessment and management of production processes is the concept of the loss function introduced by Genichi Taguchi [2]. In time, the current concept develops and is applied practically in all spheres of the human activities [3]. The main objective is the quality management of the product [4].

The modern situation and international standards impose constantly evolving concepts on the organization's management strategy [5]. The production is loaded with stringent requirements and criteria, imposed by standards defining the permissible frameworks for use of natural resources, control of emissions emitted [6], the method of consumption of energy resources [7], etc. This requires the production process to be managed simultaneously by multiple objectives. The importance for the quality of the manufactured products is paramount, but it is necessary to comply the quality of performance of processes in the Organization [5]. It is therefore necessary to look for ways of using existing theories of management and experience for implementation related to the new governance aspects.

If we try to summarize, the essence of the change involved is the displacement of the management objective: from the "quality of the produced product" to "the quality of the production processes
creating the product”. In essence, this change is decisive for achieving sustainable management of production structures. From the point of view of sustainable development, it is important that production organizations adequately report and manage both the "quality of the product" and the "quality of performance”.

The article presented, according to the competence of the authors, is limited to practical experience only in the field of manufacturing processes.

2. Quality management in the performance of the process

2.1. Interpretation of the manufacturing process

It is very important in the current global situation that production organizations can achieve the desired "quality in performance" of production processes. Understanding of the desired quality in performance, at the moment, has one main aspect and this is the quality of the product created by the process. In fact, there are other aspects of the same concept.

The first and main aspect is the quality of the product. This strand concentrates the efforts of our civilization for more than 40 years. That is why this aspect does not appear to be interesting for this article.

Each product is created by a process. The second aspect of quality is related, with how the running process influences nature and society. Resources are consumed in the execution of each process. These can be different energy carriers and/or raw materials (inputs). From an environmental point of view, it is very important to use them rationally. If reflect objectively, in fact it is a hidden product, whose customers are society and nature.

The third aspect of the quality of performance of the process is contained in its ability to meet the requirements of the organization brought to it. These are requirements determining its effectiveness and efficiency, duration and other characteristics contributing to the competitive ability of the organization. The current requirements again define a hidden product, whose customer is interested in the development of the organization parties. Conditionally we can define the current ones as the second and third aspect of quality management. By their nature, they can be defined by the term "quality of performance" of the process.

The production process is designed to create a product of a certain quality. To achieve this goal, it implements successive transformations of source material and resources until the desired objective [8]. In the first aspect of the process, the quality of performance is determined by geometric, physical, etc. characteristics [9]. In the second aspect of the process, quality is determined by the amount of resources used, the emissions generated, etc. characteristics. In the third aspect of the process, the quality of execution is determined by effectiveness, efficiency, duration, etc. characteristics. For each of the presented aspects, the presented interpretation of the production process is adequate.

Each product is possible to be realized in multiple trajectories, as the main requirement is the unity of the initial (opening) and final stages. Each trajectory essentially represents a different technology for converting a specific "blank" into a desired "product" [9]. The performance of a particular technology in the conditions of the production plant is defined as the "production process". The production process can be presented as a sequence of operations. The production process consists of separate operations, each of them often defined as "sub process” (figure 1). It is possible to present itself as a vector in the n-dimensional space of decisions, determined by the number of significant characteristics of the survey, depending on the aspect. The trajectory represents the change of the starting material until the desired parameters of the product or process are achieved. The points define the intermediate states of the change after the appropriate process is completed. The present interpretation is possible to be presented for each of the aspects of process evaluation, in different spaces of a solution defined by the active parameters according to their specifics.
2.2. Quality design

Genichi Taguchi developed a very powerful theory called "Quality Engineering", which allows achieving various objectives of optimum quality management [2]. The implementation of the presented approaches is also related to another due to the Taguchi achievement identified, such as "Robust Engineering", allowing optimization of production processes. It is important to emphasize that Taguchi's scientific developments are fully applicable to all products of production processes in the new aspects presented. The application of the methods presented in the evaluation, optimization and management of production processes has taken a significant place in the management of modern organizations [10]. The products in the second and third aspects of the process are respectively: the consumption of resources and their transformation, and the fulfillment of the requirements for the implementation of the process of achieving competitive ability.

According to the principles of the "loss function" [2], the level of quality is determined by the economic losses that are imposed on society from the moment when the product is delivered (realized or implemented). A typical example is the loss caused by the functional deviation from the desired product or process characteristics. Typically, the desired value determining a particular characteristic is determined by the term "nominal (target) value". Values actually achieved, to one degree or another, differ from nominal value. Such a difference causes significant losses to society due to the impaired functional characteristics of the product or process.

According to the basic principles of Quality Engineering, for each of the main aspects it is possible to build a system of characteristics defining requirements for each of the processes. Our attention is needed to concentrate on a system of functional characteristics, the modification of which is significant for the quality of the process.

The definition of the quality management system is carried out in three steps [2]: System design, parameters design and design of tolerances.

2.3. System design

This stage involves the development of a production process in accordance with desirable characteristics determining its implementation, in the appropriate aspect. The desired characteristics should be achievable and provide minimum deviations from the target values. The stage concludes by
compiling a list of characteristics through which it is possible to define the losses from the performance (operation) of the process or product.

2.4. Parameter design
This stage includes the determination of the optimum levels of the parameters, which is a quantitative assessment of each of the desired characteristics of the system. The quantified values determined are defined as 'nominal' should be achievable and provide conditions for minimum deviations from target values. The stage ends with the determination of the desired quantity values, which are the nominal value for the specific parameter.

2.5. Design of tolerances
After setting the system and parameters, the next step is to determine the optimum values of tolerances for each parameter. The choice of tolerances requires coordination and balance between product price and loss from poor quality performance. The stage finishes by determining the type and size of the tolerance, as well as its distribution to the nominal parameter.

2.6. Types of tolerances
Taguchi defines three types of tolerances: The Nominal the Best; The Larger the Better and The Smaller the Better.

The Nominal the Best (N type)
This type of tolerance has a positive value and in its ideal case equals zero. It is the main way to define tolerances in solving engineering tasks in Europe and the USA. The tolerance may be symmetrical or unsymmetrical in relation to the nominal value of the parameter. Losses at the limits of the interval limiting allowed may be equal or different. In the literature [2, 3], options were presented to calculate the loss function in both cases.

The Larger the Better (L Type)
This type of tolerance is not typical for use in Europe and the USA. A positive value is allowed and in some cases the zero value is desired. An example where its use is appropriate is sizing of tensile strength or effectiveness. In these cases, we have a certain parameter value that is minimal. Any value greater than the proposed minimum value is better for application. In the literature [2, 3] are presented ways to determine the function of losses, according to the possible options and statistical information about the process.

The Smaller the Better (S Type)
This type of tolerance is also not typical for use in Europe or the USA. There is a positive value and in some cases zero value. An example of the appropriate use is sizing of undesirable impurities (%), noise level or efficiency. In these cases, we have a certain parameter value, which is the maximum. Any value less than the proposed minimum value is better for application. In the literature [2, 3] are presented ways to determine the function of losses, according to the possible options and statistical information about the process.

A major advantage of the loss function is that it assesses the level of quality based on objective statistical information and the quantification is dimensioned in a [$/rated item$]

In cases where we have a system of the n-parameter, the quality level of the assessed element is determined by the equation:

$$L_q = \sum_{i=1}^{n} L_i$$  \hspace{1cm} (1)

where:
$\text{}L_q$ – the overall function of loss of product quality;
$n$ – number of items to be assessed;
$L_i$ – function of losses of the $i$-th element.
2.7. Design quality performance in resource management aspect

Society is interested in preserving the resources of nature and the planet. Excessive exploitation leads to significant environmental changes, affecting nature and quality of life. The damages are related to the depletion of the planet's resources and creating emissions threatening the ecological balance in nature.

Each of the processes is designed to create a product demanded by the society. Certain resources are involved in its implementation. They can be subject to processing and from them to create the desired product, but can be auxiliary or energy resources, which in the process are transformed in a different way.

In the design of the system determining the quality of performance in the resource aspect, we must incorporate parameters reflecting each of the resources involved.

Losses from the resources used can also be assessed through the three types of tolerances, but process optimization will achieve different objectives. In cases where we are only interested in the amount of the specific resource, the assessment can be realized by N type. This approach allows us to assess at the same time overspending losses or shortages of the specific resource.

If we strive to achieve a possible quantitative reduction in resource consumption, we need to use S Type or L Type, depending on the parameter being evaluated.

The function of losses, in defining in the aspect management of resources, for a specific operation is determined according to (2).

\[
L_{OR} = \sum_{i=1}^{n} L_i
\]  

where:

- \(L_{OR}\) – the general function of losses from the used resources for a particular operation included in the production of the product;
- \(n\) – number of items to be assessed;
- \(L_i\) – a function of losses of the \(i\)-th resource for a specific operation.

The total loss function for a defined production process shall be determined in accordance with (3).

\[
L_R = \sum_{j=1}^{m} L_j
\]  

where:

- \(L_R\) – the general function of the losses of resources used for the production process;
- \(m\) – number of operations assessed;
- \(L_j\) – a function of the losses of the \(j\)-th operation for a specific operation.

2.8. Design the quality of performance in aspect management of the competitive ability of the organization

The organization is interest by the effective and efficient execution of the production processes. Achieving appropriate values of efficiency and efficiency allows us to be competitive and achieve sustainable development of the Organization. The customer interested in sustainable development is the organization itself or in exactly all the stakeholders from its operation. Allowing a violation of the effectiveness and efficiency of the realized processes leads to significant losses, affecting the potential of the organization and the quality of production.

The definitions used in the present terms are as follows: effectiveness -“the extent to which the planned activities are implemented and the planned results are achieved” and efficiency-“correlation between the result obtained and the resources used” [5].
In the design of the system determining the quality of performance in a competitive aspect, we must incorporate parameters reflecting each of the mentioned criteria. It is necessary to note that in this case both criteria are relative.

Losses from non-performance of the efficiency requirements imply the use of L Type tolerance. This is because the minimum efficiency is usually defined and any greater is better and accordingly conducive to the development of the organization. While losses from the non-compliance with the efficacy imply the use of S Type tolerance, which requires the opportunity to achieve better results with the use of fewer resources.

The function of losses, subject to the competitive ability of the organization, for a specific operation is determined according to (2):

$$L_{OC} = \sum_{i=1}^{n} L_i$$  \hspace{1cm} (4)

where:

$\text{LOC}$ – the general function of performance losses for a particular operation used for the production of the product;
$n$ – number of items to be assessed;
$L_i$ – Function of losses of the $i$-th criterion of effectiveness and efficiency for a particular operation.

The total loss function for a particular production process shall be determined according to (4):

$$L_C = \sum_{j=1}^{m} L_j$$  \hspace{1cm} (5)

where:

$L_C$ – the overall loss function of a specific criterion to assess the effectiveness and efficiency of the production process;
$m$ – Number of operations assessed;
$L_j$ - a function of the losses of the $j$-th operation for a specific operation.

2.9. Optimal management of production processes

The current requirements for objective management of production processes determine the need to define adequate and objective decision-making criteria. As defined in point 2.1, it is possible to define objective quality criteria for the production process, including an objective assessment of "product quality" and "quality of performance". The target quality management function of the production process may be presented in the following form:

$$L_{PR} = L_Q + L_R + L_C$$  \hspace{1cm} (6)

where:

$L_{PR}$ – a function of loss of product quality and production process;
$L_Q$ – product quality loss function;
$L_R$ - a function of losses of the quality of performance of the process related to the resources used by it;
$L_C$ – a function of loss of quality of the process performance related to its effectiveness.

The quality engineering theory offers many tools to: Assess the quality level; The determination of optimum tolerances of the parameters used by the system; Optimal design of process control processes; Monitoring and evaluating improvements in processes; Management optimization and many other options.
Decision-making in all cases presented is based on the function of losses. The optimization of the processes and their management is again realized based on the familiar approaches.

The presented approach opens up new opportunities for achieving objective management at the level of the quality of the functioning of the processes and the achievement of objectivity in their selection. Its use enables us to optimally design, evaluate and manage the production processes in the aspects of resource management and competitiveness-ability.

3. Practical application

The presented approach is used by the authors in the selection of production processes for mass production. The information needed to take decisions is based on the behavior of the processes investigated by the practice and after their statistical treatment the functions of loss are determined according to the methodology of Taguchi [2].

The general function of losses of product quality and production process is determined according to (6).

In the manufacture of the desired product (a cylindrical roller used in the heavy engineering), requirements are applied to three basic parameters: diameter, deviation from cylindricality and roughness. According to the methodology adopted, they determine the function of loss of product quality ($L_Q$). The function of losses in the Process execution quality ($L_R$) includes assessment of the impact of the electricity used, operator time, the quantity of processed material and the tools used. In the given study, the presented parameters are significant and comparable. The function of losses related to the effectiveness and efficiency of the process ($L_C$) is assessed against the standard perceptions of these criteria. The effectiveness was assessed by the percentage of the production time relative to working time, and the efficiency by a relative estimate of the invested cash compared to the value of the realized product.

The aggregated data from the conducted studies of two competing variants, by the presented parameters, are presented on a table 1 and table 2. The values of the total loss function and its components in euro (€) are presented on table 3.

| Table 1. Study results of a competitive variant 1. |
| --- |
| Loss function | Name of evaluated parameter | Value (dimension) | Nominal Type of tolerance | Max | Min | Prise (€) | MSE | Quality loss (€) |
| Quality of product | Diameter | mm | 20 | N | 20.01 | 20 | 20.00 | 0.004574331 | 5.79 |
| | Roughness Deviation from cylindricality | μm | 0.016 | S | 0.016 | - | 14.50 | 0.003329731 | 0.63 |
| | Roughness Deviation from cylindricality | μm | 0.012 | S | 0.012 | - | 9.20 | 0.002843988 | 0.52 |
| Quality of resource management | Electricity | kWh | 1.25 | S | 1.25 | - | 0.11 | 0.009740536 | 0.00 |
| | Processed material | kg | 0.23 | N | 0.24 | 0.22 | 3.55 | 0.013069793 | 6.06 |
| | Operational time | h | 0.1 | N | 0.12 | 0.08 | 8.50 | 0.009740536 | 2.02 |
| | Tools | h | 1.2 | N | 1.4 | 1 | 8.00 | 0.163009109 | 5.31 |
| Quality of management | Effectiveness | % | 92 | L | - | 88 | 125.40 | 1.567021236 | 19.25 |
| Quality of product | Efficiency | - | 1.18 | L | - | 1.08 | 125.40 | 0.043256342 | 19.39 |

* Type of tolerance – N - The Nominal the Best; L - The Larger the Better; S - The Smaller the Better
Table 2. Study results of a competitive variant 2

| Loss function                          | Name of evaluated parameter | Value (dimension) | Nominal Type of tolerance | Max | Min | Prise (€) | MSE | Quality loss (€) |
|----------------------------------------|-----------------------------|-------------------|---------------------------|-----|-----|-----------|-----|-----------------|
| Quality of product                     | Diameter                    | mm                | N                         | 20.01 | 20 | 40.00 | 0.003442029 | 6.56 |
|                                        | Roughness Deviation from cylindricality | μm                | S                         | 0.016 | -  | 12.00 | 0.002246949 | 0.24 |
|                                        | Electricity                | kWh               | S                         | 1.25 | -  | 8.00  | 0.002068344 | 0.24 |
|                                        | Processed material         | kg                | N                         | 0.23 | 0.24 | 3.55  | 0.005652541 | 5.54 |
|                                        | Operational time           | h                 | N                         | 0.1  | 0.12 | 10.00 | 0.005652541 | 0.80 |
|                                        | Tools                       | h                 | N                         | 1.2  | 1.4 | 10.00 | 0.050155314 | 0.63 |
| Quality of resource management         | Effectiveness              | %                 | L                         | 92   | -  | 140.0 | 2.057506582 | 16.46 |
| Quality of product                     | Efficiency                 | -                 | L                         | 1.18 | -  | 140.0 | 0.030568684 | 3.62 |

* Type of tolerance – N - The Nominal the Best; L - The Larger the Better; S - The Smaller the Better

Table 3. The values of the total loss function and its components in euro (€)

| Loss function                          | 1 Variant (€) | 2 Variant (€) |
|----------------------------------------|--------------|--------------|
| Quality of product (€)                 | 6.94         | 7.03         |
| Quality of resource management (€)     | 13.39        | 6.97         |
| Quality of management (€)              | 38.64        | 20.09        |
| Total Loss (€)                         | 58.97        | 34.09        |

It is desirable to pay attention to some interesting facts:
- Although the value of the operation and the used equipment of variant 2 in almost all positions is higher, the total loss function \( L_{PR} \) is less by almost 42%.
- The main difference in the production equipment tested is the degree of operator involvement in the process. Under variant 2, operator involvement is minimal.
- The high value of the production equipment and the manufactured product is due to the desired precision, the high value of the workpiece processes and the desired performance.

This paper presents the possibilities of the proposed approach and is part of the research of the authors, which are subject to further study.

4. Conclusions

Based on the rich experience of the implementation of the developed tools of Quality Engineering, we offer their application in quality management of production processes. The concept of "product quality" extends to the notion of "quality of performance", which integrates an objective assessment of the resources consumed, as well as the effectiveness and efficiency achieved in the execution of production processes.

An opportunity to achieve an objective assessment of a complex criterion for assessment of "quality of production" and formation of a target function is presented. The formed target function
integrates the aspects of "product quality" and "quality of performance". The proposed approach has significant implementation opportunities to achieve the sustainable development of production plants.

5. References

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Acknowledgements

The scientific researches, the results of which are presented in the present publication, have been carried out under a project within the framework of the Technical University of Varna scientific work, financed by the state budget.