Application of qualimetry methods for quality assessment of production processes at components suppliers enterprises

A V Kuznetsov¹, N A Vitchuk², Yu Antsev¹ and A L Sabinina¹

¹Tula State University, 92, Lenina Ave., Tula, 300012, Russian Federation
²Kaluga State University named after K.E. Tsiolkovsky, 26, ul. Stepan Razin, Kaluga, 248023, Russian Federation

E-mail: anzev@yandex.ru

Abstract. It is practically impossible to efficiently manage the quality of the production process without determining the quantitative values for the indicators of its properties. Assessing the quality of the production process on a single, even decisive, indicator gives a one-sided, limited characteristic of the process, usually with a large number of properties. Therefore, for almost any process, especially for complex and multi-operational ones, it is necessary to carry out a comprehensive assessment on several parameters. In this regard, the indicator of the quality of the production process can be a complex, comprehensive indicator, depending on the single indicators of individual properties of the process. Such indicators include the indicator of continuity, the indicator of specialization, the indicator of plan fulfillment, the indicator of defect-free production, the indicator of progressivity, and the indicator of technical and economic efficiency.

The purpose of the study is to develop a methodology to use qualimetry methods for assessing the quality of industrial processes at industrial enterprises.
The objectives of the study: to determine the stages of qualimetric assessment of the quality of production processes; to develop the methods for calculating individual and integrated indicators of the quality of production processes; to practically implement the proposed stages of qualimetric assessment of the quality of production processes.

Research methods: qualimetric assessment methods, including expert method (preference method), integral assessment method.

Results. Indices that can act as single indicators of the quality of the production process are listed. The method to calculate the comprehensive indicator of the quality of the production process is shown on the example of the production process of manufacturing pipelines for gas turbine engines.

Findings. The proposed methodology for qualimetric assessment of the quality of production processes can be used when improving processes, and a comprehensive indicator of the quality of a process can act as a criterion for the efficiency of ongoing improvement activities.

1. Introduction
Quality management of any process, including production, is impossible without determining the parameters characterizing its quality. The quality of the production process is a set of properties that are quantitatively evaluated by the system of organizational and production indicators, and determine the compliance of the main parameters of the production process and products (work performed, services) with the established requirements [1, 12]. Quantitative assessment of a process’ parameters is possible through the methods of qualimetry.
Evaluation of the quality of production processes can be based on the implementation of the following steps:

1. Identify the composition of individual indicators characterizing the quality of the production process.
2. Determine the interval for changes in the values of individual quality indicators of the production process.
3. Determine the weighting factors of individual indicators for the quality of the production process.
4. Determine the comprehensive indicator for the quality of the production process.
5. Analyze the obtained value of the comprehensive indicator of the production process quality and adopt an appropriate management decision.

2. Target setting

The composition of individual indicators characterizing the quality of the production process is determined on the basis of the specifics of the production process itself, the current state of the process, the enterprise, and the result of the process. For example, to assess the quality of the production process, it is possible to use continuity indicator $K_1$; specialization indicator $K_2$; plan fulfillment indicator $K_3$; production deficiency indicator $K_4$; progressivity indicator $K_5$; indicator of technical and economic efficiency $K_6 \ [2-4]$.

The interval of changes in the absolute values of individual quality indicators can be set by a two-sided or one-sided limit. For example, the proposed single indicators for the quality of the production process can vary in the range from 0 to 1 \ [5, 11].

3. Theory

Qualimetric quality assessment of production processes is based on determining the values of individual indicators. The proposed quality indicators for production processes can be calculated on the formulas:

1) the indicator of continuity is calculated by the formula:

$$K_1(t) = 1 - \frac{T_{aux}(t)}{T_{pr}(t)},$$

where $T_{aux}(t)$ is the duration of auxiliary operations; $T_{pr}(t)$ is the duration of the production cycle; $t$ is the time span for which the duration of auxiliary operations and the duration of the production cycle are determined.

2) the indicator of specialization is calculated by the formula:

$$K_2(t) = 1 - \frac{C(t)}{n},$$

where $C(t)$ is the number of production workers; $n$ is the number of operations; $t$ is the time span for which the specialization indicator is calculated.

3) the rate of plan implementation is calculated by the formula:

$$K_3(t) = \frac{P_{act}(t)}{P_{pl}(t)},$$

where $P_{act}(t)$ is the actual output in absolute terms; $P_{pl}(t)$ is the planned amount of production; $t$ is the time span for which actual and planned output are compared.

4) the indicator of the defect-free production is calculated by the formula:

$$K_4(t) = 1 - \frac{N_{def}(t)}{N_{v}(t) + N_{def}(t)},$$
where \( N_{\text{def}}(t) \) is the number of defective production, determined for the \( t \) span; \( N_v(t) \) is the quantity of valid products, determined for the \( t \) span.

5) the indicator of progressiveness is determined by the formula:

\[
K_{\text{pr}}(t) = 1 - \frac{n - n_{\text{pr}}(t)}{n},
\]

(5)

where \( n \) is the total number of operations; \( n_{\text{pr}}(t) \) is the number of operations performed by progressive methods; \( t \) is the time span for which the progressiveness index is calculated.

6) the indicator of technical and economic efficiency is determined by the formula:

\[
K_{\text{te}}(t) = \frac{CS_{\text{an}}(t) \cdot k_d}{K(t)},
\]

(6)

where \( CS_{\text{an}}(t) \) is the annual cost savings on production, calculated for a certain time span, rubles; \( k_d \) is discount rate to bring the cost of annual savings to the value of the current assessment period; \( K(t) \) is capital investments in the improvement of the production process in a certain period of time, rubles.

Weighting factors of individual quality indicators of the production process can be determined by various methods, for example, by the method of parametric and cost regression dependencies, by the method of limiting and nominal values, by the method of equivalent ratios, by the expert method [2, 6].

In this case, the expert method or, the pair-wise comparison of objects (preference method) [7, 14], was used to determine the weighting factors. This method is used when the number of evaluated objects is even.

Under this method the weighting factors are found according to the formula:

\[
\mu_i = \sum_{i=1, j=1}^{m \times n} \frac{F_{i,j}}{C},
\]

(7)

where \( F_{i,j} \) is the frequency of preferences of the \( i \)-th indicator by the \( j \)-th expert; \( C \) is the greatest number of preferences of one; \( m \) is the number of indicators; \( n \) is the number of experts [8, 13].

To determine the comprehensive quality indicator of the production process, it is proposed to use the method of weighted average arithmetic integral evaluation:

\[
K_{\Sigma}(t) = \sum_{i=1}^{n} \mu_i \cdot K_i(t),
\]

(8)

where \( K_{\Sigma}(t) \) is a comprehensive quality indicator of the production process; \( \mu_i \) is the weighting factor of the \( i \)-th single indicator; \( K_i(t) \) is the value of an individual quality indicator of the production process; \( n \) is the number of single indicators; \( t \) is the time span for which individual quality indicators and the comprehensive quality indicator of the production process are determined.

4. Experimental results

Let us consider the methods for assessing the quality of the production process at industrial enterprises with the use of qualimetric methods on the example of the production of pipelines for gas turbine engines. Pipelines provide for the fuel and air systems operation in a gas turbine engine.

On the basis of the available initial data of the production process for manufacturing pipelines, individual indicators of its quality were determined [9, 10]. The calculation results are presented in figure 1.
Figure 1. Values of individual quality indicators of the production process when manufacturing pipelines

The current value of the indicator of technical and economic efficiency in assessing the quality of the production process when manufacturing pipelines, was taken to equal 0, since at the time of the assessment there were no capital investments in improving this production process.

Five experts were involved to determine the weighting factors of individual quality indicators of the production process. The table of preferences is shown on the example of evaluations by one of the experts (table 1).

| Number of indicator | 1   | 2   | 3   | 4   | 5   | 6   | Number of preferences |
|---------------------|-----|-----|-----|-----|-----|-----|-----------------------|
| 1                   | x   | 1   | 3   | 4   | 1   | 6   | 2                     |
| 2                   |     | x   | 3   | 4   | 5   | 6   | 0                     |
| 3                   |     |     | x   | 4   | 3   | 6   | 3                     |
| 4                   |     |     |     | x   | 4   | 4   | 5                     |
| 5                   |     |     |     |     | x   | 5   | 2                     |
| 6                   |     |     |     |     |     | x   | 3                     |

Basing on the results of the pair-wise comparison of objects, all experts determine the frequencies of preferences for the indicators presented in table 2.

The greatest number of preferences for one indicator will be:

$$C = \frac{m \cdot (m-1)}{2} = \frac{6 \cdot (6-1)}{2} = 15.$$

The results of calculating the weighting factors of individual quality indicators of the production process are presented in table 3. The obtained values of weighting factors add up to 1, which demonstrates that the indicators were evaluated by experts with a sufficient degree of accuracy.

The value of a comprehensive quality indicator of the production process in manufacturing pipelines is presented in table 4.
Table 2. Frequency of preferences

| Number of expert | $F_1$ | $F_2$ | $F_3$ | $F_4$ | $F_5$ | $F_6$ |
|------------------|-------|-------|-------|-------|-------|-------|
| 1                | 0.4   | 0     | 0.6   | 1     | 0.4   | 0.6   |
| 2                | 0.6   | 0     | 0.6   | 0.4   | 0.4   | 0.8   |
| 3                | 0.4   | 0.4   | 0.6   | 1     | 0     | 0.6   |
| 4                | 0.2   | 0.2   | 0.4   | 1     | 0.4   | 0.8   |
| 5                | 0.4   | 0     | 0.6   | 0.8   | 0.6   | 0.6   |
| $\sum F_{i,j}$  | 2     | 0.6   | 2.8   | 4.2   | 1.8   | 3.4   |

Table 3. Values of weighting factors for individual quality indicators for production process

| №   | Individual quality indicator                      | Weighting factor |
|-----|---------------------------------------------------|------------------|
| 1   | The indicator of continuity                        | 0.14             |
| 2   | The indicator of specialization                     | 0.04             |
| 3   | The rate of plan fulfillment                        | 0.19             |
| 4   | The indicator of the defect-free production         | 0.28             |
| 5   | The indicator of progressiveness                    | 0.12             |
| 6   | The indicator of technical and economic efficiency  | 0.23             |

Table 4. Assessment results for quality indicators of production process, taken into account the weighting factor

| Individual quality indicator                      | Weighting factor |
|---------------------------------------------------|------------------|
| The indicator of continuity                        | 0.10             |
| The indicator of specialization                     | 0.01             |
| The rate of plan fulfillment                        | 0.16             |
| The indicator of the defect-free production         | 0.27             |
| The indicator of progressiveness                    | 0.05             |
| The indicator of technical and economic efficiency  | 0.00             |
| Comprehensive quality indicator                     | 0.58             |

5. Discussion of results
The analysis of the obtained value of the comprehensive indicator for the quality of the production process and the adoption of an appropriate managerial decision depends on the objectives of the qualimetric process quality assessment. For example, for the production of pipelines, the obtained value of the integrated comprehensive quality indicator is a guideline for improving the process and selecting the most efficient measures aimed at improving the value of this indicator: 1) if $K_{\Sigma} \leq 0.58$ the proposal for improving the production process should not be implemented; 2) if $0.58 < K_{\Sigma} < 1$ the proposed improvement can be implemented, however, further improvements are possible, which will allow obtaining individual indicators for the quality of the production process close to the maximum values.

6. Summary and conclusions
The article proposes a methodology to assess the quality of industrial processes at industrial enterprises using methods of qualimetry. It covers several stages and is based on determining a comprehensive indicator for the quality of the production process, which includes six individual indicators of quality: continuity, specialization, plan fulfillment, defect free production, progressiveness, technical and economic efficiency. Evaluation of the process quality according to the listed indicators is carried out with the involvement of experts, i.e. specialists competent in solving the question. Processing the results
of expert assessment can be carried out using various methods. In this case, the preference method was used, demonstrated by the example of assessing the quality of the production process for manufacturing pipelines of gas turbine engines. A comprehensive indicator for the quality of the production process is calculated by the method of average weighted integral evaluation.

A comprehensive indicator for the quality of the production process both demonstrates the current quality of the process, and can also be used as a benchmark to monitor the dynamics in process changing, to compare several options for process improvement, to evaluate the efficiency of planned or implemented options for process improvement with the aim to improve its quality.

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