Assessment of technical level of new, promising models of equipment at the stage of their development in modern engineering practice

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Abstract. The problems of optimizing the selection of the best new model of technology are considered, based on an assessment of its functioning as part of the complex system. The composite indicator of the product technical level is proposed as such an assessment characteristic. It is represented by six basic components and can be used at all stages of the model development. Models and methods for calculating a generalized indicator of quality, novelty of technical solutions, functional and constructive organization, adaptability to advanced technology, reliability of a sample, its graphical representation based on classical methods of probability theory, expert and heuristic estimates, an ideal center, graph theory taking into account the functional cost analysis have been prepared.

The timely development of new effective models of equipment is one of the important tasks in modern conditions. Developing organizations are interested in receiving a state order due to a reduction in tax deductions, the establishment of incentive premiums on contract prices for scientific and technical products, the preservation of skilled employees, etc. On the other hand, ordering organizations want to get a more efficient technical object in a short time and with a minimum cost. The resolution of this contradiction can be a competition, which is understood as the selection of the best of the proposed technical facilities developed in parallel by several developers.

When developing a new generation technology, it is necessary to perform the following steps: prepare a functional structure; determine the principle of action; specify technical solutions (TS); find the optimal parameters. The appropriateness of choosing one or another TS will be based on assessments of the effectiveness of its use as part of a system or a facility [1]. The indicator of the technical level (TL) of the product can be considered as a characteristic for assessing the efficiency of use. The choice of this indicator is explained by the following: it depends only on TS and does not depend on the quality of its manufacture, that is, the TL indicator can be used at any stage of the product creation [2]. This is especially important in the early stages when choosing a schematic diagram of a facility under
development. Moreover, taking as the basis for comparison the best world models, it is possible to predict the technical and economic indicators of the products being developed, which allows us to exclude the situation when the equipment being created turns out to be obsolete during design [3].

Modern engineering practice of creating new models of equipment is unambiguously trying to solve the issue of developing such products that would meet the best world standards [4]. The choice of a base sample for modeling the best global predicted image with achievable TL is based on the processing of patent materials. Such processing of patent information using electronic technical resources allows us to improve the information component of new developments, which affects the appearance of modern technology. Analysis of the descriptions of inventions serves as an indicator of the development of technical ideas. The developed technical facility is a complex technical system consisting of many units, parts, elements. Therefore, it is necessary to find out which unit is the most important, from the point of view of its technical perfection. Also, the most important parameter determining the trends of the current stage of the product development is “Universalization” (standardization, unification), which is understood as the unity of technologies, of individual blocks that allows to use them without additional modifications in any facility, involving the combination of the functions of individual elements [5].

The existing methodology for TL assessment involves summing the “weighted average” values of the groups of indicators of product properties and their weight coefficient. This technique was mistakenly transferred to complex products from the field of consumer goods evaluation.

Numerous attempts to improve the methodology by changing the values of indicators and their weight coefficients did not lead to an objective assessment. On the contrary, the dominant indicators “dissolved” in the abundance of secondary ones, which created the appearance of an “accurate” assessment and distorted the true state of affairs [6].

Thus, the theoretical imperfection and practical bias of the current concept of evaluating TL products makes it unpromising.

This shows that a new concept is needed, in the development of which it is proposed to use the following basic principles:

- concept should be based on a new definition of the term TL in its broad, modern interpretation;
- when developing a criterion for assessing TL, one should proceed from the physical nature of the operation of the products, i.e. consider it as a process of achieving a beneficial effect inherent in this type of device;
- functional measure for assessing the performance of products can only be a physical quantity that reflects energy, time, probability and other characteristics;
- result of the assessment should be expressed in absolute units (as is customary in physics), reflect the quantitative and qualitative sides, have its own dimension; it should be compared with the absolute scale for measuring TL of similar products that are globally competitive;
- absolute value of the TL criterion should be the basis for determining the development dynamics of all types of products, based on current needs, forecasting progress and developing mandatory standards for their development.
- TL criterion should guarantee complete independence and objectivity at all stages of the technical examination of products, at all stages of the life cycle, according to common indicators and methods for all types of devices of a certain functional purpose.

The TL assessment of the products being created is provided for by existing standards systems and a range of typical indicators of the quality of development and production.

In accordance with the main provisions of normative documents, TL products are a relative characteristic of its quality, obtained by comparing the values of indicators that determine the technical perfection of its evaluated type with the corresponding base values.

In this case, the technical perfection of the product is determined by special TL cards by the relevant commissions or individuals. This means that this assessment will to some extent depend on the
subjective views of the Contractor and the Customer. It is possible to change the established practice only by improving the content of the concept of TL samples. For this, the following work has been done:

- substantiation of the composition of the basic components of a technical level (ITLI) composite indicator
- preparation of models and methods for their calculation;
- ITLI calculation algorithm [7];
- creation of a graphic representation method of the ITLI components [8].

The following components, allowing to assess TL of new developments, were used as basic:

- quality of the development of the sample, expressed in numerical determination of the generalized quality indicator (GQI) of the product [9];
- novelty of technical solutions (NTS), determined by the coefficient of new technical solutions ($K_{NTS}$) [10];
- functional organization (FO) of the sample development, characterized by the coefficient of functional organization of the sample ($K_{FO}$) [11];
- constructive organization (CO) of the sample, expressed in numerical determination of the coefficient of structural organization of the sample ($K_{CO}$);
- adaptability of the sample to advanced production technology ($K_{PT}$) [12];
- the reliability of the sample calculated through the availability factor (has probabilistic nature) or the sample failures experience [13].

In each group, the corresponding indicators are determined on the basis of known methods of probability theory, expert and heuristic evaluations, an ideal center, one-dimensional metric scaling, graph theory, a functional-cost analysis apparatus, logical-statistical models [14].

Therefore, a new approach is proposed to determine one of the components of ITLI - GQI, which should be determined by the implementation of the following provisions:

- selection of values of quality indicators;
- determination of the comparison base, in which it is proposed to use a set of indicators established in the form of a requirement of a tactical-technical task (TDP) for the development of products;
- dividing indicators into two groups: essential, conditionally proportional in nature, determining the main purpose of the product, and non-essential, conditionally alternative in nature, characterizing the secondary functions of the product. This partition is performed according to the degree of their influence on TL and the excess of the actually achieved values of the indicators over those specified in the TDP, taking into account the correlation coefficient.
- calculation of GQI, which is a weighted arithmetic average, geometric average or harmonic average convolution of the indicators of the selected groups [15].

Previous studies have shown the need for planning for each GQI product, which is an indicator, the numerical value of which can be obtained by comparing the characteristics of the developed product and the best available world analogues, taking the correlation coefficient R “cost-indicator” as a criterion (figure 1).
An approach taken from the subject area for organizing patent information is used to evaluate NTS. According to [10] and in relation to the problem under consideration, tables are prepared. In them, the qualitative characteristics of TS are uniquely matched by numerical values [16]. If the characteristics are identical in significance, then their weight coefficient (Kj) is calculated as

$$\frac{1}{d} \leq K_j \leq 1$$

If they have different importance, then Fishburn’s formula can be used [17], then the weights of their characteristics even at $d=4$ will have a big difference. In this case, to reduce a sharp decrease in the weight coefficient between the characteristics, the following approach is used. The assumptions are introduced:

a) the significance of the first characteristic ($b^1$) is the largest and equal to unity, the last - zero;

$$b^j \lim_{j \to \infty} \frac{b^{j+1}}{b^j} < S \quad (1)$$

where:

S is a certain number to which the series in should strive to achieve in convergence;

c) coefficients of significance of the characteristics are a descending sequence:

$$b^j > b^{j+1} \ldots > b^d \quad (2)$$

where $d$ is the number of characteristics;

d) the relative ratio of nearby, located characteristics should have the least value:

$$\frac{b^{i-1}-b^{i+1}}{b^j} \rightarrow min \quad (3)$$

Figure 1. GQI calculation model.
Using the method of combinatorial selection of the coefficient, the type of function based on assumptions (1-3), we obtain:

\[ b^j = \frac{1}{2 \prod_{i=1}^d}, \quad j = 1, d, \quad (4) \]

Then:

\[ K_{NTS} = \sum_{j=1}^d \sum_{i=1}^e B_{ji} \cdot \text{sign} B_{ji}, \quad (5) \]

where:

\[ \text{sign} B_{ji} = \begin{cases} 1, \text{if in the } j - \text{th position is selected by the } i - \text{th characteristic;} \\ 0, \text{otherwise.} \end{cases} \]

To develop the FO model, a functional-cost analysis apparatus [18] and a functional-physical description of samples [19] are used (Fig. 2). Therefore, \( K_{FO} \) is calculated as:

\[ K_{FO} = \sqrt{K_{upd\text{main}} \cdot K_{upd\text{minor}} \cdot K_{cf} \cdot K_{exf}} \quad (6) \]

where:

coefficients \( K_{upd\text{main}(\text{minor})} \) – actualization of the main (secondary) functions; \( K_{cf} \) – concentration of the main functions; \( K_{exf} \) – extensions, determined depending on the number of secondary and main functions.

The development of a new product involves informational, energetic connections between elements, defined by TS with physical principles of action, therefore, \( K_{CO} \), is introduced, calculated by expression (7):

\[ K_{CO} = \frac{\ln(E)}{D \cdot E^2}, \quad (7) \]

where:

the number of E - elements in the sample; D - bonds.

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**Figure 2.** An approximate model of the product FO.

When developing a prototype, one must consider:
• modern technology, taking into account scientific and technological progress [20];
• new modes of operation under the necessary operating conditions [21];
• “smart” materials that retain their performance under the influence of aggressive factors of various emergencies on them [22];
• global trends for the training of qualified specialists, providing a “breakthrough” of technical ideas in this area.

This is taken into account by the introduction ITLI $K_{PT}$, determined by using expert judgment.

If the organization that forms TDP and puts it up for tender (competition) has data on the features of the technological process, the materials used, the level of training of engineering and technical workers, this makes it possible, using modern methods, to quickly, better identify the inconsistency of the developed products with the requirements of existing regulatory documents [23-25].

The graphical presentation of the main values included in the ITLI will promote the objectivity in decision-making by the ordering organization (figure 3).

![Graphical representation of ITLI features.](image)

This set of basic ITLI components will allow the customer to comprehensively evaluate the proposed development, taking into account the dynamics of the product life cycle, to choose the best sample from the set of developments submitted to the competition.

Consistently assessed by the customer ITLI facilities will also allow him to remove some of them from the competition in stages.

This distinguishes the proposed TL products assessment approach from those in practice of ordering organizations.

This approach allowed the customer to correctly formulate the TDP for the development, taking into account the prospects of the products; it also allowed the developer to implement them in design decisions with high-quality, without unnecessary costs.

Thus, the customer in a short time with minimal cost solves the problem of creating effective technical facilities, optimizes processes.

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