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# EVALUATION OF THE STATE OF INNOVATIVE ACTIVITY OF MACHINE-BUILDING ENTERPRISE

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**Abstract:**
The innovative activity of machine-building enterprises is the main guarantee of their sustainable and effective development, which makes it possible to compare technical and technological innovation in the production of products in different periods and between different enterprises in points. Quantitative numerical assessment of the innovative component of the enterprise is a prerequisite for developing a strategy for further effective production management. After all, in addition to financial performance indicators, technical innovations play a decisive role in the modern market environment, although little attention is paid to them. In the work, based on organizational and technical modeling and logical methods of exploratory evaluation, the author's method of establishing a quantitative comparative level of innovative activity of a machine-building enterprise was built. The developed methodology for evaluating the innovative component of machine-building production is based on three basic criteria: mastering new machines, mastering technological processes, and the effectiveness of implementing design and technological solutions. The first two criteria take into account the nomenclature, novelty, the risk of introducing a new solution and the technical level of products. To determine these criteria, several levels of novelty of machines and technologies are proposed and the author's understanding of their content is given. The third criterion, the effectiveness of implementation, is evaluated by indicators that take into account the intensity of adjustments at various stages of design. The result of the study is a method of comparative assessment of the level of innovative components of the development of machine-building production with a set of indicators that provide professionals with a tool for monitoring the processes of introducing new equipment and technologies into production and the subsequent formation of an effective innovative strategy for the development of a machine-building enterprise. The capability of the proposed methodology is presented in the given example of evaluating the innovative development (state) of an abstract machine-building enterprise.

***Key words:*** *technological process, mechanical engineering, technological innovations, production development*

## INTRODUCTION

In today's market world, the competitiveness of product manufacturing dictates the further sustainable development of industrial sectors, especially in engineering. The main guarantee of the successful development of machine-building production and maintenance of the corresponding dynamics of successful promotion on the market of finished products of enterprises is the desire of the manufacturer to continuously master the production of new competitive technological machines, applying effective technological processes of their manufacture. For the effective management of machine-building enterprises and the formation of the vector of their development, experts in the machine-building industry need practical methods of establishing integrated comparative numerical indicators (criteria) of the level of innovative activity of production. The intensity of the development of machine-building production is directly influenced by factors related to the development of new technological production processes and the creation of the design of new technological machines, which are related to the ability of the technical staff of the manufacturing enterprise to quickly master new technological manufacturing processes, timely updating of the machines of the manufacturer's technological park, the readiness of other branches of the national economy to effectively operate a new technological machine, the opportunity to enrich the working environment with qualified specialists and much more. However, they do not change the content of the problematic issues of innovative development, but only ensure its competitive level. In modern science, although the nature of innovations is sufficiently substantiated and studied, certain aspects remain insufficiently researched and have not received proper theoretical and practical development. These include approaches to quantitative assessment of the state of innovative activity of a machine-building enterprise based on a set of classification features and methods of its determination.

## LITERATURE REVIEW

A lot of scientific research is devoted to the study of innovative processes in production. Particular attention is paid to the backbone machine-building industry, which determines the production potential and defense capability of the country as a whole. However, these research [1] studies mainly deal with the issues of enhancing innovation in the context of economic systems. Also, in particular, the difficulty of assessing and identifying the intellectual capital of enterprises is pointed out. Little attention is paid to the assessment of the state of product renewal, technology and professionalism of industry personnel, which is the main indicator of innovation and the result of the intellectual asset of mechanical engineering.

The issues of a deeper study of the ways and possibilities of rational use and the construction of a methodology for evaluating the innovative activity of production as the basis for economic growth in the areas of management are of particular importance [2]. Enterprises of the engineering industry are a catalyst for the development of the economy [3, 4] and determine its level as a whole [5, 6, 7]. The key to the successful development of machine-building production is the desire of the manufacturer to continuously master the production of new competitive technological machines [8, 9], using effective technological processes for their manufacture [10, 11], with the best indicators of their adaptability to the prototype to solve a specific technical problem under given conditions [12, 13, 14].

The development of the machine-building enterprise is achieved through its innovative activities [15, 16, 17]. These are, first of all: the development, release and confirmation on the market of new competitive products [18]; the increase in production intensity with the development of new technologies [19, 20]; high-quality intellectual work of creators of new technology [21, 22]. Therefore, the company is interested in the activation and comparative evaluation of its innovative activity, which would provide it with a guaranteed profit and the possibility of rapid accumulation of capital for its further investment in the development of production [23]. Also, its employees are provided with jobs and guaranteed payment of decent wages, and the consumer receives new, higher-quality goods [24, 25].

New technological processes are becoming the main factor in economic and social transformations, thanks to which people change all areas of their activity and change themselves [20, 26]. The creation and introduction of new technological processes and machines into production, ensuring the innovative activity of the enterprise is a rather complex scientific problem that requires special attention of scientists and production workers [27, 28, 29].

The work [30] analyzed 1361 scientific works, starting from 1961, to study the evolutionary development of the concepts of introducing technological innovations. It is indicated that the innovation process includes the introduction of innovative solutions, which leads to the production of a new product, service, technology or method. This is preceded by the study of different dimensions of technological innovation. However, researchers do not properly rely on such theoretical estimates. The method of scoring the comparative assessment of the innovative aspect of enterprises is proposed in [31] by Akbari et al. in 2021. However, here the evaluation of such a performance indicator is focused on management and is aimed at benchmarking analysis. But not enough attention is paid to technique and technology.

The works [32, 33, 34] analyze innovative ways of managing and regulating the innovative activities of engineering companies and their impact on performance. It is indicated that a reliable assessment of the intellectual capital of a machine-building enterprise and the reflection of intangible assets in the balance sheet makes it possible to increase the market value of the enterprise and attract new investors and partners. The important role that engineers play in solving the problems of sustainable development and designing technical systems is shown. Research [35, 36] created a design automation system of technological processes.

The determination of priorities for the innovative development of a machinery manufacturing enterprise is described in research [37]. It describes the main stages in the formation of a strategy for innovative development, taking into account regional innovative opportunities, based on a subjective and objective assessment of the state of innovative activity of industrial enterprises, as well as identifying factors that stimulate and hinder the innovation process. In the context of the modern market environment and dynamic changes caused by the influence of information technology and the rapid development of scientific and technological progress, the urgent need for innovative development of domestic machine-building enterprises is considered [38]. Here is a model for a comprehensive assessment and analysis of the level of innovative potential for choosing a strategy for stimulating the innovative and investment activities of an enterprise.

In publications [39, 40, 41, 42], the current state of the machinery manufacturing industry in Ukraine and its innovation activity are examined. The main factors restraining the development and modernization of the industry are outlined, and the key problems in its functioning are identified. It is mentioned that to ensure the viability and sustainability of economic entities, their managers should develop adequate development strategies. The main stages of strategic planning at the enterprise are formulated. One of them is the analysis of the internal environment, i.e., the state of the internal potential of the enterprise, which is the focus of our work.

In the paper [43], using the example of auto carriers, it is argued that active development of related industries is achieved through the use of innovative products in machinery manufacturing. In [44], the processes of innovative machine design are discussed, its stages are proposed, and the overall design process is shown. It is noted that innovative machine design is a fundamental prerequisite for producing competitive products among the goods of advanced industrial countries. The rationale for the implementation of high-tech products and intelligent systems, which are the main trends in the innovation development of machinery manufacturing, is provided in [45].

In the work [46], various approaches to interpreting innovation potential are discussed, and the advantages and disadvantages of each are presented. A methodology for evaluating the level of innovation potential of a machine-building enterprise based on the method of economic analysis is proposed.

Summarizing the results of scientific research, it can be concluded that the development of the innovation sphere in machinery manufacturing, aimed at adopting progressive technologies, will lead to a qualitatively new level of industrial production. Therefore, the foundation for the successful development of the machinery manufacturing industry lies in addressing the issues that can only be solved through structural and technological modernization of production to produce modern competitive products. This process is preceded by the assessment of the level of innovation potential of a machinery manufacturing enterprise, which is complex and labor-intensive. At the same time, information about the state of innovation potential and its indicators is crucially needed. However, in most scientific studies, the primary focus is on the management and financial aspects of innovation activities, and there is limited research on the key technical criteria for the innovation activity of a machinery manufacturing enterprise in the form of numerical indicators.

The purpose of the work is to build a methodology for quantitative evaluation of the innovative activity of a machine-building enterprise based on the proposed criteria for the development of new machines (products), technological processes and the effectiveness of the implementation of design and technological solutions.

## RESEARCH METHODS

The methods of the modern direction of the organizational and economic science of "technology management" were used in the studies, to assess the quality of the machine-building enterprise to assess the quality of the machine-building enterprise, particularly, the methods of organizational and technical modeling - statistical methods of data analysis, the theory and practice of expert evaluations. The analysis of the company's efficiency was performed using the three-factor model "Human-Machine-Environment". It takes into account the technological readiness of the enterprise, the technical level of products and the qualifications of personnel (current state and dynamics of changes) - a comprehensive indicator of its innovativeness.

To achieve the goal, logical methods of exploratory evaluation of the innovative activity of machine-building enterprises in which logical rules of analysis, comparison and generalization prevailed, were used. Initially, an aspect approach was applied, which allowed, with the existing experience of the creative team of performers, to focus on the study of the most important components of the innovative development of machine-building production. The principle of practicality, focused on the practical implementation of the results of the previous search, was used later.

## RESEARCH RESULTS

We single out three, in our opinion, main strategic problems (criteria), the successful solution of which determines the level of innovative development of machine-building production [47]:

- development of new products (production of competitive products);
- development of new technological processes for manufacturing products;
- effectiveness of the implementation of technical solutions implemented.

The three-factor model "Human-Machine-Environment" is used here, where the first criterion corresponds to the Machine factor, the second to the "Environment" factor, and the third to “Human”.

Let us specifically consider each of these indicators, according to which we propose to evaluate the level of the innovative component of a machine-building enterprise, which is based on the relevant criteria for the development of new machines, technological processes and the effective implementation of design and technological solutions. To take into account the peculiarities of a particular production, the number and nature of the evaluation criteria can be changed, while maintaining the proposed approach to their analysis. Each of the indicators is determined for a certain period and analyzed in a comparative assessment of the level of innovation activity of a machine-building enterprise (enterprises).

**Criterion 1 "Adoption of new products"**

The adoption of the production of new products (machinery and equipment) is a daily task in the development of an enterprise, ensuring its competitiveness and profitability. However, it comes with risks since there is the possibility of a project "failure," which can result in the loss of time, reputation, and resources. The level of design for a new product directly depends on market competition and the readiness of the manufacturing enterprise to take on potential risks.

Developing a new machine is a complex, multifaceted, and technically challenging task. Its successful resolution depends on both the professional level of the developer and the state of the machinery manufacturing capabilities of a particular enterprise.

Here, it should be specified that a technical task is a localized part of a technical problem that pertains to a specific machine or a particular technological process and requires immediate resolution based on the latest advancements in science and technology. On the other hand, a technical problem is a cumulative negative technical-economic situation that develops over time in a particular sector of the economy and hinders its progress.

To assess the performance of a specific machinery manufacturing enterprise in terms of adopting (producing) new products, we propose using an indicator expressed by the following dependency:

$$C_{SP} = \frac{\sum_{i=1}^{n} c_{nov.i}(1-c_{r.i})c_{tl.i}}{N_p}, \quad (1)$$

where:

$C_{SP}$ is the coefficient (indicator) of the state of production of new technical objects (machines) at the enterprise,

$\eta$ is the nomenclature number (number of standard sizes or models) of mastered new technical solutions (machines) for a given period of production,

$c_{nov.i}$ is the novelty coefficient of the *i-th* new technical solution (product),

$c_{r.i}$ is the risk coefficient of introducing the *i-th* technical solution into the structure, related to the possibility of the manufacturing enterprise to adopt the new machine and compensate the costs by selling it,

$c_{tl.i}$ is the coefficient of technical level of the design of the *i-th* new product (machine),

$N_p$ is the total nomenclature number (number of standard sizes or models) of products mastered by the enterprise.

This indicator $C_{SP}$ is directly proportional to the sum of the products of the coefficients of novelty, risk and technical level and is inversely proportional to the total nomenclature number of models and sizes of products manufactured by the enterprise.

We offer our understanding of the coefficients of novelty $c_{nov.i}$ and the risk $c_{r.i}$ of introducing technical solutions adopted when creating new technological machines or other technical objects of mechanical engineering production, based on generally accepted standards for the creation of new equipment, and the determination of a quantitative assessment of these coefficients.

The novelty of technical solutions for the creation of objects of new technology plays a major role in determining the product's ability to compete in the world market of such products. Therefore, the novelty of products must be determined at all stages of creation, starting from design development and ending with the organization of mass production, to objectively assess one's capabilities and establish ways to correct mistakes.

The novelty of technical solutions can be assessed on at least five levels. At the same time, one should take into account the probability of risk, that is, the probability of failure of a certain project. With each subsequent level, the quotient of novelty, as well as risk, increases.

*Level 1. Ordinary technical solution*

The product is modernized without changing its structural design and physical principle of action, i.e. the method of impact on the workpiece or raw material. Improve the design of individual nodes, increasing their reliability and durability. At the same time, individual technical indicators (characteristics) of the product are increasing. The general layout and appearance remain unchanged. The level of novelty, as well as the riskiness of the project of such a product, is the lowest.

*Level 2. Advanced technical solution*

The product is modernized without changing its structural design and physical principle of action. Improve the design of the main nodes that affect productivity, increase their reliability and durability. Individual technical indicators of the product are increasing. The general layout and appearance remain unchanged.

*Level 3. Complex technical solution*

The product is modernized without changing the physical principle of action. They improve the design of almost all nodes, increase their reliability and durability. They achieve an increase in productivity and quality of product processing. Greater productivity is achieved than at the previous level. The general layout and appearance of the product remain the same.

*Level 4. A new technical solution*

The product is modernized without changing the physical principle of action. Rework and improve the design of almost all nodes, increasing their reliability and durability. The main nodes undergo radical processing and receive a unique performance. Improve general communication. The product acquires a more attractive appearance and better ergonomic indicators, it becomes more convenient to manage and maintain, and the productivity of the product (machine) increases. Special and main attention is paid to the reduction of energy costs when performing the technological process. The product ensures high-quality product processing. The design is protected by a patent.

*Level 5. Original technical solution*

The product is developed on a new physical principle of action, which significantly improves technical and economic indicators. All nodes have original execution. The overall layout and appearance of the product changes. Energy consumption per unit of manufactured products is less. All indicators of the technical characteristics of the product are increasing. High quality of product processing is achieved. The product has improved ergonomic performance and minimal harmful impact on the environment. The design is protected by a patent.

Table 1 presents summary data of the criteria for the changes made and the results achieved for evaluating each level of novelty of the product (machine).

Since the risk of introducing a new technical solution into production is always present, the risk coefficient $c_r$ is introduced into formula (1), which, of course, reduces the weight of the coefficients of novelty $c_{nov}$ and technical level $c_{tl}$. That is, the more perfect the technical solution, the higher the risk of its implementation and the more effort the developer needs to make to promote their product on the world market.

To quantify the innovative activity of the enterprise, according to the criteria adopted here, certain logical values are assigned to the coefficients of novelty and risk for each of the levels of novelty of technical solutions. The author's view of the values of these coefficients is shown in Table 3, although the selectivity of such values does not affect the comparative assessment. But it is quite logical that with each subsequent level the novelty factor increases, but the probability of successful completion of the project (risk factor) decreases.

The value of the coefficient of the technical level $c_{tl}$, which is included in the dependence, is determined by well-known methods [48].

***Table 1***

***Criteria for changes and achieved results***

| Novelty level | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Technical solution | | ordinary | advanced | complex | new | original |
| No. | Criterion name | application of changes in a new product (machine) | | | | |
| **1. Changes to the product (technological machine)** | | | | | | |
| 1.1 | Changes in the physical principle of action (method of influence on the workpiece or raw material) | | | | | + |
| 1.2 | Changes in the constructive execution | + | + | + | + | + |
| 1.2.1 | modernization of individual units | + | | | | |
| 1.2.2 | modernization of basic units | | + | | | |
| 1.2.3 | modernization of almost all units | | | + | | |
| 1.2.4 | radical reworking of almost all units | | | | + | + |
| 1.3 | Change in the structural construction and layout of the product | | | | + | + |
| **2. Significant improvements achieved by design changes** | | | | | | |
| 2.1 | Technical and economic indicators | | | | | |
| 2.1.1 | reliability | + | + | + | + | + |
| 2.1.2 | durability | + | + | + | + | + |
| 2.1.3 | productivity | | | + | + | + |
| 2.1.4 | quality of processing of raw materials or workpieces | | | + | + | + |
| 2.1.5 | energy saving | | | | + | + |
| 2.2 | Ergonomics | | | | | |
| 2.2.1 | appearance | | | | + | + |
| 2.2.2 | management and maintenance | | | | + | + |
| 2.3 | Environmental friendliness (harmful impact on the environment) | | | | + | + |
| **3. Protection of intellectual property** | | | | | | |
| 3.1 | Patentability of individual technical solutions | | | + | + | + |
| 3.2 | Patent ability of a complex technical solution | | | | + | + |

**Criterion 2 "Development of new technological processes"**

New technological processes of manufacturing and assembling make it possible to more efficiently master new products within the established time frame and positively influence the quality and technological cost of manufacturing a new technological machine. To assess the state of machine-building production of a certain enterprise when mastering new manufacturing processes of certain technical systems, we suggest using an indicator expressed by a dependency similar in structure to (1).

$$C_{SE} = \frac{\sum_{i=1}^{n} c_{nov.i}(1-c_{r.i})c_{tl.i}}{N_{tp}}, \quad (2)$$

where:

$C_{SE}$ is the coefficient of the state of enterprise for the development of new technological processes in its production,

$n$ is the nomenclature number of new technological processes mastered by production,

$c_{nov.i}$ is the coefficient of novelty of the *i-th* technological process,

$c_{r.i}$ is the risk coefficient of the *i-th* technological process, associated with the ability of the manufacturing enterprise to master a new technological process and compensate for the costs of its development by selling new machines,

$c_{tl.i}$ is the coefficient of technical level of the *i-th* technological process,

$N_{tp}$ is the nomenclature number of technological processes used in production.

As in the previous case, the indicator $C_{SE}$ is directly proportional to the sum of the products of the coefficients of novelty, risk and technical level and inversely proportional to the total nomenclature number of technological processes used in production. And the higher the value of this indicator, the better the machine-building enterprise is prepared for innovative production.

We note that one of the main conditions for the development of new technological processes is the improvement of the quality of the work performed, the intensification of production, the reduction of the technological cost of production and the increase of the ability to master the production of new machines in the shortest possible time.

The coefficient of the state of the enterprise for the development of new technological processes ($C_{SE}$), as well as the coefficient of the state of production ($C_{SP}$), will also be attributed to five scientific and technical levels, our understanding of the content of which is as follows.

*Level 1. Regime*

The technological process is characterized by the intensification of technological regimes. In this case, the method of influencing the processed product is the same. Only the regimes change.

*Level 2. Post-operative*

The technological process is characterized by a change in the sequence and ordering of transitions in individual operations with simultaneous intensification of technological modes, without changing the method of influence.

*Level 3. Complex*

The technological process is characterized by a change in the sequence and order of transitions in most operations, including their combination, with the simultaneous intensification of technological modes without changing the method of influence.

*Level 4. New*

The technological process is characterized by a change in the sequence and order of transitions in all operations, including their combination, with the intensification of technological modes and the use of a more stable tool without changing the method of influence.

*Level 5. Original*

The technological process is built on a new way of influencing the processing product. It is characterized by fundamentally different technological regimes. It requires the development of new technological operations and, usually, new means of technological equipment (machines, devices, tools, technological fluids, etc.), as well as additional training of service personnel.

Table 2 presents summary data of the criteria for evaluating each level of novelty of the technological process.

***Table 2***
***Criteria for assessing the newness level of the technological process***

| Novelty level | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Name of the technological process level | | Regime | Post-operative | Complex | New | Original |
| No | Criterion name | Changes in the technological process | | | | |
| 1 | Intensification of technological regimes | + | + | + | + | + |
| 2 | Changing the sequence and order of post-operative transitions | | | | | |
| 2.1 | on separate operations | | + | | | |
| 2.2 | on most operations, including their combination | | | + | | |
| 3 | Using a more durable tool | | | | + | |
| 4 | A new method of influence | | | | | + |

The author's view of the values of the coefficients of novelty and risk of the project at each level of novelty of the technological process is shown in Table 3. As the level increases, the coefficient of novelty increases, but the prospect of successful completion of the project decreases.

***Table 3***
***Coefficients of novelty and risk of a technical solution and a technological process***

| Novelty level | Technical solution | Technological process | Novelty coefficient, $c_{nov}$ | Project risk coefficient, $c_r$ | $c_{nov}(1-c_r)c_{tl}$ |
|---|---|---|---|---|---|
| 1 | Ordinary | Regime | 1 | 0.1 | $0.9c_{tl}$ |
| 2 | Advanced | Post-operative | 2 | 0.2 | $1.6c_{tl}$ |
| 3 | Complex | Complex | 3 | 0.3 | $2.1c_{tl}$ |
| 4 | New | New | 4 | 0.4 | $2.4c_{tl}$ |
| 5 | Original | Original | 5 | 0.5 | $2.5c_{tl}$ |

The value of the coefficient of the technical level $c_{tl.i}$, included in the dependence (2), is determined by well-known methods, including expert evaluation [17].
The values of the coefficients given by the authors in Table 3 are not dogma and are offered as an example. After all, each specific machine-building enterprise produces a certain assortment of products that have its own specifics. One product can be improved for a long time with ordinary or advanced technical solutions and at the same time ensure a significant increase in the technical and economic efficiency of its production. Other products require frequent and more complex improvements to maintain their novelty and competitiveness. Likewise, the introduction of new technical solutions of one or another level for various types of machine-building products have different degrees of risk.
Therefore, when evaluating machine-building production, an expert group of its own or engaged specialists must independently take into account the experience and effectiveness of the work of its own and related enterprises in the production of certain products. Guided by this, propose your weighting scale of coefficients for different levels of novelty, taking into account the achieved economic indicators from improvements in previous periods.
The higher the value of $c_{nov}$ and $c_{tl}$, the better the state of machine-building production and the more prepared it is for mastering new technological processes of manufacturing and assembling machines.

**Criterion 3 "Effectiveness of implementation of technical solutions"**
This article describes the effectiveness of the implementation of technical solutions introduced into production. A sample of a product (machine) or a process that has passed all tests is the basis for organizing mass production of new equipment. Based on their results, at all stages of production preparation, the working documentation for the manufacture of a new technical object is adjusted.
The responsible check is the check of the adopted technical decisions at the stage of technical design, when an unambiguous constructive construction of the product is required. It is natural that the verification of decisions does not begin and does not end at the stage of technical design, when experimental samples of individual products are tested, but also continues on experimental samples of the machine during factory and acceptance tests. Errors found in the course of such tests are corrected by appropriate adjustments to the working documentation. After the product is put into production, the verification of the adopted technical decisions continues more meticulously on serial samples in real operating conditions during the entire life cycle of the product up to its physical or moral wear and tear. Before the start of serial production, an installation batch is sometimes produced, based on the results of its operation, additional corrections are made to the working design documentation with subsequent serial production.
Therefore, the intensity of design and technological adjustments at various stages characterizes the quality of implementation of technical solutions. The following four can be identified as the main stages at which adjustments are made:
1. Technical design;
2. Testing of research and experimental samples;
3. Technological preparation of production;
4. After putting the product into production.
However, each machine-building enterprise, depending on the specifics of the organization of production, can further refine the structure of the stages at which adjustments are made. The more adjustments are made in the previous stages of implementation and less in the following ones, the lower the production costs, the more perfect the new product will be.
We offer a quantitative assessment of the intensity of adjustments, which will characterize the quality of the design and technological implementation of the project, in this form.

$$c_{p.i>1} = {}^{k_{i>1}}/_{k_{i-1}}, \quad (3)$$

$$c_{kk} = {}^{k_n}/_{\sum_{i=1}^{n-1} k_i}, \quad (4)$$

where:
$C_{p.i>1}$ is the efficiency coefficient of staged adjustments during the design and technological implementation of the project stage (for the first stage, this coefficient does not exist a priori, because adjustments are made after the completion and approval of the project),
$C_{kk}$ is the efficiency coefficient of the complex of adjustments during the design and technological implementation of the project, $k_i$ is the number of adjustments made at the *i-th* stage,
$k_n$ is the number of adjustments made at the final stage and *i* is the stage of project implementation, in this case *i* = 1…4.
The proposed coefficient of adjustment intensity characterizes the quality of the enterprise's technical staff, which takes part in the development and production of new products.
If a new technical object launched into serial production shows significant defects during operation that negatively affect labor safety, the state of the environment, etc., then the issue of removing it from production is raised.
Therefore, another quantitative indicator that characterizes the efficiency of innovations in machine-building production $C_{EI}$ is the ratio of the number $\eta_w$ of new types of products withdrawn from production due to their

identified shortcomings to the total number $n_i$ of successfully implemented and implemented projects for the production of new products.

$$c_{EI} = {}^{n_w}/_{n_i}, \quad (5)$$

The smaller this indicator, the more effective the innovative activity of the enterprise. The value of $C_{EI}$ is the coefficient of technical efficiency of innovations of a machine-building enterprise.

**DISCUSSION OF RESULTS**

As confirmation of the ability of the obtained results, let us give an example of using the proposed methodology for evaluating a conditional (abstract) machine-building enterprise with a product range of 3 units of products. The technological processes of its manufacture are of the same type, the total number of technological processes of manufacturing each type of product is 30. For the calculation, we take the necessary values from Table 4, which characterize the introduction of new equipment and technologies, and Table 5, which shows the intensity of adjustments at various stages of its development. We assume that the coefficients of the technical level of products and technological processes $c_{tl.i}$ are the same for all items and are stable over time. There are no new products discontinued due to their defects.

***Table 4***
***Abstract initial values of mastering a new product and technological processes (TP)***

| Novelty level | Product, No. | | | TP | Product, No. | | | TP | Product, No. | | | TP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | | 1 | 2 | 3 | | 1 | 2 | 3 | |
| | Period T1 | | | | Period T2 | | | | Period T3 | | | |
| 1 | + | - | - | 3 | - | + | - | 5 | + | - | + | 0 |
| 2 | - | + | - | 2 | - | - | - | 3 | - | - | - | 3 |
| 3 | - | - | + | 2 | + | - | + | 2 | - | - | - | 1 |
| 4 | - | - | - | 1 | - | - | - | 0 | - | + | - | 2 |
| 5 | - | - | - | 0 | - | - | - | 0 | - | - | - | 1 |

To evaluate the dynamics of changes in the innovative component of production, we set three conditional periods. Table 4 shows the abstract values of the level of novelty of introduced improvements (marked with "+") and the number of mastered new technological processes (TP) in each period for each type of product. Table 5 contains abstract values of the number of introduced design and technological adjustments at each of the four stages of the technical design of the proposed three new products in the given periods.

***Table 5***
***Abstract output values of the implementation of adjustments to technical solutions when mastering the release of a new product***

| Implementation stages | Product, No. | | | Product, No. | | | Product, No. | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| | Period T1 | | | Period T2 | | | Period T3 | | |
| 1 | 12 | 9 | 11 | 9 | 7 | 8 | 10 | 10 | 9 |
| 2 | 4 | 5 | 4 | 4 | 5 | 3 | 5 | 4 | 3 |
| 3 | 2 | 2 | 1 | 2 | 2 | 1 | 2 | 1 | 1 |
| 4 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |

We will evaluate the innovative activity of the enterprise according to the proposed three criteria.

1. The criterion *"Development of new products"* is determined by formula 1 for three periods. We take the values of the coefficients from Table 3, according to the level of innovation of the product introduced into the design, which is indicated in Table 4 with the sign "+".

$$K_{SP}^{(1)} = \frac{(1\cdot(1-0.1)+2\cdot(1-0.2)+3\cdot(1-0.3))\cdot 0.95}{3} = 1.46$$

$$K_{SP}^{(2)} = \frac{(3\cdot(1-0.3)+1\cdot(1-0.1)+3\cdot(1-0.3))\cdot 0.95}{3} = 1.62$$

$$K_{SP}^{(3)} = \frac{(1\cdot(1-0.1)+4\cdot(1-0.4)+1\cdot(1-0.1))\cdot 0.95}{3} = 1.33$$

The results of the calculations show the dynamics of changes in the indicator of innovative production activity over time. Even though all three-product nomenclature were improved, innovations according to the "Development of new products" criterion in the second period increased compared to the first due to the introduction of new technical solutions of a higher level. In the third period, due to a greater number of improvements of a lower technical level (two improvements of the first level), this indicator significantly decreased. Therefore, in the next period, the enterprise should pay more attention to the modernization of production by introducing technical solutions of a higher level.

2. The criterion *"Development of new technological processes"* is determined by formula 2 for three periods. Similarly to the previous calculation, we take the values of the coefficients from Table 3, and the number of new technological processes from Table 4. The first multiplier of each term of the numerator means the number of mastered new technological processes of the same level of novelty (i.e., to simplify the form of the formula, the multiplier sums up the equivalent quantitative assessment of technological processes of a certain level of novelty).

$$K_{SE}^{(1)} = \frac{[3(1(1-0.1))+2(2(1-0.2))+2(3(1-0.3))+1(4(1-0.4))1+0(5(1-0.5))]0.95}{30} = 0.40$$

$$K_{SE}^{(2)} = \frac{[5(1(1-0.1))+3(2(1-0.2))+2(3(1-0.3))+0(4(1-0.4))+0(5(1-0.5))]0.95}{30} = 0.45$$

$$K_{SE}^{(3)} = \frac{[0(1(1-0.1))+(3(2(1-0.2))+1(3(1-0.3))+2(4(1-0.4))+1(5(1-0.5))]0.95}{30} = 0.45$$

According to the obtained values of the "Development of new technological processes" criterion, growth dynamics in the second period and stabilization in the third period can be seen. However, in the third period, the fewest, only 7, new technological processes were implemented, while in the first and second periods, there were more – 8 and 10, respectively. Guided by this, based on an objective analysis of production processes, it is necessary to outline the ways of innovative development in the future – either by increasing the number of introductions of new technological processes or by increasing their level.

3. The criterion *"Effectiveness of implementation of technical solutions"*. The values of this criterion are determined by formulas (3), (4) for three conditional periods. We take the initial abstract values of the number of adjustments made from Table 5. The results of the calculations are shown below in Table 6.

***Table 6***
***Value of the criterion "Effectiveness of implementation of technical solutions"***

| Formula | Product, No. | | | Product, No. | | | Product, No. | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| | Period T1 | | | Period T2 | | | Period T3 | | |
| $C_{p.2} = \frac{k_2}{k_1}$ | 0.33 | 0.56 | 0.36 | 0.44 | 0.71 | 0.38 | 0.2 | 0.4 | 0.33 |
| $C_{p.3} = \frac{k_3}{k_2}$ | 0.50 | 0.4 | 0.25 | 0.5 | 0.4 | 0.33 | 0.4 | 0.25 | 0.33 |
| $C_{p.4} = \frac{k_4}{k_3}$ | 0.50 | 0 | 0 | 0 | 0.5 | 0 | 0.5 | 0 | 0 |
| $C_{p.2} = \frac{k_4}{\sum_{i=1}^{3} k_i}$ | $56 \cdot 10^{-3}$ | 0 | 0 | 0 | $71 \cdot 10^{-3}$ | 0 | $59 \cdot 10^{-3}$ | 0 | 0 |

It should be noted that the smaller the values of the efficiency coefficients of the implementation of technical solutions ($C_{p.j}$ and $C_{kk}$), the better the results of the work of the involved team at each of the stages and in general. The comparison of coefficients in different periods shows the tendency of efficiency changes: in the case of a decrease in the value of the coefficients, the efficiency increases; as the value of the coefficients increases, the efficiency decreases. The results of the evaluation of the effectiveness of the implementation of technical solutions by a certain abstract enterprise indicate the following:

- the creative design team, involved in the implementation of product No. 3, worked best in all periods.
- during the modernization of product No. 2 in the second period, the creative team allowed the work to deteriorate, but significantly improved it in the following third period.
- the creative team involved in the production of product No. 1 showed the worst results in the first and third periods, as it allowed correction twice in the last fourth stage, and the sum of the coefficients $C_{p.j}$ is the highest.

Therefore, the team involved in the creation of product No. 1 needs to strengthen its work with various organizational and technical methods. The team involved in the creation of product No. 2 analysed and took into account the shortcomings that were admitted in the second period.

For example, if new machines were withdrawn from production due to their shortcomings, each subsequent stage was not, then for all periods the coefficient $C_{EI}$.

Let's note that it is also possible to compare different related productions. In the case we have discussed, instead of periods, it can be assumed that these are three different enterprises.

## CONCLUSIONS

Monitoring the implementation of new technology in production is one of the methods for assessing the effectiveness of an enterprise's innovation activities. To do this, it is proposed to use quantitative assessment based on the following indicators:

1. The production status coefficient for the introduction of new products (new technological machines);
2. The enterprise status coefficient for the introduction of new technological processes for the production of new products;
3. The efficiency coefficient of implementing technical solutions at all stages of the project.

The proposed method of comparative evaluation of the innovative activity of machine-building production with a set of indicators makes it possible to quantitatively assess the potential efficiency of a machine-building enterprise when introducing new models of technological machines, to apply these values in benchmarking processes, and to comprehensively evaluate the innovative and technical efficiency of the enterprise.

Observing the changes in the values of the proposed coefficients during different periods makes it possible to evaluate the dynamics of the enterprise's development.

The results of the work are intended for engineering specialists and the management of engineering enterprises. They provide professionals with a methodical approach to forming an innovative strategy for the development of the enterprise.

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