Project-based Management of the Production Equipment Maintenance and Repair Information System

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Abstract

The relevance of the research is due to the need to create an effective maintenance and repair planning system based on the development and implementation of methods that allow ranking and selecting the most priority maintenance and repair activities, depending on the degree of their impact on the current goals of the enterprise, taking into account financial, labor, regulatory and other types of restrictions. The development of a maintenance and repair management system is impossible without the use of information technology. A solution of this type of questions is proposed based on the project management methodology, which allows taking into account the uncertainty inherent in random events of failures of technical systems. The purpose of this research is to develop a model for managing the equipment maintenance and repair information system based on the use of project and project portfolio management methodology. It has been established that an important advantage of the methodology for planning maintenance and repair work, based on a project-based approach, is its universal nature. It can be used in different industries, for different types of equipment and companies of any level. An information system of indicators of the economic efficiency of the equipment maintenance and repair system has been formed, which contains six coefficients – plan fulfillment, cost intensity, cost proportionality, cost adequacy, outsourcing and downtime. The results of the research are the following: the expediency of using the project, program and portfolio management methodology in solving the problem of developing a comprehensive strategy for managing the maintenance and repair information system at enterprises was confirmed; a structural model for the formation of the architecture of programs and portfolio of maintenance and repair projects was developed; a system of criteria and an integral indicator of the effectiveness of the equipment maintenance and repair strategy are proposed, which will allow the enterprise to reduce the cost of products when using the proposed information system.

Keywords 1

Project-based management, information technology, maintenance and repair system, production equipment, uncertainty

1. Introduction

In Western industrialized countries, the system for arranging maintenance and repair (MAR) is called the "maintenance system", and in Asian countries - the "conservation system" [1].

According to various literature sources [2,3], the cost of MAR of complex systems is 10-15 times higher than the cost of a new system. At the same time, the chosen strategy has a direct impact on the total service life of the system, its reliability, safety and operational efficiency.

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At domestic enterprises, the general concept of maintaining equipment in good condition and constant performance is still the preventive maintenance system (PMS), which has developed in accordance with the requirements of GOST 18322-78 [4-5]. The obvious disadvantages of such a strategy are economic losses due to the incomplete development of the resource by the time of MAR and the lack of consideration of the enterprise production needs at any given time.

The use of the "pure form" of the traditional PMS in today's conditions is complicated not only by the lack of relevant standards. Measures of the PMS, from the point of view of ensuring operability at the overhaul interval, are guaranteed, i.e. they are redundant. At the same time, the system assumes that all of them must be carried out in full, but often (almost always) enterprises have neither time reserves nor resources to perform such an “excessive” amount of work. In addition, as experience shows, excessive execution of work on the PMS for various reasons can lead to a decrease in reliability, for example, due to errors in the performance or violations in the running-in of nodes, non-compliance with assembly technologies, etc.

The key issue in creating an effective MAR planning system is the development and implementation of methods that allow ranking and selection of the highest priority MAR activities depending on the degree of their impact on the current goals of the enterprise (production indicators, lost profits), as well as taking into account financial, labor, regulatory and other types of restrictions. The development of a maintenance and repair management system is impossible without the use of information technology. The solution of this type of problems is carried out on the basis of the project management methodology, which allows to take into account the uncertainty inherent in random events of failures of technical systems.

2. Analysis of Literature Data and Resolving the Problem

Since failures of technical systems are random events, in the process of making decisions on the implementation of certain work on MAR, the inherent uncertainty should be taken into account. One of the potential models in this direction is presented in [6].

Let the Gaussian random process X(t) be written as

$$X(t) = A(t) + X\varepsilon(t), \quad (1)$$

where A(t) – deterministic, continuously differentiable function$

$X\varepsilon(t)$ – stationary ergodic normal random process with zero mean.

To predict the output of the process X(t) beyond a fixed level, some auxiliary process is used

$$Y(t) = A(t) + Y\varepsilon(t), \quad (2)$$

where $Y\varepsilon(t)$ – predictor for $X\varepsilon(t)$, calculated at the moment (t – m), m>0, m is the chosen constant.

If the value of Y(t) calculated at the moment t – m is more than some critical value $\hat{u}$, then a warning is given about the possible exit of the process X(t) at the moment t beyond the level u ($\hat{u}<u$). In [6], the properties of such a prediction procedure are studied: the probability of correct prediction of X(t) going beyond a fixed level and the probability of a false alarm.

Another example of describing the change in the state of the system from deterministic positions (the aging model) is contained in [7], where the average aging over time is proposed to be described using a deterministic equation.

The inspection strategy for determining equipment wear, which is characterized by N levels of quality, is presented in [8]. The author considers the technical system in the form of a semi-Markov process with (N + 1) state, as a result of the analysis of which optimal policies are developed that lead to minimal losses.

The problem of determining the time of repair and replacement of failed equipment belongs to the field of production resource management. Poor management due to the use of a suboptimal repair and replacement policy can have significant financial consequences. The aim of [8] is to describe the problem, analysis and results of the research related to determining the optimal repair and replacement strategy for the organization that manages a large number of wooden pallets.

During the operation of machine repair systems, it is important in plans to increase their reliability in use to have suitable methods for state maintenance programs that take into account the characteristics of the systems. An example of taking into account the features of the system (and its elements) in the organization of maintenance and repair according to the state is indicated in [9]. The Markov model is used to show the change in the states of the system.

An interesting and unique model of aggregate replacement of elements in a multicomponent system using the MAR strategy by state is given in [10]. With the mass use of homogeneous machine repair systems, the results of this model can become widespread.

The methodology of project-based management has become widespread in recent years due to a number of obvious advantages [11-15], namely:

- Increasing the service life of equipment;
- More efficient performance of restoration repairs;
- Reducing excess inventory;
- Reducing the number of breakdowns and downtime;
- Increasing the return on the company's fixed assets;
- Effective budgeting of repairs;
- Increasing the profitability of the company.

However, in order to obtain these benefits at a particular enterprise, taking into account the specifics of the types of equipment, its actual state, planned load, and the capabilities of existing repair facilities, it is necessary to constantly optimize the content of repair projects and the portfolio of projects of the repair unit, ensuring maximum efficiency.

3. The Purpose of the Research

The purpose of this research is to develop a model for managing the MAR equipment system based on information technology taking into account the use of project and portfolio management methodology.

4. Materials and Methods of the Research

The use of the traditional PMS in today's conditions is complicated, firstly, by the lack of the necessary standards, and secondly, by their economic inexpediency. The activities of the PMS are guaranteed, that is, they are redundant.

At the same time, the system assumes that all of them must be carried out in full. At the same time, in reality, enterprises do not have sufficient time reserves or resources to perform such an "excessive" amount of work. In addition, as experience shows, excessive execution of work on the PMS for various reasons can lead to a decrease in reliability, for example, due to errors in the work performance or violations in the running-in of nodes, non-compliance with assembly technologies, etc.

These circumstances today lead to the fact that at many enterprises there are significant deviations between the developed PMS plans and the actual scope of work on the MAR. In other words, PMS work planning ceases to perform its main function, which is the optimal allocation of resources to achieve production goals.

Since the external and internal environment of the enterprise is constantly changing, the key issue in creating an effective management system for MAR is the development and implementation of information technology methods that allow ranking and selecting the most "important" projects in terms of their impact on the current goals of the enterprise (production indicators, lost profits) .

In accordance with the standards of the ISO 55000 Asset Management [16], the realization of the value of an asset should be carried out by finding a balance between the benefits of owning it, the costs of maintaining it and the risks inherent in the asset and associated with the ability to achieve the goals related to it. In the field of MAR, the use of a risk-based approach in planning is aimed at solving the following tasks:

• Distribution of available resources between equipment;
• Determination of terms of service, repair or replacement (modernization) of equipment;
• Distribution of capital and operating costs of the enterprise repair department.

One of the important advantages of the MAR planning methodology based on a project-based approach is its universal nature. It can be used in different industries, for different types of equipment and companies of any level.

The main stages in the formation of projects for MAR of this type of equipment based on a risk-based approach are schematically shown in Figure 1.

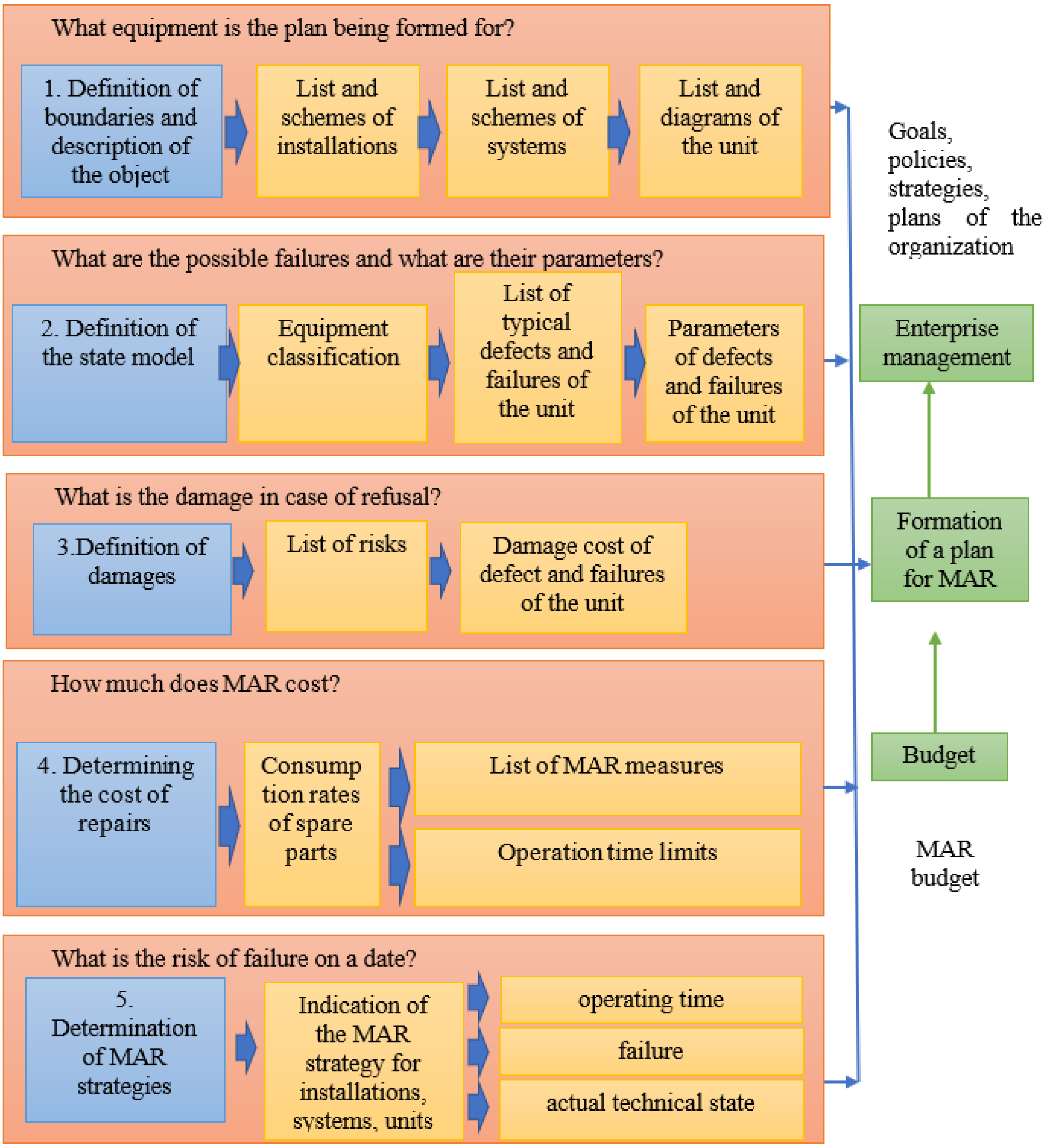

Figure 1: Model for the formation of projects for MAR

The main task of the first stage is to describe the object by forming lists and diagrams of its elements, for which the planning of measures for MAR will be carried out. Moreover, the description of the object must have a hierarchical structure and take into account the links between the elements.

At the next stage, a directory of typical defects and failures is formed. Each element of the object is associated with its characteristic defects and failures, their probabilities of occurrence are determined, as well as physical parameters.

Damage arising in the event of failures or defects is assessed in the third stage. To do this, a directory of typical damages is formed. Each failure and defect of an element is associated with damages expressed in money equivalent.

At the fourth stage, a directory of MAR measures is formed, which includes the norms for the consumption of inventory items and the lead time for a certain impact (MI-1, MI-2, repair). Typical impacts and individual operations are assigned to one or more failures and defects.

At the final stage, the formation of strategies for managing the MAR system is carried out - a program of projects for diagnosing, maintaining and repairing each type of equipment separately.

Types of various MAR projects of equipment are shown in Figure 2. Each type of project, in accordance with the standards adopted by enterprises, requires a variety of resources: material, labor, financial, etc.

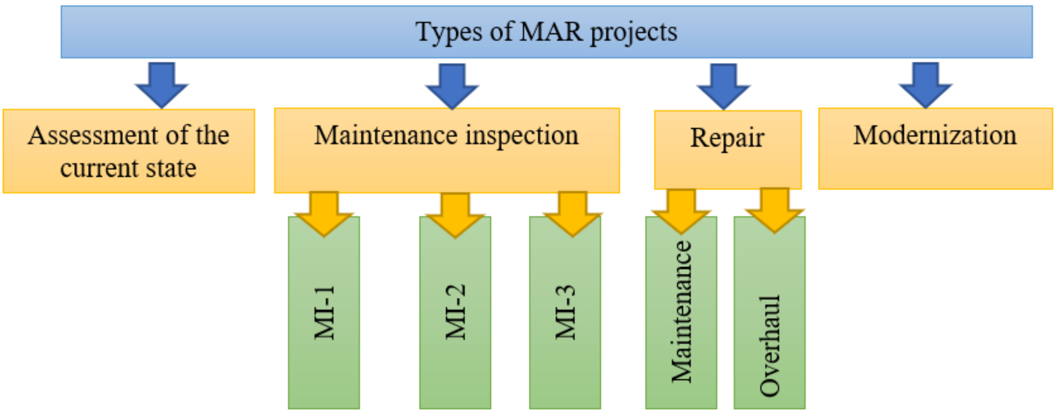

Figure 2: Types of equipment maintenance projects (MI – maintenance inspection)

The project program is developed for each type of equipment separately and includes diagnostics, maintenance, repair and modernization projects.

The mission of such a program is to minimize the objective function:

$$E = Z_1(t) + Z_2(t) + Z_3(t) + Z_4(t) \quad \to min, \tag{3}$$

where t – planning period;

Z_1 – mathematical expectation of the operating costs of the enterprise for the period t;

Z_2 – mathematical expectation of the costs of the enterprise for carrying out planned work on MAR for the period t;

Z_3 – mathematical expectation of the costs of the enterprise for carrying out unscheduled work on MAR for the period t;

Z_4 – lost profit of the enterprise due to downtime from the inoperable state of equipment for the period t.

The set of programs for projects of various types of equipment makes up the organization's project portfolio. At the same time, if the production capacity of the repair department does not allow the portfolio to be realized in full, the management decides on the possibility of transferring individual projects or programs in the form of outsourcing. In the process of implementing the organization portfolio, the actual state of the equipment is constantly monitored, which leads to the adjustment of the planned indicators of programs and project portfolio.

The block diagram of the project-based management system for MAR of equipment based on information technology is shown in Figure 3.

The information basis of the strategy is:

- Directory of enterprise equipment;
- Base of projects for MAR of each type of equipment;
- Directory of resources required for the implementation of a particular project.

In addition, the basis for the formation of the MAR program is the load graphs for certain types of equipment, which are determined by the enterprise production plan. It is advisable to build such graphs in the EAM environment adopted at the enterprise.

As a result of the analysis of various program architectures, we choose the optimal function (1) according to the minimum criterion. This architecture of the program allows calculating the list of required resources.

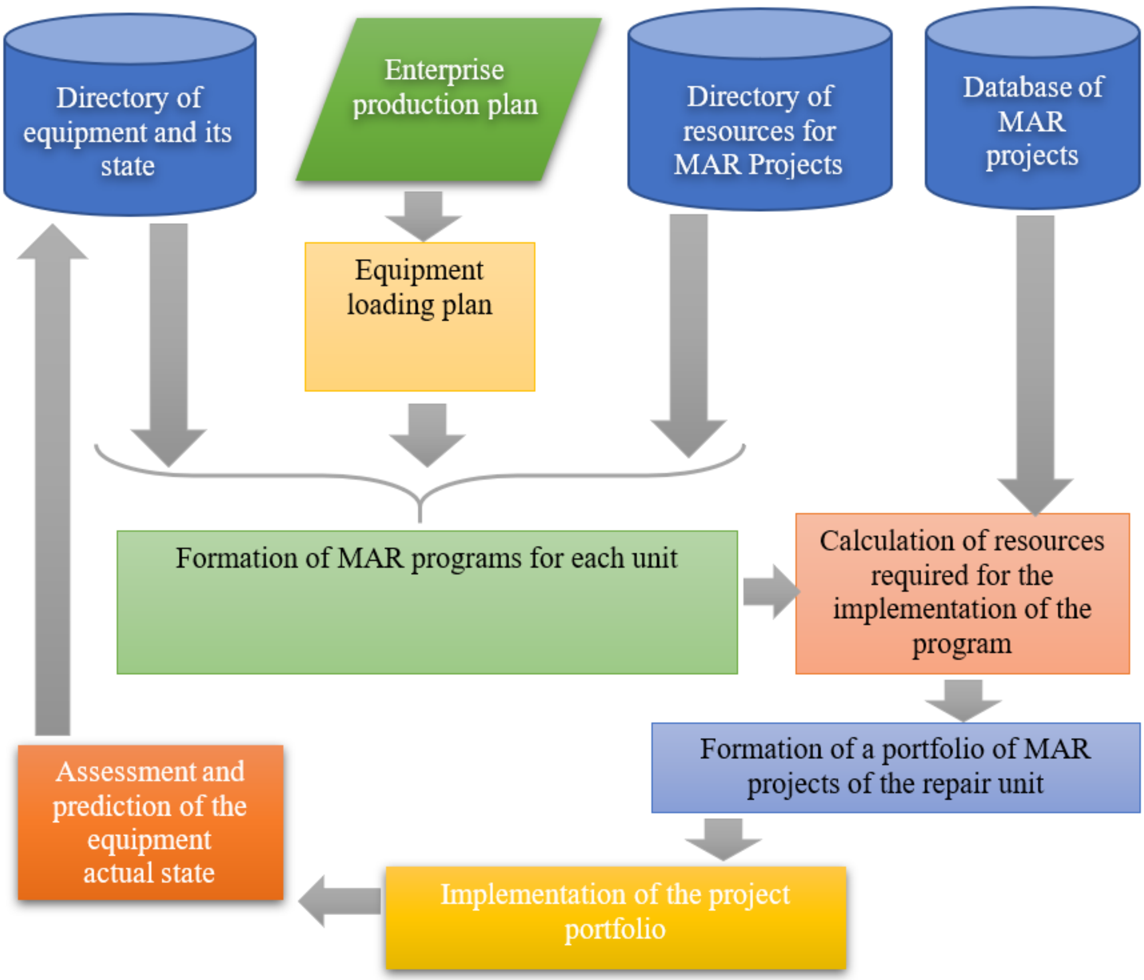

Figure 3: Project-based strategy for the management of MAR of equipment

The set of MAR programs for certain types of equipment determines the portfolio of projects for the planned period of time. At the same time, if the enterprise does not have the necessary production repair capacities for the implementation of a particular project (program), it can transfer them on an outsourcing basis.

In the process of implementing the portfolio, the diagnostics projects are carried out, that is, to determine the actual technical condition of certain types of equipment. The results of these projects constantly replenish the equipment base and make adjustments to the program of projects. The basis for adjusting the program may be changes in the enterprise production plan (equipment loading graph).

An important element of the process management system for equipment MAR based on information technology is a comprehensive assessment of its effectiveness. In our opinion, such an assessment should be based on the following principles:

• Implementation of the plan: the allocated limits for the portfolio of operations on MAR, both for repairs on their own, and for the services of contractors, must be implemented in full [17];

• Proportionality: MAR costs should be consistent with sales volumes and operating costs, not ahead of their dynamics [18, 19];

• Priority: the MAR portfolio should be primarily directed to the technological equipment of the main production and key infrastructure facilities [20-23];

• Financial rationality: MAR should be carried out in an optimal form, allowing to reduce non-production costs and increase the financial efficiency of the organization [24-26];

• Sufficiency: MAR should not impede the free movement of funds in both the inflow and outflow of fixed assets;

• Innovativeness: all work within the MAR portfolio should be carried out using modern high-performance technologies;

• Technical effectiveness: MAR of fixed production assets should lead to an increase in equipment fault tolerance and a reduction in downtime of fixed assets [17, 27].

Based on the above principles, quantitative indicators of economic efficiency have been developed.

Due to the fact that private indicators reflect economic phenomena of various scales, they should be given a relative character for the purpose of objective comparison. It should also be noted that in order to generalize the values of the coefficients, they should be given the same direction. The formed system of indicators of the economic efficiency of the equipment maintenance and repair system contains 6 coefficients.

1. The coefficient of implementation of plan $К_1$ shows the degree of development of the allocated limits on the costs of MAR projects of the main production assets:

$$К_1 = \begin{cases} 1, & \text{if } Z_{\text{act}} \leq Z_{\text{pl}} \\ Z_{\text{pl}}/Z_{\text{act}}, & \text{if } Z_{\text{act}} > Z_{\text{act}} \end{cases} \quad (4)$$

where Z_{act} – total actual costs for MAR projects of fixed assets, \$; Z_{pl} – the planned amount of costs for MAR projects of fixed assets, \$.

2. The cost coefficient $К_2$ shows the amount of costs for MAR projects per 1 hryvnia of sales volume

$$К_2 = 1 - Z_{\Phi}/D, \quad (5)$$

where D – sales value, \$.

3. The coefficient of proportionality of costs $К_3$ shows the ratio of the growth rate of operating costs and the growth rate of costs for the portfolio of MAR projects:

$$К_3 = 1 - \frac{\lfloor \Delta Z_o - \Delta Z_{\text{act}} \rfloor}{\Delta Z_{\text{act}}}, \quad (6)$$

where ΔZ_o – growth rate of operating costs of the enterprise, %; ΔZ_{act} – growth rate of actual costs for MAR projects, %.

4. The cost adequacy coefficient $К_4$ shows the ratio of the replacement cost of fixed production assets to the amount of costs for the portfolio:

$$К_4 = 1 - Z_{act}/S, \quad (7)$$

where S – replacement cost of fixed production assets, $.

5. The outsourcing coefficient K_5 shows the proportion of equipment maintenance work performed by a contract to the total cost of the MAR portfolio:

$$K_5 = 1 - {Z_{out}}/{Z_{\text{act}}}, \tag{8}$$

where Z_{out} – costs of payment for work performed by a contractor, $.

6. The downtime coefficient K_6 shows the ratio of equipment downtime due to its inoperable state to the planned working time fund of this unit:

$$K_6 = 1 - {T_{dt}}/{T_{\Sigma}}, \tag{9}$$

where T_{dt} – equipment downtime, h.; T_{Σ} - total planned load of this type of equipment.

The formulas for calculating the coefficient based on the conditions of their dimensionlessness and standardization are proposed. In addition, when calculating all performance indicators, the following relation is fulfilled:

$$0 \leq K_i \leq 1 \; \forall \, i = 1, \dots 6 \tag{10}$$

This allows us to determine the integral indicator of the effectiveness of the MAR strategy as the Euclidean distance K according to the following formula:

$$K = \sqrt{\frac{\sum_1^6 K_i^2}{6}} \tag{11}$$

The results of calculating the strategy performance indicators are presented in Table 1 and Figure 4.

Table 1

Calculation of MAR equipment strategy performance indicators

Initial data		Calculation results	
Indicator	Value	Indicator	Value
Z_{act},$	8500	K_1	0,965
Z_{pl},$	8200	K_2	0,888
D, $	76000	K_3	0,818
ΔZ_{act},%	3,25	K_4	0,943
ΔZ_o,%	2,657	K_5	1,000
S,$	150000	K_6	0,996
Z_{out},$	0		
T_{Σ}, h	2400	K	
T_{dt}, h	10		

5. Conclusions

1. The expediency of using the methodology of managing projects, programs and portfolios in solving the problem of developing a comprehensive strategy for managing the MAR system at enterprises has been confirmed.
2. A model for managing the MAR equipment system based on information technology has been developed taking into account the use of project and portfolio management methodology.
3. A structural model for the formation of the architecture of programs and a portfolio of MAR projects aimed at improving the organization efficiency has been developed.

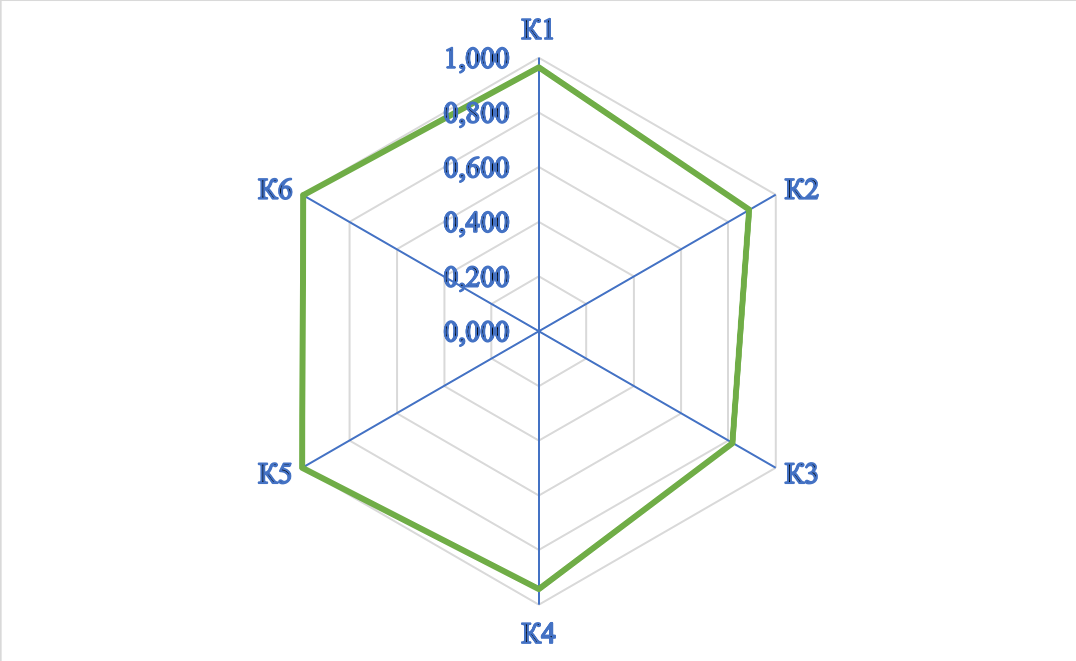

Figure 4: Analysis of the effectiveness of the MAR equipment strategy

4. A system of criteria and an integral indicator of the MAR equipment strategy effectiveness are proposed, which will allow the enterprise to reduce the cost of products by 2–3%.

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