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ENHANCING EFFICIENCY BY IMPLEMENTATION OF INTEGRATED MANAGEMENT SYSTEM IN ORDER TO ALIGN ORGANISATIONAL CULTURE AND DAILY PRACTICE

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Abstract:
The main aim of presented article is present methodology how sophisticated products as compressor equipment can be considered and analyzed as a complex technical system which consists of jointly operating components – a set of hardware, software, operational staff and documented information. In process modeling, these components can be in different processes of inputs, outputs, mechanisms (resources) or management. Based on the regulatory requirements for each component of the system, a key indicator efficiency can be identified. This will allow to control the process and make appropriate decisions to improve the system. The application of the proposed methodology for the development and implementation of an integrated management system reduce the cost of resources and significantly improve the quality of the implementation of processes.

Key words: *complex technical system, integrated management system, standards, sustainable operations, product lifecycle management (PLM)*

INTRODUCTION

Existing concepts of sustainable consumption and production of goods are necessary to ensure the careful use of resources and energy, create environmentally friendly and stable jobs, and provide access to basic services and information resources. Sustainable economic development is becoming an important condition for effective planning and implementation, reducing economic, environmental, social costs and losses, increasing the competitiveness of enterprises, can significantly improve the index of the quality of life of the population and provides higher living standards [1].

Modern signs of competition: randomness, dynamism, aggressiveness, unpredictability require the development of appropriate regulatory and methodological support to identify competitors, assess the competitive status of enterprises and their competitiveness. The competitive position of national companies in the market depends on: the scientific and technical level and the degree of perfection of production technology; use of the latest inventions and discoveries; introduction of modern information technologies and production automation tools.

The competitive advantage is the formed chain of business processes. The subject of intra-chain competition is its existing and potential participants (or their subdivisions, business processes) that create or may create part of the aggregate value of the chain product, affecting its competitiveness in the product markets.

A characteristic feature of complex products (for example, metal-cutting, compressor, printing equipment and others) that is used to manufacture the finished product is an ordered hierarchical multifunctional and multi-element organizational structure of interrelated processes at the stages of their lifecycle.

The disadvantage of existing process models at the stages of the life cycle of complex products is their fragmentation, inconsistency of results and the inability to reflect the most general, fundamental nonlinear laws of the organizational and technical mechanism for the sequential formation of emergent properties of software. in the period from the justification of their development to the end of operation and further disposal [2].

The lack of scientific approaches and appropriate regulatory and methodological support that take into account the organization of the structure of processes in the design, manufacture and operation of SW depending on dynamic changes in the internal and external environment leads to significant unreasonable costs. information, material and energy resources while satisfying the requirements of consumers and other interested parties [3]. His decision will allow to develop recommendations for appropriate regulatory and methodological support.

The criterion for optimal management of the lifecycle processes of a complex product, as a rule, is a set of technical and economic parameters, and the limitation is the internal environment of the enterprise and the strategic goals and objectives of its development.

The nature and characteristics of the conversion of resources into products are determined by a variety of technological tools and the characteristics of organizational and economic restrictions on their implementation. Unfortunately, so far the general theory of scientific and technological progress, which is recognized as a decisive factor in economic development and leads in the number of publications in the economic literature, is mainly used not for production purposes. It has not yet become the basic tool for the formation of scientific and technical programs and projects in industry. In this regard, the construction, by analogy with the P. Romer model of a general model of the joint functioning of processes at the stages of the life cycle, is important to ensure a qualitatively new set of characteristics and the degree of usefulness of complex technical products that are used in the manufacture of other products and services.

Thus, the modern scientific direction of research is the rationale for the effective use of technical and economic information at the stages of the product life cycle and decision making, taking into account the self-consistent interaction of processes in the design, manufacture and operation of an open system, the self-organization of which affects the results achieved to meet customer needs.

LITERATURE REVIEW

A literature review is dedicated to researching industry best practices and production rules for managing the life cycle of complex products. The article analyses the organizational perspectives found in the literature.

The papers [4, 5, 6] consider product life-cycle management (PLM) as a strategic business approach to support the joint creation, management, dissemination and use of product information within and within the expanded enterprise, bringing people, processes and technologies together. So far, most of the effort has been in a study on the use of knowledge-based methodologies in production management. The PLM system must be designed with evolution and adaptability in mind, depending on the environmental conditions, i.e. there is always the risk of short-term narrow planning based on the direct extrapolation of past experience, and the main source that allows the system to exist for a long time and to keep updated, is its adaptive capacity that manifests itself in the path of evolution. The industrial application of these approaches is not yet well understood. To do this, you need to review the scenarios of a PLM environment that extends it to manage the data of complex organizational systems. It is necessary to formalize and define best practices and standard rules for the joint interaction of technical systems, software products and qualified professionals to meet specific production and customer demands.

A lot of research [7, 8, 9, 10, 11] is devoted to the concept of sustainable development. An integrated regulatory framework is being developed to understand the persistent problems and factors affecting the economic, environmental and social aspects of production and consumption.

The papers [12, 13] emphasize the development and implementation of process-oriented control systems that comply with international standards for control systems. The main goal of introducing such systems is to satisfy the needs of various stakeholders, and their satisfaction indicator becomes a criterion for the excellence of the enterprise.

In papers [14, 15, 16], the options for improving the productivity, availability and productivity of the initial test processes using modern technologies available on the market are analyzed.

Articles [15, 16, 17, 18, 19] deal with one of the modern methods of managing economic systems – the analysis of functional costs. The set of works on introduction and use of functional cost analysis is considered, the stages of analysis using the IDEFO functional modeling method are described. In addition, a work schedule, in the form of a Gantt diagram, is available for the management of the functional cost analysis work to agree on the timelines for the phases of the work.

Unfortunately, the generally accepted practice is the use of completely irrelevant approaches and tools for managing company business processes, which exclude a detailed analysis of production features, product specifics and current market requirements [20, 21, 22, 23, 24, 25, 26].

Our research involves the integration of the design, production and consumption phases. The results can be useful in the development of long-term sustainable PLM models [27, 28, 29].

The aim of the work is to improve the methods of processing and using technical and economic information in the design of complex products based on structural-parametric models, which take into account the possibilities for increasing the efficiency of use of resources and energy [30, 31, 32, 33], as well as the development of sustainable infrastructure of processes at the stages of the life cycle [34, 35, 36, 37].

METHODOLOGY OF RESEARCH

The information that circulates in the system of processes of the life cycle of a complex product can be divided into three types: data on the product (product) data on the processes performed; data on the resources needed to complete the processes.

The information contains specific property values that determine the objective, true sides of a complex technical product at different stages of its existence. This information can be used in many information systems, including systems implemented in various organizations. The exchange of information between different hierarchical levels of the life cycle of a complex product is carried out due to the structure of existing feedbacks: some generalized information arrives at a higher level, and it is specified at the lower levels. The information received is compared with the existing one.

Evaluation of the efficiency of creating complex products in the research is based on data on the actual costs of time and material resources at the stages of the life-cycle.

At the first stage (the design stage), a functional configuration of the future product is formed in the form of a vector of requirements (Req) for its characteristics (Char):

$$\overline{Req_{Char_0}} = \left[\bigcup_{k=1}^{K}\left(Req_{Char_{P_i}}, Req_{Char_{P_j}}, Req_{Char_{P_l}}, \cdots\right)_k\right], \quad i,j,l \in 1,N \qquad (1)$$

The processes at the stages of the life cycle of any complex product can be described using three parameters: cost *C*, time *T*, and technical characteristics of the Char complex product. These parameters are interconnected. Their relationship is described by the equation of state of processes at the stages of the life cycle of a complex product, which in the general case has the form: $f(C, T, Char) = 0$.

The specific form of the equation depends on the products and multifunctional and multi-element complex technical systems that carry out their design, manufacture and operation guides.

When processes are implemented at the stages of the life cycle, their cost and time can change. At the same time, the characteristics of the product also change.

A convenient way to visualize these changes is to use a chart. Each point in the diagram (Fig. 1) corresponds to a different state of the process.

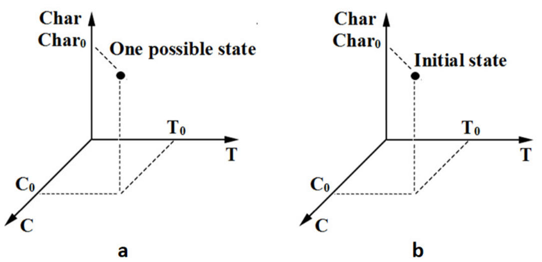

Fig. 1 The state diagram of the life cycle of a complex product at a specific point in time (one for each possible cost C, time T, and technical characteristics Char)

Each point in the diagram represents a separate state (one possible state) for the process. When the product goes through the stages of the life cycle, its state (the state of the corresponding process) will change in the diagram.

The ability to decrypt the information shown in the diagram allows us to make statements about changes in efficiency when implementing an integrated process management system at the stages of the life cycle.

On the basis of market research of the use of complex products, customer preferences, market requirements and competitors' activities, there are parameters: (T_O, C_P, $Char_P$) for decision making (Fig. 2):

T_O – the terms for fulfilment of the orders;
C_P – the product's cost;
$Char_P$ – product characteristics.

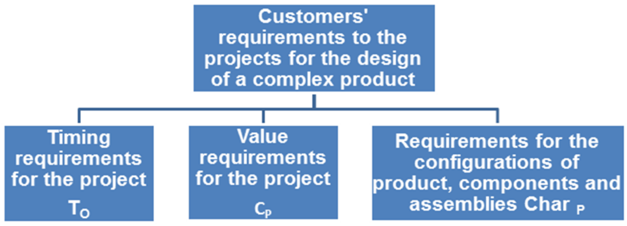

Fig. 2 The schema of the formation of the necessary parameters for project management

Considering the state diagrams of the product and processes at its stages of the life cycle, we can conclude that if the cost and time increase compared to the basic (planned) indicators, then the performed work (efficiency of integrated management system) can be identified as negative (Fig. 3a).

If we see a shift to the left in the diagram in the direction of reducing the cost and time of work compared to the baseline (planned) indicators while maintaining the characteristics of the product unchanged or improved, we can conclude that the performed work (efficiency of integrated management system) can be identified as positive (Fig. 3b).

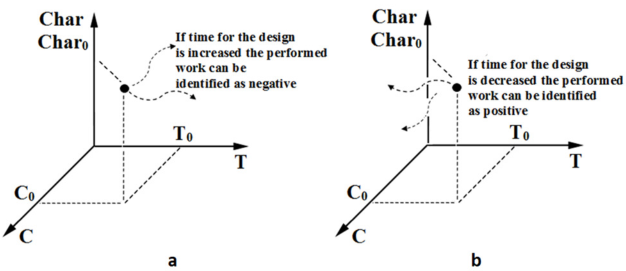

Fig. 3 The sign of the efficiency of integrated management system from a state diagrams

The performance of complex product lifecycle processes is largely related to the existence of relevant objective management laws that can account for the conditions and changes in the internal (resource conversion to production) and external (enterprise resource) environment.

The efficiency of process management at the stages of the product life cycle is determined by the accepted range of variation of parameters of independently functioning multipurpose complex technical system (CTS). As a part of a STS, in general, three different components can be distinguished – a sophisticated of technical means (STM), software (SW) and operational personnel (OP).

There are different models of forming elements of the organizational and technical mechanism at the stages of the life cycle of complex products by standardizing a certain set of works and rules of interaction of their participants in order to typify the procedures of research and justification of development, development, production, operation (use, storage, maintenance, repair) and recycling of products. Some of them are regulated in regulatory documents.

The logical relationship between the parameters (*C*, *T*, *Char*), which reflects the efficiency of the Integrated Management System processes at the stages of the life cycle of a complex product, can be expressed by the formula (2).

$$C \cdot T = M \cdot R \cdot Char \qquad (2)$$

where:

M – the parameter characterizing the level of effectiveness of a *STM* that implements this process of the product life cycle;

R – the parameter that characterizes the efficiency of Integrated Management System for each enterprise (an individual criterion for the effectiveness of organizational *complex* systems management at the product life cycle stages).

Using T_O, C_P and $Char_P$ as critical planning parameters, it is convenient to pass to dimensionless variables

$$\bar{T} = \frac{T_0}{T_i}, \quad \bar{C} = \frac{C_P}{C_i}, \quad \overline{Char} = \frac{Char_P}{Char_i} \qquad (3)$$

Scientific and technological progress allows the use of new materials, technological equipment and technical solutions. This leads to increased opportunities in the creation of new products that must meet the growing needs of society. In turn, the development of these needs leads to the continuous development of science and technology. The regularity of the evolutionary process of development is that the share of costs of past labor and the accumulated information necessary for the development of advanced products and technologies is continuously increasing.

At the second stage (product development), the possibilities of satisfying customer requests are considered as accurately as possible, taking into account the required number of products, manufacturing productivity, market prices, proposals of cooperating organizations (suppliers of basic systems, components, subassemblies and materials). At the same time, the volume of necessary investments and the timing of their receipt are calculated, the projects of the marginal estimated full cost of the product and batch are determined and approved.

Assessment of product quality is carried out using appropriate indicators: purpose, reliability, manufacturability, standardization and unification, patent law, transportability, ergonomics, aesthetics, safety, environmental friendliness, economy.

The quality of the product as a set of characteristics is laid in the process of scientific research, design and technological development, materializes in the manufacture, and is implemented in the process of operation. The dynamic of the quality category is that requirements for products and services are changing very quickly. What is fit today is tomorrow not enough to meet the needs of the buyer, that is, of poor quality. The most optimal allocation of priorities according to the set goals, as well as the market positions, depends on political, economic, scientific and technical and many other factors, which must be taken into account in the complex in all their complexity. At the same time, there are a number of criteria most often taken into account by consumers when choosing a product, which must necessarily be considered by the manager.

In the course of development the design characteristics of the product and its constituent elements are determined, which form the same groups as the components of the vector Req_Char_0:

$$\overline{Char_P} = \left[\bigcup_{k=1}^{K} \left(Char_{P_i}, Char_{P_j}, Char_{P_l}, \cdots\right)_k\right], \quad i, j, l \in 1, N \qquad (4)$$

The analysis and formation of the characteristics of sophisticated products can be carried out on the basis of determining the factors that affect their level.

At this stage, in general terms determine the design of the product to be designed. Often the initial data are the technical results of previous research, ideas, solutions and prototype designs. Quality management at the stage of development is to establish the conformity between the requirements and design values of the product as a whole, as well as to promptly eliminate the deviations that arise:

$$\overline{Char_P} = \sum_{i=1}^{N} a_i q_i \qquad (5)$$

where:

$q_i = \left(\frac{Char_{P_i}}{Req\_char_{P_0}}\right)^{k_i}$ relative consumer satisfaction with the product's i-th property,

k_i = 1 is taken for a property whose growth leads to an increase in consumer satisfaction,

k_i = (-1) is taken for a property whose growth leads to a decrease in consumer satisfaction,

a_i is a weighting factor that takes into account the importance of the *i*-th property of the product to the consumer.

The next stage is the development of the product itself: the overall dimensions of the structure are determined, the structural material is selected, production and other restrictions are established [38, 39]. The design decisions made at this stage mainly determine the cost of the future product.

At this stage, detailing of the product is performed, calculations of structural elements and blocks are performed, as well as the entire product and formalized in the technical drawings and specifications, determine the manufacturing processes, perform work planning and production preparation. Planning time for the development and manufacture of the product itself, as well as delivery to the consumer in the form of work schedules.

Obviously, not all the procedures preceding the development of the product at the early stages of its life cycle are given here, but this data is enough to state that managing the cost, time and quality parameters during design and trim level becomes a decisive factor in ensuring competitiveness.

The planned parameters of the possible implementation (T_{O_0}, C_{P_0}, $Char_{P_0}$) of the product project are determined (Fig. 2), which are related by the objective function

$$\overline{F_P} = \frac{\overline{Char_P}}{\overline{T_O} \cdot \overline{C_P}} \qquad (6)$$

where:

$\overline{F_P}$ is the current planning figure of the product in dimensionless form,

$\overline{Char_P}$ is the overall assessment of quality, taking into account the conformity of the product to the consumer's requirements,

$\overline{C_P} = \frac{C_{P\,end}}{C_{P\,plan}}$ is the valuation the cost of the project of the product,

$\overline{T_O} = \frac{T_{O\,plan}}{T_{O\,end}}$ is the evaluation of project implementation in time.

As already mentioned, under the influence of internal and external factors deviation of the project parameters from the normative values at each stage of the life cycle may occur, which will be accompanied by a corresponding change in the actual characteristics of the project (Fig. 4).

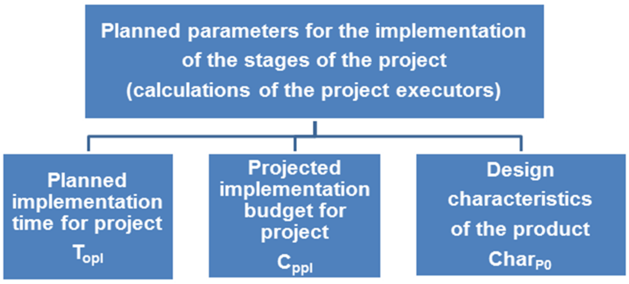

Fig. 4 Scheme for the formation of the planning parameters of the project

After the requirements and design characteristics are agreed upon between the developer and the customer, the vector $\overline{Char_{P_0}} \rightarrow \overline{Char_{FMSS_i}}$ becomes a vector of requirements for the characteristics of the functional manufacturing subsystem (FMSS). During the manufacturing process of each product instance, a vector of its physical configuration is formed:

$\overline{Char_{FMSS_P}} = \left[\cup_{k=1}^{K}\left(Char_{FMSS_{Pi}}, Char_{FMSS_{Pj}}, Char_{FMSS_{Pl}}, \dots\right)_k\right].$

The task of configuration management involves ensuring that the components of the vectors $\overline{Char_{FMSS_P}}$ and $\overline{Char_{FMSS_i}}$ match for each FMSS and for the whole product. When such compliance is established and validated by a developer, manufacturer and their customer, the vector $\overline{Char_{FMSS_i}}$ becomes a vector of requirements for the product being operated.

The decision-making process at the stages of the life cycle of a complex product is based on the use of minimizing the deviation of the $Char_{end}$ project characteristics from $Char_{plan}$ and their components. The nature and particular characteristics of resource development in products are represented by a large number of technological concerns and special features of organizational and economic sharing in real estate.

The following is a calculation of a similar estimate of the effectiveness of the current project based on actual costs of time and material resources that occurred in the production of the prototype of the compressor equipment.

In calculations, estimate of marginal costs involved are obtained by using an exponential and linear relationship between material and temporal resources.

It is recommended to determine the estimate of marginal costs involved of material and time resources by minimizing such functionality

$$U = \sum\left[\left(1-\frac{\overline{Char}}{\overline{T}\cdot\overline{C}}\right)^2 + (1-D)^2\right] \qquad (7)$$

where:

D is the Harrington desirability function that can be defined by an expression

$$D = \sqrt{e^{-e^{(-\overline{T})}} \cdot e^{-e^{(-\overline{C})}} \cdot e^{-e^{(-\overline{Char})}}} \qquad (8)$$

Model (5) were created experimentally. These researchers use the Gauss-Newton algorithm to construct a data model by minimizing the sum of the squared deviations of the data and the model.

In this case, the calculations can be carried out by two methods:

– determine its cost by varying the product design time;
– determine the time taken for the design by varying the cost of product development.

The parameters obtained in this case remain dimensionless. To determine the dimensional values, they should be multiplied, respectively, by the actual time taken for the design of the prototype and the actual cost of developing the product.

Method 1. When varying the product development time, the following exponential dependence of the development cost on its duration was used in dimensionless values:

$$\bar{C} = \overline{C_P} + 2\cdot\frac{\overline{T_0}-e^{\overline{C_P}}}{\overline{T_0}+e^{\overline{C_P}}} \qquad (9)$$

With a linear dependence of the development cost on its duration, the calculation was carried out according to the following formula:

$$C = C_{0pl} + \frac{\overline{T_0}max\cdot C_{0pl}}{\overline{T_0}+C_{0Pl}} \qquad (10)$$

The calculation showed that when the development time exceeds one third ($\overline{T_0} = 1.3$), the cost increases by 57% ($\overline{C_P} = 1.57$), and the desirability function D = 0.786 defines the project as a good level.

Method 2. When varying the cost, you can use such a dimensionless dependence of duration on the cost obtained on the basis of formula (8) by solving it relative to time:

$$T = T_{0pl} - \frac{\overline{C_P}max\cdot T_{0pl}}{\overline{C_P}+T_{0Pl}} \qquad (11)$$

Thus, the type of functional dependence between the controlled parameters of projects significantly affects their predicted value. If you use a function of the form

$$C = C_{0pl} + \alpha\cdot\left(\frac{T_{0max}-T_{0pl}}{T-T_{0pl}}\right)^{\beta} \qquad (12)$$

then you can get average estimates of the cost and time characteristics of the project. It should be borne in mind that to obtain reliable estimates of the value and duration of the current development, the parameters should be determined on a relatively larger number of prototypes.

RESULTS OF RESEARCH

In Fig. 5 show the change in the characteristics of the project $\overline{Char}$ depending on the duration $\overline{T}$ and cost of development $\overline{C}$. The source data are shown in Table 1.

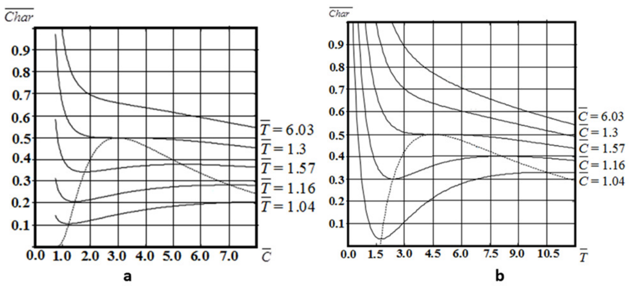

Fig. 5 Change the project characteristics $\overline{Char}$ depending:
a) from the duration of development $\overline{T}$,
b) from the cost of development $\overline{C}$

Table 1
Criteria for evaluating of the results of processes at the stages of the life cycle, which determine their planned and actual values and establish the dependence of output on the characteristics of functional subsystems

№ n/n	The value of the project parameters $\overline{T}$	$\overline{C}$	D	Project characteristics
1	1.3	6.03	0.87	high level
2	1.04	1.3	0.73	good level
3	1.3	1.57	0.78	good level
4	1.16	1.3	0,74	good level

The results of the calculation of the project parameters can be presented in the form of ranges of change:

– when changing the development time $\overline{T} = 1.3 \ldots\ 10$, $\overline{C} = 1.57 \ldots 6.03$, $\overline{Char} = 0.37 \ldots\ 0.95$;
– when changing the cost of development $\overline{T} = 1.04 \ldots\ 1.16$, $\overline{C} = 1.3 \ldots 10$, $\overline{Char} = 0.37 \ldots\ 0.95$.

Dependencies in Fig. 5a, b show that the modes of realization of complex products at the stages of their life cycle are determined by a set of conditions and means of many economic, technical and social processes that have different environmental impact and which have different degrees of inertia.

DISCUSSION

Based on the results of comparing the possible use of resources at the stages of the life cycle of complex products, the structure of the processes is selected, which ensures compliance with the established requirements at minimal cost. This provides a reliable estimate of the future costs and results of using complex products for their intended purpose, which reduces the risk and is a decisive argument in the analysis, planning and quality management.

The results of the conducted researches allow to carry out the procedures of unified submission, storage, structuring and exchange of data on processes at the stages of the life cycle of complex products, standardized, selective and regulated access to this data, their organized support and formation on this basis of management decisions, which can be adjusted depending on changing requirements.

The proposed methodological approach to the formation of management decisions in complex organizational systems of the life cycle has a general character, which provides the possibility of its application in various fields of mechanical engineering. Consistent deployment of these provisions allows you to describe the object of control – the life cycle of complex products in the form of a hierarchical system, and to decompose the processes to the level of operations and functional purpose of each element. Decision-making in such systems is purposeful, which allows for the formation of an interconnected system of local quality indicators of a hierarchical set of processes.

Thus, in the uncertainty of the decision to ensure the conformity of complex products to the established requirements at the stages of their life cycle, the possibility of complex application of structural-parametric modeling, methods of dynamic programming, cluster analysis and tools of inverse point calculations which allows to obtain the integrated result of a consistent function.

Formation of the configuration of complex products is as follows: on the basis of the information model, the project parameters are formed, which, after agreement between the developer and the customer, are considered as an object of minimizing the costs of the corresponding CTS at the stages of technological preparation, logistics, production and operation. The mathematical tools considered on the example of dynamic programming methods are an algorithmic basis for optimal control of the configuration of a machine-building product at the stages of its life cycle when solving problems of forming an integrated information environment.

CONCLUSIONS

The results of the studies allow us to carry out procedures for the unified presentation, storage, structuring and exchange of data on processes at the stages of the life cycle of complex products, standardized, selective and regulated access to these data, as well as their organized support and the formation on this basis of management decisions that are subject to adjustment depending on changing requirements.

From the position of a systematic approach to managing the configuration of a complex product, it looks like a multi-stage formation process: optimal characteristics, functions, goals and objectives, limitations, advantage criteria, ways of presenting design documentation for design, technological and production solutions.

The formation of the optimal configuration of a complex product is as follows: on the basis of the information model, the design configuration of the product is formed, which, after agreement between the developer and the customer, is considered as an object of minimizing the costs of the corresponding FPS at the stages of technological preparation, logistics, manufacturing and operation. The mathematical tools that are considered is the algorithmic basis for optimal configuration management of a complex product at the stages of its life cycle when solving problems of forming an integrated information environment.

The proposed methodical approach to the formation of management decisions in complex organizational systems at the stages of the product life cycle is of a general nature, which provides the possibility of its application in various fields. The sequential deployment of these provisions allows you to describe the object of control - the life cycle of a complex product in the form of a hierarchical system, and to decompose processes to the level of operations and functional purpose of each element. Decision-making in such systems is purposeful, which allows for the formation of an interconnected system of local quality indicators of a hierarchical set of processes.

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