Development of a technology design model for a science-intensive product

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Abstract. The paper deals with the issues of ensuring the required quality of products at various stages of the life cycle. It is shown that significant progress in solving this issue can be achieved through the implementation of the concept of CALS / FDI technologies, which is due to the use of an integrated information environment that allows you to organize information support in a new way in the technological design of complex and / or high-tech products. To implement the technological design model, such design levels as strategic (target) and detailed (operational, tactical) planning were considered, which made it possible to form a model for the formation of a set of technological solutions, which in turn made it possible to form a mathematical model of the information image of processes and objects for an idealized object. As a result, a model of multi-criteria evaluation and technological decision-making was developed based on the hierarchy analysis method.

1 Introduction

Ensuring the required quality of products at various stages of the life cycle is one of the goals of implementing the concept of CALS / FDI technologies.

The main task of technological design is the creation of a technological project for the materialization of a high-quality product based on the latest scientific and technological achievements. At the same time, many particular problems are solved: ensuring the manufacturability of the product; design of technological processes (assembly, installation, manufacturing of parts, control and testing); design and coordination of technological equipment; ensuring accuracy, reliability and stability of technological processes [1].

The quality of the technological project of a complex product significantly affects the quality of the product.

A key role in the process of creating a technological project is occupied by systems for the automated formation of options for technological solutions, systems for evaluating and choosing optimal solutions [2].

For effective project management, the process design system must be well structured. The essence of structuring (decomposition) is to break down the project into separate stages that can be managed.

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2 Model and method

Strategic (target) planning is the process of developing strategic, enlarged, long-term plans for product improvement (Fig. 1).
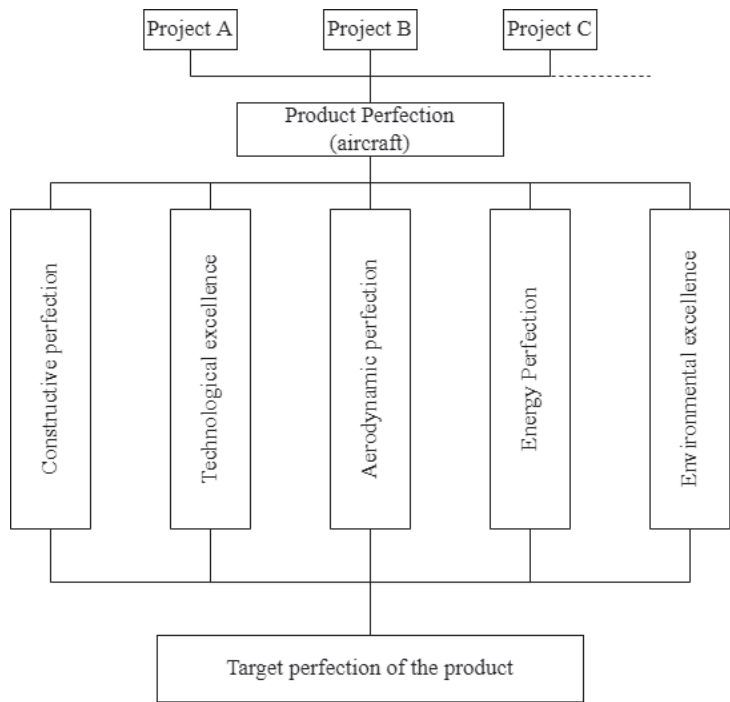

Fig. 1. Strategic product quality planning.

At the stage of strategic planning of a technological project, various methods of additional analysis in quality management systems can be used. For example, the SWOT analysis method (Strengths, Weaknesses, Opportunities and Threats - advantages, weaknesses, opportunities, threats).

Detailed (operational, tactical) planning is associated with the development of tactical, detailed plans (subgoals) for the operational management of technological design at the level of responsible executors of departments [3].

The division (decomposition) of work on the creation of a technological project into separate parts allows you to build responsibility matrices. The responsibility matrix is a form of description of the distribution of responsibility for the implementation of project work, indicating the role of each of the departments in their implementation and the person responsible [4].

Organizational units are interconnected by information flows, with which planned and actual management and technical information is transmitted. For the purposes of technological design, it is proposed to build a quality assurance subsystem (Fig. 2) into the overall design process, with the main elements: a system for generating a set of technological solutions and a system for evaluating and making technological decisions [5].
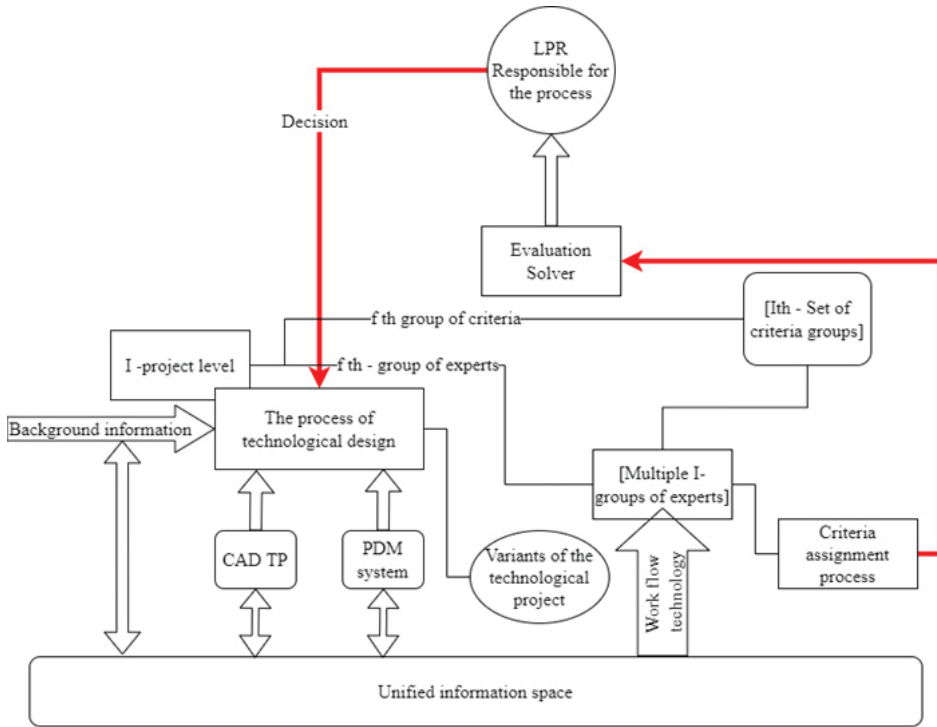
Fig. 2. Scheme of the subsystem for quality assurance of a technological project.

The decision-making process is the process of choosing the optimal (satisfactory) solution from alternative options [6]. Decision support system - a combination of a set of software tools, simulation, statistical and analytical models of processes and work on the project to prepare decisions for its implementation. The purpose of the decision support information system is the organization and management of decision making in the development and implementation of projects based on modern information processing technologies [7].

3 Research and results

3.1 Model of formation of a set of technological solutions

As noted earlier, the subsystem for ensuring the quality of a technological project contains a subsystem for generating a set of technological solutions.

Figure 3 shows a typical, structured, hierarchical model of technological design, on the basis of which an automated system for the formation of alternative options for technological solutions is built.

Under the model of technological design of a product, we mean a special design created on a set of process models used in the production of parts of the product and the product as a whole [8].

The design of the process design model should:

1. be a hierarchical system and be characterized by vertical decomposition into subsystems for solving technological problems at various levels of abstraction;

2. have full or partial orderliness of processes at each level;

3. allow the possibility of using structured processes for automated design of materialization processes for a particular product.
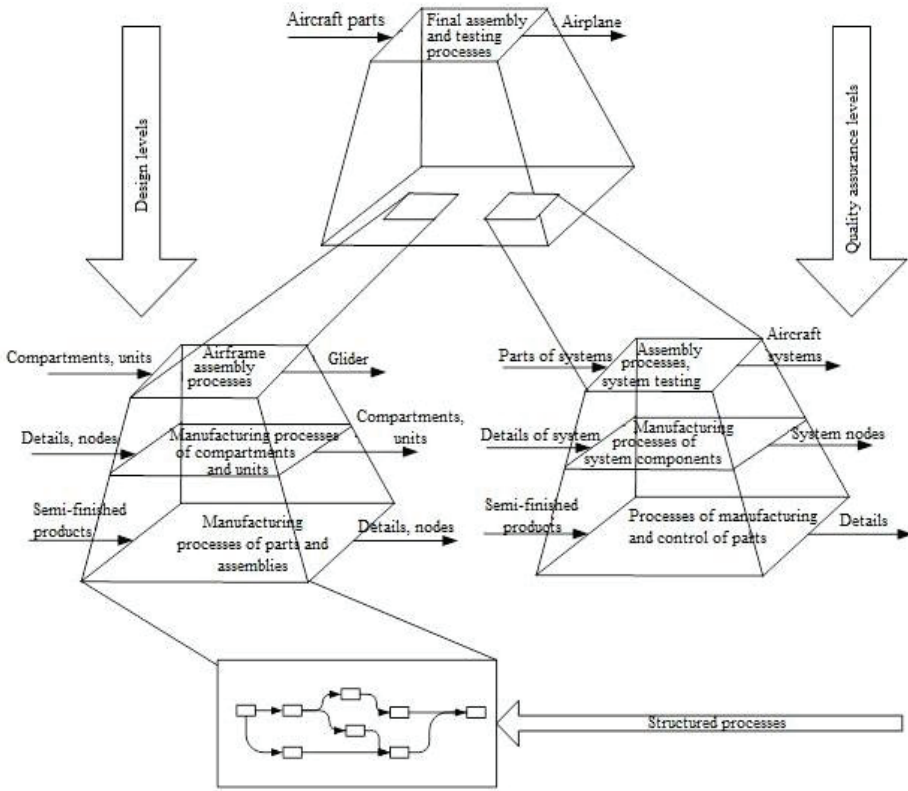

Fig. 3. Process design model.

3.1.1 The principle of regularity

There are regular structures of technological processes, regular structures of technology objects, regular relationships and functional relationships between processes and objects that allow for a preliminary systematization of design technological knowledge [8, 9].

3.1.2 Process decomposition principle

The technological process as a complex system can be decomposed into sub-processes or objects and actions.

Another form of process decomposition is the selection of objects involved in the process, according to the scheme:

items => action name, where => relationship "items participate in the process".

Objects, in turn, can be considered as integral formations and decomposed into parts, while considering the properties of the parts, the connections and relationships between the parts that form the whole. Consideration of objects as integral systems and their decomposition makes it possible to form classes of objects, perform a detailed analysis of the presence of properties, relationships, qualities, and ultimately build an information image of objects or parts [10].

The most general form of information representation of processes and objects are constructions based on the use of predicate calculus and methods of its extension [11].

For the information image of processes and objects, you can use an idealized object:

$$I = < V, S, \textstyle\sum, R> \qquad (1)$$

where V - set of elements v^i, owned V; S: $V \to V'$ - favor rule; R - element union rule v^i into structure $\sum$, i.e. binary relations $R_i(v^i, v^j)$.

As items v^i, owned V, we use: v^1 - object name; v^2 - process name; v^3 - property (of an object, process); v^4 - quality (object, process); v^5 - parameter; v^6 - decision rule; v^7 - limitation; v^8 - functional connection; v^9 - attitude [12].

The information image of processes and objects is represented in the form of a graph G=<V,R>, where v^i, owned V, - set of graph vertices; r^i, owned R - set of connections of vertices (double predicate $r_i(v^i,v^j)$).

When constructing idealized objects, we use the following binary relations:

$r_1(v^{1-2}, \lambda)$ - naming relation, where λ - real thing or process;

$r_2(v^1,v^2)$ - element usage relation v^1 element v^2;

$r_3(v^1,v^2)$ - attitude subject v^1 involved in the process v^2;

$r_4(v^1,v^2)$ - subject v^1 converted by process v^2;

$r_5(v^{1-2}{}_i, v^{1-2}{}_j)$ - subprocess (subject)$v^{1-2}{}_i$ is part of the process (subject) $v^{1-2}{}_j$;

$r_6(v^3, v^{1-2})$ - element belongs to (characterizes) element v^{1-2};

$r_7(v^{1-2}, v^4)$ - element v^{1-2} evaluated by element v^4;

$r_8(v^3,v^4)$ - element v^3 is part of the element v^4;

$r_9(v^5,v^6)$ - element v^5 - characteristic v^6;

$r_{10}(v^6,v^3)$ - element v^6 determines the presence v^3;

$r_{11}(v^5,v^6)$ - element v^5 (checked) is related to the element v^6;

$r_{12}(v^7,v^5)$ - э element v^7 limits v^5;

$r_{13}(v^5,v^8)$ - element v^5 belongs v^8; v^9 - relationship between elements v^{1-2}, v^3, v^4.

As a formal apparatus for actions with idealized objects, an algebraic system is used:

$$<J,W_p,W_1> \qquad (2)$$

where J - set carrier; W_p - set of predicates; W_1 - many functions.

As a set W_P take two-place predicates:

R_1 - following relation; R_2 - precedence relation;

R_3 - relation of predestination; R_4 - inclusion relation;

R_5 - relation of part to whole; R_6 - abstraction relation;

R_7 - detail ratio; R_8 - definition relation;

R_9 - relation of equality; R_{10} - dominance attitude;

R_{11} - quality formation relation; R_{12} - matching relation; R_{13} - relation is used.

For each relation, the properties of reflectivity, symmetry, transitivity, etc. are formed.

As a set W_1 use a set of functional dependencies that are considered "significant" when building a process model.

When operating with idealized objects, a number of conditions are used.

Condition 1 (following processes, objects) [13].

If the properties of processes (objects) are in the relation of precedence, then the processes, objects follow each other:

$$\forall v^{1-2}, \exists v_2^{1-2} \exists v_1^3(v_1^{1-2}) \exists v_2^3(v_2^{1-2})[v_1^3(v_1^{1-2}) \cap v_2^3(v_2^{1-2}) \cap (v_1^3), v_2^3 \to R_1(v_1^{1-2}, v_2^{1-2}] \qquad (3)$$

3.1.3 Condition 2 (object predeterminations)

If the properties of the first object require the presence of the properties of the second object, then the presence of the first object predetermines the presence of the second object.

$$\forall v_1^2 \exists v_2^2 \exists v_{11}^3 \exists v_{21} [v_{11}^3(v_1^2) \cap v_{21}^3(v_{21}^2) \cap R^3(v_{11}^3, v_{21}^3) \to R_3(v_1^3, v_2^3)] \qquad (3)$$

The system of meaningful conditions is added to the usual logical axioms of the theory of the first order of the predicate calculus and allows us to formulate a number of theorems that are the basis for the development of algorithms.

3.2 Model of estimation and acceptance of technological decisions

At the stage of project implementation, it is necessary to ensure the collection of actual data on the state of work, optimally present them for analysis, ensure the exchange of information and interaction between project participants, and choose the optimal technological solution [14]. To perform these functions, specially designed software is used.

The quality of a technological project is influenced by many factors that must be taken into account at various stages of technological design. After the formation of many alternative options for technological solutions, they must be evaluated and a solution that meets the specified criteria must be selected [15]. The formation of a system of criteria for evaluating a technological project is a complex, creative task. This complexity stems from the diversity of the evaluated processes and objects, their close relationship (Fig. 4) and the inconsistency of the requirements (criteria).
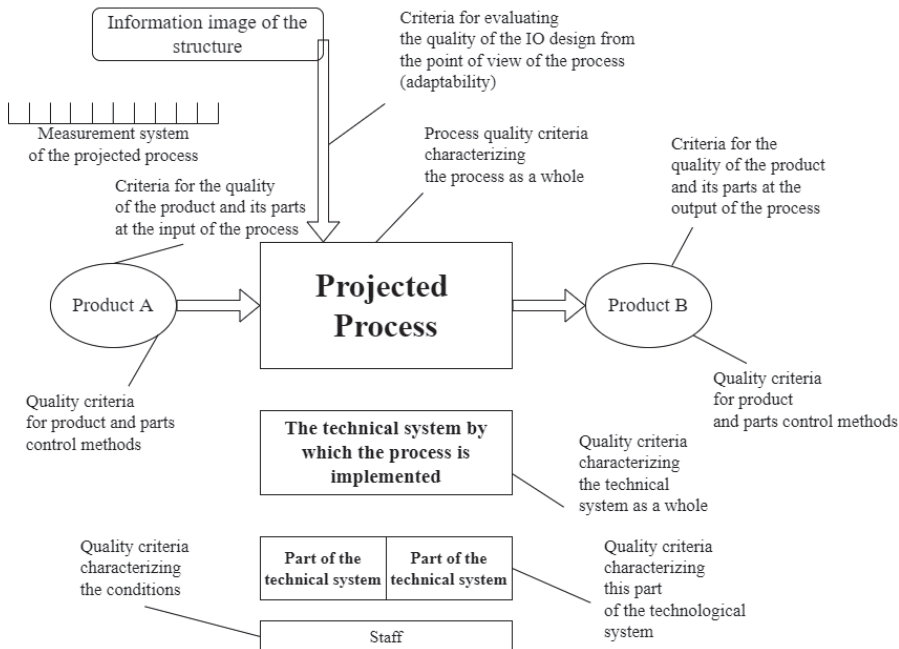

Fig. 4. Scheme for assigning criteria in process design.

To create a system of quality indicators, it is necessary that the indicators: have a quantitative expression; reflected the qualitative shifts characterizing the development of the considered technological project; provided a design evaluation taking into account the influence of design levels. In the process of expert evaluation of technological project

proposals, along with quantitative criteria-indicators, it is possible to use qualitative criteria-indicators [16]. In this case, the numerical value of the qualitative criteria-indicators is replaced by an expert assessment.

The work uses general quality indicators such as: accuracy, interchangeability, manufacturability, standardization, reliability, technological cost and private (for example, the quality of the surface layer). A three-dimensional taxonomy of success factors for a technological project has been developed (Fig. 5).
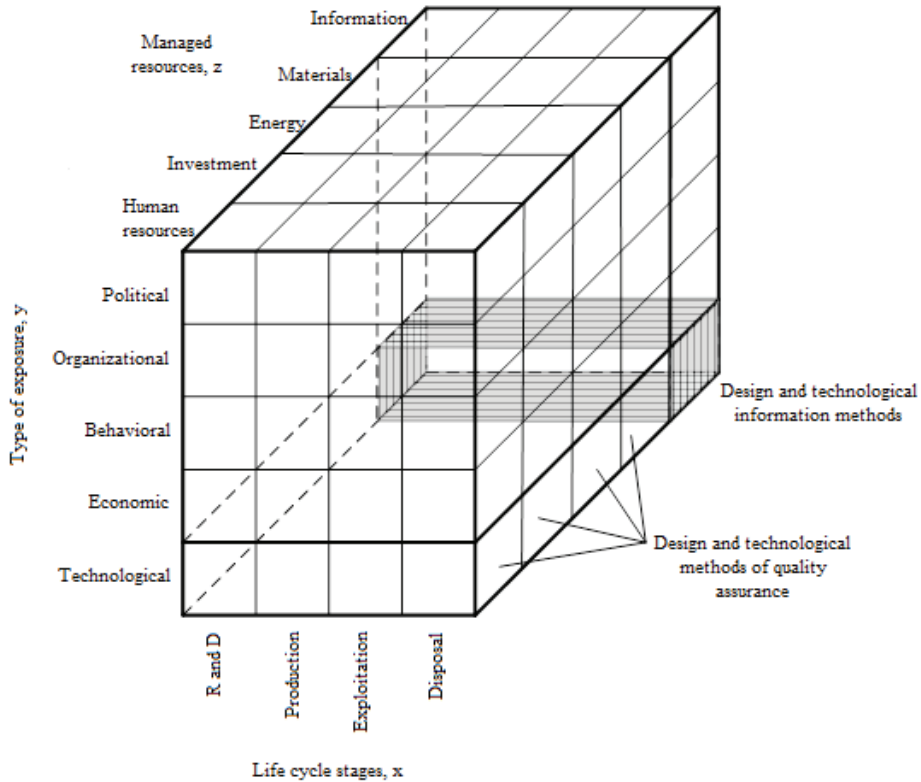

Fig. 5. 3D Taxonomy of Technology Project Success Factors.

For multi-criteria evaluation of alternative design options, the method of hierarchical pair comparison is used. Hierarchy analysis is one of the most powerful and effective methods of examination and decision making. The hierarchy analysis method proposed by Thomas Saaty combines the idea of pairwise comparison of objects with an analytical approach to the formation of an evaluation solution. The analytical approach, based on the algebraic theory of matrices, allows, based on the results of paired comparisons, to build an ordered series of objects one by one or a set of hierarchically related indicators (comparison criteria) and thereby determine the best option [17]. The hierarchy analysis method has an important advantage: this method is focused on the analysis and evaluation of complex hierarchical structures, which is a complex technological project [18]. Other advantages of the hierarchy analysis method are: focus on solving problems (expertise) using qualitative, informal characteristics; universality of the method in relation to a wide class of technological problems; availability of mechanisms for monitoring the consistency of expert decisions; ease of examination by any number of experts. These advantages are especially important in the early stages of developing a technological project [19].

The application of the hierarchy analysis method to solving the problem of assessing the quality of technological project proposals includes three main stages:

1) a hierarchical representation of the examination task, in which the lower level of the hierarchy is represented by alternatives (project proposals), the upper level of the hierarchy is represented by the goal (by assessing the quality of a technological project), intermediate levels of the hierarchy are occupied by criteria - single and complex quality indicators, by which project proposals are compared;

2) conducting paired comparisons to determine the quantitative assessment of the influence of elements of each level of the hierarchy (alternatives, criteria) on each element of the upper level of the hierarchy (criterion, goal);

3) alternatives (evaluated project proposals) through the criteria (a system of single and complex quality indicators) to the goal - assessing the quality of a technological project [20].

4 Conclusion

Thus, quality assurance in the process design of a complex science-intensive product can be achieved within the framework of CALS / FDI technologies by embedding a quality assurance subsystem into the overall process of process design, consisting of subsystems: the formation of a set of technological solutions; multi-criteria evaluation and technological decision-making based on the hierarchy analysis method. The developed software showed high efficiency of technological design according to the new methodology with a high level of the main groups of quality indicators of the technological project.

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