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FORMALIZATION OF THE PROCESSES OF PROJECTS FOR THE DEVELOPMENT OF HIGH-TECH ENTERPRISES

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The paper considers the problems of regulating the processes of projects for the development of high-tech enterprises. An approach to the formalized representation of processes based on set theory, graph theory and functional modeling has been developed. As an example, the problem of formalizing the process of creating technological project documentation is considered. For this, a set of input, output data, regulatory documents and basic operations, update and exit functions are formed. It is noted that all implementations of the update function form a single process database. For a separate implementation, it is shown how the input data is refined based on the requirements of regulatory documents, templates of technological documents are formed, an algorithm and a web-oriented module for accessing the database to select a set of document templates are presented. The function of outputs has been formed. Its tabular and graphical representations made it possible to move to a functional model of the process, which determines the sequence of its implementation and the rules for converting input information into output, taking into account the requirements of regulatory documents.

Introduction

In the context of increasing economic integration between countries and a simultaneous increase in the aggressiveness of competition methods in sales markets, economic ties become more complicated, scientific and technological progress accelerates, the role of consumers in the formation of the properties of the final product increases, and technological advantages become a necessary condition for increasing productivity and improving the efficiency of cost management in production of goods and services [1]. World leaders (Japan, Germany, Switzerland, China, France, USA, etc.) effectively implement national innovation strategies, form science-intensive and high-tech industries, and contribute to the development of industry within the framework of Industry 4.0 [1], [2].

In order not to lose competitiveness, not to lack financial resources and avoid

technological degradation, domestic enterprises adapt to changes in the internal and external environment, turning "... into flexible, open interactive structures for rapid response to changes in consumer demands and world market conditions, devoid of the industry principle of production organization and clear structuring of the processes of creation, market entry, production and service of final products" [p.p. 4, 3]. All this requires companies to constantly implement development projects related to improving management methods, developing marketing functions, decision-making, control, communications, and so on. The stages of development and creation of prototypes of high-tech products in the conditions of interaction of various enterprises require special attention of managers of high-tech enterprises [1], [2]. Managing such projects is a complex task of organizing a continuous process of preparing new products that are characterized by technological novelty based on modern scientific achievements [1], [4].

Project preparation - technical preparation of production combines a complex of scientific, project, technological and managerial work on the creation and development of new products and the introduction of new technologies. Project activities provide that when creating high-tech products, it is necessary to develop individual technical solutions in order to ensure optimal (in terms of time and resources) the technological readiness of production in accordance with the requirements of the customer or the market. These types of work are carried out at the initial stages of the product life cycle and go through interrelated stages of project, technological and organizational preparation of production. As a result, a set of documents is formed, which determines the project, operational and repair features of high-tech products. The presence of such documentation is a prerequisite for the sale of these products on the market; it is also considered as an additional factor that ensures an increase in production efficiency and quality, an increase in labor productivity and, as a result, an increase in competitiveness [2], [5]. However, according to statistics, most of the errors that require revision and / or project changes and, as a result, lead to a change in the timing and cost overrun of the project, are associated with the initial stages of the product life cycle. At the same time, the

elimination of these errors accounts for almost half of the labor costs of the later stages of the project and up to 36% of the cost of changes [5] - [7]. Therefore, the directions related to the formalization of the processes of technical preparation for the production of high-tech products in the implementation of enterprise development projects in order to ensure a common understanding of the requirements, reduce project errors, coordinate the interaction of structural units, identify areas of responsibility and, ultimately, increase the efficiency of project management, are relevant.

Generalized approach to formalizing processes

Modern requirements for project activities provide for a reduction in the cost of project work and an increase in the quality of project documentation while reducing the time for its development. The quality of project documentation is understood as the degree of compliance of its characteristics with the customer's requirements, normative and technical documentation and technical specifications for development [8]. At the same time, the level of quality of project documentation is determined by the number of inconsistencies present in it and, as a consequence, by the additional labor intensity associated with the need to eliminate them [6], [8]. This means that the quality of project work depends on inconsistencies found in the process of document control, and is characterized by the frequency of their occurrence [5], [9], the value of which is:

$$F_H = \frac{H_i}{H} 100\%, \quad (1)$$

where H_i – number of inconsistencies of the i-th type in the documentation set; H – total number of inconsistencies.

In their works, specialists from the National Institute for Strategic Studies [3] and their foreign colleagues [5], [8], [10] emphasize the effectiveness of the introduction of digital technologies and information systems to support the development and production of prototypes. This allows you to reduce the value of F_H, and the ability to automate the processes of creating project documentation

almost completely solves the problems of routine, improves quality, reduces the labor intensity and resource intensity of its development, shortens the stages of project and technological preparation of the production of high-tech products, reduces the time of projects for the creation of prototypes.

As part of the technical preparation of production, as an example, consider the process of creating project documentation, the development of which at a high-tech enterprise involves the introduction of an information system aimed at automating project work. Such systems, based on the concept of a single source, allow you to create and maintain up to date a single database of projects, which, within the allocated budget, provides a quick technological readiness of production for the manufacture of new products [10]. Unfortunately, the development of such information systems is associated with certain difficulties, among which one can single out [10], [11]:

– lack of a unified approach to describing the processes of creating project documentation;

– the need to combine in a single document many documents containing a significant amount of text and graphic information, the volume of which is often hundreds and thousands of pages;

– the presence of partial or complete duplication of information in different documents when describing the same objects;

– limited use of the modular approach, widely used in the creation of software systems, due to the fact that the project documentation is a text in a natural language with its own lexical and grammatical rules, established traditions, considerations of stylistics and aesthetics;

– the need for constant updating of the received project documentation at all stages of the product life cycle by repeatedly making amendments, additions and changes to documents consisting of many separate files, etc.

The ISO/IEC 12207 standard in the life cycle of information systems separates the stages of project and writing of program code, which allows at the initial stages of development to analyze the subject area, form a conceptual model of the system

with a description of the main functions performed [11].

We represent the conceptual model of the process of creating project documentation in the form [11]:

$$I\_Pr = (V, Z, \varphi, A, O, \psi), \quad (2)$$

where $V = \{v_1, v_2, ..., v_n\}$ is a lot of input data required to create project documentation for high-tech products in the context of the project under consideration; $Z = \{z_1, z_2, ..., z_k\}$ – a set of documents regulating the process; φ – update function, the implementation of which is associated with the refinement of input data depending on the requirements of regulatory documents; $A = \{a_1, a_2, ..., a_j\}$ – many functions (operations) that implement the process of creating project documentation; $O = \{o_1, o_2, ..., o_m\}$ – a lot of outputs from the process of creating project documentation; ψ – function of outputs, the execution of which produces the output.

The composition and type of project documentation is regulated by a number of state standards, which stipulate requirements for the project and content of this type of documents [12]. These elements form data modules in a single centralized repository - a database (library) of the development project obtained when the update function is implemented [11]:

$$\varphi : V \times Z \to V, \quad (3)$$

which, in addition to clarifying the input data, involves determining the type, form and procedure for preparing project documentation in accordance with the requirements of regulatory documents.

The most convenient way to represent the function φ is enumeration, when for each element of the set V, implementations of the function are formed:

$$v_1 = \varphi(v_1, z_1);$$

$$v_1 = \varphi(v_1, z_2);$$

$$\ldots\ldots\ldots\ldots\ldots;$$

$$v_n = \varphi(v_n, z_k).$$

For example, the requirement of the technical assignment "one-off production" entering the input of the process (2), when implementing the function φ, taking into account the requirements of state standards governing technological documents, is transformed into the input requirement "development of a route map of the technological process", the form, type and content of which is standardized. Accordingly, if the terms of reference provide for the creation of a set of additional documents, then the input data – elements of the set V-is also refined taking into account the normative documents.

Thus, the implementations of the function φ are the basis for projecting templates and styles when creating project documentation. For them, a text is written, on the basis of which documents are formed with a certain degree of readiness. This allows reusing project data (forms, templates, texts, drawings, pictures, etc.) by “connecting” and publishing them in files of different formats. At the same time, it is enough to correct a section, figure, table, paragraph, any other fragment that should appear in several places, if necessary, once in a single source [13]. A single change to a template, for example, a user manual, is enough for all documents of this type to be changed as needed after processing.

After the refinement as a result of the execution of the function φ of the input data, the process (2) is implemented by performing certain functions (operations) during the formation of the mapping [11]:

$$\psi : V \times Z \to O, \tag{4}$$

unambiguously determining what will be the output of the development project process depending on the inputs $V = \{v_1, v_2, ..., v_n\}$ and certain operations $A = \{a_1, a_2, ..., a_j\}$.

In this case, it is convenient to represent the function ψ in tabular or graphical form.

Output table is a tabular representation of a function ψ, in which each row corresponds to one function (operation) a_j (j = 1,2, ...), and a column corresponds to one admissible input element of the set V. In a cell at the intersection of a row and a

column, an operation a_j is indicated to be executed if the input received an element v_n (n = 1,2, ...) and an output element o_m (m = 1,2, ...), which appears as a result of the operation a_j [12].

State diagram is a graphical representation of the output function using a directed graph, the vertices of which correspond to functions (operations) a_j (j = 1,2, ...), edges correspond to transitions from one process operation to another, edge weights to elements v_n (n = 1,2, ...), along which there is a transition from the execution of one operation a_j to another, and elements o_m (m = 1,2, ...), which will appear as a result of the operation a_j [12].

The proposed approach to the formalization of development project management processes for a visual presentation allows the use of methods of functional modeling methodology IDEF 0 [11], [13]. Thus, the set-theoretical description of the process (2) allows it to be presented in the form of a context diagram, the ICOM codes of which identify the sets $V = \{v_1, v_2, ..., v_n\}$, $Z = \{z_1, z_2, ..., z_k\}$ and $O = \{o_1, o_2, ..., o_m\}$, and the graphical representation of the output function is transformed into child diagrams (functional models) describing the sequence of the process implementation (2) [11]. We also note that the proposed approach is suitable for describing any development project management processes if:

– the process is described at the level of setting the dependence of the values at its output from the values at its input;

– the sets V, Z, O are finite;

– set A is finite, but due to the complexity of connections between operations, it is recommended to limit its power to the range from 2 to 6 (otherwise, it is advisable to represent the process as a set of hierarchically organized subprocesses, the formalized description of which for a certain level of hierarchy occurs in accordance with the proposed approach).

An example of formalization of processes in the tasks of developing technological project documentation

All project documentation is divided into two types [12]:

– technological documentation that fixes the entire cycle of creating high-tech products from technical specifications and preliminary design to the successive stages of its implementation;

– design documentation containing a list of documents describing the principle of operation, the specifics of operation, maintenance, repair and disposal of products.

Due to the specifics of the content of each type of documentation, we will focus on the process of creating technological documentation.

In accordance with expression (2), we define the set:

1. Input data of the process V, which consists of: v_1 - terms of reference for the development of high-tech products, containing the basic requirements for a sample, a set of technical documentation, rules for sample acceptance, etc.; v_2 - design documentation for a sample of high-tech products; v_3 - data from the sales department about the planned production volumes.

2. Regulatory documents, Z, consisting of: z_1 - requirements of the "System for the development and launching of products (SDLP), Unified system for design documentation (USDD)" and "Unified system of technological documentation (USTD)"; z_2 - industry standard recommendations; z_3 - development project management plan.

3. Output data of the process O, the elements of which are: o_1 - technological and organizational solutions; o_2 - set of technological documentation; o_3 - the results of testing the structure for manufacturability.

Let's get a context diagram - a graphical representation of the process (2) when creating technological documentation, taking into account certain sets (fig. 1).

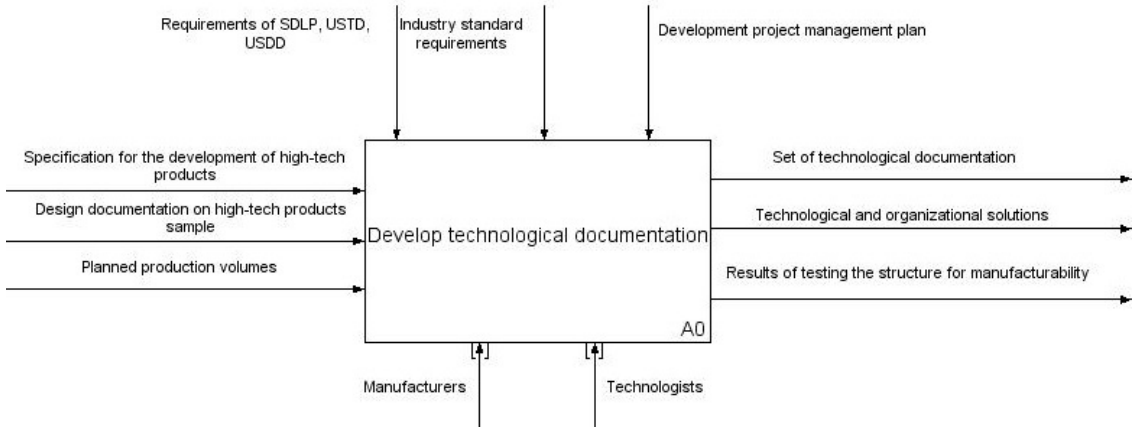


Fig. 1. Graphic representation of the process (2) when creating technological documentation

Thus, technologists and production workers, when performing the process of creating technological documentation, taking into account the requirements of regulatory documents from the set Z, must transform the requirements of the technical assignment based on design documentation and production volumes into technological documentation with the development of organizational and technological solutions based on the results of working out the structure for manufacturability, which will ensure manufacturing of high-tech products.

To determine the update function φ we will analyze the requirements of GOST 2.103-68 and GOST 3.1102-81. They determine the structure and volume of technological documentation, which depend on a number of factors, the main of which are [11]:

1. Type of production, depending on which the documentation is distinguished for a single (with a production volume of about ten products), serial (with a production volume of up to a thousand products) and mass (with a production volume of more than a thousand products) production;

2. The stage of development, depending on which documentation for the production of a prototype or documentation for serial (mass) production is formed;

3. The level of detail, which determines either route, route-operational, or operational description of the technological process.

There are also technological documents:

– auxiliary - documents used in the development, implementation and operation of technological processes (operations);

– basic - documents that completely and unambiguously define the technological process, containing generalized information necessary to solve one (complex) engineering, economic planning and organizational task. Documents of this type share:

– for documents of general purpose (map of sketches, technological instructions, etc.);

– special-purpose documents (route map, technological process map, bill of materials, etc.).

All these data are contained in a variety: the type of production depends on its volume, the stage of development is indicated in the terms of reference, which additionally provides a list of the necessary technological documentation, etc. But each of these requirements in conjunction with the input data will lead to the formation of a different set of technological documentation, different technological and organizational solutions, will determine a different procedure for testing for manufacturability. As a result, a set of implementations of the update function (3) is formed - a unified database of the process of creating technological documentation.

Fig. 2 shows an algorithm for accessing the database to select a specific implementation of the function φ when generating templates for technological documents (here blocks 1, 2 and 3 have an identical structure, therefore, the structure of only one of the blocks is presented in detail).

The algorithm provides for accessing a single database to select document templates from it based on the following characteristics:

– type of production;

– documentation development stage;

– the nature of the description of the technological process;

– additional technological documents.

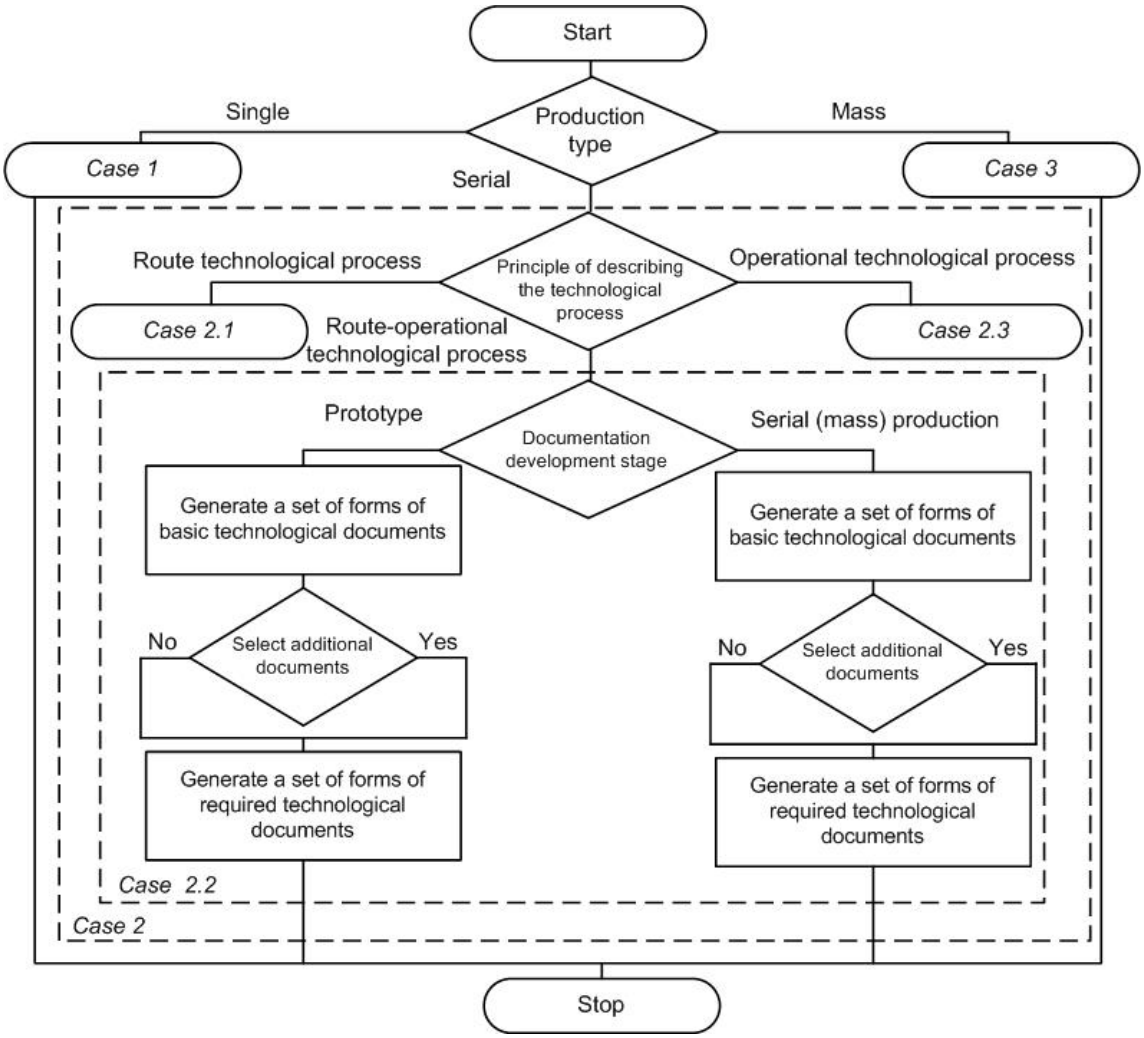


Fig. 2. Generalized scheme of the algorithm for accessing the unified database of the process of creating technological documentation

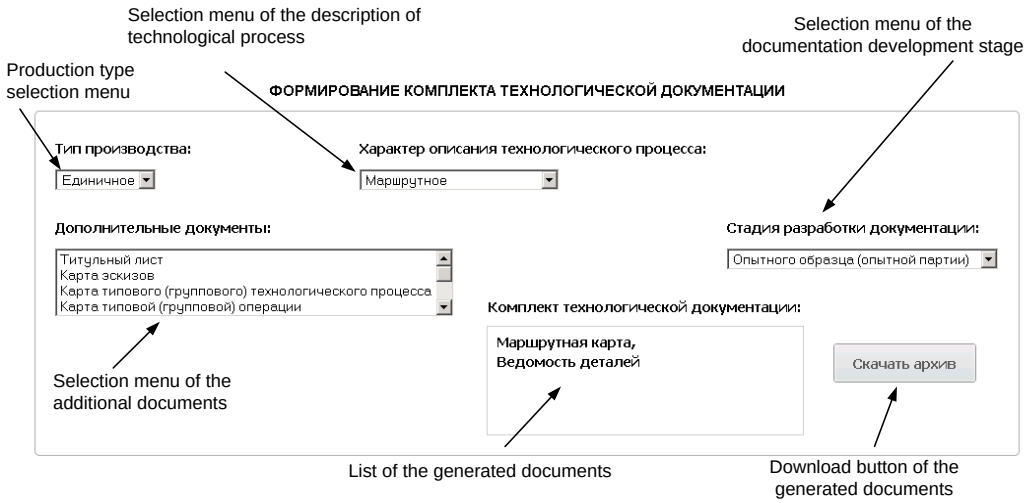
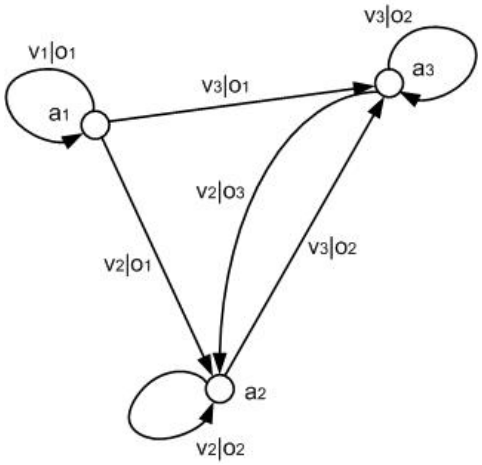


Fig. 3. Interface of the web-based module for generating templates for technological documentation

In accordance with the algorithm, a web-oriented module is implemented for the automated generation of templates for technological documentation, the interface of which is shown in fig. 3. Other implementations of the φ function are presented in the same way, forming not only the structure of a single database, but also its main content.

A unified system of technological documentation, in particular GOST 3.1102-2011, defines the rules for the development of documentation and the main stages of its creation, the analysis of which makes it possible to form a set A.

Set A consists of the following elements: a_1 - the function of forming technological and organizational solutions; a_2 - the function of developing technology for the manufacture of high-tech products; a_3 - the function of testing the structure for manufacturability. The execution of each of the listed functions of the set A ends with the formation of a certain set of output documents recorded in the set O. This allows to represent the process model in the form of a graph (fig. 4, a), the vertices of which a_j $(j=1,...,3)$ are defined by the set A, the edges show the sequence of these functions, the weight of the edge is determined by the input and output data from the sets V and O. By the graph we write the table of outputs (fig. 4, b)



a - graph

Process functions	Process input		
	v_1	v_2	v_3
a_1	$a_1\|o_1$	$a_2\|o_1$	$a_3\|o_1$
a_2	-	$a_2\|o_2$	$a_3\|o_2$
a_3	-	$a_2\|o_3$	$a_3\|o_2$

b - table of outputs

Fig. 4. Formal presentation of the process of creating technological documentation

From the formal representation of the process, it can be seen that, for example, to obtain the output o_2 when the function a_2 is executed, the output o_1 is needed, obtained when the function a_1 is executed by generalizing the input data v_1 and v_2, as well as the output o_3, obtained from the function a_3.

Based on fig. 4 for clarity and facilitation of people's perception of information flows of the process of creating technological documentation while observing the rigor and formality of the image [13], [14], we represent the process under consideration as a functional model (fig. 5), combining its verbal and formalized description.

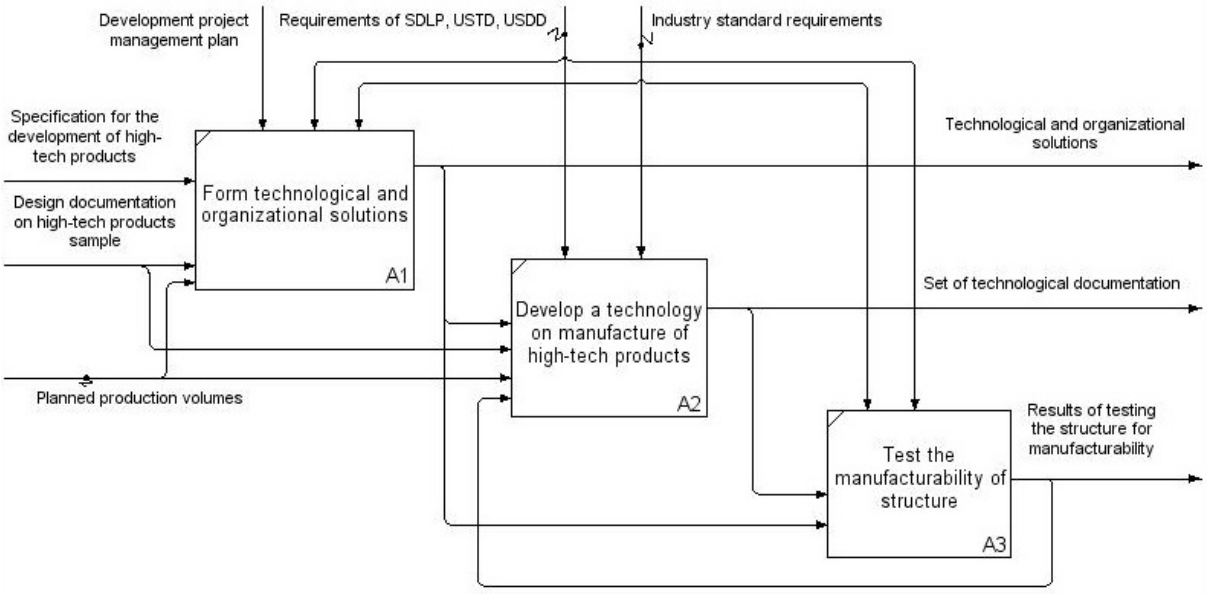


Fig. 5. Functional model of the process of creating technological documentation

Thus, the considered example showed the possibility of creating a unified approach to describing project management processes. Their formalization allows the introduction of a modular principle, which, in particular, in documentation tasks, allows one to abstract from unnecessary detail, systematize information flows, combine the results of individual functions into a single system, involve different specialists in the implementation of individual process elements, allowing parallel development, redesign technical documentation in service for all participants in the development of high-tech products.

Conclusions

For a timely response to changes in the internal and external environment, high-tech enterprises need constant development aimed at improving various approaches and methods of management, decision-making and control. At the same time, approaches aimed at maintaining the stages of development and release of prototypes of high-tech products are acquiring special significance. Considering the high "cost" of mistakes at these stages, development projects, in particular, their processes aimed at reducing the frequency of FH in the design documentation and reducing the cost of design work, are relevant.

Focusing on the technological preparation of production, the work proposes an approach to formalization of processes based on set theory, graph representation and functional modeling. Its implementation on the example of the process of creating technological documentation of the project showed the following advantages:

– the possibility of "integral" presentation of the process;

– the ability to systematize heterogeneous input data coming from different sources (standards, regulatory and technical documents, organizational process assets, etc.), and their unified presentation;

– the possibility of typing the output data of the process;

– introduction of a modular approach based on dividing the process into separate functions and implementation;

– through the use of graph and functional modeling, increased visibility, better perception of the structure of the process, the sequence of its execution.

Thus, the proposed approach to formalizing processes can be considered as the basis for their regulation to ensure technical and organizational interaction in projects for the development of high-tech enterprises. The resulting process models can be used in artificial intelligence systems, expert systems in the development of multivariate design solutions, and their formalization not only at the project level, but also at the level of organizations will allow successfully creating high-tech products.

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