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DEVELOPMENT OF A METHOD OF COORDINATION OF PROJECT AND OPERATIONAL ACTIVITIES IN THE PROCESS OF MANUFACTURING COMPLEX KNOWLEDGE-INTENSIVE PRODUCTS

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It is shown that the production processes of project-oriented enterprises focused on manufacturing complex knowledge-intensive products combine project and operational activities. Analysis of project management methodologies in terms of their suitability for managing the activities of project-oriented enterprises engaged in manufacturing these products was conducted. It was found that project management methodologies do not address this issue, remaining outside the scope of project managers. To eliminate this shortcoming of the project management methodology, it was proposed to supplement it with the concept and method of coordination of project and operational activities in the process of manufacturing complex knowledge-intensive products.

The concept of integration of project and operational activities in the process of manufacturing complex knowledge-intensive products was proposed. A method of coordination of project and operational activities in the process of manufacturing complex knowledge-intensive products was developed. The following criteria were proposed: management of operational processes as processes depending on the progress of projects; evaluation of the success of projects taking into account the assessment of their provision with products of operational activities. A model for calculating the number of components to be produced during the implementation of projects of manufacturing complex knowledge-intensive piece products was developed. The method of multiple simulations of project and operational processes in projects of manufacturing complex knowledge-intensive products was proposed.

The developed concept and method passed practical testing at enterprises engaged in manufacturing complex knowledge-intensive products, in particular, Karbon Invest, LLC (Ukraine), and showed high efficiency of managing projects of manufacturing complex knowledge-intensive products. The developed tools allow creating integrated management systems for project and operational production of complex knowledge-intensive products

Keywords: project management, project provision management, projects of manufacturing complex knowledge-intensive products

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1. Introduction

The activities of enterprises producing complex knowledge-intensive piece products (machine-building, shipbuilding, aircraft engineering, instrument-making, etc.) are always associated with both project implementation and operational production. Therefore, these activities require a management system that can effectively coordinate both project and operational production processes. For example, the manufacture of aircraft or ships requires coordination of the processes of assembling these products with the processes of purchasing components and manufacturing various parts, assemblies, units on their production bases.

This requires the development of new management methods for project-oriented enterprises producing complex knowledge-intensive piece products (CNIPP). In particular, methods that allow coordinating all processes of the enterprise, from receiving an order and financing it to producing components and manufacturing the final product.

Coordination of project and operational activities is now beyond the scope of project management methodologies. Indeed, it would seem impossible to manage processes related to the operational activities of enterprises, their logistics, the work of other enterprises that supply a variety of resources using the project management methodology. But in this case, the efficiency of project management is significantly reduced, as part of the project environment is beyond the management system itself.

Therefore, project management functions must include management functions of the part of operational activities aimed at providing projects with a variety of resources. It is also necessary to present the provision functions as a single management system for project-oriented businesses of the company. So, the development of methods integrating the processes of project and operations management of project-oriented enterprises in the process of manufacturing complex knowledge-intensive piece products is an urgent scientific and practical problem.

2. Literature review and problem statement

The paper [1] reflects the development of organizational tools for coordinating enterprise project portfolios, considers the practical experience of the authors in using the portfolio strategy matrix, portfolio model, the use of project portfolio management methodology. But the problems of integrating project and operational activities in knowledge-intensive industries need additional research. The possibility of building a model of an adaptive resource management system for knowledge-intensive production projects based on a management system with a predictive model that will improve the quality of project management by ensuring proper decision-making efficiency is presented in [2]. At the same time, the paper does not consider organizational features of project and operations management of production enterprises. From the standpoint of the organizational structure, we can only note the scientific direction related to the development of matrix information technologies, as technologies at the intersection of project (project teams) and functional (functional units) management processes. In this area, conceptual bases of matrix management of the portfolio of standard projects and programs have been formed [3]. Conceptual bases of matrix management of portfolios of standard projects and programs in project and operational activities of production companies are proposed. But there is no matrix evaluation mechanism. A continuation of the research is the work [4], which proposed a model for assessing development matrices by technological maturity and readiness for changes. In particular, the main tools within the matrix technologies of project management of organizational development are presented. But the work [4] mainly focuses on mechanisms for proactive management of organizational development programs. The search for opportunities for effective use of flexible matrix management structures in the formation of internal quality assurance systems is formed in [5]. But the authors of [5] do not take into account the specifics of production activities of enterprises. From the standpoint of the engineering project, the application of the matrix approach is reflected in [6]. The disadvantage is that the matrix is formed in terms of risks in engineering projects.

So, we can single out the works that offer operations management during an incomplete project management life cycle. For example, [7] presents elements of setting up traditional operations management approaches in terms of technological tools for production planning. The work [8] focuses on the functioning of supporting project management subsystems. These include issues of providing resources, including those produced by the enterprise itself. A continuation of the research is the work [9], which presents a project resource management system. This system, in addition to project management orientation, implements project resource management. It also integrates project management functions with project resource management functions. But the issues of coordination of operational and project processes during the manufacture of complex knowledge-intensive products, such as aircraft, small and large vessels, geophysical instruments, piece products of mechanical engineering, etc. are not considered.

The paper [10] focuses on the integration of different project risk management methodologies. It compared different risk management approaches according to modern project management standards. The work [11] emphasizes the prospect of reaching a new level in project management from the standpoint of combining project and operations management processes of project-oriented enterprises in the digital dimension.

However, from the analysis of software products that can be used to manage project and operational production [12], it was found that most functions are implemented manually. After analyzing MS Project Professional 2016 (USA) [13] and Oracle Primavera P6 Professional (USA) [14], Clarizen (USA) [15] and ProjectLibre (USA) – a software product under a free license [16], they were found to be appropriate for developing and monitoring project plans, receiving information about the project progress, responding to project changes. The disadvantage is that the presented software products allow stakeholders to view project and resource information across the unit or organization as a whole. In addition, the analysis revealed some functional inadequacy of these systems. It was found that in these systems, the issues of operational processes are open: resource provision (rather than management of resources received) and formation of the enterprise budget in terms of project activity support. Also, these systems do not have the functions to ensure control over administrative procedures and provide with products of operational activities.

The issue of integration of project and operational processes within information technology is reflected in ERP systems [17]. This is usually a feature that provides solutions to individual problems. But they do not consider the methodological part. Effective project management requires the integration of ERP systems with project management systems. This will enable the integration of supply management functions into a single project management system for complex knowledge-intensive products.

As the analysis showed, today the issue of integration of project and operational activities is solved through the integration of information databases of systems used in enterprises producing complex knowledge-intensive products. This is due to the fact that existing project management tools do not implement project portfolio management functions, which is partially implemented in MS Project Server, Oracle Primavera, Clarizen, ProjectLibre. But these systems do not implement the functions of project provision management in the company's operational activity. This is due to the fact that the project management methodology lacks methods for managing operational activities as those aimed at providing projects with products of these activities. There are no methods for managing project-operational production as a single system. Therefore, it is necessary to develop a concept and method of coordination of project and operational activities in the process of manufacturing complex knowledge-intensive products.

3. The aim and objectives of the study

The aim of the study is to create a method of coordination of project and operational activities in the process of manufacturing complex knowledge-intensive piece products. This will make it possible to create integrated project and operations management systems for enterprises manufacturing complex knowledge-intensive products.

To achieve the aim, the following objectives were set:

– to develop a concept of integration of project and operational activities in knowledge-intensive industries;

– to develop an integrated method of project and operations management of project-oriented enterprises.

4. Research materials and methods

The object of research is the processes of creating complex knowledge-intensive products. The subject of research is the processes of project provision management and project management for creating complex knowledge-intensive products.

The method of coordination of project and operational activities did not address the issues of financial and economic support of enterprises manufacturing complex knowledge-intensive piece products and procurement of material and technical resources needed for manufacturing project components. This is due to the fact that these issues are well implemented by existing ERP systems [17]. The assumption of the work is that the enterprises that will use the developed tools are fully provided with orders for manufacturing complex knowledge-intensive piece products, which leads to the need for effective management of both the project portfolio and project provision with material and technical resources produced at the enterprise.

Based on this, the hypothesis of the study is that the inclusion of the issues of project provision management when creating complex knowledge-intensive piece products in the project management methodology will increase the efficiency of project and program portfolio management, which in turn will reduce project implementation time.

To integrate the processes of project and operations management of enterprises manufacturing complex knowledge-intensive products, the provisions of the system approach were used in the work. The project management methodology was used to build project processes of manufacturing complex knowledge-intensive products and processes of manufacturing components for these projects. Simulation modeling ideas were used to develop a method of coordination of project and operational processes in projects for manufacturing complex knowledge-intensive piece products. The software that implements the proposed method was developed in MS Access using the MS SQL Server database.

Experimental studies were conducted in the conditions of existing enterprises manufacturing complex knowledge-intensive piece products in the aircraft and instrument-making industries. This allowed practical testing of the adequacy of the proposed concept and models and the effectiveness of the proposed method of coordinating project and operational processes in projects for manufacturing complex knowledge-intensive piece products.

5. Results of the study of management processes of manufacturing complex knowledge-intensive products

5. 1. The concept of integration of project and operational activities in the process of manufacturing complex knowledge-intensive products

The enterprises engaged in manufacturing complex knowledge-intensive products have the following properties:

1. The products are piecemeal, each copy is somewhat unique and requires the scientific potential of the enterprise to be produced.

2. The manufacture of each copy of the product takes time (from several months to several years) and is costly (from a million hryvnias).

3. The enterprises not only assemble the product, but also manufacture its components (parts, assemblies, units).

Such enterprises include aircraft, shipbuilding, energy companies, companies producing complex geophysical instruments, etc. Such enterprises also include construction management of complex power facilities, including nuclear power plants (NPPs), as individual metal and reinforced concrete structures are manufactured at the enterprises of such NPPs.

The peculiarity of enterprises engaged in manufacturing CNIPP is that on the one hand, the production of any complex knowledge-intensive piece product can be considered as a project. On the other hand, they produce components for these products. Each CNIPP can be considered as a separate project. Especially when customers are different and require different configurations. Besides, such enterprises produce parts, assemblies, units for their CNIPP, and the manufacture of parts, assemblies, units (hereinafter components) is performed mostly in the operational activities of this or other enterprises. In addition, the manufacture of components must be consistent with the project activities.

Operational activities play a particularly important role in the manufacture of relatively small CNIPP, when it takes more time and money to manufacture parts than to assemble them into units, assemblies and finished product. Thus, it is necessary to integrate operational processes with project ones. Usually, when integrating project and operational processes, components used in project products are made in operational processes. Despite the wide distribution and versatility of both project management tools and ERP systems, the functions of combining project and operational activities are not implemented at all.

The complexity of this issue is that operational processes cannot be considered as processes within the project. A particularly big problem arises when components are produced not for one product, but for several. After all, if components are manufactured for a separate project, these works can be considered as project works. Then you can use software tools to manage this process, such as MS Project (USA), Primavera Oracle Inc. (USA), or Clarizen (USA). However, when components are made for several projects, the production process itself is no longer part of the project, but intersects with many projects. For example, if some part is needed in the amount of 1 piece per product, and, say, 5 products are made in steps of 1 month, then no one will reconfigure the equipment every month to produce one part. Once 5 parts will be released, one will go to the current product and the rest to the warehouse, where they will wait for the readiness of "their" CNIPP. Thus, the process of releasing this part is within the first CNIPP, and not all the others. If there is one part in the warehouse, this process will be attributed to the manufacture of the next CNIPP, etc.

Another issue is the provision of material and technical resources (MTR). Since both operational and project activities require the same MTR and components that are not manufactured at the enterprise, MTR procurement should also be coordinated.

Therefore, to implement project and operational production of CNIPP, a concept is proposed, which includes the following steps:

1. Project and operational production processes should not be separated, but considered as a single integrated production system within the enterprise project management.

2. Establish criteria for determining the number of components to be manufactured once in operational processes.

3. Establish criteria for assessing the success of projects and the effectiveness of project provision with components.

4. Perform simulation of scenarios of project implementation and production of project components.

5 From the simulated models, choose the scenario for implementing operational and project processes that meets the accepted criteria.

To implement this concept, it is necessary to:

1. Build a schedule network diagram for CNIPP production, taking into account the project priorities and the relationship of assembly activities.

2. Determine the time of manufacture of CNIPP components for the developed schedule network diagram. The complexity of this issue is that the equipment for manufacturing components can also be used for manufacturing other components. Therefore, it is necessary to manufacture components before they are used to assemble many CNIPPs but not at the time of CNIPP assembly.

3. Determine the number of components to be manufactured at each time. It is necessary to produce an optimal number of components in terms of the ratio of storage cost, the cost of premature investments and the cost of reconfiguring equipment for the production of components.

To solve these problems, a method of coordination of project and operational processes of manufacturing complex knowledge-intensive products (shipbuilding, wind farms, geophysical equipment, etc.) is proposed.

Conceptually, this method is based on the transition in planning from the concept of "activity" to the concept of "activity product" (operational or project) reflecting the hierarchical organization of complex products in the structure of the network model. It is necessary to make appropriate changes to the categories, principles and methods of planning and consider the processes of manufacturing components as part of the project plan.

There is one problem with this case. When thousands of components for complex knowledge-intensive products are manufactured at different stages and at different enterprises, it is almost impossible to optimize resource allocation. Therefore, the method is based on the principle of accumulating information in the process of repeated simulation of the production process, followed by assessing the effectiveness of these decisions based on the project results (terms of manufacturing complex knowledge-intensive products). And this repeated simulation will train the decision-making model to choose components for manufacture at each time.

5. 2. Integrated method of project and operations management of project-oriented enterprises

To implement this concept, a method of integrating project and operations management processes in manufacturing complex knowledge-intensive products is proposed, which allows considering the enterprise as a single integrated production system within project management. From the standpoint of management, such a holistic production system within project management consolidates, on the one hand, the processes of project portfolio management and on the other hand, the processes of operational production management, which provides portfolio projects with material and technical resources. Based on the need for such implementation of portfolio projects, in which the implementation of each project "does not interfere" with other projects and is fully provided with components produced in the framework of operational activities, it is proposed to consolidate:

– the criterion for determining the number of products at each stage of the project; project efficiency criterion;

– the model for calculating the number of components to be manufactured during the implementation of CNIPP projects;

– the method of multiple modeling of project and operational processes in projects for manufacturing complex knowledge-intensive products.

Using these criteria in the proposed model and method will make it possible to:

a) identify the most priority portfolio projects that require priority provision with components;

b) build the production program of the enterprise "for projects";

c) guarantee the availability of components by the time of their planned use in portfolio projects.

The model for calculating the number of components to be manufactured during the implementation of CNIPP projects involves the calculation of production and storage costs of components, as well as the cost of financial resources. Production costs include MTR costs, labor costs, equipment costs, costs of reconfiguring equipment from one product to another and storage costs. The model also takes into account the cost of the financial resources invested in components that will not be used immediately after manufacture. This model is represented by the following formula:

$$\forall D_j \in P_3^n : S(D_j) = \sum_{i=1}^{m} \left(K_i(D_j) \cdot Z_i(D_j) + V^O(D_j) \right) +$$
$$+ \sum_{r=1}^{m} \left[\left(\sum_{i=1}^{r} \left(K_i(D_j) - L_i(D_j) \right) \right) \times \atop \times \left(t_{(r+1)}(D_j) - t_r(D_j) \right) \cdot Z_s(D_j) \right] +$$
$$+ \sum_{r=1}^{m} \left[\left(\sum_{i=1}^{r} \left(\left(K_i(D_j) - L_i(D_j) \right) \times \atop \times Z_i(D_j) + V^0(D_j) \right) \right) \cdot \alpha(t_r, t_{r+1}) \right], \quad (1)$$

where D_j – part j, where $j = \overline{1,d}$ (d – the number of parts);

P_3^n – the product assembled in the project Π_n;

$S(D_j)$ – the cost of manufacturing the part D_j;

$K_i(D_j)$ – the number of minimum sets of the part D_j to be manufactured at time t_i;

$Zi(D_j)$ – the cost of manufacturing the minimum set of the part D_j at time t_i;

$V^O(D_j)$ – the cost of reconfiguring equipment for manufacturing the part D_j;

$L_i(D_j)$ – the number of used minimum sets of parts D_j at time t_i;

$t_r(D_j)$ – the time the part D_j is manufactured or used;

$Z_s(D_j)$ – the cost of storing the part D_j in the warehouse per unit time;

$\alpha(t_r, t_{(r+1)})$ – the change in the reduced value of the cost unit over time $t_{(r+1)} - t_r$;

M – the number of manufacturing cycles of the part D_j.

The number of parts to be manufactured each time as needed is determined by minimizing expression (1)

$$\sum_{D_j \in P_3^n} S(D_j) \to \min, \quad (2)$$

under the constraint:

$$\forall r \le m, \forall D_j : \sum_{i=1}^{r} \left(K_i(D_j) - L_i(D_j) \right) \ge 0.$$

This means that at any given time, the number of manufactured parts must be at least as needed.

Thus, according to item 2 of the concept, the criterion for determining the number of components to be produced once in operational processes is the cost of manufacturing parts (1).

As a criterion for the success of portfolio projects, a penalty function is proposed, determined by the deviation of the actual deadlines from the directive deadlines of projects:

$$\beta = \sum_{(m=1)}^{M} \pi_m \cdot \left(l_m^{act} - l_m^{dir} \right), \quad (3)$$

where β – project penalty;

π_m – priority of the project Π_m;

l_m^{dir} – directive deadline for the project Π_m;

l_m^{act} – actual deadline for the project Π_m;

M – number of projects.

The problem of minimizing the cost of manufacturing parts (2) is solved by a simple search using modern computers and software, including Mathcad (PTS, USA). This is due to the fact that although there are many names of parts, their use is discrete with a small number of time points.

However, creating a model of the whole production, taking into account the manufacture of components, units and assembly of CNIPP in many portfolio projects is a difficult task. To solve it, a method of multiple modeling of project and operational processes in project portfolios for manufacturing complex knowledge-intensive products is proposed. It is based on a product planning method with multiple simulations of the order of manufacturing components for different portfolio projects.

Input information for the method is the consideration of the project portfolio as a set of processes of assembling complex knowledge-intensive products (project activities) and manufacturing components (operational activities). All the processes of manufacturing components described in the methods are implemented in parallel. The number of parallel processes depends on the availability of labor resources and necessary equipment (e.g. milling machines). Projects of assembling complex knowledge-intensive products are also implemented in parallel. The number of simultaneous projects often depends on the availability of space for such products.

The method consists of the following steps:

1. Preparation for simulation.

1. 1. Formation of the design-engineering schedule of CNIPP production (assembly).

1. 2. On the basis of the design-engineering schedule, formation of the schedule network diagram of CNIPP assembly for each portfolio project, including components (aggregates, assemblies, parts) as resources.

1. 3. Formation of the schedule network diagram for manufacturing units, including components (assemblies and parts) as resources.

1. 4. Formation of the schedule network diagram for manufacturing assemblies, including parts and material and technical resources (MTR) as resources.

1. 5. Development of the product model of CNIPP production on the basis of schedule network diagrams of CNIPP assembly in each portfolio project and schedules for manufacturing aggregates and assemblies (Fig. 1). The product model is a model of manufacturing aggregates, assemblies and parts integrated into the schedule network diagrams of assembling CNIPP of portfolio projects. Fig. 1 shows a fragment of the product model of CNIPP manufacture. In general, not only aggregates are used in the manufacture of project products, but also assemblies, parts and MTR. As well as parts and MTR are used in the manufacture of aggregates.

2. Simulation.

2. 1. Start of calculation of the model n.

2. 2 Selection of activities of the schedule network diagram of portfolio projects for which the conditions for execution are met (completed or missing predecessor activities). Formation of a set of activities ready for execution – P_1^n.

2. 3. If the set is empty, then go to item 3. 2.

2. 4. Selection of activities from the set P_1^n for which all MTR and components $P_2^n P_1^n$. are available.

2. 5. If $P_2^n \neq \varnothing$, then calculate the duration of execution and loading of labor resources for each activity included in P_2^n.

2. 6. If $P_2^n = P_1^n$, then go to item 2. 2.

2. 7. Selection of aggregates, assemblies, parts required for work included in the set P_1^n, but not included in the set P_2^n. Including them in the set P_3^n.

2. 8. Selection of assemblies and parts required for aggregates included in the set P_3^n. Including them in the set P_3^n.

2. 9. Selection of parts required for assemblies included in the set P_3^n. Including them in the set P_3^n.

2. 10. Exclusion of aggregates, assemblies and parts available in the warehouse from the set P_3^n.

2. 11. Calculation of priorities of parts relative to closing the resource pool, which is not enough for manufacturing assemblies and aggregates:

$$\forall D_j \in P_3^n : \pi^D\left(D_j\right) = \frac{\sum_i K\left(D_j / N_i\right)}{\sum_l \sum_i K\left(D_l / N_i\right)}, \quad (4)$$

where D_j – part;

P_3^n – the set of non-manufactured parts, assemblies, aggregates in the model n;

$\pi^D(D_j)$ – the priority of the part D_j relative to closing the resource pool;

$K(D_j/N_i)$ – the number of parts required for the assembly N_i;

$\sum_l \sum_i K\left(D_l / N_i\right)$ – the overall number of parts D_j required for the project N_i.

2. 12. Normalization of priorities of parts relative to closing the resource pool (4):

$$\forall D_j \in P_3^n : \overline{\pi^D\left(D_j\right)} = \frac{\pi^D\left(D_j\right)}{\sum_l \pi^D\left(D_j\right)}, \quad (5)$$

where $\overline{\pi^D\left(D_j\right)}$ – normalized priority of the part D_j relative to closing the resource pool.

2. 13. Calculation of the priority of parts based on the priority of project activities they are required for:

$$\forall D_j \in P_3^n : \pi^R\left(D_j\right) = \frac{\sum_i K_i\left(D_j / R_i\right) \cdot \pi\left(R_i\right)}{\sum_l \sum_i K_i\left(D_l / R_i\right)}, \quad (6)$$

where $\pi(R_i)$ – the priority of the activity R_i;

$K(D_j/R_i)$ – the number of parts required for the activity R_i;

$\pi^R(D_j)$ – the priority of the part D_j corresponding to the priority of the activity.

2. 14. Normalization of priorities of parts based on the priority of project activities (6):

$$\forall D_j \in P_3^n : \pi^R\left(D_j\right) = \frac{\sum_i K_i\left(D_j / R_i\right) \cdot \pi\left(R_i\right)}{\sum_l \sum_i K_i\left(D_l / R_i\right)}, \quad (7)$$

where $\pi^R(D_j)$ – normalized priority of the part D_j based on the priority of project activities.

2. 15. Calculation of the priority of parts based on decisions made in previous models and their results:

$$a_n\left(D_j / D_i\right) = \frac{\beta_n\left(D_i / D_j\right)}{\beta_n\left(D_j / D_i\right) + \beta_n\left(D_i / D_j\right)}, \quad (8)$$

where $\alpha(D_j/D_i)$ – priority factor of choosing the part D_j for manufacture, compared to choosing the part D_i;

$\beta_n(D_j/D_i)$ – penalty on previous models in which the set P_3^n had parts D_j and D_i, but the part D_j was chosen for manufacture, not the part D_i;

$\beta_n(D_i/D_j)$ – penalty on previous models in which the set P_3^n had parts D_j and D_i, but the part D_i was chosen for manufacture, not the part D_j.

From formula (8), $\alpha_n\left(D_j / D_i\right) + \alpha_n\left(D_i / D_j\right) = 1.$

The penalty of the models, according to (3), is calculated as the sum of the product of the project priority and the difference between the directive deadlines for project completion and the deadlines obtained in the model:

$$\beta_w = \sum_{m=1}^{M} \pi_m \cdot \left(l_m^o - l_m^w\right), \quad (9)$$

where β_w – penalty of the model w;

l_m^o – directive deadline for completion of the project Π_m;

l_m^w – deadline for completion of the project Π_m in the model w;

M – number of projects.

From (9)

$$\beta_w = \sum_{m=1}^{M} \pi_m \cdot \left(l_m^o - l_m^w\right), \quad (10)$$

where w=1,...,n–1 – model number;

t_w (D_i) – the moment of manufacture of the part D_i in the model w;

t_w (D_j) – the moment of manufacture of the part D_j in the model w.

The priority of the part based on decisions made in previous models (and their results) (8) is calculated by the following formula:

$$\forall D_j \in P_3^n : \pi^V\left(D_j\right) = \frac{\sum_i a_n\left(D_j / D_i\right)}{L}, \quad (11)$$

where $\pi^V(D_j)$ – the priority of the part D_j based on decisions made in previous models and their results;

L – the number of parts that meet the manufacturing condition in previous models $D_j \in P_3^w,\ D_i \in P_3^w,\ t_w\left(D_i\right) > t_w\left(D_j\right)$.

2. 16. Normalization of the priorities of parts based on decisions made in previous models and their results (11):

$$\forall D_j \in P_3^n : \overline{\pi^v\left(D_j\right)} = \frac{\pi^v\left(D_j\right)}{\sum_l \pi^v\left(D_l\right)}, \quad (12)$$

where $\pi^v(D_j)$ – normalized priority of the part D_j based on decisions made in previous models and their results.

The probability of choosing a part is calculated by (5), (7) and (12):

$$\forall D_j \in P_3^n : p\left(D_j\right) = \frac{\overline{\pi^D\left(D_j\right) + \pi^R\left(D_j\right) + \pi^V\left(D_j\right)}}{3}, \quad (13)$$

where $p(D_j)$ – the probability of choosing the part D_j.

2. 17. If the set P_3^n is empty, then go to item 2. 2.

2. 18. Random selection of a part for manufacture according to the calculated probabilities.

2. 19. Determining the required number of parts according to the solution of the minimization problem (2).

2. 20. If there are no resources for manufacturing the part D_j, then exclude it from the set P_3^n and go to item 2. 17.

2. 21. Exclusion of the selected part from the set P_3^n. Putting it to the "available" state. Exclusion of all resources required for manufacturing the part from the resource pool.

2. 22. Exclusion of assemblies from the set P_3^n for which all parts are available (including the one selected for manufacture). Putting them in the "available" state.

2. 23. Exclusion of aggregates from the set P_3^n for which all components and parts are available (including those excluded from the set P_3^n). Putting them in the "available" state.

2. 24. Go to item 2. 17.

3. Processing the results of modeling production processes.

3. 1. Comparison of the results of portfolio projects execution in the current model with previous ones. If the model penalty is less than the previous ones, include it in the pool of project implementation scenarios offered for implementation at the enterprise.

3. 2. If the result does not meet the management requirements, increase the model number

n=n+1.

Go to item 2. 1.

3. 3. Simulation completion.

The method allows considering not individual portfolio projects, but all projects at once. It also allows finding the necessary solution (3) due to a long search through different implementation scenarios for both operational and project processes. The method takes into account project priorities. In fact, the method implements portfolio management at enterprises engaged in manufacturing complex knowledge-intensive products.

Based on the proposed method, the NadPlan information system for project portfolio management was developed and implemented at the Karbon Invest company [18]. The main result of implementing the method of coordination of project and operational activities in the process of manufacturing complex knowledge-intensive products at Karbon Invest was an increase in the efficiency of aircraft manufacturing with a constant amount of labor resources. Each aircraft was considered as a separate project, and all aircraft produced simultaneously at the company formed a project portfolio. But in addition to aircraft production, the portfolio included other simpler projects, such as aircraft repairs, making matrix sets, production certification, etc.

All projects were conducted in the NadPlan system (Ukraine). A study of the effectiveness of using NadPlan in managing an aircraft manufacturing project portfolio was conducted. At the time of the study, the portfolio contained 12 projects (Table 1).

In addition to those listed in Table 1, the portfolio included 8 projects related to the repair and modernization of previously manufactured aircraft. In total, the projects included 1201 activities on assembling aircraft components and the aircraft themselves. The total number of different components was 1965. Labor costs for project activities ranged from 1 to 1,116 hours. The number of products per aircraft reached 1,772 (rivet 3.2×6 DIN7337). Clearly, in these conditions it was very important to calculate the number of manufactured parts, taking into account all the projects in the portfolio, as well as using the forecast of new projects. Therefore, the use of the developed method for planning the manufacture of parts and assembly of the aircraft with available labor resources was of great importance.

The fragment of the detailed task for enterprise divisions obtained in the simulation process, which meets the needs of the project portfolio and takes into account project priorities, is shown in Fig. 2.

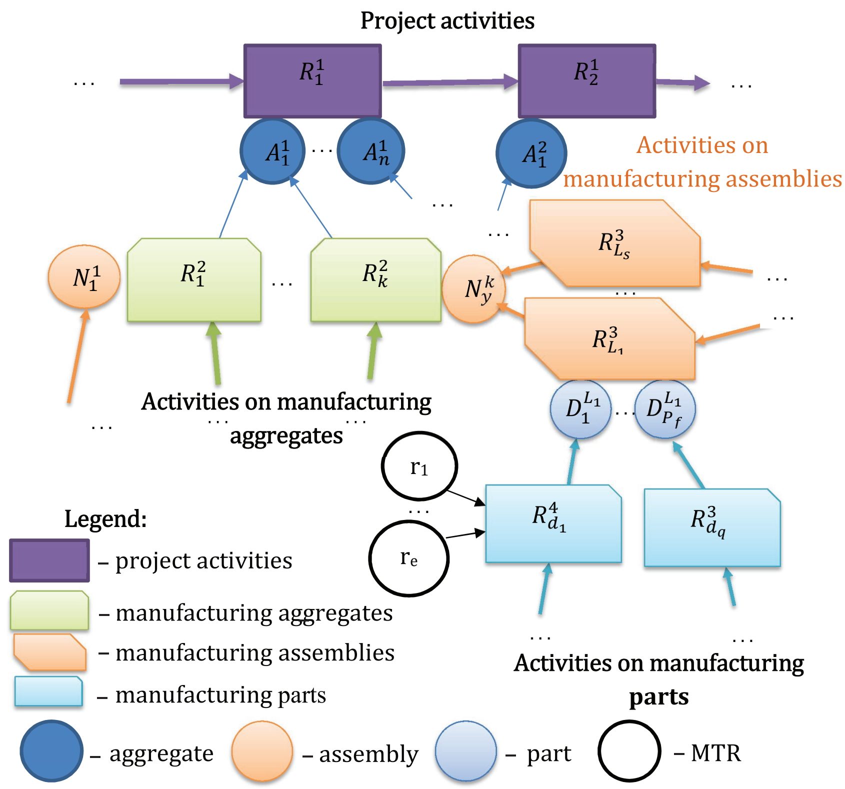


Fig. 1. Fragment of the product model of CNIPP production

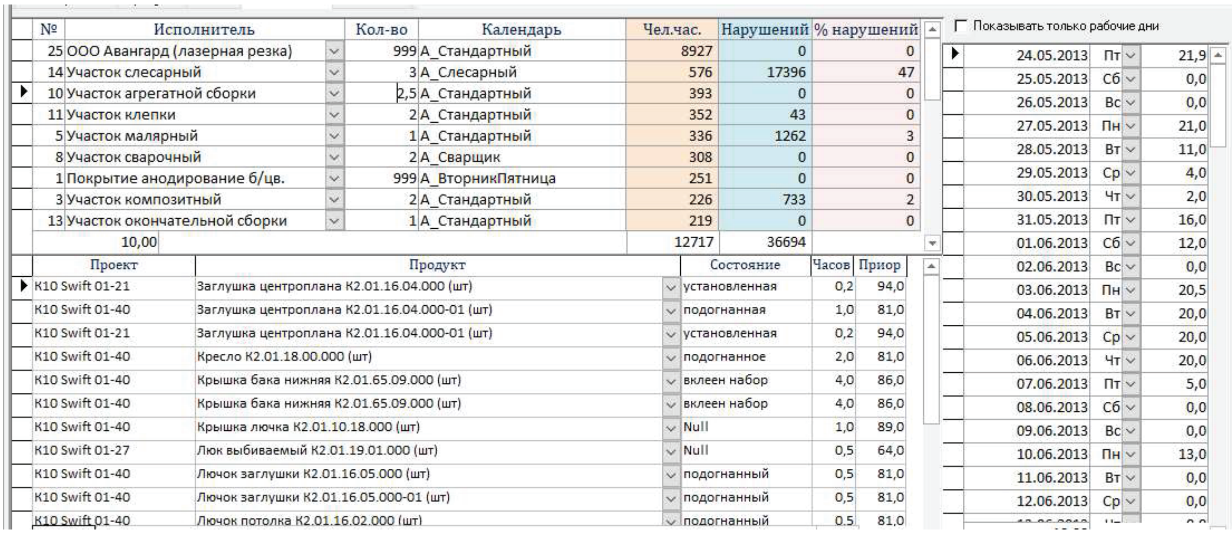
Based on current information on the actual production process, the number of products manufactured without reconfiguring equipment reached 15.5 % (485 out of 3,133), which reduced the aircraft manufacture time by 13.8 %.

The proposed method can be used not only in aircraft construction. Since the process of manufacturing complex knowledge-intensive piece products is the same: project=product, MTR=components, only the stage of simulation preparation is implemented differently in the proposed method. As the project documentation presents various manufacturing technologies, the following project portfolios will be compiled: for shipbuilding – shipbuilding projects, for enterprises producing power plants – projects for manufacturing wind farms, nuclear reactors, etc.

Table 1

Karbon Invest project portfolio

No.	Project type	Project name	Start	Finish	Project priority
1	Operational	K10 Swift 01-20	15.01.2012	–	800
2	Operational	K10 Swift 01-24	21.02.2012	–	1
3	Investment	K10 Swift 01-21	30.04.2012	–	900
4	Operational	K10 Swift 01-18 Iran	12.03.2012	12.03.2012	1
5	Operational	K10 Swift 01-19 Iran	12.03.2012	12.03.2012	1
6	Operational	USA K10-0104	30.03.2012	30.04.2012	200
7	Operational	K10 Swift 01-23	22.05.2012	–	900
8	Operational	K10 Swift 01-25	25.04.2012	–	1
9	Operational	K10 Swift 02-07	16.07.2012	–	900
10	Operational	K10 Swift 01-21	01.10.2012	–	400
11	Operational	K10 Swift 01-40	–	–	800
12	Operational	K10 Swift 01-27	–	–	600



№	Исполнитель	Кол-во	Календарь	Чел.час.	Нарушений	% нарушений
25	ООО Авангард (лазерная резка)	999	А_Стандартный	8927	0	0
14	Участок слесарный	3	А_Слесарный	576	17396	47
10	Участок агрегатной сборки	2,5	А_Стандартный	393	0	0
11	Участок клепки	2	А_Стандартный	352	43	0
5	Участок малярный	1	А_Стандартный	336	1262	3
8	Участок сварочный	2	А_Сварщик	308	0	0
1	Покрытие анодирование б/цв.	999	А_ВторникПятница	251	0	0
3	Участок композитный	2	А_Стандартный	226	733	2
13	Участок окончательной сборки	1	А_Стандартный	219	0	0
	10,00			12717	36694	

Проект	Продукт	Состояние	Часов	Приор
К10 Swift 01-21	Заглушка центроплана К2.01.16.04.000 (шт)	установленная	0,2	94,0
К10 Swift 01-40	Заглушка центроплана К2.01.16.04.000-01 (шт)	подогнанная	1,0	81,0
К10 Swift 01-21	Заглушка центроплана К2.01.16.04.000-01 (шт)	установленная	0,2	94,0
К10 Swift 01-40	Кресло К2.01.18.00.000 (шт)	подогнанное	2,0	81,0
К10 Swift 01-40	Крышка бака нижняя К2.01.65.09.000 (шт)	вклеен набор	4,0	86,0
К10 Swift 01-40	Крышка бака нижняя К2.01.65.09.000 (шт)	вклеен набор	4,0	86,0
К10 Swift 01-40	Крышка лючка К2.01.10.18.000 (шт)	Null	1,0	89,0
К10 Swift 01-27	Люк выбиваемый К2.01.19.01.000 (шт)	Null	0,5	64,0
К10 Swift 01-40	Лючок заглушки К2.01.16.05.000 (шт)	подогнанный	0,5	81,0
К10 Swift 01-40	Лючок заглушки К2.01.16.05.000-01 (шт)	подогнанный	0,5	81,0
К10 Swift 01-40	Лючок потолка К2.01.16.02.000 (шт)	подогнанный	0,5	81,0

Показывать только рабочие дни

24.05.2013	Пт	21,9
25.05.2013	Сб	0,0
26.05.2013	Вс	0,0
27.05.2013	Пн	21,0
28.05.2013	Вт	11,0
29.05.2013	Ср	4,0
30.05.2013	Чт	2,0
31.05.2013	Пт	16,0
01.06.2013	Сб	12,0
02.06.2013	Вс	0,0
03.06.2013	Пн	20,5
04.06.2013	Вт	20,0
05.06.2013	Ср	20,0
06.06.2013	Чт	20,0
07.06.2013	Пт	5,0
08.06.2013	Сб	0,0
09.06.2013	Вс	0,0
10.06.2013	Пн	13,0
11.06.2013	Вт	0,0
12.06.2013	Ср	0,0

Fig. 2. Fragment of the detailed task for enterprise divisions obtained during simulation in the NadPlan system

This is confirmed by the fact that this method was implemented in Tutkovsky Project Management, LLC (Ukraine). The company produces complex geophysical instruments. The duration of manufacturing such devices reached 8–9 months. The following results of implementing the NadPlan system at Tutkovsky Project Management, LLC were obtained:

1. Planning time and cost of manufacturing new geophysical instruments have been reduced.
2. Modeling of annual production plan scenarios decreased by 10–15 %.
3. The accuracy of project portfolio modeling has increased (before the implementation of the methodology and NadPlan, errors led to delays in directive dates by almost a year).
4. The load of the main project staff was leveled.

These results unequivocally testify to the effectiveness of the developed concept and method of integration of project and operational activities in a single production system of complex knowledge-intensive piece products.

6. Discussion of the results of developing a method of coordination of project and operational activities in the process of manufacturing complex knowledge-intensive products

The results obtained are a consequence of changing the concept of planning the activities of project-oriented enterprises manufacturing complex knowledge-intensive piece products. In the concept, instead of separating the project (basic) and operational (supporting) processes, they are integrated into a single management system of project and operational activities of such enterprises. This requires new methods of planning project and operational activities, methods of coordinating the processes of assembling products with the processes of manufacturing various components for them.

Based on the proposed concept, a method of coordination of project and operational activities in the process of manufacturing complex knowledge-intensive products was developed, which includes the concept and an integrated method of project and operations management of project-oriented enterprises. Unlike traditional methods of planning operational activities, when production is determined by the market conditions of the enterprise, this method is based on an integrative approach to coordinating project and operational activities. On this basis, a schedule of manufacturing a project product through a product model for the formation of complex knowledge-intensive piece products is formed. An illustration of such a schedule is shown in Fig. 1. The difference between the proposed method and the traditional ones is a combination of project and operations management based on criteria for assessing the effectiveness of project-operational activities ((1)–(3)).

The limitations inherent in this study are related to the type of enterprises that can apply the developed concept and method, because for enterprises with serial products, even knowledge-intensive, the use of these tools is redundant. In addition, to calculate CNIPP production plans, accurate information is needed about the costs of both the production and storage of products at all stages of the life cycle of manufacturing complex knowledge-intensive piece products. This is not only a limitation, but also a disadvantage of this work.

Another drawback of the study is that the project portfolio of an enterprise producing complex knowledge-intensive products is usually open. Projects appear constantly, which will require recalculation of the entire model of project and operational production.

Despite the fact that the issue of project-oriented enterprises is sufficiently studied, the very specifics of manufacturing complex knowledge-intensive piece products require the search for new forms and methods of project management. This problem is largely solved in this study. On the other hand, this formulation of the problem is not entirely complete in terms of developing the project management methodology. Thus, the problem of supplementing the meta-methodology of project management with tools for developing specific project management methodologies at enterprises producing complex knowledge-intensive piece products has not been solved [18, 19]. Although, as follows from the results of implementing the developed concept and method, the developed tools have successfully passed practical testing.

7. Conclusions

1. The analysis of project management methodologies in terms of integration of project and operational activi-

ties in knowledge-intensive industries was conducted. It was found that project management methodologies usually do not address the issue of resource provision of projects in operational activities, remaining outside the scope of project managers. To eliminate this shortcoming, it is proposed to develop a method of coordination of project and operational activities, which will underlie a system of creating complex knowledge-intensive products. The conceptual and logical basis of this method was developed in the form of the concept of integration of project and operational activities in knowledge-intensive industries, which includes 5 main guidelines:

– not to divide production processes into project and operational, but consider them as a single integrated production system within the project management of the enterprise;

– to determine criteria for managing operational processes, which depend on the progress of projects;

– to determine criteria for assessing the success of projects and the effectiveness of their provision with products of operational activities;

– in the framework of modeling project implementation scenarios and manufacturing project components, to find a scenario of implementation of operational and project processes that meets the accepted criteria.

It is shown that the developed concept integrates system, project and process approaches to solve the problems of integrated management of project and operational production of complex knowledge-intensive piece products.

2. An integrated method of project and operations management of project-oriented enterprises is proposed, which contains:

– the criterion for managing operational processes, as processes dependent on the progress of projects;

– the criterion for assessing the success of projects, taking into account the assessment of the effectiveness of their provision with products of operational activities;

– the model for calculating the number of components to be manufactured during the implementation of CNIPP manufacturing projects;

– the method of multiple modeling of project and operational processes in projects of manufacturing complex knowledge-intensive products.

The developed method, as part of modeling project implementation scenarios and manufacturing project components, allows finding a scenario of implementation of operational and project processes that meets the accepted criteria. It passed practical testing at a number of domestic enterprises. The NadPlan software has been developed, which adds tables containing information on operational activities to the MS Project information base, integrates these databases and uses them to model scenarios of manufacturing complex knowledge-intensive piece products. This approach, first of all, corresponds to the concept given in the paper and implements the method of coordination of project and operational activities in the process of manufacturing complex knowledge-intensive products. In addition, it allowed solving project planning problems on the basis of a single information environment, as well as managing the distribution of orders by the enterprise's production facilities. This made it possible, in particular, in the framework of aircraft manufacturing projects, to reduce the aircraft manufacturing time by 13.8 %. And in the production of new geophysical instruments, reduce the planning time and cost by 10–15 %.

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