Simulation of projects for creation of aircraft products for use in life cycle management systems

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Abstract. The article describes the elements of modeling projects to create complex technical objects in the framework of the sociophysical approach. It is shown that the proposed approach has an advantage in comparison with the approach focused on assessing the present value of the project. It is noted that the application of the sociophysical approach opens the way to solving the problems of finding reliable interpretable solutions at all stages of the life cycle of an innovative project. A feature of the sociophysical approach associated with the use of diverse economic, technical, technological, and other information are formalized. The terminology used in the sociophysical modeling of projects is given. The concepts of cooperation between the project and the enterprise are formed within the framework of sociophysical modeling. The structure of the sociophysical models of the project is disclosed. The sociophysical definition of the technological structure of the enterprise where an innovation project realizes is given. Results confirming the efficiency of using the accumulated potentials are presented.

1. Introduction

A model for assessing the current cost of a project of the life cycle of a complex technical product is presented. An aircraft engine is considered as an example. The project model uses information about the costs of an enterprise that has previously implemented similar projects. The difference between the proposed model and the current valuation models is that it does not require forecasting the revenues and costs of the project [1]. Forecasting for long periods of time always contains many uncertainties. The problem becomes apparent when one considers that forecasting is required for periods of several decades. For example, the life cycle of an aircraft engine reaches 50 years. Therefore, it is necessary to predict the design characteristics for 50 years. It is necessary to take into account that the project of creating a new generation aircraft engine requires the creation of technologies that are not available at the time of the start of the project. Predicting design performance is further complicated. As a rule, large errors in assessing the current cost of a project to create a new generation aircraft engine are observed.

An aircraft engine project is being developed within the framework of an existing enterprise or group of enterprises. In this formulation, the creation of new technologies, interpreted in a broad sense, is understood as a historically conditioned process of quantitative and qualitative development of the enterprise's competencies [1]. For this reason, it is important to understand that the sociophysical description can be applied not only to the description of the project, but also to the
description of the enterprise. The article presents a sociophysical model of an enterprise implementing a project to create an aircraft engine. On a numerical example, the possibility of constructing a model describing the dynamics of an enterprise as a sociophysical object has been confirmed. It is shown that the model is sufficiently adequate for long periods of time.

The work [2] describes a sociophysical approach to the description of complex technical objects. The implementation of the project within the framework of the interpretation of the sociophysical approach proposed by the authors is considered as a conditional movement in the sociophysical space of a sociophysical object, in the role of which the projected engine acts. The project variables form the sociophysical space. The size of the space is equal to the number of design variables. A certain trajectory in sociophysical space corresponds to a certain design of an aircraft engine. Projects with different characteristics take different paths. The project model is reduced to describing the movement of an object along a calculated trajectory in a sociophysical space. Thus, the model of the project for creating an aircraft engine is reduced to describing the motion of an aircraft engine, considered as a sociophysical object in a sociophysical space.

Decision-making on the management of an innovative project is based on the idea expressed by one of the authors that the project forms a property called sociophysical potential [3].

The idea of using action as a basis for a unified description of various aspects of the behavior of individuals, groups and organizations was substantiated in the works of T Parsons [4]. This became the basis for the development of sociophysical research in sociology. Econophysics is actively developing, within which physical relations are used to model economic processes [5]. However, the phenomenological approach used in this case to describe economic processes limits the possibility of explaining economic mechanisms [6, 7].

Sociophysical modeling focuses on the study of the sociophysical potential of the project. In the framework of sociophysical modeling, the sociophysical potential of a project is understood as a historically conditioned property of a project that reflects its holistic complex nature. The sociophysical potential of the project is formed in the process of project implementation. The magnitude and structure of the potential is determined and consistent with both the properties of the projected object and the various characteristics of the enterprise where the project is being implemented.

Sociophysical potential is numerically estimated through a variety of quantities, each of which represents the accumulated sociophysical potential of the project asset. Thus, the accumulated sociophysical potential of each project asset is a numerical assessment of one of the aspects of the project's sociophysical potential.

It can be noted that the accumulated potential can be interpreted from an economic point of view as the value of a historically formed asset. The assets of the enterprise, as well as the assets of the project, have their own accumulated potential. An enterprise, from the standpoint of sociophysical modeling, is considered as a complex system that includes various subsystems: technical, organizational, technological, social, economic and informational. Each subsystem has its own accumulated potential. The project can also be considered as a complex system that includes the following design subsystems: technical, organizational, technological, social, economic, information. The accumulated sociophysical potentials of the project are part of the accumulated sociophysical potentials of the enterprise. Economic potential characterizes the economic aspect of sociophysical potential; technical potential reflects the technical aspect of sociophysical potential, etc. [7].

The project has a socio-physical potential at the initial moment of time until it is accepted for execution, that is, until the moment of approval. The magnitude of the potential is not less than the sum of the sociophysical potentials of a person or a group of people that form the appearance of the project. The sociophysical potential of the project does not change abruptly at the initial moment of time, immediately after the project is accepted for execution. The sociophysical potential of the project changes with the implementation of project activities. The change in the project potential affects the change in the enterprise potential. Upon completion of the project, its sociophysical potential does not disappear but remains within the potential of the enterprise where it is implemented.
Some sociophysical potentials are components of other potentials. Sociophysical potentials of organizational units are components of the sociophysical potential of an enterprise; the sociophysical potential of the project is also an element of the sociophysical potential of the enterprise if the enterprise is considered as an organizational structure on which the project is carried out. On the other hand, the potential of the project is made up of the potentials of the organizational units of the enterprise involved in the implementation of the project.

From the point of view of modeling, this means that the accumulated sociophysical potentials of the project organizational unit are part of the accumulated sociophysical potential of the enterprise. The mathematical model of an enterprise as a sociophysical object is the set of the accumulated sociophysical potentials of enterprise organizational units. The mathematical model of the project as a sociophysical object is the set of accumulated sociophysical potentials of the project organizational units. The dynamics of the economic component of sociophysical potential is interpreted as an economic model of the behavior of a sociophysical object. Thus, the economic behavior of an enterprise is characterized by the dynamics of changes in the economic component of the sociophysical potential of the enterprise. Accordingly, the economic behavior of the project is characterized by the dynamics of changes in the economic component of the sociophysical potential of the project.

The aim of the article is devoted to the presentation of the elements of the apparatus, the modeling of the project based on the accumulated sociophysical potentials.

2. Methodology

The scattered scientific and technical potential is being actively consolidated as part of the development of the aircraft engine industry. This makes it possible to reduce duplication of developments, lifecycle management systems for aircraft engines of a new generation to introduce. New methods of organizing production are introduced. New technological processes are being created; the infrastructure of aircraft engine building is being reformed within the framework of the projects for creating a new generation of aircraft engines [8].

Approaches to assessing the potentials of physical objects have well studied. But it can be stated that the existing approaches to assessing the potentials of an innovative project are not formalized as an area of knowledge. There is no unified concept for determining the potentials of innovative projects and, accordingly, there is no methodological approach to manage them. There is no idea how the development of an innovative project is related to the dynamics of the enterprise's potentials. There is no understanding of the feasibility of developing an innovative project with limited potential. There are no criteria for assessing the potentials of innovative projects. Financial indicators prevail as the main indicators for evaluating project activities. Insufficient attention is paid to other equally important criteria that cannot always be quantified. These include the criteria of market prospects, the availability of scientific and technical groundwork. The complexity, low accuracy, and incomparability of the criteria are significant drawbacks of the known methods for evaluating innovative projects. The principles of a comprehensive assessment of qualitative and quantitative parameters are internally contradictory. The indicators used at different stages of the aircraft engine life cycle are not related to each other. The indicators used are either too numerous and have a correlation dependence, or do not reflect the real state of the enterprise, since they are not informative enough. There are many other unresolved issues.

The introduction of a complex parameter that integrates various factors minimizes the risk of making an incorrect decision on project implementation.

Potential as a characteristic of an innovative project should include a set of potentials that detail it. For example, the implementation of a project to create a new generation engine at an aircraft engine-building enterprise, as a rule, involves an increase in the strategic, scientific, technical, technological, and other potentials of the enterprise. Conversely, it should be clear to what extent these potentials affect the overall potential of an enterprise implementing an innovative project. Estimates should
reflect various aspects of the enterprise and project. It should be clear how the assessment of the potential of the enterprise correlates with the main factors for the success of an innovative project.

The concept of potential is interpreted in different ways in different economic sources. For example, the business potential of an innovation project is defined as a complex multifactorial, quantitative and qualitative characteristic of the state of the key parameters of an innovation project, reflecting the degree of its attractiveness for financing by a venture capitalist [9]. In another work, business potential is considered as a multifactorial characteristic of the possibilities of implementing an innovative project and identifying its weaknesses [10]. The concept of enterprise potential is widely used, various potential structures, calculation methods are given. However, studies are usually qualitative in nature and do not indicate the relationship between the potentials of the project and the enterprise where the project is being implemented. The work [11] formalizes the technological, market, financial and personnel components of the enterprise potential. In [12], this list is replenished with production, resource, economic, intellectual, innovative, technical, scientific and technical, investment, social, managerial and marketing potential. In [10], a project potential structure is proposed that differs from the enterprise potential structure. The strategic, technical, market, production, technological, economic, investment, innovation, personnel, managerial, informational, infrastructural and logistic potential of the project are highlighted.

A number of authors [13] offer step-by-step methods for assessing project potentials, involving the use of methods for analyzing hierarchies [14] and multi-criteria optimization [15]. As a rule, the methods of additive and multiplicative convolution are used. The final assessment of the potential presents a linear combination of individual potentials with weighting factors. Weights are assigned by experts. The resulting assessment has a high degree of subjectivity. This significantly devalues the results.

An expert assessment does not allow us to determine which of the considered potentials has the greatest influence on the value of the potential of an innovative project. The lack of a scale of potentials of innovative projects makes it impossible to compare the potentials of different projects. The methods used do not take into account the specifics of the designed technically a complex product, as well as the enterprise implementing the project. This does not allow taking into account the influence of these factors on various aspects of the innovation project. One can say, that evaluation of the economic efficiency of projects [16,17] does not imply the use of the concept of potential. The same can be said in relation to risk assessment, in relation to the use of scenario analysis methods and other methods [18,19]. Based on the conducted and other works, it can be concluded that there are different approaches to determining the structure of the enterprise's potentials, but there is no generally accepted classification. The question of determining the structure of the potential of an innovative project is practically not touched upon. One can state the expediency of clarifying the conceptual and categorical apparatus of the integration potentials of innovative projects for creating a new generation of aircraft engines.

It is assumed that a project for creating a complex technical device is being developed within the framework of an existing enterprise or a group of enterprises for which such activities are not entirely unknown. In this formulation, the creation of new technologies is interpreted in a broad sense and understood as a historically conditioned process of quantitative and qualitative development of competencies associated with the object. The development of the project within the framework of the sociophysical approach proposed by the authors is considered as a movement in the sociophysical space of a sociophysical object, in the role of which the designed technical device acts [2,3,7]. Decision-making on the management of an innovative project is based on the idea of managing the sociophysical potential of the project. The size and structure of the potential correspond to the properties of the designed object. From the point of view of sociophysical modeling, the enterprise is considered as a set of systems that determine the sociophysical potential of the project. In turn, the sociophysical potential of the project affects the sociophysical potential of the enterprise. Each system of an enterprise and a project participates in the formation of one or another aspect of sociophysical potential: the technical subsystem forms the technical aspect of the sociophysical potential; the information subsystem forms the information aspect of the sociophysical potential, etc.
Until the moment of its acceptance for execution, the project has a sociophysical potential determined by the sociophysical potential of a person or a group of people who form the appearance of a future innovative project. At the time the project is accepted for implementation, its potential does not change dramatically. It changes with the implementation of project activities. Changing the potential of a project is an element of changing the potential of an enterprise. Upon completion of the project, its sociophysical potential does not disappear, but remains within the potential of the enterprise or group of enterprises where the project is being implemented. Therefore, in addition to the implementation of the project itself, one of the goals of innovative project activities may be the formation of the sociophysical potential of the enterprise where the project is being implemented. The possible failure of the project may nevertheless be accompanied by an increase in the sociophysical potential of the enterprise. On the contrary, the success of the project does not necessarily mean an increase in the sociophysical potential of the enterprise.

Some sociophysical potentials are integral parts of other potentials. It is possible to decompose the sociophysical potential of the enterprise in accordance with the organizational structure of the enterprise. The set of sociophysical potentials of various organizational elements accumulated by the time of analysis forms the mathematical model of the enterprise.

A common sociophysical space for all sociophysical objects one determines. From a sociophysical standpoint, the functioning of an enterprise is viewed as a movement in a sociophysical space. Movement is accompanied by a change in sociophysical potential. A sociophysical object that corresponds to the project moves in the sociophysical space also. The design processes are consistent with the movement of the project in the sociophysical space. The change in the economic component of the sociophysical potential is interpreted as a sociophysical model of the economic behavior of a sociophysical object. The economic component of sociophysical potential is a sociophysical model of the economic process associated with the object. Similarly, a change in the informational component of the sociophysical potential is interpreted as a sociophysical model of the informational behavior of a sociophysical object. The information component of the sociophysical potential is a sociophysical model of the information process, etc.

The basic principle of the formation of sociophysical potential is called the principle of maximum sociophysical action [7]. The principle of maximum action is applied to non-physical objects. With regard to the analysis of objects in the creation of which people take part, the principle of maximum sociophysical action is interpreted as the principle of rational behavior of these people. The maximum principle reflects the limited rationality of the behavior of the subjects that form the sociophysical potential of the object. Rationality is understood as the economic rationality of human behavior [20]. Irrationality in the behavior of the subject is considered as his reasonable behavior. Irrational from a third party's point of view is reasonable from a decision-maker's point of view. Therefore, the principle of maximum sociophysical action can be called the principle of intelligent behavior.

The state of a sociophysical object is described using a variety of state variables. Each state variable is associated with the accumulated potential. The accumulated potential is a numerical estimate of the corresponding aspect of the sociophysical potential of the object. The value of the accumulated potential of the state variable \( q \) is determined by the formula:

\[
x(q, t) = \int_{\tau=0}^{t} q(t - \tau) \psi(\tau) d\tau
\]

where, \( q(t) \) – is a state variable, the set of which characterizes an object; \( t \) – time; \( \tau \) – time parameter; \( \psi(\tau) \) – sociophysical function. From a mathematical point of view, the sociophysical function \( \psi(\tau) \) has the following properties: \( |\psi(t)| \to 0, \text{если } t \to \infty; \psi(t) = 0, \text{если } t < 0; ||\psi|| = 1 \). A lot of accumulated potentials form the sociophysical model of the object.

The economic interpretation of the accumulated potential \( X \) is as follows: the accumulated potential reflects the current assessment of the economic value of the historically formed asset. The asset is valued by the state variable \( q \). For other aspects – technical, social, etc. – the interpretation of the accumulated potential is determined in a similar way. For example, the accumulated information potential of an enterprise/project reflects the information value of historically formed assets of an enterprise/project.
The sociophysical function $\mu$ is a function that reflects the idea of a sociophysical object as an integrated sociophysical system. The sociophysical system includes the external environment. In particular, the external environment of the project as a sociophysical system is the enterprise. The economic interpretation of the sociophysical function is as follows. The sociophysical function reflects the bringing of a historically formed asset in time. Accounting for the past values of the asset indicates that the sociophysical function takes into account, perhaps implicitly, the individual characteristics of the object and the external environment. With regard to the project, the sociophysical function takes into account the reduction in time of the analyzed project asset. The sociophysical function of the project takes into account the historically formed various individual properties (technical, socio-economic, etc.) of both the enterprise where the project is being executed and the product being designed.

Many resource ($x_{rs}$) and resulting ($x_{rt}$) accumulated potentials can be determined in each case. For example, the accumulated potential of non-current assets and accumulated potential of revenue could be considered as one of the accumulated enterprise resource potentials:

$$x_{rs}^{\text{ent}} = \int_{t=0}^{t} q_{nc}(t - \tau) \psi(\tau) d\tau,$$

$$x_{rt}^{\text{ent}} = \int_{t=0}^{t} q_{r}(t - \tau) \psi(\tau) d\tau. \quad (2)$$

The accumulated potential of project equipment and the accumulated potential of the part of the proceeds owed to the project could be considered as one of the project resource potentials:

$$x_{rs}^{\text{pr}} = \int_{t=0}^{t} q_{eq}^{pr}(t - \tau) \psi(\tau) d\tau,$$

$$x_{rt}^{\text{pr}} = \int_{t=0}^{t} q_{r}^{pr}(t - \tau) \psi(\tau) d\tau. \quad (3)$$

where, $q_{nc}$, $q_{r}$, $q_{eq}^{pr}$, $q_{r}^{pr}$ are, respectively, non-current assets of the enterprise, revenue, cost of equipment used in the project, and part of the income, provided by the project.

The description of the project model begins with a model in the form of a connection between different potentials:

$$x_{rt}^{\text{pr}} = f(x_{rs}^{\text{pr}}), \quad f_{pr} = \frac{dx_{rt}^{\text{pr}}}{dx_{rs}^{\text{pr}}}. \quad (4)$$

The value of the function $f_{pr}$ characterizes the technological level of the project. The technological level of the enterprise is determined by the value of the function $f_{\text{ent}}$:

$$f_{\text{ent}} = \frac{dx_{rt}^{\text{ent}}}{dx_{rs}^{\text{ent}}}. \quad (5)$$

The use of sociophysical potentials for modeling an innovative project for creating a new generation aircraft engine involves formalizing the following interrelated categories:

- an innovative project to create a new generation aircraft engine; sociophysical potential of an innovative project to create a new generation aircraft engine;
- the accumulated sociophysical potential of an innovative project to create a new generation aircraft engine;
- an asset of an innovative project to create a new generation aircraft engine;
- the effectiveness of an innovative project to create a new generation aircraft engine;
- economic efficiency of an innovative project to create a new generation aircraft engine.

The following definitions reveal the meaning of the listed concepts:

- an innovative project for creating a new generation aircraft engine is a project aimed at creating an aircraft engine with the required technical characteristics within the required time frame, involved developing and using the technologies not existing at the time of the project start;
- an asset of an innovation project is a financial or non-financial resource considered as a variable of the state of an innovation project as an integral managed system;
- the sociophysical potential of an innovative project is a historically determined property of the project, reflecting its integrated complex systemic nature;
- the accumulated sociophysical potential of an innovative project asset is a numerical assessment of one of the aspects of the sociophysical potential of the project;
- the effectiveness of an innovative project for creating a new generation aircraft engine is a category that characterizes the possibility and efficiency of achieving the goals of a stage of a
project or project as a whole by the required time. A quantitative assessment of the
effectiveness of an innovative project is determined as the result of assessing the possibility of
achieving the required value of the accumulated sociophysical potential for a given schedule of
various resource provision;
- the economic efficiency of an innovation project or its stage is an economic category that
illustrates the assessment of the possibility of achieving the set goals at a given level and a
given schedule of financial resources.

3. Simulation results
Using a sociophysical approach allows for adequate results that are valid over long periods of time. In
figure 1 presents a model of an enterprise implementing projects for the creation of aircraft engines.

Figure 1. The enterprise accumulated potentials.

The modeling horizon is 14 years. An enterprise model using social and physical potential looks
like this:

\[ x_{\text{re}}^{\text{ent}} = \alpha \cdot x_{\text{re}}^{\text{ent}} + \beta \]  \hspace{1cm} (8)

where, \( x_{\text{re}}^{\text{ent}} \) is the company's revenue potential; \( x_{\text{re}}^{\text{ent}} \) - the potential of the assets of the enterprise;
\( \alpha = 0.15 \). The reliability of determining the linear coefficient is \( \varepsilon_\alpha = 100\% \). A comparable enterprise
model using the initial values is described by the formula:

\[ q_{\text{re}} = \alpha \cdot q_{\text{nc}} + \beta \]  \hspace{1cm} (9)

where, \( q_{\text{re}} \) - is the company's revenue; \( q_{\text{nc}} \) - assets of the enterprise; \( \alpha = 0.18 \). The reliability of
determining the linear coefficient is \( \varepsilon_{\alpha^\prime} = 70\% \). Thus, the difference between comparable dynamic
coefficients is:

\[ \delta = \frac{0.18 - 0.15}{0.15} \cdot 100\% = 20\% \]  \hspace{1cm} (10)

Improving the accuracy of determining the coefficients is:

\[ \Delta = 100\% - 70\% = 30\% \]  \hspace{1cm} (11)

Equation (9) is identified by actual data. Equation (9) makes it possible to simulate aircraft engine
projects implemented at a specific aircraft engine-building enterprise.

The results of evaluating the effectiveness of a project according to the initial data and potentials
are shown (figure 2a, b). Efficiency is determined by comparing the accumulated potentials of the
planned and actual production of the project's commercial output. Comparison of graphs confirms the
high information content of sociophysical models as applied to project modeling.
Figure 2. The project effectiveness according to the initial data (a) and accumulated potential (b).

Analysis of the graphs shows that the level of uncertainty in the initial data exceeds 50%, in some cases it reaches 90%. The use of potentials improves the adequacy of the model. In addition, it becomes possible to determine the technological level of the enterprise. One can note that the application of the sociophysical approach opens the way to solving the problems of finding reliable interpretable solutions at all stages of the life cycle of an innovative project.

4. Conclusion
The use of a sociophysical approach makes it possible to create models of aircraft engine-building enterprises and projects focused on the life cycle of an aircraft engine. The sociophysical potential is used for this. Reliable interpretable solutions are generated at all stages of the life cycle of an aircraft engine development project. New modeling and management tools for aircraft engine-building projects are emerging.

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