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Methods of evaluation of life-cycle resource provision for science-intensive products

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***Abstract* – The paper is dedicated to the developing methods of evaluation of life-cycle resource provision for science-intensive products. This method estimates and explains why a particular volume of resources should be involved to execute science-intensive projects. The method of estimation and evaluation of resource costs that are needed for completion of a science-intensive project provides a glimpse of maximum resource costs required for completion of particular types of work, as well as planned organizational and technical activities that ensure rational and effective use of resources. It uses direct resource cost calculation methods and those based on information about analogs. the method allows for evaluation of an enterprise's resource capacity and offers a resource potential calculation pattern, which helps evaluate the amount of work that needs to be carried out to male science-intensive products and which an enterprise can manage with the help of its resource potential.**

Keywords: life-cycle; resource provision; science-intensive projects; economic planning; management; resource potential.

I. INTRODUCTION

As today's high-tech and innovative technology markets skyrocket, Russian manufacturers have to face a lot of global challenges, which influence the viability of domestic products and the entire economy. Therefore, companies tend to move in one key direction, which preserves the existing market niche and creates an opportunity for new markets to grow; that is stimulating their innovative work through intensive development of their innovative potential, which requires continuous investment in innovative science-intensive projects and improving their investment prospects [1,2].

It should be noted that high tech product manufacturers gain competitive leadership not just thanks to high investment that stimulates innovative work, but also thanks to effective manufacturing with proper distribution of all resources owned by the company (material, personnel, intellectual, temporal, etc.) at all stages of development, production and marketing of science-intensive products within the life cycle [3]. Therefore, the research relies on resource-based organizational theory.

II. LITERATURE REVIEW

The resource-based organizational theory has evolved in works written by many foreign scientists, and key aspects of their research are described in Table 1.

TABLE I. EVOLUTION OF THE RESOURCE-BASED MANAGEMENT THEORY

№ п/п	Scientist	Key aspects
1.	F. Selznik [4]	In many ways, *economic success depends on the resources* used by a company, particularly corporate resources - personnel and their expertise, which create and develop the so called "distinctive competence."
2.	A. Tchandler [5]	*Distribution of resources* is one of the *key mechanisms* involved in the process of reaching an enterprise's long-term goals and solving its basic tasks that are part of a unified *strategic enterprise activity planning* program.
3.	B.Vernerfelt [6]	The main thesis of the resource concept implies that every *firm* possesses *unique resources and capabilities*, which act as sources of economic rents and *define its competitive advantages.*
4.	R. Rumelt [7]	In the process of economic activity, *homogeneous firms build unique behavioral patterns* and accumulate differences *based on* the heterogeneousness of the *resources and resource management approaches applied.*

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5.	K. Andrus et. al. [8]	Every company has its own existing and potential strong and weak points; therefore, *the success of its activity and competitive prospects depend on* the availability of *resources and the firm's ability to effectively manage them.*
6.	K. Prahalad and G. Khamel [9]	A competitive advantage arises from the top management's ability to combine *resources* that are distributed around the firm – technologies and skills, which enable a *flexible response to the changing market environment*
7.	R.Grant [10]	A firm should possess *resources and abilities,* which can be characterized as long-standing and difficult to replicate and could help it *preserve and control its position*
8.	D. Tis [11]	*A firm,* particularly one specializing in science-intensive products, can obtain *competitive advantages through effective use of its resources* by way of diversification.
9.	J. Nikolas [12]	A company *gains competitive advantages* as a result of *effective resource planning and cost management.*

The key theory research aspects highlighted in Table 1 and developed by leading economy experts, testify to the fact that the resource theory plays a major role in company management and proves the importance and necessity of using resources and capabilities to create a competitive advantage, as well as for the use of effective approaches, tools and mechanisms in resource management and in formation of a business potential catering to flexibility in the rapidly changing market environment. Meanwhile, it should be noted that the works do not highlight the economic toolkit for evaluation of resources' provision (concerning all types of resources) for the life cycle of a firm's science-intensive product.

III. RESEARCH METHODS

To carry out the economic planning of an organization's main activity, a method of resource evaluation should be applied. This can be difficult, because implementation of science-intensive projects may entail resource costs arising out of the uniqueness of work carried out by innovative enterprises.

Analysis of existing resource cost evaluation methods has provided for a general list of standards and recommendations concerning the structuring the resource evaluation procedure for science-intensive projects.

The most important elements of the procedure are:

- General elements: basic aspects of science-intensive projects and R&D, terms and definitions, legislative control of relationships within scientific and technological projects, stages of science-intensive projects' life cycles, and boundaries between these stages;
- Stages and types of work: outlining characteristics of activities typical of designing, pre-production and production, stages of projects' life cycles and their characteristics, list of activities;
- Evaluation of resource provision at different stages of a life cycle: the basics of resource cost standardization in the implementation of science-intensive projects, the concepts of resource cost standards, basic standard resource cost, methods of standardization of labor and other resources, cost certification rules, resource provision evaluation methods based on resource costs for a basic engineering design.

For each type of resources, cost calculation can be described as follows. Financial resources reflect the sum invested in a science-intensive project and are usually included in innovative project implementation plans as absolute or relative values. Temporal resources are expressed in days (planned launch and termination dates within each stage of a science-intensive project's life cycle). Manpower resources are evaluated by multiplying the amount of working time by its average value and the number of staff involved. Material resources comprise the total cost of equipment, materials, raw materials, components, etc. Information assets are evaluated based on the cost of software, expertise and databases saved on hard drives and also include costs resulting from the use of paid global information services.

This method is aimed at evaluation and certification of resources used in development and production of science-intensive goods. The use of the method can provide validated estimates of admissible resource costs resulting from the completion of specific work within a science-intensive project of the entire project, including planned technical activities that ensure rational and maximally effective use of resources.

This method of evaluation and certification of resource provision helps calculate resource provision for an entire science-intensive project, as well as its segments.

Implementation of this evaluation and certification method requires:

- Time of execution of the science-intensive project;
- Specification of scientific work;
- Goals and objectives of work carried out as part of R&D;
- A list of basic work carried out at particular execution phases and percentages of this work relative to performance stages;
- Financial R&D performance indicators;
- Basic resource certification concepts of scientific research in aerospace;
- Substantiated standard cost and resource cost values needed for performance of work, completion of project stages and the project itself;
- Distribution of current work and, consequently, resource provision between separate divisions;
- Submitting appropriate materials and specific equipment; general information on similar work and projects, if any;
- Characteristics of complexity and complexity parameters concerning the current project and existing similar ones.

Methods and algorithms

I. Evaluation of resource investment in the science-

intensive project.

Phase 1. Outlining a list of appropriate project phases and activities being executed. Analyzing types of work specified with the help of keywords and expected performance. Statement of the content and scope of work for each phase.

A comprehensive list of appropriate project phases should be based on consistent initial data. Next, the content and scope of separate activities should be defined at each project execution phase in keeping with their goals and objectives, and with due regard to end result quality standards; i. e., the entire scope of work is divided into separate types.

The system of phases and activities should consecutively complete scientific, technical, technological, design, production, etc. tasks to fulfill the project's goals, meet the terms of contracts and reference documentation, and reflect the project's specifics. Descriptions of work should include keywords.

All types of work described with the use of keywords are subject to additional analysis to ensure that the work meets the goals, objectives and end result of the project as specified in the work statement; this should enable division of the entire scope of work into reasonably specified separate types of work.

The final division of the entire scope of work to be executed as part of the project, into separate types of work, should be carried out as described in the work statement.

Phase 2. Checking the existence condition and the presence of norms and standards of the work under way (data on standard resource costs).

If norms and standards exist, can be applied, and are described in the standards, specifications and guidelines regulating project-specific resource costs, or there is information on standard resource costs obtained from alternative sources (for example, execution time statistics data for various types of work under way within the project and specific area), analytical resource cost calculation methods (standard calculation) can be used (refers to Phase 5).

If there is no data on standard resource costs, or it is insufficient, the existence of projects similar to this one or specific activities that could be part of the project within the sphere should be verified.

Phase 3. Using analytical (standard) methods. Building the basis for calculation. Standardization at different levels of extension.

The resource costs are calculated based on the data obtained from analysis of the content of the work under way, norms and standards of different degree of extension, which are defined by the standard, specifications and guidelines, as well as the size of resource costs resulting from this type of work, with due regard to the conditions of the execution of the work being analyzed.

To calculate the project's resource provision, a basis for calculation should be formed based on standard materials, standard resource costs, execution time, staff size and/or contractor number standards for different extension levels: they should describe the project in general, its phases, specific activities under way, or provide execution time statistics concerning the project.

Also, the content of the anticipated work should be studied. Every type of work, which is standardized to analyze and calculate resource costs that are needed for its execution, consists of segments and components.

For further standardization of the work within the project, extension levels should be specified, and their number depends on the levels and periodization of planning, as well as on stages and phases of development. These extension levels are: calculating total resource costs per project; calculating resource costs entailed by the execution of separate phases; calculating resource costs for the types of works under way; calculating resource costs claimed by clusters of activities, which are performed by different divisions.

Phase 4. Evaluating the novelty of work.

This phase implies evaluation of the novelty of each type of work under way, as well as of phases or the project in general, depending on the extension levels specified. It evaluates the general complexity and novelty of the work being executed. Reference tables can help you calculate the adjusting factor of novelty.

Phase 5. Calculation of the resource cost standard for execution of work types with regard to the degree of complexity, novelty, groups of performers, and resource costs.

Appropriate standard data can be obtained from respective standard materials or calculated based on the experience of executing similar branch projects and retrospective statistical average data.

All work executed as part of the project is divided into standardized and non-standardized.

Resource costs required for execution of all standardized activities are expressed in respective units (H_{RES}):

$$H_{RES} = H \cdot K \cdot k_1,$$

where H is the resource standard (for each type of work in question) of execution of each particular standardized activity, which is set by existing standards, specifications and guidelines;

K is the factor of resource costs not relating directly to execution, yet pertaining to performers' workspace, leisure time and personal needs. It is set based on end performance statistics or percentages of performers' working time allocated for each particular activity;

k_1 is the adjustment factor, which reflects the degree of novelty and specifics of resource cost distribution according to the types of execution by various groups of contractors. It is imperative that all key factors relating to the execution of each particular work be regarded.

Resource costs of standardized work (T_H) are calculated as follows:

$$T_H^i = H_{RES} \cdot V_i,$$

where V_i is the amount of a particular type of standardized work executed within the project execution time;
H_{RES} stands for resource costs required for execution of a particular standardized work in respective units.

In general, the project's standardized resource costs are viewed as a total resource cost embracing separate project execution phases.

Phase 6. Evaluation of non-standardized work

When it is not possible to set resource cost standards relating to execution of separate activities within the project, these activities are defined as non-standardized. For this type of work, resource cost (T_{HH}) is evaluated with the help methods described in Stages 7-11 of the methodology.

Phase 7. Using research and statistics (or analogies). Building a database on analogies

When research and statistics methods are used, resource costs are evaluated based on statistical data on similar work either the entire project, which were carried out previously, if necessary - with consideration of extra adjustment factors referring to the contractor team and their qualification, as well as separate parts of this work, complexity of subject area or methodological support of execution, complexity of simulation, and project execution time.

Research and statistics resource provision evaluation methods are best used in particular applied research and the majority of design engineering activities.

An analog makes a basis for this method (a basic project, basic resource provision). The analog implies a system of data, which reflects actual resource costs relating to previously executed work that are similar to those being evaluated according to the basic indicators. A base project is one, the scientific, technological, technical and economic indicators of which are used to calculate the characteristics of the project under evaluation.

Next, analogs of the project or of separate activities are collected to build a basis for calculation.

The basis for calculation comprises the following data: analogs of activities being evaluated, as they are distributed across different research vectors and complexity groups; characteristics and ranges of the project's complexity values for different performance groups and relating activities being executed; lists of main activities carried out during execution phases and correlations between these activities' proportions and the project's phases; distribution of the current activities and resource costs relating to them between particular contractors; consolidated general data on resource costs for projects operating within the branch.

Phase 8. Calculating the general complexity factor

The complexity factor k_C of the project being evaluated, as relative to an analog or basic project, should be calculated based on the results of comparison between the project being evaluated and the basic - the previously completed one, with the use of reference tables.

Stage 9. Evaluating resource costs within the project.

For each type of work, resource costs are calculated at a certain phase of a project being evaluated, using the formula:

$$T_{i,j}^m = k_C \cdot T^Б,$$

where $T^m_{i,j}$ is the resource cost with work type (*j)* and phase (*i*) for division (*m)* of the enterprise involved in the project;

$T^Б$ – resource costs for the analogous work;

k_C – the general complexity factor for the current work, which was calculated based on reference tables.

The resource costs of each project execution phase viewed as the total resource costs of activities executed during these phases.

Costs of non-standardized resources are generally defined as the total resource costs of separate project execution phases.

If there are no data on analogs available, and there is general data on the project only, the project resource costs should be calculated based on the data on the resource costs of the project's analog.

The resource costs for activities executed at a respective stage expressed in appropriate units are defined as a total sum of standardized and non-standardized ones.

In cases whereby the project's resource costs have been calculated in different ways, results should be grouped according to the Gurvitz model. It calculates the integral resource cost criterion, which takes the interval uncertainty into account.

II. Evaluation of a company's resource potential

Let us view an organization's resource capacity E^{RES} per type of resource as a correlation between the amount of resources of this type that is needed for completion of the projects and the amount the organization already has in possession:

$$E^{RES} = \frac{\sum_{i=1}^{s} \tau_i^{fact}}{\sum_{i=1}^{s} \tau_i} \cdot 100\%,$$

where $\sum_{i=1}^{s} \tau_i^{fact}$ is the amount of the resource that is needed for the execution of the company's engineering and production program, and $\sum_{i=1}^{s} \tau_i$ is the amount of resources that is available.

With $E^{RES} < 1$, the enterprise's resource potential is not fully in use; with $E^{RES} = 1$, the resource potential is used fully and effectively; with $E^{RES} > 1$, the enterprise is too low on resources to complete all its projects.

If part of the resources remains unused, the enterprise, to ensure their optimal use, should launch other potentially competitive projects, which can embrace its entire resource potential and use it with maximum effectiveness.

IV. RESULTS OF PRACTICAL USE

Verification of the method with a high-tech company has provided estimates of the provision of a science-intensive project with the main types of resources: financial, material, temporal, manpower, information. It should be noted that the estimates of financial, material, temporal, manpower and information resources were expressed in monetary terms. This sort of evaluation has highlighted the general availability of these types of resources for the company and its resource potential, which can be used to run an extra project.

TABLE II. RESOURCE CAPACITY CALCULATION

Type of resource	Financial	Material	Manpower	Information	Total
Resource capacity, %	70.83	86.67	85.96	61.33	80

The calculation provided estimates on all basic types of resources: financial, material, temporal, manpower, information (Table 2). It should be noted that the estimates of financial, material, temporal, manpower and information resources were expressed in monetary terms. This sort of evaluation has highlighted the general availability of these types of resources for the company. An analysis of resource capacity allows for the following conclusions: based on initial conditions, material and manpower are the most involved resources. The verification embraced three science-intensive projects. The estimated 80% resource capacity suggests that the company can redistribute resources and complete one more minor project using the extra 20% resource (in monetary terms). On the other hand, the resource potential has provided the company a margin of safety, which should help it overcome risk factors.

V. CONCLUSIONS AND DISCUSSIONS

Thus, a method of evaluation of resource potential of science-intensive products at different life cycle phases has been developed and verified, and its distinctive feature is the opportunity of simultaneous analysis of all types of resources that are used throughout science-intensive products' life cycle. This method estimates and explains why a particular volume of resources should be involved to execute science-intensive projects. The method of estimation and evaluation of resource costs that are needed for completion of a science-intensive project provides a glimpse of maximum resource costs required for completion of particular types of work, as well as planned organizational and technical activities that ensure rational and effective use of resources. It uses direct resource cost calculation methods and those based on information about analogs. This results in the formation of an integrated estimate of resource costs that are needed for project execution.

Also, the method allows for evaluation of an enterprise's resource capacity and offers a resource potential calculation pattern, which helps evaluate the amount of work that needs to be carried out to male science-intensive products and which an enterprise can manage with the help of its resource potential.

The algorithms and methods described here has proved their effectiveness during tests and can be implemented by science-intensive enterprises.

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