Risk-based forecasting methods of knowledge-intensive product life-cycle resource provision

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Abstract. The paper is dedicated to the development of methods for predicting risk-based life-cycle resource provision in science-intensive projects. This method of whole-cycle prediction of changes in resource provision for science-intensive projects, which embraces risk factors, estimates appropriate real volumes of resource provision needed for engineering and producing science-intensive goods. It uses adaptive methods to estimate resource provision based on statistical data that is obtained at each phase of the project’s life cycle. The method enables prognosis of appropriate resource provision levels at different phases of the science-intensive project with consideration of risk factors. This method implies PC calculation. Minimal use of expert estimates is its crucial characteristic, as it enables automated computation.

1. Introduction

Today, with macroeconomic storms raging and high-tech and innovative markets booming, Russian manufacturers have to face countless global challenges, which influence the viability of domestic industry and the entire economy [1,2]. One key direction for companies, which preserves the existing market niche and creates an opportunity for new markets to grow, is stimulation of their innovative work through intensive development of the innovative potential and use of modern digital technologies in planning, management and monitoring of all business processes within an enterprise [3-6]. Companies have to apply new methods of operation with the use of systems to process and analyze huge databases, industrial Internet technologies, artificial intelligence, expert systems, etc. This, in turn, requires continuous investment in innovative projects that focus on production of science-intensive goods and to boost their investment potential.

Implementation of projects, which create science-intensive products, necessitates prediction of the intake of resources to ensure successful fulfillment of activities that are part of a project with an emphasis on ensuing uncertainties and risks. It should be noted that each phase of a project’s life cycle (engineering, pre-production, production) has its own resource provision level, and each resource (financial, temporal, material, manpower, information) has its own share within a phase. For example, at the stage of engineering, resources provided by designers and engineers are paramount, while material resources are less important. At pre-production stages, material resources come to the fore, as they signal readiness for technological conversion. Other types of resources become important at the production stage and include the availability of flexible production systems, sales channels, etc.
2. Literature review
Russian scientists do not provide clear descriptions of simultaneous resource management process either. All of them have attempted to closely consider the process of management and effective use of particular types of resources. For example, Yu. P. Anyskin [7], as well as I.A. Blank, A.V. Basharina, N.N. Ilysheva [8], A. I. Samylin [9], put emphasis on management of financial resources and investment planning in enterprises that produce science-intensive goods. P.V. Zhuravlev [10], V.V. Sinov [11], I. B. Durakova [12] highlight the importance of studying personnel management tools and mechanisms, as they consider management to be the most effective use of manpower in solving an enterprise’s economic tasks. Lately, both Russian and foreign scientists have mentioned expertise as a key factor for personnel and an enterprise in general. The role of expertise in operation process, organizations’ effectiveness, and competitive ability of science-intensive products is the main focus of works by I.V. Danilov [13], A.L. Nosov [14], and other economists.

However, we believe that synchronized and optimal use of all types of resources will provide an all-in-one solution for an organization to make its work more economically effective against the backdrop of reduction and redistribution of resources between projects under way and key directions of innovative work.

3. Research methods
The use of methods of predicting changes in resource provision at different life cycle phases of science-intensive projects is a must for an enterprise to plan its main activity. The biggest challenge is the likelihood that engineering and production of high-tech goods may necessitate resource provision levels different from the planned ones. This may result from improper planning and risk factors.

Resource costs, which are related to engineering and production of science-intensive products, embrace a number of factors, such as the design and engineering process, pre-production and production itself. Partially, these activities can be predicted and evaluated from the standpoint of resource provision. However, the uniqueness and complexity of the process may entail unexpected resource costs, which depend on the specifics of the project observed at a particular time. The innovative potential of the science-intensive project is addressed providing that the innovative project should use a set of resources (financial, material, technical, temporal and informational), and each one has its share in the appropriated funds and project investment, and the sufficiency/insufficiency of resources should be defined by the ratio between the appropriations and required investment.

To justify additional resource costs that occur as science-intensive projects are run, various econometric methods can be applied, which relate to regressive analysis of statistical data, as well as adaptive models, which embrace risk factors.

Because the work, which is carried out as part of project implementation process, is diverse, both linear regressive and adaptive models should be applied; the latter clearly reflect the fact that an indicator’s dynamics may prevail over its persistence.

The effectiveness of resource provision, considering prediction, is calculated with the use of the resource capacity factor $k_{res}$:

$$k_{res} = \sum_{i=1}^{n} \left( \omega_i \frac{K(P_i)}{Z_i} \right),$$

where $K(P_i)$ is the basic predicted provision volume for each type of resource $P_i$, and $Z_i$ is the actual provision level required for each type of resources, $\omega_i$ is the importance of each resource, $\sum_{i=1}^{n} \omega_i = 1$.

The use of resource provision change prediction method at different life cycle phases requires:
- planned resource provision volumes for basic activities throughout the project’s life cycle;
- statistical database with information on the economic characteristics and amount of resources required for implementation of the science-intensive project;

For the use of the method, various empirical factors can be used as original data, their values chosen by trial or expertise, as the method is applied.

The resource provision change prediction method used throughout the project’s life cycle helps identify the following factors:

- List of factors that influence resource provision
- Adaptive estimate of resource provision based on estimation factors and statistical data.

Methods and algorithms

Implementation of the prediction method throughout the life cycle comprises three stages:

1. Evaluation of planned volumes of resource provision based on standard data.
2. Calculation of generalized adjustment factors of resource provision based on the adaptive model.
3. Final justification of required resource provision and assessment of the efficiency of resource provision with justification of innovative potential.

Phase 1. Determining resource provision based on standard values throughout the science-intensive project’s life cycle.

This stage of the algorithm requires a table showing appropriate resource provision volumes for basis activities and specifying types of work, types of resources, their volume and importance.

Phase 2. Calculation of the general adjustment factor of resource provision based on the adaptive model.

The general adjustment factor of resource provision on each type of resources \( K^i \). It is related to actual and planned resource provision volumes and is expressed as follows:

\[
K^i = \frac{P^i_{\text{fact}}}{P^i_{\text{plan}}} - 1.
\]

Evaluating the general adjustment factor of resource provision with the help of the adaptive model.

Step 1. Building a statistical database of original data for the adaptive model.

Expert estimates of factors influencing resource provision are the original data, which we are going to use to build the adaptive model. These factors include:

- Technical infrastructure (including industrial funds per employee);
- Automation;
- Quality of control systems;
- Quality of operations and process control;
- Degree of implementation and development of automated operation control systems;
- Material, technical and technological infrastructure;
- Management of operation;
- Management of auxiliary services and departments;
- Division and coordination of labor;
- Use of advanced operation and management technologies;
- Work station management;
- Use of various labor organization forms (including flexible forms);
- Macroeconomic factors (inflation, currency volatility)
- Expertise level.

This is not a fixed list of factors, and it can be changed and/or modified if necessary.
To evaluate the factors (let’s use symbol $\lambda_i$, where $i$ is the respective factor number), we are going to use the expert method, which will provide the estimate of factors’ intensity on the Harrington’s verbal/numeric scale.

Each factor has its own weight and influence on resource provision, with equal intensity estimates. The factors’ weight is calculated expertly by paired comparison [15]. The method uses factors’ weight as a constant value.

The general resource provision factor for each type of resource is calculated as follows:

$$\kappa_i = \sum_{j=1}^{N} \omega_j \lambda_j$$

where $N$ is the number of factors analyzed.

It should be noted that different life cycle phases use different weight indicators.

Next, a statistical database of estimates of factors and general resource provision factors should be developed for each type of resource. This database can be presented in the form of a table 1.

Table 1. The form of statistical database.

| Time $t$ | Factor 1 $\lambda_1^t$ | … | Factor N $\lambda_N^t$ | General resource provision factor $\kappa_t$ |
|----------|-------------------------|---|-------------------------|---------------------------------------------|
| 1        | $\lambda_1^1$          | … | $\lambda_N^1$          | $\kappa_1$                                 |
| 2        | $\lambda_1^2$          | … | $\lambda_N^2$          | $\kappa_2$                                 |
| …        | …                       | … | …                      | …                                           |
| $t$      | $\lambda_1^t$          | … | $\lambda_N^t$          | $\kappa_t$                                 |

Step 2. Adjusting the adaptive model

The statistical data shown above can be used as a basis for linear regression estimates:

$$\lambda_i^t = a_0 + b_0 t$$

These estimates can be obtained automatically in MS Excel or other digital calculation systems.

However, we believe that given the complexity of the process of implementation of a science-intensive project, it would be more reasonable to use the adaptive model, because it does not suggest that all original retrospective data of the temporal series could be equally instrumental in the formation of future values.

In our adaptive model we are going to use the Brown’s linear adaptation, in which prediction estimates $\bar{X}$ per $\tau$ steps ahead are calculated, for example, at time $t$ as follows from the equation:

$$\lambda(t + \tau) = a(t) + b(t) \times \tau$$

where $a(t)$ and $b(t)$ are parameters of the linear prediction model, which relate to the moment of the generation of the prognosis $t$.

To calculate $\lambda(1)$ for time $t = 1$, one should be aware of original estimates $a(0)$ and $b(0)$,
which are borrowed from the linear regression model built on several primary levels of the empirical series. This method is also implemented in MS Excel and other digital calculation systems.

The parameters of the Brown’s linear model are corrected (adapted) in the following way:

\[
a(t) = a(t-1) + b(t-1) \times 1 + (1 - \beta^2) \times e(t-1)
\]

\[
b(t) = b(t-1) + (1 - \beta^2) \times e(t-1)
\]

\[
\varepsilon(t) = \lambda(t) - \hat{\lambda}(t)
\]

where \(\varepsilon(t) = \lambda(t) - \hat{\lambda}(t)\) is the error of the retro-prognosis made within period \(t\) and based on the statistical database; \(\beta \in [0,1]\) is the confidence factor, which reflects the degree of confidence in earlier (previous) data.

Thus, the Brown’s model functions as follows. Any deviation of actual values of the temporal series from predicted values, which are usually calculated on a step-ahead basis, is viewed as a prediction error. The error enters the modeling system and is registered by it (feedback) according to a set state transition procedure. Next, a prediction estimate is calculated for the following time point, and the process is repeated until all actual levels of the series are out. At this point, a short-term prognosis is formed, and it tends to be more accurate than the one built on the linear regression model.

The adaptive model can provide either a point estimate or an interval estimate of the influence of a particular factor on resource provision.

Therefore, every next step made over time will provide adaptive estimates of influence on the resource provision volume. It should be noted that the estimation of factors’ influence on resource provision should be carried out at every phase of the science-intensive projects’ life cycle separately.

**Phase 3. Final justification of factual resource provision volume required for implementation of a science-intensive project.**

The predicted factual resource provision volume is calculated as follows:

\[
P_{i,\text{fact}} = (1 + \kappa) \cdot P_{i,\text{plan}}
\]

Where all values are calculated relative to the same time point.

The effectiveness of resource provision, based on the prognosis presented, can be evaluated with the help of the resource capacity factor:

\[
k_{\text{res}} = \sum_{i=1}^{n} \omega_i \cdot \frac{P_{i,\text{fact}}}{Z_i}
\]

where \(P_{i, \text{plan}}\) stands for predicted resource provision values, \(Z_i\) are the actual resource costs of the implementation of the science-intensive project. The resource provision factor amounting to 1 is believed to be optimal. If it is \(k_{\text{res}} < 1\), the planned resource volume proves insufficient, and \(k_{\text{res}} > 1\) results in excess resource.

**4. Implementation**

To generate and analyze indicators reflecting changes in resource provision throughout the life cycle, which result from risk factors, it would be convenient to use the information and analysis software as a computing facility. This approach is believed to be relevant, because the majority of studies, which require a lot of analytical work and analysis of statistical data, prove effective thanks to the use of PCs and advanced computing facilities. This can be explained by the complexity of algorithms, large
amount of information, and having to use complex and bulky formulas. The adaptive model, which is used in the method, is shown in the diagram, figure 1.

This algorithm can provide adaptive estimates $\lambda_i$ of risk factors’ intensity based on statistics received during the previous life cycle stages of the science-intensive project or during the implementation of other projects. A linear regression estimate is based on this data. The parameters of this model are actually original default data that is used for adjusting the adaptive model. These parameters are adjusted (adapted) at each step in time. The parameters generated by the adaptive model are used to calculate the intensity of risk factors. The newly obtained risk factor intensity indicators are used to calculate the general resource provision factor with consideration of the risk factors’ weight. The calculated resource provision factor is used to predict the factual resource provision value and evaluate the effectiveness of resource provision.

![Implementation of the adaptive model](image)

**Figure 1.** Implementation of the adaptive model.

5. **Conclusion and discussion**

This method of whole-cycle prediction of changes in resource provision for science-intensive projects, which embraces risk factors, estimates appropriate real volumes of resource provision needed for engineering and producing science-intensive goods. It uses adaptive methods to estimate resource provision based on statistical data that is obtained at each phase of the project’s life cycle.

The method comprises two stages. The first stage includes unbiased assessment of appropriate resource provision at each phase of the project’s life cycle. This stage states appropriate volumes of financial, material, manpower, temporal, and informational resources at the time when science-intensive products are designed and engineered, pre-produced and, finally, produced. The second stage of resource provision change prediction implies prediction of appropriate resource volumes with consideration of existing risk factors.
The method enables prognosis of appropriate resource provision levels at different phases of the science-intensive project with consideration of risk factors. This method implies PC calculation. Minimal use of expert estimates is its crucial characteristic, as it enables automated computation.

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