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METHODICAL APPROACHS TO CALCULATING THE COST OF DEVELOPMENT WORK ON THE ROCKET AND SPACE TECHNOLOGY

Annotation. Proposed a system of analytical relationships for the calculation of the expected costs of development work on the development of systems and products rocket and space technology given the data uncertainty.

Keywords. Development work, expected beneficial effect, expected costs, rocket and space technology.

The Problem Statement

The decision whether or not to include project into the state target scientific and technical program should be made exclusively on the basis of thoroughly performed assessment of expected effectiveness with consideration for potential risks. The expected costs are one of the major components of the criterion of effectiveness. Therefore it is important today to develop methodological approaches to calculation of costs for development work on rocket and space technology.

State of the problem

Today in Ukraine formed the methodological basis for the development of methodological support calculations of expected costs of implementing the scientific and technological projects and the expected beneficial effect [1, 2], as well as for calculation of the indicators of technical level [3]. Methodology to assess the potential risks in the calculation of the costs of development work on the rocket and space technology in the face of uncertainty data, has not been found by the authors. For that reason, the paper describes a system of analytical relationship for calculations of the expected costs on development work on rocket and space technology taking into account data uncertainty.

The Task Statement

The aim is to improve the quality of technical and economic feasibility of development work in rocket and space technology.

The task is to develop methodological approaches to the calculation of the costs required for the implementation of development work in rocket and space technology.

The main provisions

The expected costs and expected beneficial effect are key indicators on the basis of which decisions are made about the feasibility of the development work on the development of systems and products rocket and space technology.

When calculating the expected costs well-known methods such as the method of calculation and the method of economic elements may not be used. Their use is possible only when there is of design and technological documentation (but it is the end result of the development work). Parametric methods may not be used due to the high technical and structural complexity and novelty of the design of rocket and space technology which is created.

Therefore it necessary to develop a system of analytical expressions to estimate the expected costs for the creation of rocket and space technology that fully take into account its features.

Given the technical complexity and novelty of products rocket and space technology which is created the expected costs may not be of deterministic variable. The input data which are part of analytical expression have the uncertainty which cannot be attributed in general to the probabilistic uncertainty due to the lack of required volume of statistical data.

Therefore the calculated expected costs will be a random variable with unknown distribution law.

To solve problem of calculating the expected costs we assume that the costs of implementation of the development work Z_{OKP} can be represented as the sum of nominal costs $Z_{OKP}^{н}$ and a random component δZ_{OKP}.

$$Z_{OKP} = Z_{OKP}^{н} + \delta Z_{OKP}.$$

The value $Z_{OKP}^{н}$ can be calculated from the constructed system of analytical relationships in the case of using the most anticipated values of the output data.

We introduce the following constraints on the random value δZ_{OKP}:

– mathematical expectation equal to zero and variance equal to σ^2;

– the aleatory variable is distributed under the normal law of the distribution truncated at the left.

Based on these assumptions, the task of calculating the of anticipated costs of development work can be reduced to solving three simple tasks:

– construction of the analytical relationships;

– construction of engineering system of preparation of the initial data;

– construction of expression for a root mean square deviation σ estimation.

The composition and sequence of the preparatory works for the calculations:

– definition of key technical and operational characteristics of the new rocket and space technology (the space systems, the rocket and space complexes, the critical technologies);

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– working out of the scheme of distribution on components of each new sample (decomposition of purchased and borrowed products into its component parts do not fulfill);

– definition of technical and operational characteristics of each component of this scheme;

– selection of products-analogues for each component which to be developed;

– gathering and the analysis of the initial data on products-analogues, carrying out of an estimation of reliability of the data

– bringing the cost indexes of products-analogues to the economic conditions of the base year;

– the central element of space-rocket complexes and space systems is the first flying prototype model (in the space-rocket complexes this is the launch vehicle, in the space systems - the spacecraft).

The choice of products-analogues is carried out to following basic indications:

– functional purpose;

– operating conditions;

– principle of operation;

– constructive-technological characteristics.

For each domestic product-analogue the basic actual (or forecasted if analogues are at stage of development work) technical-and-economic indexes are defined:

– the basic technical and operating performances (indexes of technical efficiency);

– the common costs on development work an product-analogue and their distribution (in %) in design stages: (conceptual design and the preliminary design), working out of the working designer documentation for manufacture and holding of trials of prototype models, manufacture and land trials of prototype models;

– the proportion of material costs and costs of labor for each stage;

– the proportion of material costs and costs of labor in the cost of production and testing of the first prototype model of the product-analogue and its component parts;

– the number of experimental samples made for conducting ground tests;

– the costs of technical preparation of production;

– the level of continuity from products-analogues;

– the costs of correcting of working designer documentation based on the results of test (proportion of costs on development of design and technological documentation).

In the absence of data on foreign products-analogues their the techno-economic parameters are determined by an expert. These data lead to economic and technological conditions of Ukraine taking into account the purchasing power parity of the national currency.

Below the analytical expressions represent the relations the costs of development and manufacture of rocket and space technology with the values of their technical and operational characteristics.

Analytical relations for calculations of costs for working out and manufacturing of the products having the analogues

$$Z_{ji}(t_0) = Z_{ji1}(t_0) + Z_{ji2}(t_0) + Z_{ji3}(t_0) + Z_{ji\,ДЗ}(t_0) + Z_{ji\,ПВ}(t_0) + Z_{ji\,РКД}(t_0),$$

$$Z_{ji1}(t_0) = Z^a_{ji}(t_0) \cdot \mu^a_{i1} \times \left[(\alpha^a_{i1} \cdot k^{-1}_{i1} + \beta^a_{i1}) \cdot (exp(q_{i1} \cdot k_{iн}) - 1) + (1 - \alpha^a_{i1} - \beta^a_{i1}) \right],$$

$$Z_{ji2}(t_0) = Z^a_{ji}(t_0) \cdot \mu^a_{i2} \times \left[(\alpha^a_{i2} \cdot k^{-1}_{i2} + \beta^a_{i2}) \cdot (exp(q_{i2} \cdot k_{iн}) - 1) + (1 - \alpha^a_{i2} - \beta^a_{i2}) \right],$$

$$Z_{ji3}(t_0) = Z^a_{ji}(t_0) \cdot \mu^a_{i3} \times \left[(k^{\gamma}_{i\,ТР}(\alpha^a_{i3} \cdot (1 + \alpha_{iРКД}) + \beta^a_{i3} \frac{ln(1 - P_i)}{ln(1 - P^a_i)}) + (1 - \alpha^a_{i3} - \beta^a_{i3}) \right],$$

$$Z_{ji\,ДЗ}(t_0) = Z^a_{i\,ДЗ}(t_0) \times \left[k^{\gamma i}_{i\,H}(\alpha^a_{i\,ДЗ} + \beta^a_{i\,ДЗ} \frac{ln(1-P_i)}{ln(1-P^a_i)}) + (1 - \alpha^a_{i\,ДЗ} - \beta^a_{i\,ДЗ}) \right] + \frac{\delta_{i0} \cdot \delta_{i1} \cdot Z^a_{i\,ДЗ}(t) \cdot A_i}{N_i},$$

$$Z_{ji\,ПВ}(t_0) = \delta_{i0} \cdot \delta_{i1} \cdot Z^a_{i\,ДЗ}(t) \cdot k^{\gamma i}_{i\,H},$$

$$Z_{ji\,РКД}(t_0) = \alpha^a_{i\,РКД} \cdot Z_{ji2}(t_0),$$

where (t_0) – the base year; $Z_{ji}(t_0)$ – the costs of developing the i-th new product that is part of the j-th products that is unparalleled, are adapted to the base year (t_0); $Z_{ji1}(t_0)$ – the development costs of the project documentation for i-th new products; $Z_{ji2}(t_0)$ – the development costs design and production documentation required for the manufacture and testing of prototype models of the i-th product; $Z_{ji3}(t_0)$ – the costs of production and testing of prototype models of the i-th product, the costs of correcting of working designer documentation based on the results of experimental testing; $Z_{ji\,ДЗ}(t_0)$ – the costs of production of the first prototype model of the i-th product; $Z_{ji\,ПВ}(t_0)$ – the costs of technical preparation of production to ensure the production of the i-th product; $Z_{ji\,РКД}(t_0)$ – the costs of correcting of working designer documentation of the i-th product based on the results of test; $k_{i\,ДЗ}$ – the coefficient of design and technological complexity of manufacturing i-sample (determined by an expert); $\mu^a_{i\,ДЗ}$, $\alpha^a_{i\,ДЗ}$, $\beta^a_{i\,ДЗ}$ – the specific coefficients of the costs of manufacture of the first prototype model of the i-th product-analogue; $\alpha^a_{i\,РКД}$ – the share of expenses for revision of working designer documentation; N_i – the mid-annual release program of the i-th new product; A_i – the average depreciation rate of new production and technological equipment used for manufacturing of the i-th product; $Z^a_{ji}(t_0)$ – the development costs on the i-th product-analogue, are adapted to the base year (t_0); μ^a_{i1}, μ^a_{i2}, μ^a_{i3} – the share of expenses for stages 1, 2 and 3 respectively in the total development costs of the

i-th product-analogue; α_{i1}^{a}, α_{i2}^{a}, α_{i3}^{a}, $\alpha_{i\,ДЗ}^{a}$ – the share of labor costs in costs on the stages of design and fabrication of the prototype model of the i-th product-analogue considering of the contributions to social funds; β_{i1}^{a}, β_{i2}^{a}, β_{i3}^{a}, $\beta_{i\,ДЗ}^{a}$ – the share of material costs in costs on the stages of design of the i-th product-analogue; k_{i1}, k_{i2} – the relative (relative to the product-analogue) level of automation of project and design works respectively; k_{iH} – the level of relative novelty of the new developed the i-th product (it is defined by an expert method); $k_{i\,TP}$ – the relative (to the product-analogue) index of a technological level of the new developed i-th product (it is calculated by a method similar to that described in GOST 15467-79); P_i , P_i^a – the level of reliability of the new developed product and product-analogue respectively; $Z_{ji\,ДЗ}^{a}(t_0)$ - the costs of production of the first prototype model of the product-analogue, are adapted to the base year (t_0); δ_{i0}^{a} – the level of costs of technical preparation of production for product-analogue (per unit accepted the costs of production of the first prototype model of the product-analogue); δ_{i1}^{a} – the indicator of increase (reduction) of costs on production technical training in provision of production new i-th products (it is determined by an expert method, proceeding from the basic konstruktorsko-technological features of the developed product, a composition, a possibilities and a technical condition of available production-technological and experimental base); q_i , γ_i ,$\alpha_{i\,РКД}$ – the statistical or empirical coefficients.

Analytical relations for calculations of costs for working out and manufacturing of the products not having the analogues

$$Z_j(t_0) = Z_{j1}(t_0) + Z_{j2}(t_0) + Z_{j3}(t_0) + Z_{j0}(t_0) + Z_{j\,ПВ}(t_0) + Z_{j\,РКД}(t_0),$$

$$Z_{j1}(t_0) = \sum_{i=1}^{n_j} Z_{ji1}(t_0) \cdot (1+\eta_{i1}^{c}),$$

$$Z_{j2}(t_0) = \sum_{i=1}^{n_j} Z_{ji2}(t_0) \cdot (1+\eta_{i2}^{c}),$$

$$Z_{j3}(t_0) = \sum_{i=1}^{n_j} Z_{ji3}(t_0) \cdot (1+\eta_{i3}^{c}),$$

$$Z_{j0}(t_0) = \sum Z_{ji0}(t_0) \cdot (1+\eta_{i0}^{c}) + \frac{Z_{j\,ПВ}(t_0) \cdot A_j}{N_j},$$

$$Z_{j\,ПВ}(t_0) = \sum_{i=1}^{n_j} Z_{ji\,ПВ}(t_0) \cdot (1 + \eta^c_{i\,ПВ}),$$

$$Z_{j\,РКД}(t_0) = \sum_{i=1}^{n_j} Z_{ji\,РКД}(t_0) \cdot (1 + \eta^c_{i\,РКД}).$$

For products top-level (the complex technical system or subsystem) is additionally calculated the costs of developing and manufacturing of ground-based mechanical and electrical auxiliary equipment:

$$Z_{j\,НО}(t_0) = Z_{j0}(t_0) \cdot \alpha_{j\,НО},$$

where $Z_j(t_0)$ – the costs of creating the i-th new product, are adapted to the base year; $Z_{j1}(t_0),\ Z_{j2}(t_0),\ Z_{j3}(t_0)$ – the costs on stages respectively: design, development of working designer documentation, production of prototype models and their experimental verification; $Z_{j0}(t_0)$ – the costs of production of the first prototype model; $Z_{j\,ПВ}(t_0)$ – the costs of technical preparation of production; $Z_{j\,РКД}(t_0)$ – the costs on correcting of working designer documentation; $Z_{j\,НО}(t_0)$ – the costs of creating of ground-based mechanical and electrical equipment; $\eta^c_{i1},\ \eta^c_{i2},\ \eta^c_{i3},\ \eta^c_{i0},\ \eta^c_{i\,ПВ},\ \eta^c_{i\,РКД}$ – the coefficients of system costs; A_j – the average coefficient of amortization.

Analytical expressions for the calculations of the expected costs onto the preparation and launch of a prototype model of the launch vehicle

The costs onto the preparation and launch of a prototype model of the launch vehicle $Z_{КП}(t_0)$ include payment for:

– transporter of the launch vehicle and the corresponding Electromechanical equipment onto the spaceport;

– travel allowance of technical personnel of enterprises of rocket and space industry to the spaceport ;

– preparation of the launch vehicle to start-up;

– holding of start-up of launch vehicle;

– holding of processes after start-up of launch vehicle.

The costs of the prototype model of launch vehicle is accounted for in the costs on the development work.

$$Z_{КП}(t_0) = \alpha^c_{СК} \cdot Z_{и\,СК} + \alpha_{РН} \cdot Z_{и\,РН},$$

where $Z_{КП}(t_0)$ – the costs onto the preparation and holding of the qualification start-up of launch vehicle; $\alpha^c_{СК},\ \alpha_{РН}$ – the statistical coefficients; $Z_{и\,СК}$ – the costs of the production and mounting of launch complex; $Z_{и\,РН}$ – the costs of the production of the launch vehicle.

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Analytical expressions for the calculations of the expected costs onto the preparation and launch of a prototype model of the spacecraft

The costs onto the preparation and launch of a prototype model of the spacecraft $Z_{3KA}(t_0)$ include payment for:

– transporter of the spacecraft and the corresponding Electromechanical equipment onto the spaceport;

– travel allowance of technical personnel of enterprises of rocket and space industry to the spaceport ;

– preparation of the spacecraft to launch;

– freight of the launch vehicle;

– holding of processes after launch of spacecraft.

$$Z_{3KA}(t_0) = \alpha^{c}_{KA} \cdot Z_{KA}(t_0) + S_{PH}(t_0),$$

where $Z_{3KA}(t_0)$ – the costs onto the preparation and launch of a prototype model of the spacecraft; α^{c}_{KA} – the statistical coefficient; $Z_{KA}(t_0)$ – the costs of production the prototype model of spacecraft; $S_{PH}(t_0)$ – the freight costs of the launch vehicle.

Analytical expressions for the calculations of the expected costs onto the operation of space systems

The mid-annual costs of operation of space systems $Z_{EKC}(t_0)$ include payment for:

– content of the Technical personnel;

– maintenance of technical earth-based systems;

– operation of technical buildings and structures;

– payment of services of the life-support systems.

Additionally, operating expenses may include costs incurred on restoring the grouping spacecrafts in orbital flight.

$$Z_{EKC}(t_0) = N_{\Pi} \cdot З_{\Pi}(t_0) + \alpha_{HC} \cdot Z_{HC}(t_0) + \Delta Z_E(t_0) + \Delta Z_{СЖ}(t_0),$$

$$\Delta Z_E(t_0) = \alpha_{T3} \cdot S_{T3}(t_0),$$

$$\Delta Z_{СЖ}(t_0) = \alpha_{\Pi} \cdot N_{\Pi} + \beta_{HC} Z_{HC}(t_0),$$

where N_{Π} – mid-annual number of the personnel involved in the operation; $З_{\Pi}(t_0)$ – mid-annual payment for work of one person on staff duty shifts; $Z_{HC}(t_0)$ – the costs of technical equipment ground stations and mission control center spacecraft; $\Delta Z_E(t_0)$ – mid-annual costs to operate the existing technical buildings and structures; $\Delta Z_{СЖ}(t_0)$ – the Average size of fee for life-support systems: energo, warmly, and water supply, etc.; $S_{T3}(t_0)$ – the cost maintenance of buildings, structures, tools and systems used in the operation of the space systems; α_{HC}, α_{T3}, α_{Π}, β_{HC} – the Statistical Coefficients.

Analytical expressions for determining the value of the standard deviation σ

Below the relations are empirical and are constructed on the basis of generalization of materials of working out of space systems of the rocket and space technology . More correct value of magnitude can be received with use of the theory of fuzzy sets and simulation.

$$Z_{\Phi} - Z_H = q \cdot \sigma ,$$

$$P_Z = F(q, \sigma),$$

$$\sigma = \left\{ a \cdot (exp(b \cdot \chi) - 1) + k_{\delta} \cdot \frac{1-\delta}{3} + k_t \cdot \Delta T^{3/2} \right\} \cdot 100\%,$$

$$\chi = k_{HK}^{\alpha} \cdot k_{TP}^{\beta} \cdot k_{TC}^{\gamma} \cdot k_{TC}^{*} \cdot k_{TP}^{*},$$

$$\alpha + \beta + \gamma = 1,$$

$$\alpha = \frac{n^* - n_1}{N}, \quad \beta = \frac{n^* - n_2}{N}, \quad \gamma = \frac{n^* - n_3}{N},$$

$$N = 3n^* - (n_1 + n_2 + n_3),$$

$$n^* = n_{max} + 1, \ n_{max} = max\{n_1, n_2, n_3\}.$$

where Z_{Φ} – possible actual costs ; Z_H – nominal actual costs; P_Z – an estimation of the degree of probability that actual costs will be equal to the value Z_{Φ}; q – the coefficient that determines the width of the confidence interval; a, b, k_{δ}, k_t – the statistical coefficients; χ – the reduced indicator of the complexity of the sample; k_{HK} – the coefficients of novelty of a design; k_{TP} – the coefficient of a relative technological level of working out; k_{TC} – the coefficient of relative technological complexity; k_{TC}^{*} – the greatest possible value k_{TC}; k_{TP}^{*} – the greatest possible value k_{TP}; δ – the average level of validity of input dates; ΔT – the term of a delay of performance of the project for reasons of unevenness of financing, year; α, β, γ – the weight coefficients; n_1, n_2, n_3 – influence degree (in points) of the corresponding parameter onto magnitude σ, $n_i \in \{0 - 10\}$ is defined by the method of expert estimations on the basis of the analysis of the declared technical characteristics

The Coefficient of novelty of a design defined as follows:

$k_{HK} \le 0{,}1$ – a insignificant modernization of an existing design ;

$k_{HK} = 0{,}11\text{-}0{,}20$ – a modernization the average level;

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$k_{НК}$ = 0,21-0,30 – a essential modernization;

$k_{НК}$ = 0,31-0,40 – a deep modernization;

$k_{НК}$ = 0,41-0,50 – a new design;

$k_{НК}$ = 0,51-0,60 – a new design with separate essentially new elements;

$k_{НК}$ = 0,61-0,8 – a new design with use in separate elements (except rocket motors of the big draught) of new physical principles;

$k_{НК}$ = 0,81-1,0 – a essentially new design.

Conclusions

The article presents the methodological approach to the calculation of the expected costs of the development work on space technology. This approach was used in the preparation of expert opinion about the justification of the cost of components of the development work at to build the spacecraft "Sich-2-1". This methodological approach may be used in conducting a feasibility study of projects for development activities at forming of the space programs of Ukraine

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