Indian Journal of Science and Technology, *Vol 9(28), DOI: 10.17485/ijst/2016/v9i28/97660, July 2016*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Models of Economic Evaluation of High-Tech Products

Aleksandr Mikhaylovich Batkovskiy[1*], Aleksandr Vasilyevich Leonov[2], Aleksey Yurevich Pronin[3], Elena Georgievna Semenova[4] and Alena Vladimirovna Fomina[1]

[1]Joint Stock Company, Central Research Institute of Economy, Management and Information Systems, Electronics, Moscow, Russia; batkovskiy_a@instel.ru, fomina_a@instel.ru
[2]Moscow Aviation Institute (National Research University), Moscow, Russia; alex.clein51@yandex.ru
[3]Bauman Moscow State Technical University, Moscow, Russia; pronin46@bk.ru
[4]Institute of Innovation and Basic Postgraduate Training, St. Petersburg State University of Aerospace Instrumentation, St. Petersburg, Russia; egsemenova@mail.ru

Abstract

Objectives: The article considers various methodological approaches to estimate the costs for creating high-tech products used in the leading countries. **Methods:** HTP economic evaluation model proposed by the authors is based on modern methods of assessing the costs for the HTP creation. In its economic essence, they are all based on a common methodology for assessing the results and costs in their various combinations and modifications. However, the current assessment techniques do not allow carrying out a comprehensive feasibility study of HTP. **Findings:** It has been specified that the existing methodologies for estimating the costs do not allow making a comprehensive feasibility estimate of options for sharing of new and traditional technologies when creating high-tech products. Specific peculiarities that are necessary to be considered in economic evaluation of high-tech products have been found. A number of models for economic evaluation of high-tech products have been suggested. These models are based on modern methods of estimating costs to create high-tech products used in leading countries. According to their economic essence, they are all based on a common methodology for estimating the results and costs in their various combinations and modifications that provides a comprehensive feasibility estimate of high-tech products. The practical implementation of the proposed models allows conducting a feasibility assessment of the sharing options for new and traditional technologies when creating high-tech products and choosing the options that ensure rational use of budgetary funds allocated for these purposes. **Applications/Improvements:** These models are universal and can be used in all sectors of the economy of the technologically developed country.

Keywords: Economic Evaluation, Efficiency, High-Tech Products, Methods, Model, Technology

1. Introduction

High-Tech Products (HTP) are advanced technology products created on the basis of the unique production processes or products realizing their consumer features with advanced physical and technical effects[1].

Creating HTP is a very complex and expensive process, which often begins from a "zero point" and involves the formation of Technological Advance (TA), creation of phantom, experimental products, and then prototyping and serial products. Thus, for example, creation of TA for carrying out Experimental Development (ED) to develop HTP includes the steps of forming scientific, scientific-technological and industrial-technological groundwork. At the same time, groundwork phase absorbs about 10% of the total budget expenditure to create HTP[1].

In general, the creation of HTP can be accomplished both through the use of new technologies, and through the sharing of traditional and new technologies. Therefore, a certain period of time, during which traditional and new technologies will be shared, is necessary. This should provide the so-called synergistic effect providing either an increase (increment) of performance indicators of HTP functional problems or reduction of costs to perform the

* *Author for correspondence*

same functional tasks, the achievement of which in both cases is not possible in the case of the use of traditional and new types of technologies separately.

It is well known that the traditional way of making any technical product is strictly regulated and provides for several stages of development and implementation of project documents (normative documents). Thus, the main stages of traditional scheme of technical design are the development and implementation of:

- technical specification (it specifies requirements for the designed system and its components);
- technical proposal (it contains a feasibility study of the possibility to create a system as a result of the estimate of the requirements equation with available technological and production capabilities);
- conceptual design (it includes the basic design decisions and their feasibility study);
- technical design (further detalization of conceptual design, in which the final shape, technical and cost characteristics are determined);
- working documents (which allow starting manufacturing HTP).

However, the design of HTP has a number of distinctive features, related to the need of conducting:

- scientific and technical research on the justification of the required level of the main HTP indicators;
- analysis of a significant number of possible options for the technological implementation of individual functional and technological blocks (FTB) to achieve the required level of the main indicators of HTP and their feasibility study considering the possibility of sharing traditional and new technologies.

In addition, when designing HTP, it is necessary to take into account a number of specific peculiarities, in particular:

- uniqueness of the development of key technologies;
- high degree of technological risk;
- absence of prototypes (analog products);
- relatively unstable level of the development of the necessary technological base;
- universal nature of most of the technologies used, with the prospects of dual (military and civilian) use.

The presence of the developed base (scientific and research, laboratory, industrial, experimental, testing, etc.) is necessary to develop HTP. The development conditions are often of unique and distinctive nature, which requires the allocation of significant resources (material, financial, etc.), on the effective use of which the success and timeliness of the HTP creation largely depends.

This article sequentially considers the following issues:

- analysis of various theoretical and methodological approaches to estimate costs for HTP creation used in Russia and leading foreign countries;
- stages of HTP process engineering with cost estimate for its creation in the sharing of new and traditional technologies;
- functional and technological model of HTP;
- model of evaluation of performance readiness (maturity), cost and risk of development of technologies, considering HTP design peculiarities;
- HTP technological design model.

2. Literature Review

The conducted analysis of a large number of international publications on the problem revealed high interest of researchers to the issue, which demonstrates its importance and relevance.

Various authors have considered various aspects of the problem and offered a variety of methodological approaches to estimate costs for high-tech product creation, and also solving issues related to this problem[2–4].

Publications of researchers from different countries (the USA, China, Japan, France, Spain, Australia, the UK and others) were analyzed, among which a number of works presented below, in our view, should be highlighted.

Justification of rational decision-making in the process of financing the development of high-tech products and new technologies is considered in[5–7].

Problems and methodological approaches to cost estimate and management in the creation of high-tech products and new technologies in the framework of international cooperation and collaboration are discussed in[8].

Works of Woertman et al.[9] are dedicated to the problem of feasibility study and selection of the optimum moment for transition from the old to the new technology based on cost estimate for its creation and optimization.

Different approaches to issues of estimation of commercial potential of new and emerging technologies, including those based on the use of fuzzy sets, are offered in[10].

Application of the Delphi method to estimate commercial potential of new types of high-tech products and new technologies is studied in[11]. J. Cho and J. Lee proposed a classification of factors determining the economic feasibility of financing the creation of new high-tech products considering perspectives of their application and potential success in the market.[11]

The problem of price justification and cost control in the development of high-tech products, considering the need to ensure the effectiveness of its creation is considered in[12].

Issues of preliminary economic evaluation of the effectiveness of research and experimental development activities in the development of new types of high-tech products considering possibility of the impact of various uncertainty factors are discussed in[13].

Problems of estimation of new technologies and high-tech products in the aspect of financing their development on the basis of the approach with the use of real options are considered in[14–17].

Generally, despite the wide range of works on the considered issue and in-depth study of certain aspects of the issue, in our view, methodological approaches offered by the authors to the cost estimate for the creation of high-tech products are characterized by a number of restrictions (sectoral limitations, the need for adaptation to the domestic economic realities, etc.), which impede a comprehensive feasibility study of options for sharing new and traditional technologies when creating HTP, including those with regard to the Russian companies.

2.1 Regulatory and Procedural Documents Review

At the end of the 20th century, HTP economic evaluation was carried out in Russia mainly on the basis of industry, interagency and national methods based on the concepts and methods accepted in those years. It was carried out according to indicators of saving total prime cost of works carried out with the help of this type of HTP that were compared with the investments ensuring this saving. All HTP economic evaluations were calculated according to their individual types associated with the production of specific HTP products, as well as to the processes of their development, absorption and modernization. The least developed in economic theory at that time were issues related to the assessment of commercial effectiveness of new technologies implementation, as this issue was hardly considered in terms of planning and the command economy. In solving this problem, there were no reliable statistical gauges and clear definitions of the used categories, for example, the concept of "novelty" did not have a clear assessment criterion.

In 90-ies Russia began the transition to the methods of economic evaluation of technologies generally accepted in the world practice, based on the so-called United Nations Industrial Development Organization methodology (UNIDO)[18]. The spread of the UNIDO methodology in the Russian practice has passed 3 main stages. The first stage was associated with the introduction of the "Integrated methodology for assessing the effectiveness of measures aimed at accelerating scientific and technological progress". The second stage was connected with the introduction of the "Guidelines on estimation of investment projects efficiency and their selection for funding" in 1994. The beginning of the third stage was the implementation of the second edition of the "Guidelines on estimation of investment projects efficiency and their selection for funding" in 2000. Despite the significant differences between these methodological recommendations, all of them determine the procedure for evaluating the effectiveness of HTP, without regard for the complex issues of commercial effectiveness of their implementation on the market[19].

This fact reduces the practical value of methods and instruments of economic evaluation of HTP and technologies currently used. Consequently, the relevance and the uncertainty to the full extent require further research the scientific problem under consideration.

Assessment of technologies readiness (maturity) is the main objective of the set of specialized organizations in the leading countries[20–23]. In Europe, for example, there is the European Technology Assessment Group (ETAG) unifying five European research institutes and performing assessment and analysis of technologies for the European Parliament[24].

The most developed and perfected in the methodical plan are issues of technology maturity assessment in the US. For this purpose, the United States uses the concept of "Technology Readiness Level" (TRL). This characteristic is a readiness measure of technology, which is used by US government agencies to evaluate new (developing) technologies (materials, components, spare parts, etc.) before their introduction in the generated output.

Data of technology readiness assessment level were originally developed by NASA in the 80s of the last century[22,23] and included 7 levels. Further, this approach was refined and generalized, and then it was admitted to the US Department of Defense (hereafter – US DoD). The demand for technology readiness level assessments is prescribed by DoD policy documents D.5000 Series[25] in the course of procurement for the Ministry.

The main purpose of the use of technology readiness levels is to support management decision making in the process of their development and implementation. In general, technologies readiness level assessment is aimed at ensuring of:

- common approach to determine the status of technology;
- risk management in the creation of technology;
- decision-making support in the implementation of funding programs for technology development, transfer and deployment of technologies.

The US DoD document[26] introduced a special verbal and numerical scale, by means of which the current level of development of any technology can be assigned to one of 9 levels of technology readiness, traditionally referred to as TRL1 – TRL9.

The problem of development of technologies and their assessment as well as issues relating to dual-use of technologies, is widely seen in a number of international documents, research reports, collective and individual research. An analysis of the various aspects of the development of dual-use technologies is presented in the report of the European Commission[27].

2.2 Development of Tools for Cost-benefit Analysis of Technologies in Russia

Until the 70s of 20th century, cost-benefit analysis of new technologies in Russia was characterized by the dominance of approaches based on prime cost category. Typical view of cost-benefit analysis model was as follows:

$$E_{(1)} = \frac{\Delta S_o}{\Delta \kappa_o} = \frac{S_b - S_o}{\kappa_o - \kappa_b} \to \max, , \tag{1}$$

where S_b and S_o are total prime cost of goods (works) according to the base and evaluated technology options; K_b and K_o are investments according to the base and evaluated options.

Since the late 80s of the last century to the present, the tools for cost-benefit analysis of technologies are based on the use of the concept of alternative cost and UNIDO methodology. This methodology focuses on the use of the following key indicators:

- net present value (other interpretations of this index is the integral effect, net present value, present value of an annuity);
- yield index of discounted investments (index of profitability of discounted investment);
- internal rate of return, and others.

The monograph[1] revealed the main aspects of evaluation of HTP cost parameters, considered the principles to be guided by and disclosed the essence of the concept of "effective use of financial resources". The considerable attention of the monograph[1] is paid to the tool for estimation of realization cost of planned measures to create HTP with different amounts of initial data in terms of financial, technological and technical and economic risks. The theoretical basis for determining the accuracy of forward-looking assessments of cost indicators is presented and formulation and solution of the problem of their verification are given.

Currently, while preparing planned documents, as a rule, various options for creating HTP products are considered, which differ by characteristics, terms of forming purchases and their volume[28]. The complexity of cost estimate of implementing the planned measures to create HTP products is due to[1]:

- diversity of HTP types, produced during events implementation at different stages of its life cycle;
- different period of pre-emption of measures cost estimate (from one year to ten years or more);
- large number of factors affecting the cost of creating HTP;
- different composition and different degree of reliability of input data used to estimate the cost of the measures;
- wide range of varying the duration of the implementation of activities, which can reach ten or more years.

These factors make it necessary to improve the existing cost-benefit analysis tools to create HTP in an environment of uncertainty of a significant amount of initial data.

2.3 Development of Methodology and Tools for Cost-benefit Analysis of Technologies in Highly Developed Countries

In highly developed countries, the development of methods for the economic evaluation technology was mostly carried out similar to their development in the Russian practice, but usually ahead. Scientists from the United States achieved the greatest success in the development of technology assessment methods.

If we omit the minor nuances in the evaluation of technologies by various agencies and organizations in the USA, then in all cases there is the same problem, which can be formally represented as a reflection of set of emerging and existing *Tech* technologies in *TRL* numerical system using a verbal numeric scale VN_Scale_TRL based on the general theory of measurement[29]

$$\Pr obl: Tech \xrightarrow{VN\_Scale\_TRL} TRL, \quad (2)$$

where, Probl is the identification of the estimated problem,

Tech=<Tech$_1$, Tech$_2$,...,Tech$_n$ > – a set of estimated problems,

TRL=<Tech$_1$, Tech$_2$,...,Tech$_n$ > – numerical grading system,

VN _ Scale _ TRL – verbal numeric scale for assessing the TRL technologies readiness level; Table 1,[13]

n – a number of assessed technologies.

Using this approach, any HTP product can be represented as a set of technologies:

$$VVST \underset{def}{\equiv} Tech_1 + Tech_2 + \ldots + Tech_n, \quad (3)$$

To assess the current level of readiness of HTP[30] product technologies in general during the process of developing or determining the level of readiness of scientific and technical basis for the creation of the product at the stage of making a decision about the opening of ED, one of the following rules is used:

$$TRL_{VVST} = \frac{1}{n}\sum_{i=1}^{n} TRL_i \text{ or } TRL_{VVST} = \min_i\{TRL_i, i = 1, n\}, \quad (4)$$

The main drawback of this approach to determine the level of technology maturity is obvious enough: it is not valid enough, because it is based on subjective expert evaluation.

However, the majority of international experts believe that a simplistic approach to evaluate the technology readiness level, used above, has played a crucial role at certain stage of birth of the methodology relating to this approach. For the present stage of development of the knowledge economy and terms of unifying complex heterogeneous technologies into the system, the existing methodology for assessing technological maturity should be improved.

Table 1. Verbal and numeric scale for evaluating the level of readiness of TRL technology

Level of readiness of technologies	Description of the technology development
First level of readiness (TRL 1)	The lowest level of readiness of the technology. Scientific studies go into applied research and development. As an example, we consider the study of basic properties of paper studies.
Second level of readiness (TRL 2)	Invention of new technology begins. The basic principles of technology and proposals for practical application are determined. Practical applications are the nature of proposals and not always backed up by detailed analysis and research. Examples are limited by analytical studies.
Third level of readiness (TRL 3)	Analytical and laboratory research aimed to confirm assumptions about the technology elements are actively conducted. As an example, we can bring the case when elements have not been determined yet and are not integrated into a single technology.
Fourth level of readiness (TRL 4)	Studies of combined into a whole specially manufactured in a laboratory mock-up equipment are conducted. As an example, we can consider layout functional test in the laboratory.
Fifth level of readiness (TRL 5)	Precision of technology simulation increases significantly. The main elements of technology are combined with real elements for the purpose of providing testing in the laboratory. As an example, we consider a well-integrated laboratory model.
Sixth level of readiness (TRL 6)	System model or its layout shown in the laboratory or simulated conditions close to reality. Representative prototype demonstration under conditions close to actual may be considered as an example.
Seventh level of readiness (TRL 7)	Demonstration of technology (system) prototype in real conditions. Demonstrating in the air, on the ground or in space can be seen as an example.
Eighth level of readiness (TRL 8)	Technology in its final form has been tested in real conditions and is ready for widespread use. An example is the test and system evaluation in HTP products, with aim to check meeting specified requirements.
Ninth level of readiness (TRL 9)	Technology is tested in practice and showed good results in the HTP products.

3. Methods

The process of HTP technological design as opposed to the traditional understanding of design as a process associated with the development and practical implementation of regulatory and design documentation has some specific features. They involve implementation, balancing and synergistic combination (arrangement) of FTB (subsystems, components, elements), separate and distinct for the purpose intended, into a single constructive-technological scheme – a single structure. Technological design procedure contains types and number of FTB, the level of their technological elaboration, synergies between them, as unknown parameters, to achieve the required values of high-tech product indicators.

In the modern design practice, the necessary functional and technological blocks are selected in two ways: either from the set of existing blocks, i.e. already well tested and used in the design and technological schemes of other product types; or there is a need of full-scale development of new technologies.

As a rule, the set of the proven technologies is sufficiently representative and strong, unlike many of the FTB, built on new technologies, directly determining functionality and appearance of HTP ultimately. Usually, these technologies are the object of emerging scientific and technological base (NTB).

The main stages of technological design of HTP and their outline are shown in Table 2.

Consider the content of the stages of technological design using the standard functional-HTP process model shown in Figure 1.

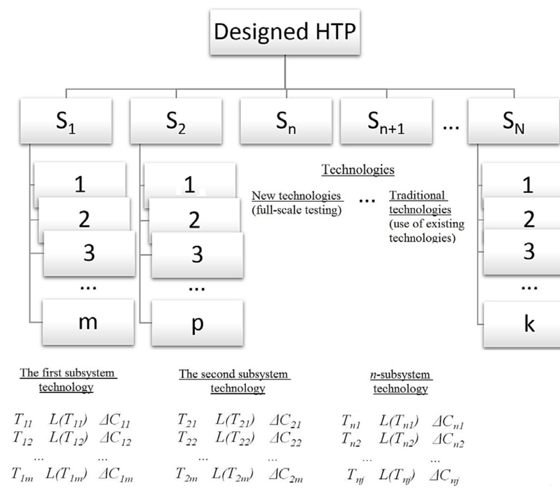

Figure 1. Typical functional and technological HTP model.

Formation of the options of functional and technological HTP construction is as follows. The projected high-tech products in accordance with its functional and technological scheme may be represented as S_n ($n=\overline{1,N}$) relating to independent subsystems for the technical implementation of which the finite set of new and traditional technologies is used:

$$\mathrm{T} = (T_{nmn}),\ n=\overline{1,N},\ m_n=\overline{1,M_n}, \tag{5}$$

Table 2. Main stages of process engineering

Stages	Synopsis
Stage 1	Updating of the list and volume of HTP tasks and demands to it
Stage 2	Development of functional-technological HTP scheme, reflecting its composition with FTB (subsystems, components, elements) and internal links between them, realized in the process of applying (operating) of HTP
Stage 3	Formation of variants of functional and technological structure and the determination of required levels of the main indicators of HTP (the rational part of the FTB is established based on their analysis, which should be created, as well as the amount of necessary costs for the development of new technologies)
Stage 4	The development of functional-technological scheme for each variant of building HTP (under the variance of building HTP in this case refers to a structure comprising a set of independent technologies and providing the fullest possible verification of the main indicators of HTP)
Stage 5	Determine the need of a full-scale development of new technologies for each of the subsystems that comprising the variant of HTP
Stage 6	Assessing the current level of technologies that are supposed to to be used in the composition of each variance of functional and technological construction of HTP
Stage 7	Assessment of the necessary level of technologies development required for the implementation of the set of indicators in relation to each variant of functional and technological construction of HTP
Stage 8	Assessment of the necessary level of funding for the creation of each variant of HTP

where: m_n is the amount of technologies, providing the creation of n-sub-system of HTP. Generally, for each S_n-subsystem, the number of the necessary technology can be different;

T_{nmn} is one of m_n technologies, used in n-sub-system;

L(T_{nmn}) - the level of development of T_{nmn} technology that is necessary for the implementation of the required HTP indicators;

ΔC_{nmn}- costs required for the transition of T_{nmn} technology from existing level to the level, that is necessary for the implementation of the required HTP indicators.

Thus, HTP is presented as a set of S_n ($n=\overline{1,N}$) subsystems, each one of which includes a set of T_{nmn} technologies with the current level of L(T_{nmn}) development and the cost ΔC_{nmn} required for its transition from the current level to the level that is necessary for the implementation of the required HTP indicators.

To determine the need for the full-scale development of new technologies for each of the subsystems that are part of HTP variation, a separation of these subsystems into two groups is provided:

- the first subsystem group includes new technologies ($S_1, S_2 \ldots S_n$) requiring the full scale development;
- the second sub-system group includes traditional (already being used) technologies ($S_{n+1} \ldots S_N$) with a high level of technological study.

The above-mentioned separation is carried out to assess the possibility of reducing the necessary financing when creating HTP by the use of already existing blocks (components) in subsystems, i.e. using opportunities of unification of element base of high-tech products creation.

Next, the specification and assessment of the current level of technology is carried out, which are suggested to be used in the composition of each option of functional and technological construction of HTP. Evaluation of the current readiness (maturity) level of ($S_1, S_2 \ldots S_n$) technologies is carried out through expert methods using verbal and numeric scale which allows establishing a correspondence between the degree of elaboration of the technology required for the development of each subsystem and its numerical evaluation. The scale allows experts to clearly define at what level the technology is currently.

Evaluation of technologies development level that is necessary for the implementation of the set of indicators in relation to each variant of functional and technological construction of HTP is performed similarly to assess the current level of the technology maturity, with the only difference that the level of development of each of the technologies used for the implementation of the specified requirements to HTP is determined by expertise.

Determining the funding needed for the transition of each new technology from the current level to the required level, is based on the following relationship:

$$\Delta C = f(\Delta\alpha),\ \Delta\alpha = \left|\alpha_p - \alpha_t\right|, \tag{6}$$

where: α_p is the required level of technology development;

α_t - current level of technology development.

This dependence is based on the total sample for the research background and allows calculating the required cost for technology transition from the lower current readiness level α_t to the higher level α_p, needed to provide the required HTP indicators.

The dependences obtained in such a way will consider the differences in capital intensity of research for different technologies.

A typical model to evaluate indicators of readiness (maturity), cost and risk of development of technologies can be applied for approximate calculations, taking into account the HTP peculiarities, one of the content option variance of which is presented in Table 3.

Table 3 lists the possible levels and stages of technology development, technological risks for each level of technology development, costs required for transition of technology from the current low level to a higher level of development α_p which is required.

When using this reference model, relationship can be represented as follows:

$$\Delta C = \left|\alpha_p - \alpha_t\right| \cdot C_t \tag{7}$$

Then, the total costs required to develop HTP, will be determined by the following formula:

$$C = \sum_{m_1=1}^{M_1} \Delta C_{1,m_1} + \sum_{m_2=1}^{M_2} \Delta C_{2,m_2} + \ldots + \sum_{m_n=1}^{M_n} \Delta C_{n,m_n} + \Delta C_{n+1} + \ldots + \Delta C_N \tag{8}$$

where, $\Delta C_{1,m_1}$ is costs necessary for transition of one of the technologies included in the first sub-system, from the current level of readiness to the required level for the implementation of the specified requirements for HTP indicators;

m_1 - a number of technologies used in the first subsystem;

Table 3. Typical model of assessing the indicators of readiness (maturity), cost and risk of new HTP technologies (variant) developing

Level of readiness (maturity) HTP technologies		Technology Development Stages	Technology risk	Costs for the development of technology
Status of technology development	1. Research of new phenomena, physical and chemical effects and patterns.	Fundamental research	Absolutely high	C_1
	2Evaluation of the possibility of creating new technology.	Exploratory research	Extremely high	C_2
	3. The technology is on the stage of development. Technology concept is defined	Applied researches	Very high	C_3
	4. Technology comes to the stage of development. Checking the layout efficiency in the laboratory.			C_4
	5. The technology is ready for use in expeimental products.		High	C_5
	6. The technology is ready for testing in experimental products. Tests of experimental products in conditions close to real.			C_6
	7. The technology is tested on experimental product and is ready for implementation in HTP.		Medium	C_7
	8. Technology (typical subsystems, modules and components) is tested in real conditions. HTP pilot product.	Experimental development	Low	C_8
	9. Technology is tested in practice and used in HTP.		Very low	C_9

$\Delta C_{2,m_2}$ - costs necessary for transition of one of the technologies included in the second part of the system from its current level to the desired level of readiness;

m_2 - a number of technologies used in the second subsystem;

$\Delta C_{n,m_n}$ - costs necessary for transition of one of the technologies included in n-system from its current level to the desired level of readiness;

m_n - a number of technologies used in n-sub-system;

$\Delta C_{n+1} \ldots \Delta C_n$ - costs necessary for revision (modernization) of each of the subsystems, used as part of HTP.

Thus, the practical realization of the above proposed stages of the design allows conducting technical and economic assessment of the sharing options for new and traditional technologies when creating HTP and selecting the options to ensure the rational use of budgetary funds allocated for these purposes.

The model, using which it is possible to formalize some stages of technological design, in particular the transition from the balanced system of requirements to HTP indicators to the specific composition of FTB, is presented in Figure 2.

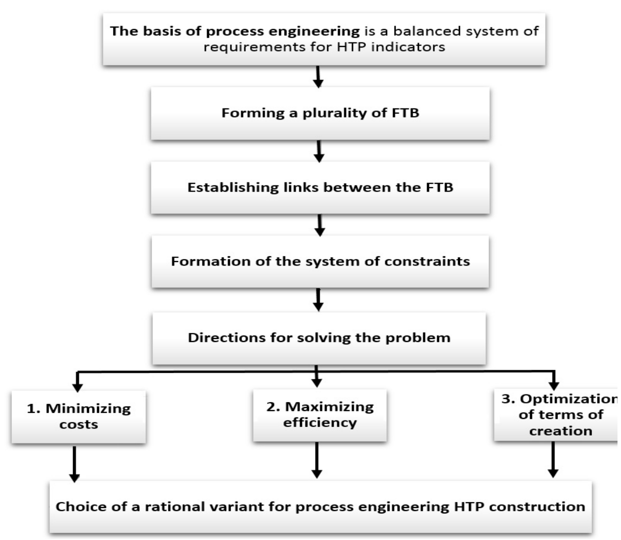

Figure 2. HTP engineering process model.

Suppose we know a set J of FTB types, and the number of blocks of each type of z_j ($j \in J$, z is an integer). Each FTB of z_j-type has certain properties (parameters) $x_{ij} = x_i(z_j)$, $i \in I$, $j \in J$. inherent only to it. At the same time, there are parameters (such as weight and size, power consumption) associated with each block.

The result of the interaction of FTB is manifested as HTP properties that are described by functional relationships of the following type:

$$\Phi r = \Phi r\,[xij\ (zj)],\ r = 1,2, ..., R. \quad (9)$$

From the set of product indicators, the most important are those that characterize the efficiency of its use (use in the functional purpose):

$$W_l = W_l\,[(x_{ij}\,(z_j)],\ \ l = 1,2, ..., L, \quad (10)$$

where, $W_l[(x_{ij}(z_j)]$ is the efficiency indicator of solving l-functional task.

The above-mentioned condition (10) allows concluding about the preference of a particular variant of functional and technological product creation.

FTB parameters and indicators are restricted as follows:

$$\alpha_{ih} \le x_{ij}(z_j) \le \alpha_{iv}\ ,\ i \in I, j \in J, \quad (11)$$

$$ß_{rh} \le \Phi_r\,[x_{ij}\ (z_j)] \le ß_{rv}\,,\ i \in I, j \in J \quad (12)$$

where, α_{ih},α_{iv} are allowable upper and lower limits of variation of the parameter value, respectively (parametric restrictions);

$ß_{rh,}$ $ß_{rh}$ are allowable upper and lower limits of variation of the parameter value, respectively (functional restrictions).

The total costs of product design in general terms can be written as follows

$$C = \sum_j C(z_j) + C_{komp},\ j \in J,\ z - \text{integral} \quad (13)$$

where, $C(z_j)$ is FTB of z_j-type creation costs;

C_{komp} are costs on aggregation technology of functional and technical blocks as part of the products.

Expression (13) includes all necessary cost components and reflects specificity of high-tech products, especially their main indicators dependence on the composition and coordination arrangements of FTB z_j considering their x_{ij} properties, which provides the appearance of stable links between them in the form of the HTP product structure by r-indicator. This means that the HTP product can be characterized by different structures, focused on a particular indicator.

When designing HTP, functional and technological blocks are subject to additional requirements, in particular:

- standardization and unification of FTB and their elements;
- terms of the feasibility of using borrowed elements of similar or different functional purpose.

Requirements for functional and technological blocks from the backbone blocks, determining its fundamental physical and technical novelty should be considered as well. In addition, in the process of technological design, the requirements on the part of the superior system, in which the projected production is seen as an integral part, must be considered.

The problem of determining FTB rational composition of the designed product can be formulated using complex criteria "efficiency – cost – feasibility", adopted in modern methodology of feasibility studies. In this case, the problem of determining the FTB rational composition is formulated in three versions:

1. Cost minimization.

It is necessary to find those values of $z^0_j \ge 0$ for which the total costs for HTP designing are minimal, i.e., $C(z) \to min$ under the following conditions:

a) the effectiveness of solutions l-problem should not be less than specified (required) $W_l\,[x_{ij}\,(z_j)] \ge W^0_l\ (l = 1,2, ..., L)$ levels;

b) the terms of HTP creation must be less than the predetermined value of $T \le T_{zad}$.

2. Maximizing efficiency.

The optimization criterion is formed by the convolution operator K from W_l indicators, at the same time, demands to the HTP from the superior system in the form of the required values of efficiency W^0_l are considered. Operator K is maximized: $K\ (W_l,\ W^0_l) \to$ max for a given level of costs for creation of HTP $C(z) \le C_{zad}$ and terms of its creation $T \le T_{zad}$.

3. Optimization of HTP creation timelines.

For a given (selected) cost amounts $C(z) \le C_{zad}$ for the design of HTP, its optimal parameters and terms of a full-scale development of main (basic) technologies are determined: $W_l \to opt,\ T \to opt$.

Solution of the problem in any version of its formulation provides receiving a rational number z^0_j of j-type FTB in the projected production.

These productions allow more fully and correctly considering inter-level hierarchical technological ties arising between different FTBs, taking into account their degree of technological development.

4. Results

The article describes a number of specific features that must be considered performing economic evaluation of HTP, the main ones are:

- uniqueness of key technologies development;
- high degree of technological risk;
- absence of prototypes (analog products);
- relatively unstable level of the necessary technological base development;
- universal nature of most of the used technologies with the prospects of dual (military and civilian) use.

Considering these characteristics, we suggest the HTP economic evaluation model, including:

- functional and technological HTP model, which is a list of relatively independent subsystems (FTB), for the technical implementation of which a finite set of new and traditional technologies is used;
- indicators assessment model of readiness (maturity), cost and risk of development of technologies, considering features of HTP design and comprising the following stages of development of technologies:

a) fundamental research aimed at obtaining new scientific knowledge about natural phenomena, physical and chemical effects, as well as the laws and regularities that can be used in HTP creation;

b) exploratory research aimed at developing new principles and technological bases for HTP creation;

c) applied research aimed at creation of technological blocks, parts and structural elements for HTP products;

g) experimental development on the creation of HTP products;

- HTP model of technological design which allows taking into account the system of technical requirements for HTP indicators and selected strategies for HTP creation (minimizing costs, maximizing efficiency and optimization of timelines of HTP construction) selecting a rational option of HTP constructing.

Practical application of the proposed models allows conducting a feasible study of sharing options of new and traditional technologies to create HTP and select the options to ensure the rational use of budgetary funds allocated for these purposes.

5. Discussion

Traditional methods and means of engineering design do not allow considering the above-mentioned aspects of high-tech product creation to a full extent. Therefore, it was necessary to distinguish process engineering in a separate type of HTP designing. Its main task is to study a rational set of functional and technological blocks that provide the required performance levels of designed HTP.

When planning the creation of HTP, it is necessary to know:

- firstly, what level of readiness the technology underlying the creation of HTP are on;
- secondly, what problems should be addressed at the scheduled time interval, using the created HTP;
- thirdly, whether the existing (alternate) option of HTP can solve the similar problems;
- fourthly, what kind of characteristics of prospective HTP product should be for solving the specified tasks with the minimum cost for the implementation of its life cycle and how they can be achieved – by the modernization of existing HTP products or developing a new generation product.

The division into these options for the development of a new generation product and upgrading the existing HTP products is caused by a number of circumstances and, above all, the practical needs of the feasibility studies in a minimum volume of input data. Under these conditions, value characteristics of the prospective HTP product have not yet been proved, but it is known that the development of product with the improved characteristics will be carried out by means of sharing traditional and new technologies. As a result of this, it is planned to implement in a perspective HTP product either the whole possible set of new technological solutions (technological advance), or part of them. This situation takes place when developing long-term plans to create HTP, and in the case when the development of long-term planning documents do not impose strict requirements on the values of long-term HTP product characteristics, and only ranges of their possible values are known.

The most important problem that is solved in the process of HTP creation is the justification of planned volumes of funding and timing of events for its creation. A concrete result of this study should be the efficient use of financial resources allocated for the creation of HTP.

Further development of the methodology and tool of economic evaluation of HTP should, in our opinion, be based on the following principles: low cost, high efficiency, performance equivalence assessment and objective utility of technologies. In modern conditions, the major among them are the criteria of low cost and high efficiency.

6. Conclusion

HTP economic evaluation model proposed by the authors is based on modern methods of assessing the costs for the HTP creation, used in the leading countries. In its economic essence, they are all based on a common methodology for assessing the results and costs in their various combinations and modifications. However, the current assessment techniques do not allow carrying out a comprehensive feasibility study of HTP.

Models of economic evaluation of technologies and HTP, proposed in the article, are universal. They can be used in all sectors of the Russian economy.

For the wide practical use of the developed tool, the further research is needed to address a number of issues that have not been considered in the article (risk assessment of new technologies development, efficiency of their import substitution, taking into account measures on the standardization and others).

The practical application of the main stages of process engineering is aimed at the feasibility study of the required values of high-tech production indicators by combining both new and traditional technologies, which is a prerequisite for the work on standardization and import substitution.

7. Acknowledgement

This study has been carried out with support from the Russian Science Foundation (RSF project No. 14-18-00519).

8. References

1. Burenok VM, Lavrinov GA, Podolsky AG. Estimation of cost indexes of high-tech products. Moscow: Publishing Group "Border"; 2012.
2. Tidd J, Bessant J. Managing innovation: Integrating technological, market and organizational change; 2013.
3. Lin R, Zhao X, Wang H, Wei G. Model for potential evaluation of emerging technology commercialization with hesitant fuzzy information. International Journal of Advancements in Computing Technology. 2012; 4(1):304–11.
4. Reinventing technology estimatement for the 21st century. New report calls for citizen participation to inform decision-making on science and technology. The Woodrow Wilson International Center for Scholars of the Smithsonian Institution; 2010.
5. Calderon M. The pillars of cost-effectiveness: A practical guideline for new technology cost-effective decision-making. Value in Health. 2015; 18(3):A102.
6. Calderon M, Ocano AS, Roording R. The new technology cost-effectiveness checklist: Introducing a practical guideline for the selection of health technologies. Value in Health. 2015; 18(7):A569.
7. Amendola B. Cost effectiveness in new technologies. 2013 Supplement; 18(1):9–11.
8. Ely A, Van Zwanenberg P, Stirling A. Broadening out and opening up technology estimatement: Approaches to en hance international development, co-ordination and de mocratisation. Research Policy. 2014; 43(3):505–18.
9. Woertman W, Van De Wetering G, Adang E. Cost-effective ness on a local level: Whether and when to adopt a new technology. Medical Decision Making. 2013; 34(3):379–86.10. Wei G, Zhao X, Wang H, Lin R. An approach to potential evaluation of emerging technology commercialization with intuitionistic trapezoidal fuzzy. Journal of Convergence In formation Technology. 2013; 8, 1:588–597.
10. Wei G, Zhao X, Wang H, Lin R. An approach to potential evaluation of emerging technology commercialization with intuitionistic trapezoidal fuzzy. Journal of Convergence Information Technology. 2013; 8, 1:588–97.
11. Cho J, Lee J. Development of a new technology product evaluation model for estimating commercialization opportunities using Delphi method and fuzzy AHP approach. Expert Systems with Applications. 2013; 40(13):5314–5330.
12. Kamae I, Sugimoto T, Yamabe K. Value-based pricing scheme for new technology in consideration of cost-effectiveness dominance to the control. Value in Health. 2015; 18(7):A732.
13. Leite L, Teixeira J, Samanez C. Ex-ante economic assess ment in incremental R&D projects: technical and develop ment time uncertainties addressed by the real options theo ry. Pesquisa Operacional. 2012; 32(3):617–642.
14. Shishko R, Ebbeler DH, Fox G. NASA technology assessment using real options valuation. Systems Engineering. 2003; 7(1):1–12.
15. Steffens P, Douglas E. Valuing technology investments: use real options thinking but forget real options valuation. International Journal of Technoentreneurship, 2007; 1(1):58.
16. Villani G. Valuation of R&D investment opportunities with the threat of competitors entry in real option analysis. Computational Economics. 2014; 43(3):331–55.
17. Ullrich C. Valuation of IT investments using real options theory. Business & Information Systems Engineering. 2013; 5:331–41.
18. The official website for the organization of United Nations Industrial Development Organization [Internet]. Available from: http://www.unido.ru.
19. Andreychikov A, Andreychikova O. System analysis and synthesis of strategic decisions in Innovation. Fundamentals of Strategic Innovation Management and Marketing. Moscow: Librokom; 2015.
20. Defense Technologies: DOD's critical technology list rarely inform export control and other policy decisions, United

States Government Accountability Office. Report to Congressional Committees, GAO-06-793, Washington, D.C.; 2006 Jul.
21. Boer FP. Estimatement of technology cost: problems of business and finance in the world of research and development; 2011.
22. Boer FP. Practical examples of valuation techniques; 2013.
23. Protecting Defense Technologies: DOD estimatement needed to determine requirement for critical technologies list. United States Government Accountability Office. Report to Congressional Committees, GAO-13-157; 2013 Jan.
24. The official website for the organization of European Technology Assessment Group [Internet]. Available from: http://www.itas.kit.edu.
25. US DoD 5000.01: The Defense Acquisition System. 2007.
26. Brock JL. Best practices: Using a knowledge-based approach to improve weapon acquisition: GAO-04-386SP, GAO Reports;1/1/2004, 1.
27. EU funding for dual use: A practical guide to accessing EU funds for European regional authorities and SMEs [Internet]. 2014. Available from: http://www.czelo.cz/files/EU-funding-for-Dual-Use-Guidebook-2-.pdf.
28. Gavva VK, Denisov AG, Arbuzova DP. Monitoring of innovative technologies and projects in the sector of essential water resource management aimed at sustainable development of Northern (Arctic) regions of Russia. Indian Journal of Science and Technology. 2016 Mar; 9(12). DOI: 10.17485/ijst/2016/v9i12/89519.
29. Hubbard J. How to measure anything. Valuation of intangible business. (Trans). Moscow: Business Olympus; 2010.
30. Yoo S, Shin HJ. Robust planning for high-tech supply chain networks under uncertainty. Indian Journal of Science and Technology. 2015 Jan; 8(1). DOI: 10.17485/ijst/2015/v8iS1/60709.