TOOLS TO MINIMIZE RISK UNDER DEVELOPMENT OF HIGH-TECH PRODUCTS[1]

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The article describes the methodological bases and the economic and mathematical tools to minimize technological risks developing high-tech products. A new, more efficient organization of the process of developing high-tech products, as well as tools for assessing the technical and economic efficiency of new technologies introduced on manufacturers of these products is offered.

Keywords: *technological risks, high-tech products, the company, tools, efficiency, development.*

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ИНСТРУМЕНТАРИЙ МИНИМИЗАЦИИ РИСКОВ ПРИ РАЗРАБОТКЕ ВЫСОКОТЕХНОЛОГИЧНОЙ ПРОДУКЦИИ

В статье рассмотрены методологические основы и экономико-математический инструментарий минимизации технологических рисков разработки высокотехнологичной продукции. Предложена новая, более эффективная организация процесса разработки высокотехнологичных изделий, а также инструментарий оценки технико-экономической эффективности новых технологий, внедряемых на предприятиях-изготовителях данной продукции.

Ключевые слова: *технологические риски, высокотехнологичная продукция, предприятие, инструментарий, эффективность, разработка.*

1. Introduction

The problem of assessing and minimizing the risks of development of high-tech products is multifaceted and therefore the complexity of its solutions commensurate with its importance.

In most degree currently financial and economic risks of this development is studied. However, given the nature of these products, which is created using high-tech, no less important is the problem of assessing the risk of its development process. Scientific fundamental and practical importance of this problem, define the following key factors:

– *low level of innovation and technological development in Russia*, which lags far behind the leading industrialized countries that have reached the fifth technological order. In Russia, more than 50% of the technology used belongs to the fourth way of almost 30% – the third. As a result, Russia, receiving natural resource rents, began to pay higher rents intellectual countries exporting high-tech and innovative products, i.e. our country imports almost 90% of the needed high-tech products [1].

– *unresolved to this problem at the moment*. Earlier analysis of this problem was carried out in insufficient, and its results were largely descriptive. Fundamental research, which concentrates on the development and test of the hypothesis that has generic and applicable to any technology evaluation process, there has been little. As a result, hitherto accepted scientifically sound and practically implemented a comprehensive toolkit to minimize the risks of technological development of high-tech products is absent [2].

– *complexity and sometimes inability to use when solving a scientific problem under consideration the results of its study foreign scientists* (particularly in relation to technology, created for national security that have secrecy). This is primarily due to the specific features of Russian production management system of high-tech products that are created in the main enterprises of the defense-industrial complex of Russia [3].

These circumstances necessitate the creation of tools that allow to minimize the risks of technological development of high-tech products.

2. Analysis of technological risks and tools to minimize them by using the previously introduced technologies

Developing of high-tech products based on the use of manufacturers have introduced earlier technology requires minimization of technological risks of its creation by the transition to a new, more efficient organization of developing high-tech products [4]. Currently, in the traditional structure of the product lifecycle (PLC), technological preparation of production (TPP) follows the development works (DW). However, in high-tech industries in the production of high-tech products as appropriate, in our view, to begin TPP at the stage of DW, i.e. these two stages of product life cycle to spend as much as possible in parallel. The organization of innovation in high-tech industries provides the following benefits:

– reduced the total duration of pre-production stages of product life cycle, as part of the TPP can be carried out before the transfer of the design documentation to the manufacturer;

– increases the consistency of design solutions and technological capabilities of the manufacturer. This reduces the risk of making the step DW technologically unrealizable or inefficient design decisions and, consequently, the risk of inefficient use of funds allocated for the development of innovative products.

Capabilities of integration DW and TPP appeared thanks to the introduc-

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tion of CALS-technologies and system of automatic project, which allow real-time information on all design changes developed product. For the analysis of technological risks creating innovative products and development tools can be used to minimize their methodological approach proposed in [5, 6]. Section discusses the stages of the product lifecycle, so that upon completion of each stage of DW appear to fulfill a certain stage of the TPP. Performing technological preparation of production stages in relation to the stages of development work allows you to quickly identify mistakes made with a certain probability during the DW, which lead to a decrease in manufacturability of the product or even the impossibility of its production in the application of existing enterprise technology manufacturer. Through the integration of the DW and TPP these errors are corrected much earlier, which reduces the loss of time and money, because under the new organization of production, they are identified at an early stage product life cycle, have not yet led to costly irreversible losses.

Assessing the probability of occurrence and error detection is performed in parallel stages of the DW and TPP can determine the expected volume of new high-tech design rework products and their corresponding losses that must be mapped to the time and cost, obtained during sequential stages of product life cycle data. As a criterion for evaluating the effectiveness of the integration of the DW and TPP indicator can take a relative reduction in the expected loss of time and money on rework errors. Integral evaluation of the effectiveness should consider the terms of creating high-tech products, as time of appearance of a new product on the market affects its competitiveness.

To work around this problem it is necessary to estimate the expected volume of work on the stages of the DW and TPP subject to possible alterations of the product associated with the correction of mistakes. Let m – number of stages of DW, denote the index $i = 1, \dots m$, and the corresponding stages of TPP, denote the index $j = 1, \dots m$. At the end of the i-th stage of DW can perform the i-th stage of the TPP. In order to simplify the model, we assume that all stages of DW have the same duration d^O and cost s^O, and all stages of TPP – respectively, d^T and s^T. Then planned durations and cost DW (D^O_{pl}, S^O_{pl}) and TPP (D^T_{pl}, S^T_{pl}), excluding errors and alterations can be determined as follows:

$$D^O_{pl} = m \times d^O;\ S^O_{pl} = m \times s^O; \quad (1)$$

$$D^T_{pl} = m \times d^T;\ S^T_{pl} = m \times s^T; \quad (2)$$

Suppose that in the course of DW can be a mistake with probability H. If the process of the DW consists of m identical successive stages , then at each i-th stage is equal to the probability of error $h = H / m$. Suppose a given probability b, that this error is detected on the corresponding i-th stage of the TPP. If the probability $(1 – b)$ it is not detected at i-th stage, then with probability $[b \times (1 – b)]$ it is likely to be found at $(i + 1)$ stage of TPP, with probability $[b \times (1 – b)^2]$ – on $(i + 2)$ stage of TPP, etc. We assume that this error is guaranteed to be detected at any stage of TPP, until his final stage m. Then the probability that an error will be allowed on the i-th stage of DW and revealed on the j-th stage of the TPP, is:

$$H_{i,j} = \begin{cases} h \times b \times (1-b)^{j-i} = \\ = \dfrac{H}{m} \times b \times (1-b)^{j-i}, \\ j = i, \dots m-1 \\ h \times (1-b)^{m-i} = \\ = \dfrac{H}{m} \times (1-b)^{m-i}, \\ j = m \end{cases} \quad (3)$$

Model (1)–(3) evaluation of the likelihood of errors at the DW and detection phases of TPP allows to determine the technological risks of innovation development of high-tech enterprises in the development of innovative products.

Upon detection of an error made at some stage of development works, all the steps performed after it, subject to alteration. The amount of data rework is an interest equal value $\kappa \subset [0; 1]$. Similarly, for the corresponding stages of technological preparation of production this amount is equal $\mu \subset [0; 1]$. One fundamental mistake made while performing a certain stage of DW can depreciate all subsequent stages of development activities even if they are performed without error, i.e. $\kappa \approx 1$. If the error is small, then $\kappa << 1$. Since the construction of the new products and the development of production methods are labor-intensive, the cost and time losses of the errors listed are closely linked. Therefore adopted in the model equation of time and cost share of losses associated with altering the design of the product because of that mistake is justifiable.

If an error made by the i-th stage of DW is found on the j-th stage of the TPP, $j \geq i$, then the following shall be subject to alteration of the number of stages of the DW (Δm^O)and the corresponding stages of TPP (Δm^T):

$$\Delta m^O_{i,j} = \Delta m^T_{i,j} = j - i + 1,\ j = i, \dots m \quad (4)$$

Durability and cost of rework for DW (Δd^O, Δs^O) and TPP (Δd^T, Δs^T) can be defined as follows:

$$\begin{cases} \Delta d^O_{i,j} = \kappa \times d^O \times \Delta m^O_{i,j} = \\ = \kappa \times d^O \times (j-i+1), \\ \Delta s^O_{i,j} = \kappa \times s^O \times \Delta m^O_{i,j} = \\ = \kappa \times s^O \times (j-i+1), \\ \Delta d^T_{i,j} = \mu \times d^T \times \Delta m^T_{i,j} = \\ = \mu \times d^T \times (j-i+1), \\ \Delta s^T_{i,j} = \mu \times c^T \times \Delta m^T_{i,j} = \\ = \mu \times s^T \times (j-i+1), \\ at\ j = i, \dots m \end{cases} \quad (5)$$

Then the expected duration and cost of rework DW (ΔD^O, ΔS^O) and TPP (ΔD^T, ΔS^T) with (1)–(3) can be expressed as follows:

$$\Delta D^O = \sum_{i=1}^{n} \sum_{j=1}^{n} \Delta d^O_{i,j} \times H_{i,j} = \\ = \kappa \times d^O \times \sum_{i=1}^{n} \sum_{j=1}^{n} \Delta m^O_{i,j} \times H_{i,j} = \\ = \kappa \times d^O \times \Delta M^O; \quad (6)$$

$$\Delta S^O = \sum_{i=1}^{n} \sum_{j=1}^{n} \Delta s^O_{i,j} \times H_{i,j} = \\ = \kappa \times s^O \times \sum_{i=1}^{n} \sum_{j=1}^{n} \Delta m^O_{i,j} \times H_{i,j} = \\ = \kappa \times s^O \times \Delta M^O; \quad (7)$$

$$\Delta D^T = \sum_{i=1}^{n}\sum_{j=1}^{n}\Delta d_{i,j}^T \times H_{i,j} =$$
$$= \mu \times d^T \times \sum_{i=1}^{n}\sum_{j=1}^{n}\Delta m_{i,j}^T \times H_{i,j} =$$
$$= \mu \times d^T \times \Delta M^T; \quad (8)$$

$$\Delta S^T = \sum_{i=1}^{n}\sum_{j=1}^{n}\Delta s_{i,j}^T \times H_{i,j} =$$
$$= \mu \times s^T \times \sum_{i=1}^{n}\sum_{j=1}^{n}\Delta m_{i,j}^T \times H_{i,j} =$$
$$= \mu \times s^T \times \Delta M^T; \quad (9)$$

where ΔM^O, ΔM^T – the expected number of steps of the DW and TPP subject to alteration.

Hence:

$$\Delta M^O = \Delta M^T =$$
$$= \sum_{i=1}^{m}\sum_{j=1}^{m}(j-i+1)\times H_{i,j} \quad (10)$$

Summing expression (6), (7), (8) and (9) can be found of increasing duration (δD) and cost (δS) DW and TPP caused by mistakes made in the design of the product and its subsequent alterations:

$$\delta D = \Delta D^O + \Delta D^T =$$
$$= \kappa \times d^O \times \Delta M^O + \mu \times d^T \times \Delta M^T; \quad (11)$$

$$\delta S = \Delta S^O + \Delta S^T + K_{add}^{O+T} =$$
$$= \kappa \times s^O \times \Delta M^O + \mu \times s^T \times \Delta M^T +$$
$$= K_{add}^{O+T}, \quad (12)$$

where K_{add}^{O+T} – the additional cost of the DW and TPP, which is necessary for their integration and parallel execution.

Inclusion in the proposed model index K_{add}^{O+T} due to the fact that the integration of the DW and TPP is only possible on the basis of modern information technologies and therefore requires the purchase of expensive software and hardware, as well as organizational changes on manufacturers of high technology products. Indicator K_{add}^{O+T} allows to take into account the additional costs caused by the transition to the new organization of the process of developing innovative products, which increases the validity of the proposed instrument.

3. Economic evaluation of effectiveness of a new organization of development process of high-tech products

In accordance with the currently in force organization of innovative developments in high-tech industries stages TPP begin only after the DW. Therefore, no matter what stage of DW or process error was made, it will not be discovered until the beginning stages of technological preparation of production, i.e. before the end of the design of the product development. Moreover, if a mistake is made on the *i*-th stage of the DW, alteration in any case subject to $(m - i + 1)$ stages of DW. Then the expected number of steps of the DW ΔM_{end}^O, to be adapted, can be defined as follows:

$$\Delta M_{end}^O = h \times \sum_{i=1}^{m}(m-i+1) =$$
$$= h \times \left[m \times (m+1) \frac{m \times (m+1)}{2} \right] =$$
$$= h \times \frac{m \times (m+1)}{2} =$$
$$= \frac{H}{m} \times \frac{m \times (m+1)}{2} = H \times \frac{m+1}{2} \quad (13)$$

Expectancy duration ΔD_{end}^O and the cost of rework mistakes ΔS_{end}^O, made during the development work in the traditional sequential execution of the DW and the TPP can be defined as follows:

$$\Delta D_{end}^O = \kappa \times d^O \times \Delta M_{end}^O =$$
$$= \kappa \times d^O \times H \times \frac{m+1}{2}; \quad (14)$$

$$\Delta S_{end}^O = \kappa \times s^O \times \Delta M_{end}^O =$$
$$= \kappa \times s^O \times H \times \frac{m+1}{2} \quad (15)$$

With regard to the number of stages of TPP to be adapted, as well as the expected duration and cost of these alterations, they are defined in the same way as in the parallel execution of the DW and TPP as at their sequential execution also have to redo only the technological preparation of production steps that follow mistakes. Therefore, the expected increase in the value δS_{end} and duration δD_{end} the DW and TPP about their planned level consistent with the traditional organization of these processes is expressed by the following formulas:

$$\delta D_{end} = \Delta D_{end}^O + \Delta D^T =$$
$$= \kappa \times d^O \times \Delta M_{end}^O + \mu \times d^T \times \Delta M^T; \quad (16)$$

$$\delta S_{end} = \Delta S_{end}^O + \Delta S^T =$$
$$= \kappa \times s^O \times \Delta M_{end}^O + \mu \times s^T \times \Delta M^T \quad (17)$$

Comparing the expressions (11) and (16), (12) and (17), we can determine the relative reduction in growth duration and cost of the DW and TPP caused by errors and the subsequent alterations:

$$\frac{\delta D_{end} - \delta D}{\delta D_{end}} = \frac{\Delta D_{end}^O - \Delta D^O}{\Delta D_{end}^O + \Delta D^T}; \quad (18)$$

$$\frac{\delta S_{end} - \delta S}{\delta S_{end}} = \frac{\Delta S_{end}^O - \Delta S^O - K_{add}^{O+T}}{\Delta S_{end}^O + \Delta S^T} \quad (19)$$

This relative reduction achieved thanks to the new principles of organization development and manufacture of high-tech products can be considered as a relative measure of the effectiveness of the integration of the DW and TPP. Implementation of assessment tools discussed economic efficiency and integration DW and TPP requires consideration of the following important conditions.

First, the tools discussed initially considered the possibility of DW on stage only one error with probability $H \leq 1$. Nevertheless, analysis of formula (18) shows that the relative reduction of rework does not depend on this probability. Therefore, we can prevent the possibility of multiple errors in the implementation of the DW with different probabilities, provided that the errors on various stages of R&D are considered as events that are not mutually exclusive and independent from the probabilistic point of view.

Secondly, after the discovery of the *j*-th stage of the TPP error made on the *i*-th stage of DW during rework appropriate milestones, it is possible to re-emergence of a new error. If repeated errors are possible and their number at this stage is not limited to the DW, the total probability of error at this stage is the sum of the following infinite and decreasing geometric progression:

$$h + h^2 + h^3 + ... = \frac{h}{1-h} \quad (20)$$

Note that if $h << 1$, then $\frac{h}{1-h} \approx h$. Otherwise, all of the expected volume alterations should be multiplied by a value equal $\frac{h}{1-h}$. But since this factor will go into all the terms of the numerator and denominator of the final expression (18), then his account will not affect the relative reduction of rework, is achieved through the integration of the DW and TPP. Consequently, the considered instrumentation is applicable in this case.

Thirdly, by integrating the DW and TPP reduced the expected number of stages development work to be remaking: $\Delta M^O < \Delta M^O_{end}$. Comparison of (11) and (16) shows that this change would not be significant under the following conditions: $\kappa \times d^O < \mu \times d^T$, $\kappa \times s^O < \mu \times s^T$, $\Delta M^O \approx \Delta M^O_{end}$. For large values of the cost of a new organization DW and TPP K^{O+T}_{add}, the total cost of product life cycle stages may even increase, which will make this integration ineffective. With $\kappa \times d^O >> \mu \times d^T$, $\kappa \times s^O >> \mu \times s^T$, $\Delta M^O << \Delta M^O_{end}$ the integration of the DW and TPP can significantly reduce the duration and cost of the expected output of the new innovative products to the market by reducing the required volume of rework due to earlier detection of errors during the DW.

4. Tools and methods for assessing technology, implemented by the manufacturer of high-tech products

If during development work developed an innovative product, the production of which require the introduction of factory new technology, the primary means of reducing the risks of its creation process is to assess the technical and economic efficiency of this technology. Criteria considered for evaluation are chosen based on the following principles: low cost, high efficiency, equivalence and objective indicators for assessing the usefulness of technology. In modern conditions, chief among them are the criteria for minimum cost and maximum efficiency [7].

Criterion of a minimum cost advisable expressed as follows:

$$Z(\lambda, \omega) = min Z(\tau, \omega)$$
$$\lambda \in G, \tau \in G, \omega \in N; \quad (21)$$

$$E^F(\lambda, \omega) \geq E^F_{TR}, \quad (22)$$

where Z – total cost of implementing the technology; $\lambda\{g_1, g_2, ..., g_n,\}$ – characteristic values of technology, providing the minimum total cost; ω – conditions feasibility assessment; $\tau\{g_1, g_2, ..., g_n,\}$ – current values determined by the characteristics of technology; G – set of admissible values defined characteristics; E^F – an indicator of efficiency of technology; E^F_{TR} – the desired value indicator of the effectiveness of technology; N – the set of admissible values of the conditions of technical and economic evaluation of technology.

Criterion (21) are useful in the presence of mandatory limits on the values of the effect of the introduction of technology.

Criterion of maximum efficiency is applied on a limited budget for the implementation of technology and therefore it has the following form:

$$E^F(\lambda, \omega) = max\, E^F(\tau, \omega),$$
$$\lambda \in G, \tau \in G, \omega \in N; \quad (23)$$

$$Z(\lambda, \omega) \leq Z_{TR}, \quad (24)$$

where λ – characteristic values of technology, providing maximum efficiency of its implementation; Z_{TR} – the required value of the total costs of the introduction of technology.

Advantage of these criteria is the possibility of their use of well-developed methods for single-criterion optimization. The main disadvantage is considered criteria in the absence of acceptable analytical relationships and procedures justify restrictions on the values obtained with the help of their performance. In the case where there is no clear limitations or requirements to maximize performance, if the desired search result can be performed using the method of optimization «cost-effectiveness», and the effectiveness criterion (V) of the following form:

$$V(\lambda, \omega) = \{Z(\tau, \omega), E^F(\tau, \omega)\} \quad (25)$$

Criterion (25) are useful for selecting one of several competing technology options when it is necessary to take into account technical and economic characteristics. May be other variants of determining the criteria of technical and economic assessment of the process using the concept of overall efficiency.

In assessing the technical level of new technology necessary to compare it with the predicted parameters at the time of development of the world's best examples of this type of technology and destination. An important condition for the creation of a basis for comparison, allowing objectively evaluate the technical level of technology approach is differentiated according to their classes.

Integrated approach to the technical and economic evaluation of technology requires consideration of most important indicators of its technical, economic and social efficiency. In this case the key tasks that require priority solutions are:

– update lists of the most important indicators of evaluation;

– establishing the baseline values of single indicators;

– determination of the coefficients weighting on groups of indicators;

– establishing relationships between different characteristics of technology;

– development of methodology for assessing the effectiveness of the technology;

– testing of the developed guidelines and models.

The most complex and least solved now is the problem of finding suitable for practical use dependencies between the technical and economic characteristics of the technology. To solve it, you can, from our point of view, use the following methods: deterministic analysis, regression analysis, factor analysis, expert assessments. Deterministic analytical methods are used for the necessary conditions for establishing unambiguous nonrandom relationships between economic and technical characteristics. Usually, these ratios are established between the two variables: for example, the «cost – effectiveness», «cost – development time», etc. The process of formation of analytic functions is based on the analysis of structural and functional relationships between the studied characteristics of technology or processing of statistical data containing values studied characteristics. In the case where there are no conditions for the establishment of an analytical dependence between random values of economic and technical characteristics used regression analysis.

Regression analysis methods are currently the most effective for determining the analytical relations between cost and performance technology. However, in order to increase the accuracy of determining ratios must have a sufficiently large volume of sample preparation techniques for which are generally not possible.

Factor analysis is based on the use of regression analysis and is used in cases when it is necessary to evaluate the effect of deviations performance (factors) to change the value of technology. For a small sample size, the use of regression and factor analysis does not provide the required accuracy in the determination of the required dependencies. In this case, for the solution of this problem, you can use the method of expert estimates, which, as experience shows, with proper selection of experts can provide acceptable accuracy and reliability of results.

5. Conclusion

Discussed in the article methodological approaches, indicators and evaluation algorithms of technological risks creating high-tech products have a universal character. They can be used in all high-tech industries while minimizing technological risks. At the same time, in contrast to existing models solution to the problem, developed a comprehensive toolkit enables to minimize the risks inherent in both effective and applied in production technologies. The application of this tool will improve the efficiency of the process of developing high-tech products.

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