Multi-criteria evaluation of reference terms requirements for development work performance

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Abstract. The specifics of carrying out research and development work (R&D), dictated by the requirements of legislation and standardization documents, impose a number of increased requirements on a potential contractor. The head of the organization, considering the possibility of performing R&D, makes a decision by analyzing the requirements of the terms of reference, the resources available to the organization and possible limitations. The article presents an approach to the formation of methodological support for assessing the possibility of implementing the requirements of the technical assignment for R&D within the time limits set by the contract, taking into account the resources available to the potential contractor and the level of qualification of personnel. To calculate the criteria, a modification of the PERT model is given and algorithms for analyzing the relevance of texts based on cosine similarity are applied. The proposed methodological apparatus can be used to create a model of a problem-oriented decision support system in preparation for R&D.

1 Introduction

Under the conditions of market economy, business entities need to produce competitive products, ensuring profit. One of the ways to expand the range of products and make profit is to perform research and development projects (R&D). R&D can be possible both at the expense of the organisation's own funds in order to expand the range of products and under contracts concluded with business entities or federal executive bodies.

R&D contracts include conditions on payment of penalties in case of non-fulfilment or improper fulfilment of the contract terms. In some cases, non-performance or improper performance of an R&D contract may result in the organisation being included in the register of unfair suppliers and deprived of the opportunity to perform similar work in the future [1-14].

To minimise these risks [15-18], it is advisable to develop a methodological device that allows the head of the organisation to determine the possibility of implementing the contract conditions based on the results of a multi-criteria assessment of the requirements of the terms of reference for R&D [16], taking into account the resources available to the

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potential contractor and the level of personnel qualification.

2 Criteria and constraints for R&D performance

When assessing the possibility of concluding a contract for R&D, the head of the organisation - the decision maker (DM) - should take into account the provisions of the current legislation regulating the procedure for R&D, the requirements of the terms of reference, the available resources and the level of qualification of the organisation's personnel.

The performance of R&D imposes a number of restrictions on the potential contractor due to the peculiarities of regulatory legal regulation of this sphere of activity in the Russian Federation.

As the most important regulatory legal acts and standardisation documents [19, 20], the requirements of which should be taken into account when performing R&D should be noted:

Federal Law "On standardisation in the Russian Federation" dated 29.06.2015 No. 162-FZ;

Federal Law "On Licensing of Certain Types of Activities" dated 04.05.2011 No. 99-FZ;

Federal Law No. 44-FZ dated 05.04.2013 (rev. dated 13.06.2023) "On Contract System in the Sphere of Procurement of Goods, Works and Services for State and Municipal Needs";

Federal Law "On Procurement of Goods, Works and Services by Certain Types of Legal Entities" dated 18.07.2011 No. 223-FZ;

state standards of the system of product development and placement of products into production and other standardisation documents establishing requirements for the procedure of R&D of production, technical and special purpose products.

Economic and technical criteria should be singled out as criteria determining the possibility of the contractor's participation in R&D.

Technical criteria include the availability of the economic entity's basic production assets (computer facilities, machine tools, testing and technological equipment) necessary for the implementation of the requirements of the technical assignment for R&D, specialists with sufficient qualifications to perform the work, as well as relevant experience in performing similar work.

Economic criteria allow assessing the possibility of realising the requirements of the Terms of Reference for R&D performance, taking into account the contractor's financial support and availability of the working time fund necessary for realising the requirements of the Terms of Reference for R&D performance within the time period specified in the draft contract.

In the author's opinion, the main criteria affecting the possibility of fulfilling the contract for R&D are summarised in Table 1.

Table 1. Criteria for the organisation’s participation in R&D implementation.

No	Criterion	Criterion content
1	Legislative and regulatory criterion Legislative and regulatory indicator	Compliance of the legal entity with the requirements of regulatory legal acts in the field of R&D fulfilment

2	Technical criterion Indicator of experience and qualifications	Possible extent of utilisation of information from previous similar activities
3	Economic criterion	Ability to perform R&D given the nominal working time of the organisation and the possibility of engaging co-performers

For the decision maker (DM), it is more convenient to operate with an integral criterion that takes into account legislative and regulatory, technical and economic constraints.

Various mathematical methods can be used to form an integral criterion. The criterion can be scalar or vector. A significant disadvantage of the vector criterion is the impossibility of solving optimisation problems using traditional regular methods. The most rational, from the point of view of solving the problem of ranking technical tasks according to the possibility of their implementation, is the use of a scalarised criterion.

The following scalarisation methods are used:

weighted sum method;

ideal point method;

Kemeny median;

method of successive concessions;

Pareto optimality;

Elektra group methods [2].

The simplest and most suitable for the formation of the methodological apparatus of the management decision support system is the use of the weighted sum method. In this method, the integral criterion is presented as a sum of values of indicators with weight coefficients, which are also called importance coefficients. They reflect the value of the i-th criterion (its importance) compared to the others.

The following type of convolution is most commonly used:

$$W = \sum_{i=1}^{n} \alpha_i u_i \,, \tag{1}$$

here $u_i = {}^{w_i}/_{w_{max}}$ – normalised criterion value w_i, equal to its ratio to the maximum possible value. The closer the value u_i to 1, the higher the influence of this criterion. The normalisation is introduced because all summands of the sum (1) must have the same dimensionality, otherwise they could not be added up [2]

The advantage of the method is the simplicity of the mathematical apparatus used and the possibility of assigning a decision maker a weight coefficient for each indicator, based on relevant experience or guided by expert judgement.

As an integral criterion it is proposed to use the criterion "Possibility of participation in R&D", reflecting the degree of confidence of the DM in the successful implementation of R&D and the possibility of the organisation's participation in this work.

3 Multi-criteria evaluation of terms of reference requirements for R&D fulfilment

In order to form a methodological apparatus that allows the head of the organisation to make a decision on the possibility of participation in R&D, it is necessary to outline the methods of determining each of the criteria given in Table 1.

Statutory and regulatory benchmark (SRB**).** Reflects the legal entity's compliance

with the requirements of regulatory legal acts in the field of R&D performance. The criterion may take the value of 1 if the R&D performer meets all mandatory legal and regulatory requirements for the R&D performer, or 0 if any mandatory legal or regulatory requirement cannot be met. The value of the criterion is determined by expert judgement.

Technical criterion (TC).

It reflects the possible extent to which information from previous similar activities can be used.

The availability of relevant experience of the performer in performing similar activities is an important indicator determining the possibility of performing R&D.

The study of methods of multi-criteria analysis of alternatives in the tasks of evaluating documents of complex structure (documents with complex information content) allowed us to propose the use of the cosine similarity method for evaluating the relevant experience of the performer in performing similar work [3]

Cosine similarity is a similarity measure that is used for vector models. A vector model allows the document and query texts to be represented as vectors of the same space, and the degree of similarity between these vectors is expressed through the cosine of the angle between them.

Terms of reference for previously implemented similar R&D and ToR for new R&D consist of a set of words called terms. In the vector model, term weights make it possible to describe documents as vectors whose dimensionality coincides with the number of different terms in the collection. This can be represented in a mathematical form:

$$d_j = (w_{1j}, w_{2j}, \dots, w_{nj}), \tag{2}$$

where d_j is vector representation of the j-th document in the collection; w_{ij} – weight of the i-th term in the j-th document of the collection; n – the number of different terms in the entire collection.

The ToR for a new R&D in mathematical form is defined in a similar way:

$$q = (w_{1q}, w_{2q}, \dots, w_{nq}) \tag{3}$$

Such representation allows to determine the distance between the points of space, hence, to estimate the degree of similarity between the ToR requirements for the performed R&D and the ToR requirements of the planned R&D (close location of points indicates high relevance of texts).

In the vector model the weight of a term can be defined in different ways:

Boolean weight - the weight of a term is 1 if the term is part of the document, otherwise it is 0;

TF - term weight depends on the frequency of occurrence of the term in the text;

TF-IDF - the weight of a term is equal to the product of the frequency of occurrence of the term in the document and the inverse frequency of this document.

In the context of the task under consideration, a combination of the two ways of determining the weight of a term is used. Boolean weight is used for query terms and TF-IDF method is used for document terms. The formula for calculating IDF(q_i) has several calculation variations. The most commonly used formula is:

$$\mathrm{IDF}(q_i) = \log \frac{N - n(q_i) + 0{,}5}{n(q_i) + 0.5} \tag{4}$$

and the formula for TF is:

$$\mathrm{TF}(t) = \frac{n_t}{\sum_k n_k} \tag{5}$$

here N defines the number of documents (ToR) in the collection,

n_t – is the number of occurrences of term t in the document, and the denominator contains the total number of words in the document.

This option of defining the weights is chosen so that the terms of the documents have more importance, which will provide a correct assessment of the relevance of the documents to the query.

Document relevance evaluation d_j the ToR q is determined by cosine similarity according to the formula:

$$\begin{aligned} \cos(d_j, q) &= \frac{d_j \cdot q}{\|d_j\| \cdot \|q\|}, \\ \cos(d_j, q) &= \frac{\sum_{i=1}^{N} w_{ij} \cdot w_{iq}}{\sqrt{\sum_{i=1}^{N} w_{ij}^2} \cdot \sqrt{\sum_{i=1}^{N} w_{iq}^2}}, \end{aligned} \tag{6}$$

where is the cosine between the vectors of the document d_j and request q is defined as the ratio of the scalar product of vectors to the product of their lengths (the length of a vector is assumed to be its Euclidean norm).

When evaluating relevance, the cosine similarity of document and ToR takes values from the range of 0 to 1. If the cosine value is equal to 0, the document and query vectors are orthogonal and do not converge. The document and ToR vectors are completely convergent if the value of cosine is 1.

One of the advantages of cosine similarity is its low complexity since this method explores exclusively non-zero dimensions [3, 4]

Thus, when using the cosine similarity method of comparing TToR requirements, the value of the technical criterion should be determined by the formula:

$$TC = \cos(d_j, q) \times 100\ \%. \tag{7}$$

Economic criterion (EC).

It reflects the possibility to perform R&D taking into account the nominal working time of the organisation and the possibility of involving co-executors in the work.

The economic criterion is calculated according to the following formula:

$$\mathrm{EC} = \mathrm{WTF}_1 \times \mathrm{WTF}_2, \tag{8}$$

Here WTF_1 is an indicator that determines the correspondence between the organisation's working time fund and the time required to implement the ToR requirements for R&D;

WTF_2 is an indicator determining the possibility of engaging co-executors to perform certain work if the labour intensity of R&D work exceeds the organisation's working time fund

$\mathrm{WTF}_2 = 1$ if $\mathrm{WTF}_1 = 1$;

$WTF_2 = 1$ if $WTF_1 < 100$ % and there is a possibility to engage co-executors to carry out certain works;

$WTF_2 = 0$ if $WTF_1 < 100$ %, and there is no possibility of engaging co-executors to perform individual works.

$WTF_1 = 100$ % if relative $WTF_1 \geq 100$ %,

$WTF_1 = Rel.WTF_1$ if relative $WTF_1 < 100$ %,

$$Rel.WTF_1 = \frac{T_{nom}}{T_{LIplan}} \times 100\%, \quad (9)$$

where T_{nom} is nominal working time; T_{LIplan} is planned labour input for R&D.

In order to select a method for calculating the planned labour input of R&D, the analysis of existing methods and algorithms for determining the labour input of work on the creation of scientific and technical products was carried out.

When assessing the possibility of using one or another method for determining the labour intensity of R&D, the following criteria were taken into account:

simplicity of calculation;

universality;

possibility to estimate labour inputs at all stages of product development;

applicability for estimating labour costs of software development;

scientific validity;

acceptable calculation accuracy.

According to the results of the analysis of normative methods of R&D labour intensity estimation [5], development cost models (COCOMO, COCOMO II) [6, 7], COSYSMO algorithmic model of development cost estimation [8] and Program Evaluation and Review Technique (PERT) [9] it was determined that the Program Evaluation and Review Technique (PERT) is the most preferable method for calculating the planned R&D labour intensity. The technique was developed in 1958 by Booz Allen Hamilton Inc. together with Lockheed Martin Corporation to determine the planned duration of the project to develop a two-stage solid-fuel ballistic missile UGM-27 "Polaris". The methodology is based on a thorough study of the processes of implementation of development work in the US defence-industrial complex. The developers of the method assumed that the durations of individual operations within a project have a β-distribution [10], which means that

$$E(t) = \bar{t} = \frac{1}{6}(A + 4M + B), \quad (10)$$

where *A* and *B* are the lower and upper bounds of the random variable t; M is the most probable value *t*.

The variance of a random variable is determined by the formula:

$$\sigma_t^2 = \left[\frac{1}{6}(B - A)\right]^2, \quad (11)$$

The advantage of the PERT method is the simplicity of the mathematical apparatus used and the use of a probabilistic approach to estimating the duration of individual works that are difficult to ration.

Thus, the calculation of the planned labour intensity of R&D is carried out according to the formula:

$$T_{LIplan} = \frac{1}{6}(A + 4M + B), \quad (12)$$

where *A* and *B* are the minimum and maximum value of R&D labour intensity; M is the most probable value of R&D labour intensity. The values of A, B and M are determined by the expert method.

Integral criterion "Participation Opportunity in R&D" (W). It reflects the degree of DM's confidence in the successful implementation of R&D and the organisation's ability to participate in this work.

Depending on the work performed and the organisation's relevant experience, the implementation of the above-mentioned individual criteria may have different significance in terms of the possibility of performing R&D; therefore, a normalisation condition is introduced for the weighting coefficients of the technical and economic criteria as follows $\sum\alpha_i = 1$. The weight coefficient of the criterion "Legislative and regulatory" is taken to be 1 due to the peculiarities of the requirements of normative legal acts regulating the procedure for R&D implementation in the Russian Federation [11, 12].

The integral criterion "Participation opportunity in R&D" takes a value from 0 to 100%, and is determined by the following formula:

$$W = SRB \times WTF_2 \times (TC \times \alpha_{CBTT} + EC \times \alpha_{EC}) \times 100\%$$

The working time fund indicator, along with the legislative and normative criteria, can be a limitation and influence the possibility of R&D performance.

It is proposed to use a scale from 0 to 100% as a scale of values of the integral criterion, which allows assessing the possibility of an organisation's participation in R&D on the development of a PAC. The closer the value of the integral criterion is to 100 %, the higher is the degree of DM's confidence in the successful implementation of R&D and the higher is the possibility of the organisation's participation in this work. For the convenience of decision-making, the scale of integral criterion indicators is divided into 5 zones [13] (Table 2).

Table 2. Scale of indicators of the integral criterion "Participation Opportunity in R&D".

Participation opportunity in R&D, %				
very low	**low**	**average**	**good**	**high**
0–20	21–40	41– 60	61– 80	81– 100

4 Conclusions

An approach to the formation of methodological support has been proposed to assess the possibility of implementing the requirements of the terms of reference for R&D within the timeframe established by the contract, taking into account the resources available to the potential performer and the level of personnel qualification, based on the method using cosine similarity to assess the relevant experience of the performer and the Programme Evaluation and Review Technique (PERT) to assess the possibility of performing R&D, taking into account the nominal working time of the organisation.

The use of the proposed approach will minimise the risks of nonperformance or improper performance of R&D contract terms when forming commercial proposals for participation in competitive procedures conducted by work customers.

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