Робота відноситься до області моделювання системних процесів з метою вибору найкращого варіанту для прийняття рішення. Встановлено, що для достовірності результату моделювання необхідно накладати обмеження на параметри модельованого процесу. Розроблено метод визначення параметрів обмеження на область допустимих змін параметрів моделей коротких операцій при порівнянні операційних процесів на базі операцій різної тривалості

Ключові слова: дослідження операцій, моделювання операційних процесів, метод моделювання, верифікація формули ефективності

Работа относится к области моделирования системных процессов с целью выбора наилучшего варианта для принятия решения. Установлено, что для достоверности результата моделирования необходимо накладывать ограничения на параметры моделируемого процесса. Разработан метод определения параметров ограничения на область допустимых изменений параметров моделей коротких операций при сравнении операционных процессов на базе операций разной продолжительности

Ключевые слова: исследование операций, моделирование операционных процессов, метод моделирования, верификация формулы эффективности

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DEVELOPMENT OF THE METHOD FOR MODELING OPERATIONAL PROCESSES FOR TASKS RELATED TO DECISION MAKING

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1. Introduction

Investment possibilities of the society and, therefore, the pace of development of industry depend on the efficiency of utilizing available resources.

To argue that a decision that was made improves efficiency, without using thorough methods of operations research, is possible only in one case. This is the case when, as a result of a new technological solution, operational costs and operation time decrease while the quality and cost estimation of the total output product of an operation do not decrease [1, 2].

All other cases, involving decision making, require the application of special methods of operations research. Success stability in the investment activity depends on the reliability of results of such a research.

Complexity of solving this problem is well traced in the history of formation and development of operations research [3–5]. The rhetoric and research methods have not changed much since publication of the first monographs on operations research.

The issues of operations research are well known to professionals who use results of operations research in the problems on optimization of systems processes [6, 7]. "Engineers, researchers, economists and designers continuously offer new, "universal, precise and clear" objective functions. In 1967, one author managed to collect more than 100 criteria of optimization of separation processes. Upon completion of classification it became clear that there was no universal criterion and selection of a criterion of optimization or efficiency of the process is not an easy task" [6].

Complexities, associated with the development and verification of the effectiveness formula, resulted in a rather lengthy crisis in operations research, where, up to now, it is considered preferable to explore operations by the results of modeling of operational processes [8–11].

However, similarly to the case of verification of the effectiveness formula, the key to success lies not so much in the method of research, but in the reliability of results, obtained from its use.

Since modeling of operational processes is the basic tool for direct assessment of operation effectiveness, development of a method for improving the accuracy of modeling is an important scientific task.

2. Literature review and problem statement

It is necessary to compare alternative variants of operations in order to make a well-grounded decision. In this case, one must verify the formula that is supposed to be used as a criterion for comparison. However, the verification process requires the use of the method of mathematical modeling. The use of this method, in turn, requires verification of a model of the operational process.

If verification procedure did not lead to positive results, this choice is carried out using the method of mathematical modeling. However, the need for verification of the operational process remains an open question.

As it is shown by an analysis of sources [12–15], focusing on the issue of operations research, the emphasis in these papers is shifted towards development of the methods for modeling business processes. Thus, paper [12] considers the use of the methods of linear programming, discrete programming [13], non-linear programming [14], dynamic programming [15] and so on.

At the same time, no attention is paid to assessment of reliability of research results, obtained using the methods of mathematical modeling [16–19].

Lack of due attention to the problems of validity of results of operations identification by the effectiveness criterion contributed to creation of the "industry" of optimization criteria.

It is a common practice to try using technical indicators in problems of decision making. Thus, in paper [20], there is an attempt to establish relation of effectiveness and the amount of the "critical load". In article [21], researchers try to solve the problem of effectiveness evaluation using the "reliability" indicator, in paper [22] – with the help of "filling criterion", while "energy of sampling errors" is used in [23]. In paper [24], effectiveness is defined as the magnitude of minimal deviation of an object from the assigned trajectory.

Many papers are dedicated to the issue of energy efficiency [25]. Traditionally, there are many papers, in which costs minimum [26] or a combination of indicators by the Paretto principle [27] are used as the effectiveness criterion. Such criteria are integrated, and particular indicators in their composition pass through the scaling phase with the use of weight coefficients. In this case, weight coefficients are determined based of a subjective view of developers on the extent to which a criterion corresponds to the possibility to assess the effectiveness of an operational process.

Given this, none of the considered indicators passed the verification procedure using the methods of mathematical modeling.

Thus, there is now a scientific issue related to reliability of the decision results. The abundance of various evaluation indicators indirectly point out these problems [20–27]. The structure of these indicators is different and hence, incomparable evaluation results will be obtained under the same conditions.

The developed methods of indirect evaluation [12–19] do not fully solve the problem of estimation reliability, since verification of adequacy of models is carried out at the level of checking technical parameters.

When it comes to models, everything is fine. They can adequately display the physics of the process of transition, grinding, smelting, lump formation, etc. However, to make a decision, it is necessary to compare inputs and outputs of operational processes, taking into consideration their different duration.

In article [28], it is shown that certain constraints, associated with the loss inter-operational transitions, must be imposed on parameters of models in order to obtain reliable data on a modeling result.

Thus, the scientific problem is to determine parameters of such comparable models of operational processes, the results of which can be reliable in problems of decision making.

3. The aim and objectives of the study

The aim of present study is to develop a modeling method by the introduction of constraints on the parameters of operations of the compared operational processes in decision making problems.

To accomplish the aim, the following tasks have been set:

– to state the rules of determining the region of permissible values of cost estimation of the output product of the operational process, consisting of short operations;

– to develop the method for determining the region of impermissible values of cost estimation of the output product of the operational process for problems of mathematical modeling with a view to decision making and verification of evaluation indicators;

– to carry out test studies of the method operation on the example of the two evaluation indicators, designed to determine effectiveness of the studied operations.

4. Determining the rules of comparison of results of operational processes

Any system operation is carried out for solving the problem of increasing the value (cost estimation) of the output operation products (PE) in relation to the value (cost estimation) of input operation products (RE) [29]. Operation representation as signals of registration of the value motion at its input and output is used in the problems of operations research. As a result, solutions of the problems of this class of operations are identified relative to the criterion of resource use efficiency [30]. The use of results of such identification enables making the best decision.

It is possible to directly perform identification of operations by estimating its parameters using the effectiveness formula. But to do it, it is necessary to verify the effectiveness formula [31–33]. As there is no standard of effectiveness, verification is based on the methods of mathematical modeling.

The second opportunity to identify an operation is to use the same method of mathematical modeling, when by final results of the modeled operational process one makes a judgment on effectiveness of an operation it is based on.

Motion of products at the input and output of an operation in the general case has the form of flows of resource consumption and resource efficiency, distributed in time. Reducing these flows to comparable magnitudes makes it possible to represent these flows in the form of the united flows of values at the input ($re(t)$) and at the output of an output of the operation ($pe(t)$) [29].

Such operation model is defined as a global operation model.

In cases where distributed nature of products motion can be neglected, the global operation model is replaced with a simple global operation model. In this model, function $re(t)$ is replaced with parameter RE and function $pe(t)$ is replaced with parameter PE. Here

$$RE = \int_{t_S}^{t_F} re(t)\mathrm{d}t; \quad PE = \int_{t_S}^{t_F} pe(t)\mathrm{d}t,$$

where t_S is the moment of start of the model of simple operation, t_F is the moment of end of the model of simple operation.

Transition from functions $re(t)$ and $pe(t)$ to parameters RE and PE requires explicit determining of time of a simple model of operation (TO). That is,

$$TO=t_F-t_S.$$

Subsequently, the research will be carried out with the use of the global model of a simple operation in the form of threesome of parameters (RE, TO, PE), where $PE>RE$.

It is always possible to determine coefficient of operational transformation (k). Thus,

$$PE=k\cdot RE.$$

For cost-effective operation $k>1$.

Graphically, the model of such operational transformation can be represented as a marked vector. The length of the vector displays duration of the operation model (Fig. 1).

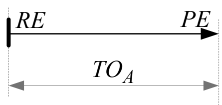

Fig. 1. Graphical model of operation in the form of a marked vector with parameters

As was noted, in order to determine which of the alternative operations (Fig. 2) is more profitable for an enterprise, it is enough to compare the values of their effectiveness indicators.

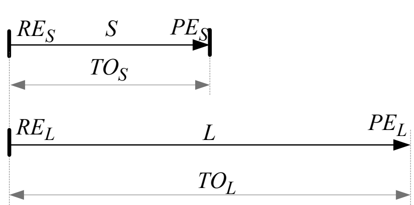

Fig. 2. Examples of models of compared operations: RE_S, TO_S, PE_S – parameters of a short operation S; RE_L, TO_L, PE_L – parameters of a long operation L

The problem is in the existence of an infinitely large set of indicators, the structure of which enables processing parameters RE, TO and PE of compared operations.

For example, it is possible to compare the operations (Fig. 2) using two alternative indicators

$$V_A = \frac{PE-RE}{RE\cdot TO} \text{ and } V_B = \frac{(PE-RE)^2}{RE\cdot PE\cdot TO^2}.$$

Let operation S be represented by the threesome (RE_S=2, TO_S=2, PE_S=2.2), and operation L – by the threesome (RE_L=2, TO_L=4, PE_L=2.4).

Then, V_{AS}=0.05, V_{AL}=0.0375, and V_{BS}=0.023, V_{BL}=0.012.

In this case, values of indicators V_A and V_B are matched. They both indicate that operation S is better than operation L.

If operation L is represented by the threesome (RE_L=2, TO_L=4, PE_L=2.4), the situation changes: V_{AL}=0.05, and V_{BL}=0.021.

That is, indicator V_A points out equality of operations S and L, and indicator V_B continues to distinguish operation S as more profitable.

The only way to verify evaluation adequacy is the method of mathematical modeling.

The use of the method implies implementation of a consistent operational process $\tilde{S}$ and $\tilde{L}$ using such unchanged parameters of initial operation S and L, as well as time and added value factor. In this case, cost estimation of the output product of every previous operation is the cost estimation of the input product of the following operation (Fig. 3).

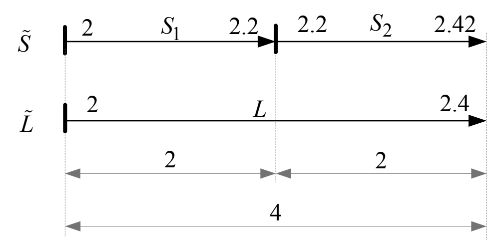

Fig. 3. Modeling of operational process $\tilde{S}$ by creating operation S_2

This approach to modeling is necessary because the resource efficiency research involves modeling the processes, within which the immediate use of the operation results in the following operations occurs.

It was established that operation effectiveness does not change unless the operation time and value-added factor change [33].

Modeling shows that operation of S type is more effective than operation of L type, because by the time of the finish of the second operation, the final result of the operational process, based on operations of S type, is higher.

There seem to be all grounds for this. The initial cost estimation of input operation products is the same and operational processes finish also at the same time. However, this statement is true only in the case if a model of an operational process is adequate.

This is due to the fact that transfer of the product from the output of operation S_1 to the input of operation S_2 cannot proceed without losses. That is why the model in Fig. 3 must be converted to the model in Fig. 4.

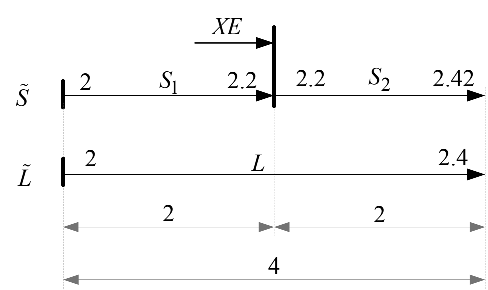

Fig. 4. Model of operational processes, taking into consideration losses of transition between short operations

It means that it is necessary to determine the value of losses of transition XE in order to verify expressions V_A and V_B.

For a particular verified indicator, the region of uncertainty of cost estimation of the output product can be determined in relation to the specific parameters of a long operation. To do this, parameters of short operation S are selected so that value PE_S of the last operation of the cycle at the moment of comparison should be numerically equal to value PE_L.

This effect can be achieved if $k_S^N = k_L$, where N is multiplicity factor of a short operation (Fig. 5).

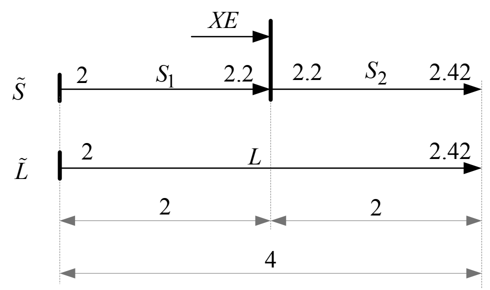

Fig. 5. Models of operational processes with the same result at the moment of comparison

The left boundary of the region of impermissible values of PE_{SL} is determined by value PE_{SL}=kRE. The right boundary is determined in each case separately for each verified indicator.

Thus, for indicator V_A, XE is determined from equality

$$\frac{PE_S + XE - RE_S}{RE_S \cdot TO_S} = \frac{PE_L - RE_L}{RE_L \cdot TO_L}, \tag{1}$$

hence

$$XE = \frac{(PE_L - RE_L) RE_S \cdot TO_S}{RE_L \cdot TO_L} + RE_S - PE_S.$$

Having substituted the data of operations S and L (Fig. 5) in equation (1), we will obtain that XE=0.01.

Then PE_{SR}=kRE+XE=2.21.

For indicator V_B, value of XE is determined from equality

$$\frac{(PE_S + XE - RE_S)^2}{RE_S \cdot (PE_S + XE) \cdot TO_S^2} = \frac{(PE_L - RE_L)^2}{RE_L \cdot PE_L \cdot TO_L^2}, \tag{2}$$

and can be determined with the use of the algorithmic methods.

Having substituted the data of operations S and L (Fig. 5) in equation (2), we will obtain PE_{SR}=kRE+XE= =0.000238.

Then PE_{SR}=kRE+XE=2.200238.

Thus, it is possible to state rules for comparing results of operational processes, based on the use of operations of different duration.

1. It is necessary to determine the region of values of output operation products in comparable cost magnitudes based on operations of different duration in order to have a possibility to compare results of operational processes. In this case, cost estimations of output operation must be within such range of magnitudes, in which the magnitude of losses of transition between successive short operations can be ignored.

2. When using results of modeling in problems of estimation indicator verification, the region of permissible values of a parameter of the output operation product is carried out by results of comparison of a short and a long operation multiple to operation duration. Such comparison is performed using the verified effectiveness criterion.

In this case, operational processes, constructed with the use of compared operations, must have the same initial investments and the same results of operational processes at the moment of their comparison without taking into consideration the losses of operational transitions.

3. In the case of making a decision on operations effectiveness, it is done by comparing results of operational processes at the moment of their simultaneous completion. In this case, the region of permissible values of cost estimations of output products of a short operation is determined either experimentally or with the use of the maximum estimated magnitude of losses as a result of processing the data of a set of evaluation criteria from p. 2.

5. Development of the method for modeling operational processes

Taking into account the above, the method of formation of models of operations in problems of decision making can be represented in the form of the following steps:

1. Parameters of a long operation (RE_L, TO_L, PE_L), where PE_L>RE_L are determined.

2. The value of added value factor of a short operation is determined from expression

$$k_S = \sqrt[N]{k_L}.$$

3. The left boundary of impermissible values of PE_{SL} of a short operation is determined from expression PE_{SL}=$RE{\cdot}k_S$.

4. Determining the width of the region of impermissible values of parameter PE_S.

4. 1. In the case of modeling of operational processes for the verification purpose, the width of the region of impermissible values of PE_S is determined from the condition of equality of the left and the right parts of the verified expression.

In this case, the data of parameters of a short operation with variable XE, taking into consideration uncertainty of parameter PE_S., are substituted into the left part of the verified expression. The data of the parameters of a long operation are substituted into the right part of the verified expression.

The width of the region of impermissible values of PE_S is determined by solving equality relative *to XE*.

4. 2. In the case of modeling operational processes with a view to decision making or optimization, it is supposed that the effectiveness formula is not verified. To determine the width of the region of impermissible values of PE_S, a set of unverified estimated indicators with the required formal features is determined. The indicator that requires the widest uncertainty region is selected among these indicators. Magnitudes of XE, determined with the use of this indicator are used to determine the width of the region of impermissible values of PE_S.

5. The right boundary of parameter PE_{SR} of a short operation is determined from expression PE_{SR}=kRE+XE.

6. Steps 3–5 are repeated for each short operation within the interval of duration of a long operation.

6. Solution to the problem of modeling operations using the developed method

Let us consider the problem of modeling operational processes with the aim of verification of formula

$$V_B = \frac{(PE-RE)^2}{RE\cdot PE\cdot TO^2}.$$

Let us assume that a long operation has the following parameters: RE_L=2, TO_L=4, PE_L=2.42.

We will determine parameters of uncertainty zone for an alternative operation:

$$RE_S=RE_L=2,\ TO_S=TO_L/2=2,\ k_S=\sqrt{k_L}=1.1.$$

The value of parameter PE_S of the left boundary of uncertainty zone $PE_{SL}=k_S RE_S=2.2$.

Determining the right boundary of the uncertainty zone from equality of the ratio

$$\frac{(PE_S+XE-RE_S)^2}{RE_S\cdot(PE_S+XE)\cdot TO_S^2}=\frac{(PE_L-RE_L)^2}{RE_L\cdot PE_L\cdot TO_L^2}.$$

Having substituted values of operation *SL* and *L*, we will obtain

$$\frac{(2.2+XE-2)^2}{2\cdot(2.2+XE)\cdot 2^2}=\frac{(2.42-2)^2}{2\cdot 2.42\cdot 4^2},$$

hence, XE=0.000238.

Thus, PE_{SR}=2.2+0.000238=2.200238.

We will construct three models of short operations, in which two values of cost estimation of the output product are at the edges of uncertainty region and one value gets into this region. Let it be values PE_{SL-}=2.19, PE_{SR+}=2.21, PE_{SN}=2.2002 (Fig. 6).

		Value added factor			
		1.21	1.095	1.1001	1.105
		Operational processes			
		$\tilde{L}_1$	$\tilde{S}_1$	$\tilde{S}_2$	$\tilde{S}_3$
Time	0	2	2	2	2
	1				
	2		2.19	2.2002	2.21
	3				
	4	2.42	2.39805	2.42044	2.442
V_B		0.227789	0.20605	0.22771	0.2494
		Estimation indicator			

Fig. 6. Comparison of effectiveness of operations by results of modeling and with the use of estimation indicator V_B

One can see that the resulting value of operational process S_2 at the moment of comparison (2.42044) is higher than the value of operation *L*, obtained at the same moment (2.42). Therefore, modeling operation with parameter k=1.001 is impermissible.

Similar results were obtained for indicator V_A (Fig. 7).

The final value of operational process $\tilde{S}_2$ is higher than the final value of the operational process $\tilde{L}$. In this case $V_{AL}=V_{AS2}$.

		Value added factor			
		1.21	1.095	1.105	1.11
		Operational processes			
		$\tilde{L}_1$	$\tilde{S}_1$	$\tilde{S}_2$	$\tilde{S}_3$
Time	0	2	2	2	2
	1				
	2		2.19	2.21	2.22
	3				
	4	2.42	2.39805	2.44205	2.4642
V_A		0.0525	0.0475	0.0525	0.055
		Estimation indicator			

Fig. 7. Comparison of effectiveness of operations by results of modeling and with the help of estimation indicator V_A

Therefore, modeling of operations with parameter k=1.105 is impermissible

7. Discussion of results of research related to the development of the method for modeling operational processes

The method for determining optimal control using the methods of mathematical modeling is quite popular. In this case, much attention is paid to accuracy of construction of models of operational processes and enhancing the accuracy of calculation methods. At the same time, little importance is attached to determining constraints that should be imposed on modeled objects.

Comparison of operational processes with similar initial investment is considered. This is a necessary condition, which allows making a judgment about comparability of final results of the operational process, of course, only if the operations of compared processes finish simultaneously.

The multiplicity condition for short operations of one process in relation to long operations of the second process is very strict and is hardly possible to be met while solving most practical tasks.

In this sense, this research rather indicates the existence of a problem in this regard than offers a ready practical solution. Obviously, the studies, connected with the necessity of taking into consideration inter-operation losses, are still to be carried out.

In addition, in the case of modeling cumulative operational processes, it is required to keep in mind that these losses increase with an increase in value added factor and the absolute magnitude of cost estimation of a transferred product (Fig. 8).

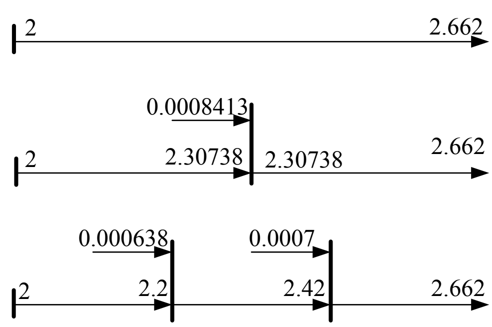

Fig. 8. Change in inter-operational losses at an increase in magnitude of value added factor and cost estimation of output operation product

On the other hand, in the vast majority of cases, there is no need to use the methods of mathematical modeling to obtain prognostic estimates of effectiveness. In the case if there is an optimization process, it is much easier to compare separate operations rather than operational processes, generated by them. In this case, the proposed method of modeling allows avoiding errors in selection of evaluation expressions, which are planned to be used as an effectiveness criterion, in verification problems.

8. Conclusions

1. The rules for determining the region of permissible values for cost estimation of output products of a short operation in problems of mathematical modeling with a view to making a decision and verification of estimation indicators were stated.

The set of rules is reduced to the following points:

– input and output quantitative parameters of operations must be reduced to comparable cost magnitudes;

– compared estimates of output products of a short operation must have the same initial investment and start simultaneously;

– cost estimates of output products of a short operation must be in such a range of magnitudes, within which losses of transition between successive short operations can be ignored;

– comparison is carried out at the time of simultaneous completion of compared operational processes.

Statement of the rules allows using the capabilities of the verified expression itself to determine parameters of modeled operational processes.

2. The method for determining the region of permissible values for parameters of short operations of compared processes was developed. This makes it possible to formalize the solution of the problem of determining constraints on generated model data.

The method is based on determining:

– parameters of an operation of longer duration;

– parameters of a short operation based on parameters of a long operation;

– boundaries of the region of impermissible values of output parameters of short operations.

3. Verification of the developed method of modeling on the example of comparing results of two operational processes was performed. Comparison of the results of operational processes with the results of estimation of separate operations of there processes was obtained. It was shown that in the region, excluded from consideration, with the use of the proposed method, there is a mismatch of modeling results with the results of direct estimation of operations using the verified indicators.

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