EXPENSE EVALUATION AND OPTIMIZATION FOR PROVIDING COMMUNICATION SYSTEM SUSTAINABILITY

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In article discusses the problem of rational distribution of costs among the forces and means ensuring the preservation of the stability of the communication system. In the given task values of probability of reduction of stability of communication system and intensity of its recovery are determined. The article specifies the limitations of the task, as well as the stages of implementation. In the work, the function of costs for ensuring preservation of the required stability and the required intensity of its restoration is justified with determination of values and detection of trends of cost change at change of values of indicators of probability of reduction of stability of the communication system and intensity of its restoration. In the resulting result, the total cost of keeping the object alive is determined by the dependency resulting from the calculations. Areas of permissible values of variables of probability of reduction of stability of communication system and intensity of its recovery are determined. In the given task the algorithm of numerical method is defined, the result of which was formation of areas of permissible values of probability of reduction of stability of communication system and intensity of its restoration. The article described in detail the method of cost minimization, which was to determine the procedure of finding the required values, at which costs are minimized according to the task. Examples of determination of costs for object survival, required minimum values of survival function are given. The figures calculated in the computer program were tabulated. Dependencies were determined from the resulting values in the table. Based on the obtained schedules of cost dependence on survival, the corresponding conclusions were drawn.

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1. Formulating the task

In the process of providing necessary sustainability for communication systems a task of reasonable expenditure distribution between sustainability providing means occurs. Indeed, a complex of expensive measures is necessary (such as extra service, increased protection etc) to reduce the probability of communication system falter, depending on its peculiarities [1]. However, even with high expenditures the chance of the system becoming non-sustainable can remain high, thus not meeting the necessary requirements. At the same time, if some part of the expenses is spent on operational sustainability restoring, this probability can be maintained at the necessary level.

Thus, we face an alternative: which part of expenses is to be spent on reducing sustainability decrease probability, and which part is to be spent on providing its restoring, so that the total expenditures are minimized, considering the given sustainability requirements.

The task can be formulated as follows. Such values of the probability of communication system sustainability decrease P^* and its restoring intensity μ^* are to be defined, so that the smallest value of sustainability function $\varphi_m(P, \mu)$ is no less than the required ($\varphi_{mтр}$) the value of total expenses $C(P, \mu)$ being minimal, i. e.

$$C(P^*, \mu^*) = \min_{P,\mu} [C_Z(P) + C_v(\mu)],\ \varphi_m(P.\mu) \geq \varphi_{m\,тр}, \quad (1)$$
$$0 \leq P \leq 1,\ \mu > 0$$

where $C_z(P)$ and $C_v(\mu)$ are expenses for maintaining the required sustainability and the necessary intensity of its restoring respectively.

This task is a non-linear programming task [2] and has the following constraints and specific features:

No uniquely determined functions $C_z(P)$ и $C_v(\mu)$, whose feasibility requires extra apriori data for correlation of expenses to P and μ values;

Analytical expressions for the sustainability function $\varphi_m(P, \mu)$, particularly for the large number of attacks, are quite complicated, thus, using those expressions explicitly is impractical;

Determination and analysis of the allowed set of values P and μ, meeting inequations $\varphi_m(P, \mu) \geq \varphi_{mтр}$, $0 \leq P \leq 1$, $\mu > 0$, deals with working out new effective algorithms and computer programs

Taking into account these features, the procedure of working out an acceptable method for solving the task includes the following stages:

Reasoning the general approach to formulating functions (P) and $C_v(\mu)$ based on the analysis of resources spent for providing communication system sustainability;

Formulating and analysis of the allowed set of values ***D*** for variables P and μ, limited by the function $\varphi_m(P, \mu) = \varphi_{mтр}$;

Choosing the most effective method of solving the non-linear programming task, taking into account the peculiarities of the objective function $C(P^*, \mu^*)$ and constraints;

Working out the algorithm and computer programs for the method and its efficiency and accuracy evaluation;

Method probation for the particular example of determining reasonable expenses, providing the required workability of the communication system.

Methods of solving such a task were examined in detail in [3-6] applicable to certain communication systems and satellite guidance systems. The article demonstrates the results of the analysis and generalization of these methods for their prospective use in reasoning communication system sustainability requirements.

2. Expense function

Feasibility of functions $C_z(P)$ and $C_v(\mu)$ is connected with determining their allowed set of values and finding the tendency of expense changes with P and μ value changes.

Obviously, whatever great expenses, sustainability $P = 0$ cannot be provided by a complex attack on the system. Therefore $C_z(P = 0) \to \infty$. At the same time, there is a tendency of rapid expense growth with P, value, close to 0. It can also be suggested that with no expenses and rejecting sustainability maintaining activities probability will be close to one, which means $C_z(P = 1) = 0$. However, the rate of expense change with P, values close to one remains very low. Such extreme values and tendencies of expense change correspond to the following logarithmic function:

$$C_z(P) = -k_z \ln P \quad (2)$$

where k_z is the protection rate taking into account expense change per $\ln P$; «–» sign used because of $\ln P \leq 0$.

One of the possible variations of $C_z(P)$ function graph is illustrated in figure 1a.

Intensity μ is a value, reciprocal to the average time of communication system element m_τ, restoring i. e. $\mu = 1/m_\tau$. Determining correlation between restoring expenses and restoring time, the following algorithm can be suggested. Suppose an object includes n damaged blocks (details, aggregates etc). The average restoring time for each block equals $m_{\tau б}$. Staff is organized for restoring operations with necessary equipment, organizational expenses equaling $C_б$. The staff can restore blocks one after another. Therefore, total object restoring time equals $m_\tau = nm_{\tau б}$, and restoring expenses equal $C_v = C_б$.

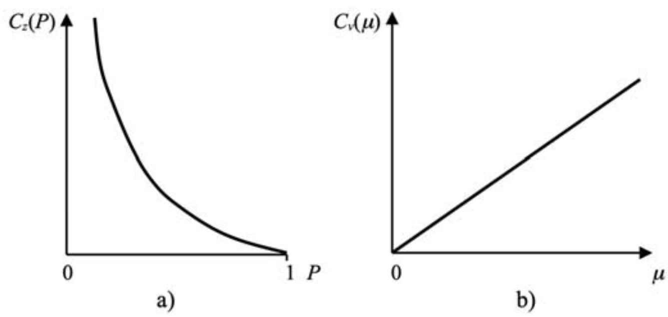

Fig. 1. Expense correlation with P and μ values

Suppose we now organize two staff units, organizing expenses equaling $C_v = 2C_б$. These units can simultaneously restore two blocks, total restoring time reducing by half and equaling $m_\tau = 2^{-1} nm_{\tau б}$. Organizing three units of staff, we have the following data:

$C_v = 3C_{\text{б}},\ m_\tau = 3^{-1} nm_{\tau\text{б}}$.

Organizing n units of staff

$C_v = nC_{\text{б}}$ and $m_\tau = n^{-1} nm_{\tau\text{б}} = m_{\tau\text{б}}$.

As a result, the product $C_v m_\tau$ will be a constant value, provided average values $_{\tau\text{б}}$, $C_{\text{б}}$ and n remain fixed, i.e. $C_v m_\tau = nC_{\text{б}} m_{\tau\text{б}} = k_v$.

Thus, according to the current research scheme, we have C_v reciprocally dependent on m_τ, $C = k_v/m_\tau$. If we now replace m_τ with $1/\mu$, we find the expense dependence on restoring intensity:

$$C_v(\mu) = k_v \mu \tag{3}$$

where k_v is the restoring rate or expense change per μ.

One of the possible $C_v(\mu)$ function graphs is illustrated in Figure 1b.

As a result, total expenses for providing object viability can be determined by the following formula:

$$C(P, \mu) = k_v \mu - k_z \ln P \tag{4}$$

3. Determination algorithm for the set of allowed values

Formulating set ***D*** of allowed values for variables P and μ, limited by the correlation $\varphi_m(P, \mu) = \varphi_{m\text{тр}}$, is only possible with using numerical methods due to implicit assignment of the transcendental function $\varphi_m(P, \mu)$. Numerical method's general algorithm includes the following stages:

1. I roducing the given data: λ – enemy's attack intensity, n – upposed number of attacks, $\varphi_{m\text{тр}}$ – viability function minimal required value.

2. signing a cycle formulating values P_i. Normally P is formulated with an accuracy within 1%, i. e. P = 0,01; 0,02; … ; 1.

3. Assigning the cycl to formulate values μ_j = 0,01; 0,02; …; μ_{max}, where μ_{max} choice is based on experience. Normally $10 \le \mu_{max} \le 30$.

4. As gning the cycle to formulate values t_k = 0; 0,1; 0,2;…; t_{max}, where t_{max} choice is based on the supposed duration of the warfare or object functioning.

5. D ermining balues of the function $\varphi(P_i, \mu_j, t_k, \lambda, n)$ with the use of the following correlations [140]:

$$\varphi(t, 1) = 1 - PF_1;\ F_1 = \lambda(\mu - \lambda)^{-1}(e^{-\lambda t} - e^{-\mu t});$$

$$\varphi(t, 2) = 1 - P[F_1 + (1 - P)F_2] - P^2 F_4;$$

$$\varphi(t, 3) = 1 - P[F_1 + (1 - P)F_2 + (1 - P)^2 F_3] - P^2[F_4 + + 2(1 - P) F_5] - - P^3 F_6,$$

where $\varphi(t, n)$ – is object viability function for n enemy's attacks; F_i – expressions determined by the resultants of the function of time distribution probability between attacks $F(t)$ and restoring time $G(t)$.

6. omparing values $\varphi(P_i, \mu_j, t_k)$ for fixed P_i, μ_j and the variable t_k. Determining function $\varphi_m(P_i, \mu_j)$ minimal value.

7. ormulating remainders $\Delta_j = |\varphi_m(P_i, \mu_j) - \varphi_{m\text{тр}}|$ with fixed P_i and variable μ_j. Finding the remainder Δ_j, corresponding to the inequation $\Delta_j \le 0{,}001$. This inequation provides high precision of the numerical method, i. e. Corresponding of $\varphi_m(P_i, \mu_j)$ to $\varphi_{m\text{тр}}$ within 0,1%.

8. xing P_i and μ_j, corresponding to the remainder $\Delta_j \le 0,\ 001$, and formulating the set of values P_i and the set of corresponding values μ_j, with $\varphi_m(P_i, \mu_j) = \varphi_{m\text{тр}}$ within a given accuracy.

9. Filling in the table with the set of values P_i and μ_j and building $\mu = f(P)$ function graph at $\varphi_m(P, \mu) = \varphi_{m\text{тр}}$.

In figure 3.2 allowed sets of values ***D*** are illustrated, limited by functions $\varphi_m(P, \mu) = 0{,}9$, at n = 1, 2, 3; λ = 1, and lines P = 0 and P = 1. The shaded ***D*** area is that limited by the function at n = 3.

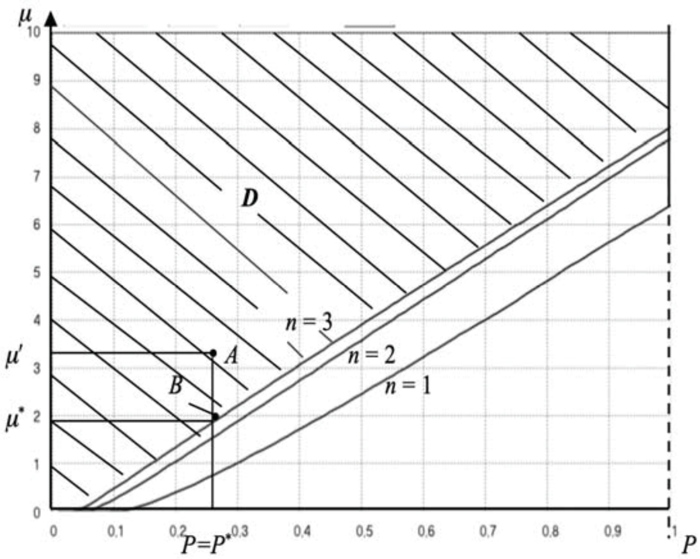

Fig. 2. Formulating sets of allowed values P and μ at $\varphi_{m\text{тр}}$ = 0, 9; λ = 1 and n =1, 2, 3

The graphs show that sets ***D*** of allowed values for variables P and μ, restrained by (1), are convex. For any poin $A(P', \mu')$ lying within these sets of values, there is a point $B(P^*, \mu^*)$ at the border of the areas $\varphi_m(P, \mu) = \varphi_{m\text{тр}}$ for which $C(P^*, \mu^*) < <\ \ < <$ $C(P', \mu')$. Indeed, if any point $A(P', \mu')$ is taken (see figure 3.2), it always corresponds to a certain point $B(P^*, \mu^*)$, for which $\mu^* < \mu'$ at $P^* = P'$. Since the expense function (3.4) is proportional to values P and μ, $C(P^*, \mu^*) < C(P', \mu')$. Based on that, a conclusion can be drawn that the expense function minimum according to the mission assigned is to be sought at the lower limit of ***D*** set of values, thus the inequation (1) can be replaced with the equation $\varphi_m(P, \mu) = \varphi_{m\text{тр}}$.

Figure 3 illustrates other variants of allowed sets of values limited by the functions $\varphi_m(P, \mu) = 0{,}9$, at n = 1 and λ = 1, 2, 3.

The shaded area ***D*** is limited by the function at λ = 3. Similar arguments are applicable for finding the expense function minimum at the lower limit of the ***D*** area.

4. thod of expense minimization

The results achieved determine the procedure of finding the required values P^* and μ^*, for which expenses are minimal according to the assigned task (1).

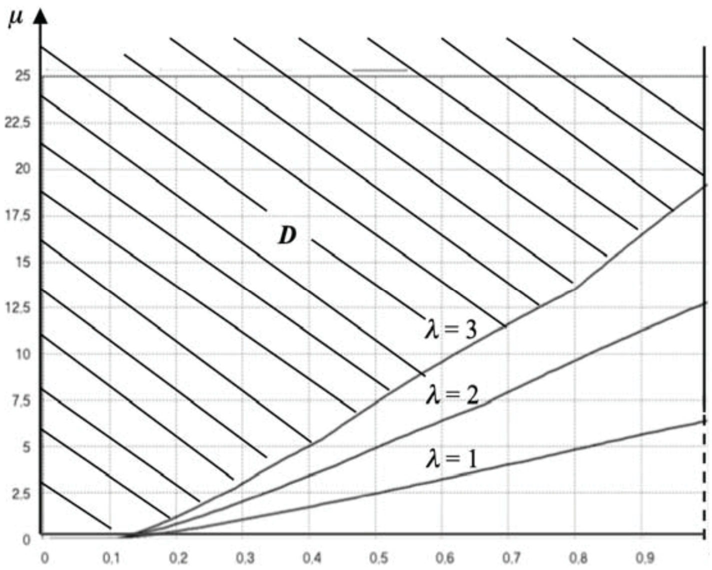

Fig. 3. Formulating allowed sets of values P and μ at $\varphi_{mтр}$ = 0, 9; n =1 and λ = 1, 2, 3

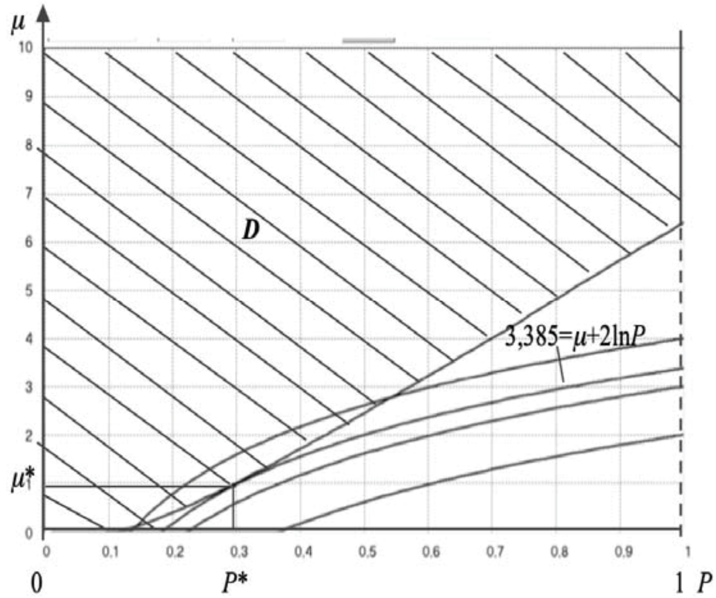

Fig. 4. Possible graphic solution of the task

To achieve the claimed goal, any of the suggested methods of non-linear programing task solving with non-linear function and limitations can be chosen [7-8]. However, taking into consideration the small amount of variables (only two), the method of targeted search can be used for the solution [9].

The method is the following:

Based on the given data λ, n и $\varphi_{mтр}$ the set of allowed values ***D*** is determined for variables P and μ;

A growing expense succession is formulated C_i, i = 0, 1, 2, …, starting with the minimal possible value C_0; $\Delta_i = C_{i+1} - C_i$ is chosen according to the required precision of calculating;

Coefficients k_v и k_z are given and values P_i и μ_i,corresponding to the following equations are determined succeedingly:

$$k_v\mu_i - k_z \ln P_i = C_i;\ i = 0, 1, 2,\ldots;$$

acquired values P_i и μ_i are compared to the values of P and μ coordinates for the point of the lower limit in the set of values ***D*** within the required precision.

At a certain n comparison level ($i = n$) tangency point is determined $B(P^*, \mu^*)$ for the curve $\varphi_m(P, \mu) = \varphi_{mтр}$ and the curve $C(P, \mu) = C_n$, whose coordinates P^* and μ^* determine the required solution.

Figure 3.4 demonstrates a variant of such graphic solution of the task for the following data: λ = 1; n = 1; $\varphi_{mтр}$ = = 0,9; k_v = 1; k_z = 2.

Tangency point for the curve determined by the equation 3,385 = μ + 2ln$P$, has the following coordinates $P^* \approx 0{,}3$; $\mu^* \approx 1$. Consequently, minimal expenses C_{min} for providing object viability for the value of 3,385 cost units, the recommended protection expenses being C_z = 2,385 cost units.

Compared to the graphic method, the numerical method gives more precise results [10]. For example, for the data given above, we acquire the following results P^* = 0,29; $\mu^* \approx 0{,}94$, C_{min} = 3,41, C_v = 0,94, C_z = 2,47.

5. xpense determining examples and results

The suggested method allows to achieve practical suggestions in rational resource distribution while providing the required communication system viability [11]. However, for the results to be trustworthy, the following steps are required.

Firstly, reasoning and applying the method of foreseeing possible consequences of enemy's attack on the communication system to determine the number of attacks, time intervals and object destruction probability.

Secondly, specifying the dependence (1) of total viability providing expenditures on its restoring possibility and protectability, based on reviewing statistics [12]. Both coefficient values k_v and k_z, and the type of functions used are to be considered.

Example 1. Let us determine minimal costs of communication system viability providing for the following given data:

Attack intensityλ = 1[1/day], i. e. an average of one attack a day is expected; expected number of attacks n = 3;

The required minimal value of the viability function $\varphi_{mтр}$ = 0,9, i. e.accurate communication system functioning probability for the whole period of warfare is required to be no less than 0,9;

k_v = 2 mln roubles per restoring intensity unit μ is given for restoring the object viability, i. e., to provide μ = 1[1/day] or m_τ = 1 day2 mln roubles is required., for μ = 2[1/cyday] or m_τ = 12h 4 mln roubles is required etc;

k_z = 3 mln roubles per negative unit ln$P$ is given for providing protection, i. e., for providing ln$P$ = –1 or $P \approx 0{,}37$ 3 mln roubles is required, for ln$P$ = –2 or P ≈ 0,136 mln roubles is required., finally, to provide practically absolute protection, where ln$P$ = –10 and $P \approx 0{,}000045$, 30 mln roubles is required

For solving the task we shall use the computer program (see part 3.6), which after input of all the given data gives the following results $\mu^* = 1{,}08 \approx 1$[1/day]; P^* = = 0,17; C_{min} = 7,47 mln roubles.

Thus, to provide the required viability it is enough to spend 7,47 mln roubles and restoring activities should be organized ensuring restoring intensity 1,08[1/day] or average restoring time $m_\tau \approx 1$ day, and attack intensity 0,17, which leads to the following expenditure decrease: restoring expenditure – 2, 16 mln roubles., protection expenditure – 5,31 mln roubles

Graphic solution of the task is illustrated in figure 5.

Based on the graph built we have the following approximate results:

$\mu^* \approx 1$[1/day] и $P^* = 0,17$

which mostly correspond to the data described above.

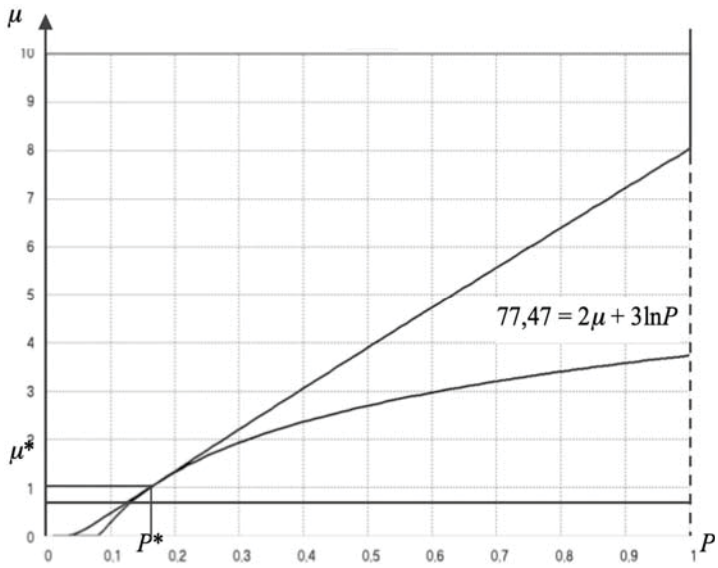

Fig. 5. Graphical solution for example 1

Example 2. Enemy attack intensity $\lambda = 1$, expected number of attacks $n = 3$, principal expenses $k_v = 2$, $k_z = 3$. The task is to find the dependence of communication system viability providing expense from the required maximal viability function value.

Let us set the required minimal values for viability function $\varphi_{мтр}$ = 0; 0,1; 0,2; …; 0,9; 0,91; …; 0,99; 1. For each value we use a computer program (see part 6) to fins the minimal required expense. Table 1 gives the calculation results.

Table 1

Expense calculation results

Fmтр	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	0,91	0,92	0,93	0,94	0,95	0,96	0,97	0,98	0,99	1
C	0	0,2	0,46	0,78	1,22	1,9	2,87	4,04	5,6	7,5	7,8	8,1	8,5	8,9	9,4	9,96	10,6	11,56	13,5	Беск.
Cв	0	0,2	0,46	0,78	1,22	1,9	2,1	2,2	2,22	2,23	2,24	2,25	2,25	2,25	2,25	2,25	2,25	2,25	2,25	2,25
Cз	0	0	0	0	0	0	0,77	1,84	3,38	5,27	5,56	5,85	6,25	6,65	7,15	7,71	8,35	9,31	11,25	Беск.

Line 1 includes values $F_{мтр} = \varphi_{мтр}$, line 2 shows total expense values C for providing viability, line 3 shows restoring expense values $C_в = C_v$, line 4 shows object protection values $C_з = C_z$

Based on the acquired results, dependence graphs $C(\varphi_{мтр})$, $C_v(\varphi_{мтр})$ и $C_z(\varphi_{мтр})$ are built, shown in figure 6.

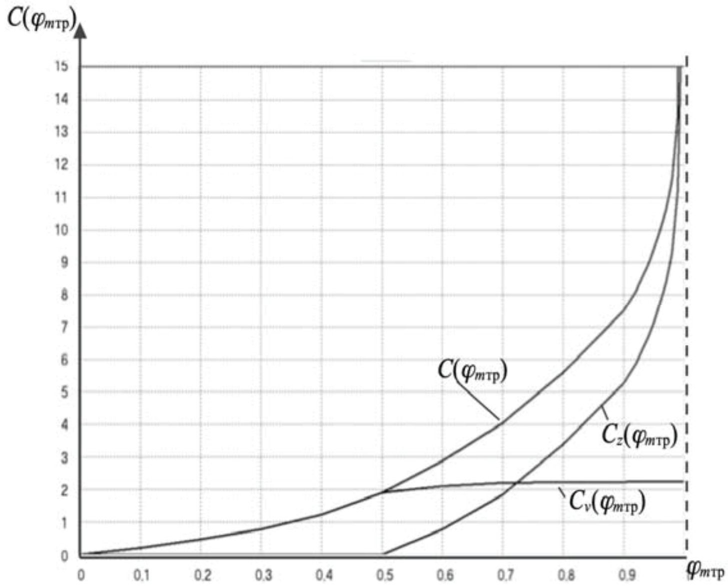

Fig. 6. Dependence of cost on viability

Analysis of these graphs demonstrates that since low requirements are set for communication system viability, where $\varphi_{мтр} < 0,5$, it is only feasible to spend resources on communication system restoring. Meanwhile, protection costs equal 0, and as additional calculations show, object destruction probability $P^* = 1$.

If higher viability requirements are claimed, where $\varphi_{мтр} \geq 0,5$, system protection costs $C_z(\varphi_{мтр})$ are growing steadily, whereas restoring costs $C_v(\varphi_{мтр})$ are stabilized and this value becomes constant whatever viability requirements are.

Thus, based on the calculations the following conclusion can be made: to minimize total expense in conditions of increasingly high viability requirements, rational constant system restoring expenses are to be determined and the reasons for increasing protection expense graph are to be provided.

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ОЦЕНКА И ОПТИМИЗАЦИЯ ЗАТРАТ ПРИ ОБЕСПЕЧЕНИИ УСТОЙЧИВОСТИ СИСТЕМЫ СВЯЗИ

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Аннотация
Рассмотрена задача рационального распределения затрат между силами и средствами, обеспечивающими сохранение устойчивости системы связи. В поставленной задаче определяются значения вероятности снижения устойчивости системы связи и интенсивности ее восстановления. В статье указаны ограничения поставленной задачи, также указаны этапы реализации. В работе обоснована функция затрат на обеспечение сохранения требуемой устойчивости и необходимой интенсивности ее восстановления с определением значений и выявлением тенденций изменения затрат при изменении значений показателей вероятности снижения устойчивости системы связи и интенсивности ее восстановления. В полученном результате суммарные затраты на обеспечение живучести объекта определены зависимостью, полученной в результате вычислений. Определены области допустимых значений переменных вероятности снижения устойчивости системы связи и интенсивности ее восстановления. В поставленной задаче определен алгоритм численного метода, результатом которого было формирование областей допустимых значений вероятности снижения устойчивости системы связи и интенсивности ее восстановления. Подробно раскрыт метод минимизации затрат, который заключался в определении процедуру поиска требуемых значений, при которых минимизируются затраты в соответствии с поставленной задачей. Приведены примеры определения затрат на обеспечение живучести объекта, требуемого наименьшего значения функции живучести. Показатели, рассчитанные в компьютерной программе, были сведены в таблицу. По результатам полученных значений в таблице были определены зависимости. По полученным графикам зависимости стоимости от живучести, были сделаны соответствующие выводы.

Ключевые слова: *устойчивость системы связи, живучесть объекта системы связи, зависимость затрат, интенсивность восстановления, алгоритм численного метода, функция затрат.*

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