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Standarty i Kachestvo 8, pp. 49-54 (1966)

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METHODS OF ESTIMATING THE ECONOMIC EFFECTIVENESS OF INCREASED RELIABILITY OF RADIOELECTRONIC SYSTEMS

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The article deals with cost calculation methods of projected radio electronic systems used for automation and control of production processes. Two methods of improving the reliability (improving the quality of the components and optimal reservation) are given, and their economic expediency is determined.

The urge to improve the technical characteristics of radio electronic systems has for its result that their complexity and cost increase year after year. However, the more complex a system is, the less will be its reliability. It is primarily due to the fact that the reliability of the components is, as a rule, considerably below the reliability required for the entire system.

An economic estimate of projected products usually confines itself to the establishment of the empirical relationships between the expenditures on planning, production, and operation, on one hand, and the technical, structural, and technological characteristics, on the other. Inadequate attention is paid to "qualitative" characteristics of products. No consideration is given to a series of structural, production, and operational factors which effect substantially the amount of expenditures.

It is known that improved reliability of radio electronic systems (other conditions being equal) improves their useful performance and reduces the quantity required for a specified volume of work. At the same time, additional expenditures are needed to improve the reliability. The presence of these (contradictory in a certain sense) tendencies requires a corresponding analysis because the effect obtained by improving the reliability must be commensurable with the extra expenditures. In principle, such a comparison is always needed for finding the optimal relationship between the indicators of the functioning of the system and the efficient (from the economic point of view) way of improving the reliability.

The reliability of any radio electronic system must be incorporated in the planning, must be assured in the series production, and must be maintained in operation.

An economic estimate of improved reliability of projected products encounters considerable difficulties because of the lack of reliable information on the proposed expenditures. In such a case it is always first necessary to disclose the factors governing the changes in the expenditures for the production and operation of radio electronic equipment, depending on the level of its reliability.

I. COST CALCULATION BASED ON STRUCTURAL CHARACTERISTICS

Let us consider the effect of the level of reliability on the magnitude of the expenditures for the production and operation of products with the quality of components improved and with an optimal reservation of the basic assemblies (blocks).

Improved Quality of Component Elements

An analysis of the information available in our country and abroad on the economic and technical characteristics of the reliability of electronic elements had established the regularity with which the cost increases with their increased level of reliability.

The cost of elements $\left(C_i\right)$ both made by the enterprise and purchased elsewhere, as a result of their improved quality, increases proportionally to the value of

$$C_i = C_{p_o} \frac{1 - P_o}{P_o} \frac{P_i}{1 - P_i} ,$$

where P_o is the initial reliability of the products;

P_i is the required reliability of the elements;

C_{p_o} is the cost of an element with the initial reliability P_o.

The overall cost of the component elements with the level of their reliability taken into account, is:

$$C_{\text{component element}} = \sum_{i=1}^{m} C_{n_{oi}} \frac{1 - P_o}{P_o} \frac{P_i}{1 - P_i} n_i \,, \tag{1}$$

where m is the number of types of elements (resistors, electronic vacuum tubes, etc., etc.);

n_i is the number of elements of the i^{th} type.

Depending on the given value of reliability, the calculation of $C_{\text{component element}}$ must be preceded by the establishment of the necessary values of the reliability of P_i of the elements. The index of unreliability of radio electronic system $\left(A_o\right)$ is determined by the probability of the required performance without failures $\left(P_{i\ \text{required}}\right)$

$$A_c = -\ell\eta P_{i\ \text{required}} \,.$$

The index of unreliability of each type of elements is:

$$A_i = A_c \frac{n_i \lambda_{\text{weighted } i} t_i}{\left(\sum_{i=1}^{m} n_i \lambda_{\text{weighted } i} t_i\right)} \,,$$

where $\lambda_{\text{weighted } i}$ is the weighted average of the intensiveness of failure to perform by the elements of the i^{th} type;

t_i is the duration of the work of elements of the i^{th} type.

Next, the index A_i is used to find the required value of reliability of each type of element.

$$P_i = e^{-Ai}$$

and the characteristics of reliability $\lambda_{\text{weighted } i}$ of one element, is

$$P_i = e^{-\lambda_{\text{weighted } i} n_i t_i}$$

or

$$\lambda_{\text{weighted } i} = \frac{-\ell\eta\, P_i}{n_i t_i} \quad .$$

Unlike the method considered above, improved reliability of a radio electronic system leads only to a quantitative change in the composition of the system, its higher weight, and larger dimensions. The use of methods of by-element and overall reservation for such expensive and labor-consuming products as the radio electronic equipment requires large expenditures of materials. In such a case it is expedient to use the method of optimal reservation which makes it possible to minimize the expenditures for a reliabiltiy not below the required [1].

The cost of a nonreserved system $\left(C_o\right)$ is defined as the sum of the expenses for the production of each assembly (blocks, elements) C_γ

$$C_o = \sum_{\gamma=1}^{n} C_\gamma \quad ,$$

where n is the number of assemblies (blocks, elements) in the system.

The probability of performing without failures of a nonreserved system consisting of n-assemblies with various degrees of reliability is determined by the expression

$$P_c = \prod_{\gamma=1}^{n} \left(1 - q_\gamma\right), \qquad (2)$$

where q_γ is the probability of failure to perform by the γ^{th} assembly.

If each assembly is reserved K times, then the cost of the reserved system, is

$$C_{\text{reserved}} = \sum_{\gamma = 1}^{n} C_{\gamma} K_{\gamma} ,$$

and its reliability is

$$P_{\text{reservation}} = \prod_{\gamma = 1}^{n} \left(1 - q_{\gamma}^{K_{\gamma}}\right).$$

Consequently, it is necessary to find integers of K > 1 at which the reliability by (2) would have the required value and its cost would be a minimum.

The reservation-multiplicity can be calculated as follows:

$$K_{\gamma} = \frac{\ell \eta \left(\frac{y + \alpha_{\gamma}}{\alpha_{\gamma}}\right)}{\ell \eta \frac{1}{q_{\gamma}}} . \quad (3)$$

Here, we have

$$\alpha_{\gamma} = \frac{C_{\gamma}}{\ell \eta \frac{1}{q_{\gamma}}} ; \quad y = \frac{P_{\text{required}} \sum_{\gamma = 1}^{n} \alpha_{\gamma}}{1 - P_{\text{required}}} .$$

The expression which determines the cost of making a radio electronic system with a higher level of reliability (improved reliability is effected by using the method of optimal reservation) will assume the following form:

$$C_{\text{reservation}} = \sum_{\gamma = 1}^{n} \sum_{i = 1}^{m} C_i n_i K_{\gamma} .$$

The change in relative costs of production of radio electronic equipment is shown in Figure 1.

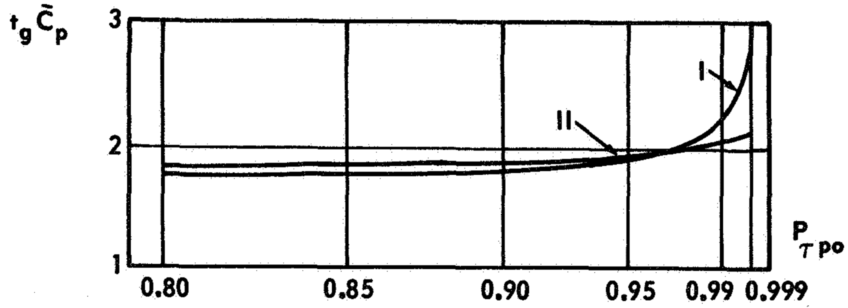

Figure 1. Change in relative cost of radio electronic systems depending on the degree of reliability. Reliability improved by improving the quality of elements (I); by the method of optimal reservation (II).

Figure 1, for example, shows that an improvement in reliability from $P_o = 0.8$ to the required $P_{required} = 0.95$ can be more profitably attained by improving the quality of the elements. For still higher characteristics of reliability, it is more expedient to use the method of optimal reservations.

In estimating the cost required to assure the required level of reliability it is necessary to take into account both the cost of building the system and also the costs of preserving its reliability in operations. These costs can be presented as a sum made up of the amortization charges deducted from the cost of various auxiliary equipment designed for periodic inspection of the reliability of radio electronic systems and the cost of servicing determined by the number of failures during a full operating period.

It may be assumed that the improvement in reliability of radio electronic systems will affect insignificantly the cost of the auxiliary equipment and the overall consumption of time and labor which determines the wages and salaries. Therefore, our further investigation will pertain only to the cost of servicing which, essentially, depends on the level of reliability, i.e.,

$$\sum_{i=1}^{m} C_{fail} N_i .$$

In Figure 2 is shown the expected change in cost of unfit elements of radio electronic systems resulting from improved reliability. These curves correspond to the rise of reliability by improving the quality of the elements (I) and by optimal reservation (II). Figure 2 shows that, beginning with a certain value $\left(P_{required} = 0.9\right)$, the magnitude of the expenses is more affected by

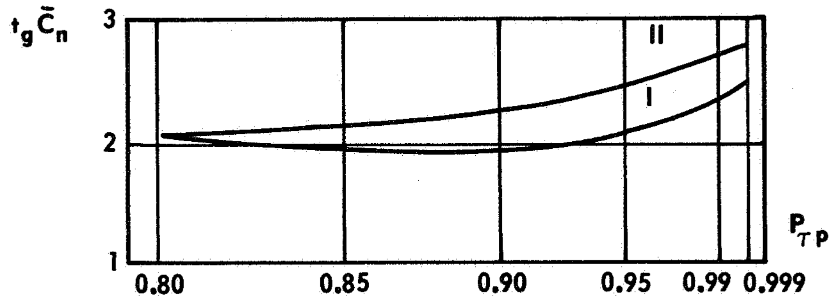

Figure 2. Change in relative cost of replacing unfit radio electronic systems elements depending on the degree of reliability.

the increased cost of the elements than by the reduced number of their failures (which increase the expenses). This increased expenditure is particularly typical when the method of optimal reservation is used.

The cost of operations maintaining the reliability of radio electronic systems when its reliability is raised by improving the quality of the elements is:

$$C_e\left(P_i\right) = \sum_{i=1}^{m} C_{\begin{pmatrix}\text{failure to}\\ \text{perform}\end{pmatrix}_i} \frac{1 - P_o}{P_o} \frac{P_i}{1 - P_i} N_i \ , \tag{4}$$

and, when the reliability is raised by the methods of optimal reservation, the operating cost is:

$$C_e\left(P_i\right) = \sum_{\gamma=1}^{n} \sum_{i=1}^{m} C_{\begin{pmatrix}\text{failure to}\\ \text{perform}\end{pmatrix}_i} N_i K_\gamma \ ,$$

where $C_{\begin{pmatrix}\text{failure to}\\ \text{perform}\end{pmatrix}_i}$ is the cost of one failure to perform by the i^{th} element;

N_i is the number of failures by the i^{th} element.

II. COST CALCULATION BASED ON TECHNICAL CHARACTERISTICS

In this case, the calculation takes into account the necessity of assuring the projected product with a reliability-level not below the level of a prototype-product, i. e.,

$$P_o = P'_{projected} ,$$

where P_o is the reliability of the prototype-product;

$P_{projected}$ is the reliability of the projected product.

Assuming that the indices of reliability $n_i \lambda_i$ for each type of elements of the existing and projected products must be equal, it is possible to find the required degree of intensiveness of failures of each type of elements:

$$\lambda_{projected_i} = \frac{n_{o_i} \lambda_{o_i}}{n_{projected_i}} \quad (5)$$

where λ_{o_i} ; $\lambda_{projected_i}$ are, respectively the intensiveness of failures of existing and projected products.

n_{o_i} ; $n_{projected_i}$ are the number of elements of the i^{th} type in the existing and in the projected products.

It follows from the expression (5) that in order to establish the requirements for the reliability of all elements and, therefore, for forecasting the cost of improving the reliability of the projected system, it is necessary to know its quantitative composition. At the initial projecting stage, when only the weights and the basic specifications of radio electronic systems are known, the quantitative composition can be calculated approximately by taking these parameters into account. The method of approximate calculation of the quantitative composition is based on the statistical processing of the physical materials, the result of which is the derivation of analytical expressions showing the number of elements of each type as a function of the basic specifications. These averaged relationships are generalized and can be extrapolated to the perspective systems of a definite class. An analysis of the statistical material had established the existence of a relationship between the quantitative composition of the system and its weight.

It is best to approximate the specific value $n_{specific_i} = \frac{n_i}{G}$ (the number of elements of the i^{th} type per unit of weight of the system). As an example, in Figure 3 is shown the change in $n_{specific_i}$ depending on the weight of a radar system.

The total number of elements of the projected system $\left(n_{projected}\right)$ is determined by the expression

$$n_{projected} = \sum_{i=1}^{m} n_{specific_i} G ,$$

where G is the weight of the system.

The cost of production and operation of the radio electronic systems is then calculated by using the expressions (1) and (4) and by taking into account the level of reliability.

In using the method of optimal reservation and in calculating the additional costs, it will be the cost of the basic assemblies (blocks) (as the initial data) and the probability of their failures to perform that must be taken into account.

The investigations that have been carried out had shown that between the basic specifications of the radio electronic systems and their weight there is a relationship of the following form:

$$G = \alpha P_{average}^{b_1} V^{b_2} ,$$

where α is the parameter of the equation which determines the weight at $P_{average} = 1$ and $V = 1$;

$P_{average}$ is the average power in kilowatts;

V is the volume of the system in cubic decimeters;

b_1, b_2 are the indices of the change in weight of the system, depending on the changes in its power and volume, respectively.

Also, between the production cost of the basic assemblies of a radio electronic system and its weight, there is also a relationship in form of $C_i = \alpha G b$ (Figure 4).

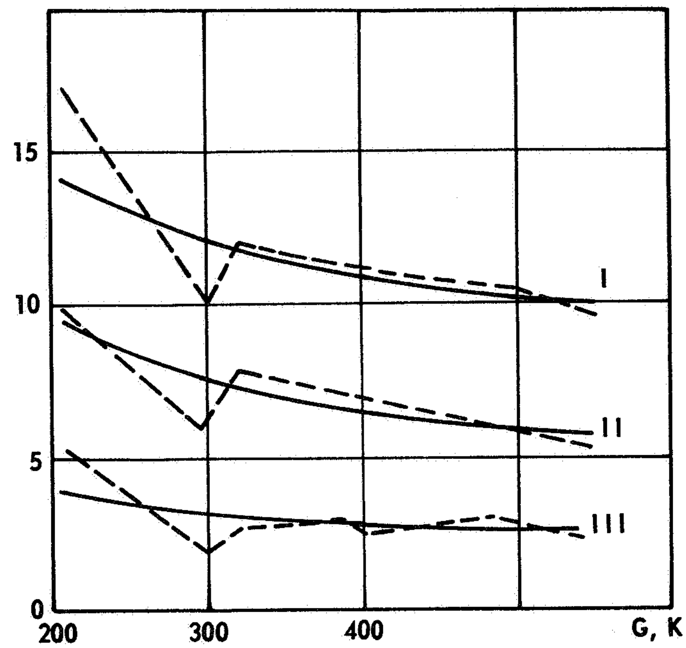

Figure 3. Change in value of $n_{specific_i}$ depending on the weight of the radio electronic system: I) number of elements per 1 kilogram of the system's weight; II) correspondingly, the number of resistors; III) correspondingly, the number of capacitors.

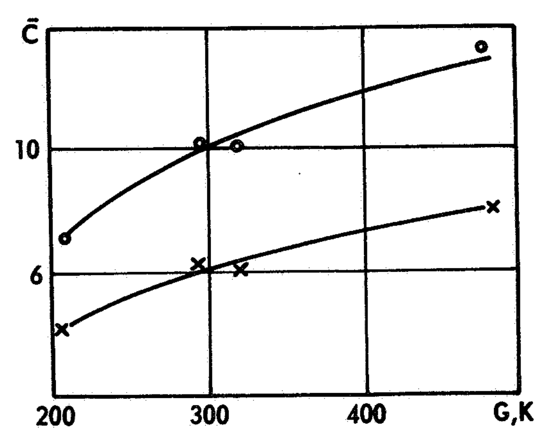

Figure 4. Relationship between the relative cost of basic assemblies and the radio electronic system weight.

In forecasting the cost of the basic assemblies, with the aid of expression (3) it is possible to establish the multiplicity of reservation K_γ and to determine the value of the additional cost spent to improve the reliability by the method of optimal reservation.

In Figure 5 is shown the character of the changes in the increment in the cost of radio electronic systems, $\frac{\Delta C}{C_o} = \bar{C}$, for two methods of improving the reliability. A radio electronic system with a reliability of $P_o = 0.8$ was used as the prototype-product for calculating the function $C = f(P)$. As it follows from Figure 5, the expediency of using one or the other method depends on the value of $\frac{\Delta P}{P_o}$. For example, an improvement in reliability by 25 percent requires an increment in value of $\bar{C}$ equal to 150 to 200 percent by using the first method and 250 percent by using the second method. For higher values of $\frac{\Delta P}{P_o}$, the method of optimal reservation is more profitable. Thus, at $\frac{\Delta P}{P_o} = 40$ percent, for the first case we have $\bar{C} = 400$, and for the second case, it is approximately 250 percent.

III. CALCULATING THE ECONOMIC EFFECTIVENESS OF IMPROVED RELIABILITY

As noted, the improvement in reliability of radio electronic equipment is stipulated by the interaction of two very important factors. On one hand, the improvement of reliability is connected with considerable additional costs, and on the other, higher characteristics of reliability reduce the number of systems required to obtain the planned volume of production with a probability not less than the specified $\left(\bar{W}_{sp}\right)$. An investigation of the economic effectiveness of radio electronic systems must determine the "optimum" zones or boundaries of the values of reliability that will reduce to a minimum the cost of their production and operation.

Serving as a criterion in calculating the economic effectiveness of improved reliability is the cost of producing a radio electronic system that can assure the obtaining of the planned output of products. Such an index will determine with adequate accuracy the effectiveness of improved reliability, because it takes into account the above-mentioned contradictory factors. These costs can be presented as follows:

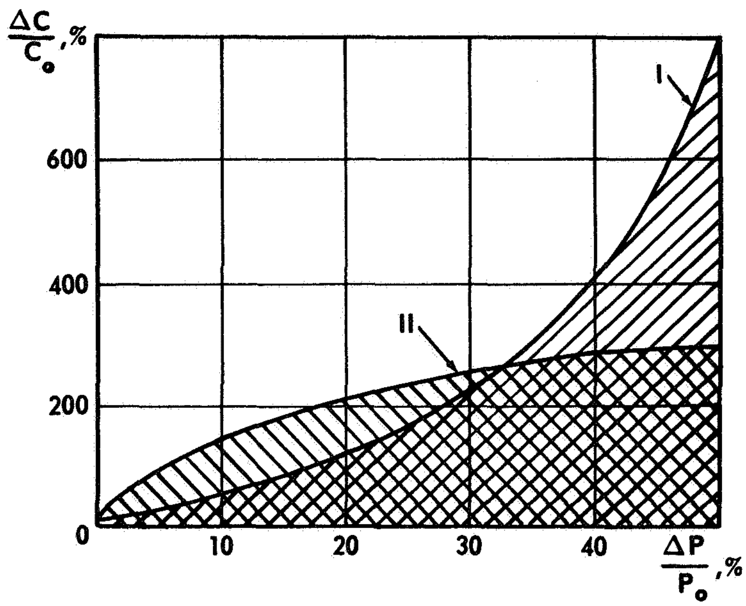

Figure 5. Relationship between the increment in cost of radio electronic systems, $\frac{\Delta C}{C_o}$, and the increment in reliability $\frac{\Delta P}{P_o}$: curve I) by improving the quality of the elements; II) by the method of optimal reservation.

$$C_{\overline{W}}\left(P_{\text{required}}\right) = \sum_{N=1}^{N_o} C_{RES} + \left(\Delta C_{\text{projected}} + \Delta C_e\right)\eta_o ,$$

where C_{RES} is the cost of a radio electronic system without taking into account the additional cost of improving the reliability;

$\left(\Delta C_{\text{projected}} + \Delta C_e\right)$ is the additional cost of production and operation needed to assure the required level of reliability;

N is the number of systems which assure the obtaining of the planned output of products with a specified probability $\overline{W}$;

η_o is a coefficient that takes into account the time differences of the expenditures.

The average number of systems (N) that can assure the planned output of products with a probability not less than specified can be determined by using the expression

$$N = \frac{\ell\eta\left(1 - \overline{W}_{specified}\right)}{\ell\eta\left(1 - P_{required}\right)}$$

Figure 6 shows the expected change in the relative value of $C_{\overline{W}}$, which represents the sum spent for the production of N systems, ΣCN_i, and the additional costs $\Sigma C_{add\ i} = \left(\Delta C_{projected} + \Delta C_{specified}\right)$ required to assure the necessary level of reliability.

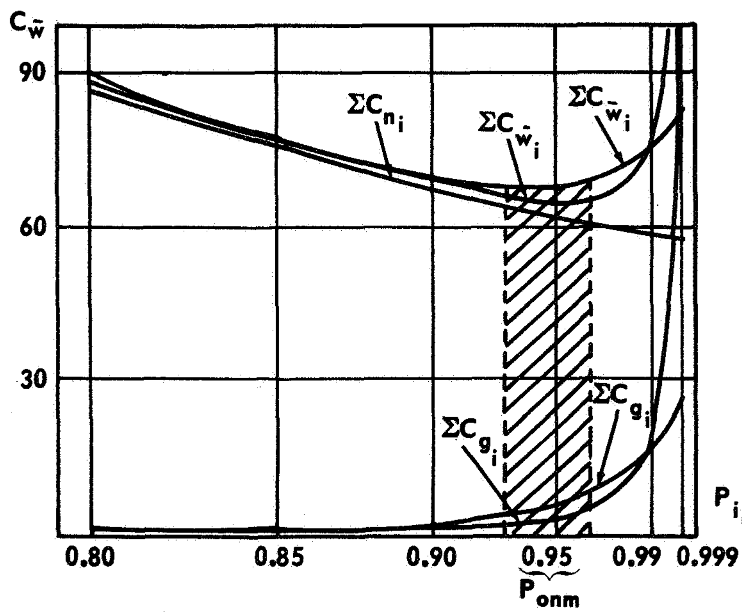

Figure 6. Relative cost of radio electronic systems assuring the planned volume of production as a function of their level of reliability: curve I) by improving the quality of the elements; II) by the method of optimal reservation.

As shown in Figure 6, the determination of the economic effectiveness of improved reliability of the radio electronic system is connected with a search for "optimal" zones that will assure the smallest cost (for definite specified conditions). The formation of such zones is due to the fact that, beginning with a certain level of reliability, the additional costs for its improvement begin to increase faster than the economy obtained from the reduced number of systems N and, as a result, the total cost will increase. For this reason, it is necessary to try to obtain economically justified characteristics of reliability.

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13. ABSTRACT

The article deals with cost calculation methods of projected radio electronic systems used for automation and control of production processes. Two methods of improving the reliability (improving the quality of the components and optimal reservation) are given and their economic expediency is determined.

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