# Substantiation of model for air navigation equipment operation costs

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#### Abstract

The paper is devoted to the substantiation of the model for the operation costs of electronic navigation equipment. The air navigation equipment includes a set of ground, near-ground, and onboard technical means, the quality and reliability of which significantly influence on the safety and regularity of civil aviation. These technical means include ground radio navigation and radar systems, radio communications, and automated air traffic control systems, which generate and provide consumers with information on flight parameters along the entire route from take-off to landing. The tasks of maintaining the required efficiency level and reliable operation of this equipment are solved in the operation systems. The article considers the issues of obtaining analytical relations and determining mathematical relations for estimating the resources cost for current repairs. Normative documents usually use mathematical expectation as a cost indicator concept, although the efficiency indicators of resource costs for current repairs are objectively random variables and therefore the most complete characteristic is the probability density function or a number of characteristics, not only mathematical expectation but also variance, asymmetry, kurtosis and other moments of a higher order. In this paper, the authors considered two options for financing the repair procedures. The first option is related to the case when the level of the reserve for repairs is determined at the mathematical expectation level. The second option is related to the case when the maintenance and repair system has a resources reserve for repair procedures, which differs from the traditional approach to cost planning. The article analyzes the calculations results of resource costs mathematical expectations for different interest rates levels and different reserve funds indicators. Analytical relations are obtained to solve the problem of the resource fund optimal choice for current repairs. At the same time, modeling was performed and histograms were built for different reserve funds for repairs values. Based on theoretical calculations, a nomogram is constructed, which shows that at certain interest rates there is an optimal total operating costs value. The research results can be used in the process of designing and improving the ground-based air navigation equipment operation systems.

#### Keywords

Operation system, ground air navigation equipment, repair, operating costs optimization, efficiency indicator

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## 1. Introduction

The technical basis of the air navigation system information and technical support is a set of ground, near-ground and onboard technical means, the quality and reliability of which largely depends on the safety and regularity of civil aviation (CA). The complex of ground-based radio electronic equipment includes ground-based radio navigation and radar systems, radio communication equipment, automated air traffic control systems (hereinafter ground-based electronic air navigation equipment – GEAE), which form and provide consumers with information on flight parameters throughout the entire route from take-off to landing of the aircraft (AF).

The tasks of maintaining the required efficiency level and reliable operation of the GEAE are solved in the operation systems (OS) [1]. The GEAE OS includes the GEAE's equipment, technological processes (TP), personnel, documentation, technical equipment means (buildings, structures, etc.) [2]. TP includes processes of maintenance, repair, resource renewal, monitoring, control, etc. [3]. In general, the OS can be considered as a design and improvement object [4]. Therefore, technological processes in the OS can be selected as the development and modernization objects [5].

This article considers the issues of estimating the resources cost for the GEAE current repairs processes implementation.

#### 2. Literature review and problem statement

The issues of technical systems and in particular electronic equipment current repair are considered in the scientific and technical literature and regulations [6]. Resource costs estimation for current repairs in [7] is considered in the framework of such efficiency indicators as average cost, average labor intensity, average time of current repairs, etc.

At the same time, it is clear that in the current repair process the technological operations of technical diagnosing, i.e. search of the failed element, are carried out. Then the failed element is replaced on serviceable and the equipment serviceability as a whole is re-checked.

The GEAE OS functioning analysis shows that the cost of resources for the maintenance processes implementation is stochastic due to the random nature of failure and damage events in the GEAE [8, 9]. Accordingly, the certain effectiveness indicators values of the GEAE current repair are stochastic. In [10 - 14] the attention was paid to the fact that the efficiency of resource costs for current repairs are objectively random variables and therefore the most complete characteristic is the probability distribution density or a number of factors such as mathematical expectation, variance and moments of higher order.

Meanwhile, in the normative documents, the current repairs efficiency indicators are considered within the framework of resource costs mathematical expectations [15 - 25]. Thus, there is a contradiction between the recommended estimate of resource costs for maintenance in regulations and the objective costs level that occur during the GEAE operation.

In this paper, as a continuation of the research carried out in works [26], numerical examples and mathematical relationships are considered, which more thoroughly allow to assess the additional costs level that occur during a certain contradiction.

The purpose of this paper is to obtain analytical equations that will more fully assess the conditions under which the optimal parameters for planning the resources cost for current repairs can be found in the framework of the above contradiction.

To achieve the goal of the study, the following tasks were solved:

• Resource costs for GEAE repairs calculation for practically possible distribution of resource costs for one repair;

• Obtaining analytical ratios for one scheme of planning the resources cost for the current GEAE repair;

• Constructing the nomograms of the repairs total cost dependence on the reserve expenditures amount and drawing the conclusions about the accuracy of the method used to overcome the contradiction formed above.

#### 3. Substantiation of Model for Operation Costs

Usually, Poisson's law [27] describes the number of GEAE failures for a certain observation period if the failures probability density distributions (PDD) have an exponential model. In cases when the failures or damages intensities in the GEAE are big enough, i.e. the number of failures or damages is big enough, then the discrete distribution of the number of events may coincide with the normal distribution [28 – 32]. To simplify the calculations in this article, a PDD of arbitrary form will be used, which is as a normal PDD has an asymmetry coefficient equal to zero. Consider the example of calculating the resources cost for the GEAE repair, which is associated with the justification of the approach more adequately taking into account the statistical characteristics of the costs that occur in GEAE OS during the electronic equipment repair.

Let there be a repair body and equipment that needs to be repaired. Suppose that during the observation time  $T_{obs}$  a distribution of the number of GEAE failures is as shown in Fig. 1. Suppose that the average cost of one repair is equal to  $C_{rep} = 10 \text{ c.u}$ .



Figure 1: Example of the number of failures distribution

Then, taking into account Fig. 1 the resource costs distribution for the GEAE repair  $P_1(C_{\Sigma}/T_{obs})$  will be as shown in Fig. 2.



Figure 2: Distribution of resource costs for GEAE repairs

Let's solve the problem of determining a new costs distribution for the GEAE repair  $P_2(C_{\Sigma}/T_{obs})$  if there are the initial distribution of costs  $P_1(C_{\Sigma}/T_{obs})$  and different options for financing repair work -Option A and Option B.

Option A. In the operation system, the required repair costs level was determined at the mathematical expectation level  $m_1(C_{\Sigma}/\text{Opt. A})$ , taking into account the costs distribution  $P_1(C_{\Sigma}/T_{obs})$ . That is, the design decision on the resources cost for repairs is equal to  $m_1(C_{\Sigma}/\text{Opt. A}) = 100 \text{ c.u.}$ , which is determined as follows

 $m_1(C_{\Sigma} / \text{Opt. A}) = 0.1 \cdot 60 \text{ c.u.} + 0.2 \cdot 80 \text{ c.u.} + 0.4 \cdot 100 \text{ c.u.} +$ 

 $+0.2 \cdot 120 \text{ c.u.} + 0.1 \cdot 140 \text{ c.u.} = 100 \text{ c.u.}$ 

Consider that the operating system has a sufficient amount of resources to perform GEAE repairs in the range from 60 to 140 c.u. depending on how many failures occurred in the observation interval

 $T_{\rm obs}$ . In this case, the expected project cost is equal to  $m_1(C_{\Sigma} / \text{Opt. A}) = 100 \text{ c.u.}$ 

Option B. The system has a certain resources reserve to perform repair work. If the actual resources

cost is greater than  $C_{\text{reserve}}$ , then the OS attracts credit, which then needs to be repaid with a specified level of interest M %. When calculating, consider the options of interest rates M % at the levels – 0%, 2%, 5%, 7%, 10%, 20%, 30%, 40 – 100%. Of course, in this case, the OS has additional resources costs for the GEAE repair.

Let's define mathematical expectations of resources costs for GEAE repair  $m_1(C_{\Sigma}/\text{Opt.}B)$  for interest rates from 0 – 100 % and various resources reserve values  $C_{\text{reserve}} = 60;80;100;110;120 \text{ cu.}$ 

Taking into account the reserve, the expenditures distribution will change and take a different form  $P_2(C_{\Sigma}/T_{obs})$ , as shown in Fig. 2.

Need to be recalled that for option A, the design decision on future resource costs in the OS was selected as  $m_1(C_{\Sigma} / \text{Opt. A}) = 100 \text{ c.u.}$ 

Suppose OS has a resources stock  $C_{reserve} = 60$  c.u. and the interest rate level *M* % is equal to 0 %.

If on the  $T_{obs}$  interval it is necessary to spend 60 c.u., then these resources in the OS will be - $C_{reserve} = 60$  c.u. The probability of such a case is 0.1.

If on the  $T_{obs}$  interval it is necessary to spend 80 c.u., then from the resources stock will take  $C_{reserve} = 60$  c.u. and add 20 c.u. without interest on additional costs. This event, taking into account Figure 2, has a probability of 0.2. If it is necessary to spend 100 c.u., then from the stock will take  $C_{reserve} = 60$  c.u. and add 40 c.u. without percent with increase in resources. This event, taking into account Fig. 2, has a probability of 0.4. And so on. Then the mathematical expectation of resource costs will be defined as following:

$$m_1(C_{\Sigma} / \text{Opt.}B; C_{\text{reserve}} = 60 \text{ c.u.}; M = 0\%) = 0.1 \cdot 60 + 0.2(60 + 20) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60 + 40) + 0.4(60$$

+0.2(60+60)+0.1(60+80) = 100 c.u.

This example corresponds to the case when the repair organization was provided with missing resources without interest.

Now let the interest rate M be 5%. Then:

$$m_1(C_{\Sigma} / \text{Opt.B}; C_{\text{reserve}} = 60 \text{ c.u.}; M = 5\%) = 0.1 \cdot 60 + 0.2(60 + 20 \cdot 1.05) + 0.4(60 + 40 \cdot 1.05) + 0.2(60 + 60 \cdot 1.05) + 0.1(60 + 80 \cdot 1.05) = 102 \text{ c.u.}$$

Particular attention is drawn to the option when  $C_{\text{reserve}} = 100 \text{ c.u.}$  That is, the OS is set to a cost level that corresponds to the design solution  $m_1(C_{\Sigma}/\text{Opt.A}) = 100 \text{ c.u.}$  Then for  $T_{\text{obs}}$  for costs equal to 60 c.u., 80 c.u. and 100 c.u., it will be enough to have resources at the level of  $C_{\text{reserve}} = 100 \text{ c.u.}$  The probability of such an event is equal to 0.7. Here are two formulas for the variant when  $C_{\text{reserve}} = 100 \text{ c.u.}$ , and the interest rates of M% is equal to 0% and 10%

$$m_1(C_{\Sigma} / \text{Opt.}B.; C_{\text{reserve}} = 100 \text{ c.u.}; M = 0\%) = 0.7 \cdot 100 + 0.2(100 + 20) + 0.1(100 + 40) = 108 \text{ c.u.},$$
  
 $m_1(C_{\Sigma} / \text{Opt.}B.; C_{\text{reserve}} = 100 \text{ c.u.}; M = 10\%) =$ 

 $= 0.7 \cdot 100 + 0.2(100 + 20 \cdot 1.1) + 0.1(100 + 40 \cdot 1.1) = 108.8$  c.u.

The Table 1 shows the calculations data of total costs for GEAE current repairs for options when

M % varies between 0 – 100%, and  $C_{\text{reserve}}$  is equal to 60, 80, 100, 110 and 120 c.u.

Based on the calculations results of total repair costs, which are given in the Table 1, the conclusions can be drawn.

For any fixed  $C_{\text{reserve}}$  value with an increase in the interest rate M%, the average total costs increase. The total repair costs are the lowest among all results for  $C_{\text{reserve}} = 60$  c.u. in the range of 0% – 10%. The same effect for  $C_{\text{reserve}} = 80$  c.u. when M% changes in the range of 20% – 40%. For  $C_{\text{reserve}} = 100$  c.u. average repair costs are lowest when M% changes from 50% to 100%.

Thus, to use a traditional design solution at the level of mathematical expectation of repair resource costs is optimal for high interest rates. Therefore, for the interest rates level in the range of 0% - 50%, it is more appropriate to use the resources reserve for precise repairs, which are less than the

mathematical expectation of the expected costs (meaning options when  $C_{\text{reserve}} = 60 \text{ c.u.}, 80 \text{ c.u.}$ ). Thus, the traditional approach for planning the resource costs level for the GEAE current repair is not optimal.

М%	$C_{\text{reserve}} = 60.$	$C_{\text{reserve}} = 80$	$C_{\text{reserve}} = 100$	$C_{\text{reserve}} = 110$	$C_{\text{reserve}} = 120$
	c.u.	c.u.	c.u.	c.u.	c.u.
0	100	102	108	115	122
2	100.8	102.44	108.16	115.1	122.04
5	102	103.1	108.4	115.25	122.1
7	102.8	103.54	108.56	115.351	122.14
10	104	104.2	108.8	115.5	122.2
20	108	106.4	109.6	116	122.4
30	112	108.6	110.4	116.5	122.6
40	116	110.8	111.2	117	122.8
50	120	113	112	117.5	123
60	124	115	112.8	118	123.2
70	128	117.4	113.6	118.5	123.4
80	132	119.6	114.4	119	123.6
90	136	121.8	115.2	119.5	123.8
100	140	124	116	120	124
In the general case, it is expedient to have correlations by means of which it would be possible to					

 Table 1

 The GEAE repair total cost calculations results

solve the optimization problem of resources reserve volume  $C_{\text{reserve}}$  during current repair subsystem designing in GEAE OS. In this case, we make the assumption that the PDD of the current repairs total cost for a certain observation period  $f(C_{\Sigma}/\bar{\Theta};T_{\text{obs}})$  has a continuous form. This assumption may exist despite the fact that the failures number probabilities distribution per  $T_{\text{obs}}$  period is discrete, but the resources cost needed to perform certain technological operations has its own PDD with a continuous function type. We also keep in mind that the parameter vector  $\vec{\Theta}$  includes a failures number model description per  $T_{\text{obs}}$  interval and PDD parameters of the resource costs per one repair.

We give a formula to calculate the  $m_1(C_{\Sigma} / \text{Opt.B}; C_{\text{reserve}}; T_{obs}; K; \vec{\Theta})$  and the conditions that the resources cost for repairs over  $T_{obs}$  time are continuous PDD –  $f(C_{\Sigma} / \vec{\Theta}; T_{obs})$ .

The K coefficient is a multiplier of resources increase, which are not enough based on the interest rate M %

$$K = \frac{100\% + M\%}{100\%} = 1 + \frac{M\%}{100}$$

where M% is the interest rate for attracting additional resources

To analytically solve the problem of substantiating the optimal resource costs level for repairs consider two variables  $X_1$  and  $X_2$ . We believe that the  $X_1$  variable allows to estimate the resource costs mathematical expectation for more accurate repairs under the conditions that it is planned to reserve funds according to the traditional method (repairs cost mathematical expectation where  $C_{\text{res.des.}}$  – corresponds to the design solution).

The  $X_2$  variable is designed to solve the problem of minimizing the resources for repairs cost by defining a parameter  $C_{\text{res.var.}}$ .

Formulas for mathematical expectations of  $X_1$  and  $X_2$  parameters has the following form:

$$X_1 = m_1(C_{\Sigma} / \text{Opt.B}; C_{\text{res.des}}; T_{\text{obs}}; K; \Theta) =$$

$$= C_{\text{res.des}} \int_{0}^{C_{\text{res.des}}} f(C_{\Sigma}) dC_{\Sigma} + \int_{C_{\text{res.des}}}^{\infty} [C_{\text{res.des}} + (C_{\Sigma} - C_{\text{res.des}})K]f(C_{\Sigma})dC_{\Sigma}.$$

$$X_{2} = m_{1}(C_{\Sigma} / \text{Opt.B}; C_{\text{res.var}}; T_{\text{obs}}; K; \vec{\Theta}) =$$

$$= C_{\text{res.var}} \int_{0}^{C_{\text{res.var}}} f(C_{\Sigma}) dC_{\Sigma} + \int_{C_{\text{res.var}}}^{\infty} [C_{\text{res.var}} + (C_{\Sigma} - C_{\text{res.var}})K]f(C_{\Sigma}) dC_{\Sigma}$$

If a priori data on  $f(C_{\Sigma}/\vec{\Theta};T_{obs})$  and the interest rate level of *M*% are known, then a  $\Delta$  variable can be found

$$\Delta = X_1 - X_2$$

Selecting the  $C_{\text{res.var.}}$  parameter we try to maximize the  $\Delta$  value.

In the given expressions for X1 and X2 the interest rate M% is a constant value. In the general case, it can be considered as a function of borrowed funds. In this case, the functional form of the expressions for X1 and X2 will be complicated.

Modeling was performed in the MathCad software environment for the data shown in the Table 1.

As can be seen from Fig. 3-5 with  $C_{\text{res}}$  increasing there is a decrease in the number of total costs possible values.

The mathematical expectation of costs theoretical calculations results are presented in the nomogram form in Fig. 6.



Figure 3: Total repair costs histograms (  $C_{\rm res}$  = 60c.u. )



Figure 4: Total repair costs histograms ( $C_{res} = 80c.u.$ )

Graphs in Fig. 6 analysis shows that at certain credit rates there is an optimal value of the maximum resources stock, which provides a minimum of operating costs. In Ukraine, the loan rate is about 20 - 30%. As can be seen from the graph at 20% there is already an optimum. The optimum value can be found by studying the analytical ratios above, which compare the cost of resources according to the traditional method and the method proposed in this paper.

The proposed approach to substantiate operation costs can be considered within the framework of the methodology for the design and modernization of systems for the operation of ground-based radioelectronic equipment. According to this methodology, the main attention should be paid to statistical data processing procedures [30 - 32] regarding reliability parameters and defining parameters of equipment and parameters of operation system.



Figure 5: Total repair costs histograms ( $C_{\rm res} = 100 {\rm c.u.}$ )



Figure 6: Repair costs nomogram

The results of this paper as a whole can be considered as the basis for solving an important operational problem related to the optimization of operational costs during intended use of radioelectronic equipment.

## 4. Conclusion

The analysis carried out in the paper showed that to calculate the operation costs it is not enough to take into account only the mathematical expectation of the forecasted costs. In this paper, the authors considered two options for financing the repair procedures. The first option is related to the case when the level of the reserve for repairs is determined at the mathematical expectation level. The second option is related to the case when the maintenance and repair system has a resources reserve for repair procedures, which differs from the traditional approach to cost planning.

Taking into account the cost probabilities density distribution makes it possible to design the operation system more optimally in terms of expected costs for GEAE maintenance and repair. It is necessary to have some a priori information on the failures number distribution, interest rates and other data as needed.

The research results can be used in the process of designing and improving the air navigation groundbased radioelectronic equipment operation.

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