Methodology for substantiating the infrastructure of aviation radio equipment repair centers

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Abstract

Nowadays aviation radio equipment is an important technical tool for solving various problems in the civil and military spheres related to flight safety and regularity. To ensure the effective use of aviation equipment for its functional purpose, it is usually necessary to develop and implement a functionally complete infrastructure of interconnected elements, which in particular include state regulatory bodies, enterprises that implement the stages of the life cycle of the equipment (design, manufacture, operation, and disposal), educational and research institutions and laboratories. During the use of the equipment for its functional purpose, situations arise when it is necessary to maintain and restore the performance of these devices. This task is implemented by carrying out maintenance and repairs in the relevant divisions of operating enterprises. Taking into account the large number of operated devices, the wide geographical location of centers of their use, the task of substantiating the infrastructure of repair centers for aviation radio equipment is urgent. This task was solved by developing a step-by-step methodology for calculating the efficiency indicators of the process of aviation radio equipment repair.

Keywords

operation, aviation radio equipment, repair, infrastructure of repair hubs, data processing

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1. Introduction

Nowadays aviation radio equipment (ARE) is an important technical tool for solving various problems in the civil and military spheres related to flight safety and regularity [1]. To ensure the effectiveness of the use of ARE for its functional purpose, it is necessary to systematically consider four stages of the life cycle of these means: design, manufacture, operation, and disposal [2, 3]. The longest stage is the stage of operation [4]. During the operation, we need to ensure the reliability and effectiveness of the tasks performed by the equipment [5].

To implement this task, it is necessary to develop and realize a functionally complete infrastructure of interconnected elements [6]. According to the concepts of the system approach to the composition of the infrastructure, it is appropriate to include the following elements of the triad:

- Bodies of state regulation in the field of ARE use.
- Enterprises, organizations, and military units, in which the stages of the life cycle of equipment are implemented.
- Educational and scientific research institutions and laboratories that collect information and data, perform their processing and formulate recommendations and proposals for improvement, execution and implementation of the processes of ARE operation [7, 8].

State regulatory bodies perform the following main tasks:

1. Development of a regulatory framework for the use of ARE for the tasks of airspace control, certification of equipment, personnel, specialized enterprises and organizations.
2. Audits of infrastructure elements.
3. Monitoring and control of the state of safety levels, the efficiency of ARE used for its functional purpose.
4. Analysis of international experience and communication with international organizations in the field of ARE operation.
5. Organization and participation in certification tests [9, 10].

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Enterprises, organizations, and military units, in which the stages of the life cycle of equipment are implemented, perform the following basic tasks:

1. Design and manufacture of new ARE.
2. Implementation of the main and auxiliary processes of the operation, in particular: use for its functional purpose, maintenance, repair, extension of the resource, monitoring, control, and others.
3. Collection and processing of primary data characterizing the implementation of operational processes.
4. Modernization of ARE and the corresponding infrastructure from the point of view of ensuring and improving the reliability of the equipment and the efficiency of the operation processes.
5. Checking the technical condition and determining the remaining useful life of the equipment.
6. Disposal [11, 12].

The educational and scientific research institutions and laboratories perform the following basic tasks:

1. Training, retraining, and advanced training of personnel, in particular operational stuff.
2. Carrying out research and development works in the field of ARE use.
3. Design and modernization of ARE operation systems.
4. Development of state and industry standards, enterprise standards.
5. Development of algorithmic and software to process the data on reliability indicators and diagnostic parameters.
6. Development and maintenance of data hubs.
7. Development of new methods, models, procedures, and techniques based on artificial intelligence and modern information technologies [13, 14].

2. Literature review and problem statement

The repair is the process of the equipment operation, on which procedures are performed to restore the product's operability [15]. The repair process includes the following procedures:

1. Technical condition monitoring and control.
2. Diagnostics.
3. Restoration of operation capacity.
4. Functionality control after recovery [16, 17].

Repair processes are implemented in repair centers [18]. At the same time, two approaches to repair procedures are distinguished. In the first case, a partial restoration of the structural or informational elements of ARE is possible. Moreover, it is required to have a fund of spare parts with their constant replenishment. In the second case, a complete replacement of ARE, which is no longer subject to recovery, is performed [19, 20].

To carry out repair procedures, we need to have a certain resource provision. It includes workplaces, measuring equipment, bench equipment, documentation, computer equipment, and office equipment [21, 22].

A characteristic feature of ARE is that it contains both hardware and software parts [23, 24]. Therefore, the repair process can be considered within the framework of two components. This imposes additional requirements on the level of qualification of repair center personnel. That is, the composition of the repair team should be not only engineers but specialists in the field of information technologies.

An important issue of the synthesis and analysis of the infrastructure of the repair centers is the substantiation of their number and location, taking into account logistical parameters. The criterion when solving this problem can be the minimum expenditure of resources [25].

These issues are insufficiently considered in the literature, but their significance is great since significant material resources are currently being spent and it is important to ensure the high efficiency of the tasks assigned to ARE [26].

The main efficiency indicators that determine the meaningfulness of repair processes include expected values and standard deviations of the time duration, cost, and complexity of the performed procedures [27, 28]. For more in-depth and comprehensive detailing, it is advisable to consider the laws of distribution for the specified efficiency indicators [29].

Let's consider the generalized formulation of the research problem.

We believe that there is a generalized efficiency indicator Ψ. This indicator has an interpretation in the form of the expected value (standard deviation) of resource costs, which can be represented as

$$\Psi = \varphi(CP/M),$$

where CP is parameters to be controlled, M is a vector of models that describes the processes that occur during ARE repair.

The parameters to be controlled include:

- the number of repair centers,
- the location of repair centers.

The vector of models takes into account:

- equipment failure flow,
- parameters characterizing certain procedures of the repair process,
- the number of operated ARE,
- diagnostic programs and their effectiveness,
- vector of possible errors,
- resource costs,
- constraint vector,
- quantitative characteristics of personnel and their qualifications,
- additional equipment,

- spare parts supply logistics,
- fund of spare parts.

Therefore, the aim of this paper is to determine the number and location of repair centers that will provide maximum efficiency within the defined model vector parameters and established constraints.

3. Materials and methods

Let's consider the methodology for calculating numerical values of the efficiency measures for the process of aviation radio equipment repair. It can be applied during the evaluation of the effectiveness of the current organizational structure, its modernization and the creation of a new structure. The methodology contains mathematical equations for efficiency calculation, certain assumptions about the flow of failures, analysis of operating and transport costs, and organizational aspects of the construction and operation of the repair process.

Assume that we consider the i-th airport and it has the j-th type of equipment, which includes r structural units that can be repaired.

Let us assume that the flow of failures for the faulty structural units is the simplest, while the failure rate of the r-th unit of the j-th equipment type in the i-th airport is equal to some predetermined value λ_{rji}.

Taking into account the well-known theorem of probability theory, the total flow of failures for the structural units is also the simplest, and its rate

$$\lambda_{ji} = \sum_{r=1}^{l_{ji}} \lambda_{rji},$$

where l_{ji} is the number of structural units in the j-th equipment at the i-th airport.

A similar assumption can be made regarding the fleet of equipment located at the i-th airport. Let the i-th airport contain K_i different types of aviation radio equipment, then the total flow of failures is defined as

$$\lambda_i = \sum_{j=1}^{K_i} \lambda_{ji}.$$

It is known from the theory of probabilities that if structural unit failures occur during the observation interval T_Σ, which are characterized by the simplest flow of repair requests λ, then the distribution of the number of units n with failures corresponds to the Poisson law with the parameter b [30], i.e.

$$P(n/T_\Sigma) = \frac{b^n}{n!} e^{-b}, \tag{1}$$

$$b = T_\Sigma \lambda. \tag{2}$$

Thus, if we consider the total number of units with failures during the observation interval for the j-th equipment type, then in formulas (1), (2) instead of λ, we should use λ_{ji}. If the set of aviation radio equipment of the i-th airport, then in formulas (1), (2) instead of λ it is necessary to use λ_i.

Let's consider the issue of calculating the total costs for repairing the j-th type of radio equipment. We will highlight two technological procedures: 1) delivery of structural units with failures to the repair center and 2) running repair of structural units in the repair center at the workplace of a repair engineer. For one r-th unit of the j-th type of radio equipment in the i-th airport, we have the costs C_{rji} for the delivery operation of $C_{d\,rji}$ to the repair center and back, as well as the repair of the $C_{rep\,rji}$ unit in the form

$$C_{rji} = 2C_{d\,rji} + C_{rep\,rji}. \tag{3}$$

For simplicity, we will consider the variable $C_{d\,rji}$ to be a non-random variable. At the same time, the variable $C_{rep\,rji}$ is random, which in general is characterized by the probability density function (PDF). For an approximate calculation, we can use points moments: expected value $E(C_{rep\,rji})$ and variance $\sigma^2(C_{rep\,rji})$. If the inequality of the form is true

$$\sigma(C_{rep\,rji}) \ll E(C_{rep\,rji}), \tag{4}$$

then the random variable $C_{rep\,rji}$ can be completely characterized by the expected value $E(C_{rep\,rji})$. If we consider the total costs for the repair of the r-th block for the period T_Σ, then we get

$$C_{rji}(n_{rji}/T_\Sigma) = \sum_{l=1}^{n_{rji}} 2C_{d\,lrji} + \sum_{l=1}^{n_{rji}} C_{rep\,lrji} = n_{rji}(2C_{d\,rji} + C_{rep\,rji}), \tag{5}$$

where $C_{rep\,lrji}$ is a random variable for the cost of repair for the r-th unit of the j-th equipment type in the i-th airport for the l-th number of the failure of this unit, provided that the repair center is located in the same geographical point.

In formula (5), we will assume that the sample of failures of the r-th structural unit is homogeneous, so the index l for the random variable $C_{rep\,rji}$ will not be taken into account in the final equation. According to the known results regarding the representation of the random variable $C_{rji}(n_{rji}/T_\Sigma)$ in the form of a linear approximation of its random arguments n_{rji} and $C_{rep\,rji}$ at the point equal to the expected value of these arguments, we obtain

$$E\left(C_{rji}(n_{rji}/T_\Sigma)\right) = E(n_{rji})\left(2C_{d\,rji} + E(C_{rep\,rji})\right), \tag{6}$$

$$\begin{aligned}\sigma^2\left(C_{rji}(n_{rji}/T_\Sigma)\right) &= \left(\frac{\partial C_{rji}}{\partial n_{rji}}\right)^2 \sigma^2(n_{rji}) + \left(\frac{\partial C_{rji}}{\partial C_{rep\,rji}}\right)^2 \sigma^2(C_{rep\,rji}) = \\ &= \left(2C_{d\,rji} + E(C_{rep\,rji})\right)^2 \sigma^2(n_{rji}) + \left(E(n_{rji})\right)^2 \sigma^2(C_{rep\,rji}).\end{aligned} \tag{7}$$

If condition (4) is true, then the variance of total repair costs can be determined as follows

$$\sigma^2\left(C_{rji}(n_{rji}/T_\Sigma)\right) = \left(2C_{d\,rji} + E(C_{rep\,rji})\right)^2 \sigma^2(n_{rji}). \tag{8}$$

Taking into account the assumption that the flow of failures is the simplest, then in formulas (5) – (8) we will have

$$\begin{aligned} E(n_{rji}) &= T_\Sigma \lambda_{rji}. \\ \sigma^2(n_{rji}) &= E(n_{rji}) = T_\Sigma \lambda_{rji}. \end{aligned} \tag{9}$$

The parameters in formulas (3) – (8) can be calculated based on information about the tariffs and the length of the delivery route, as well as the tariffs and duration of repair works. In this case

$$C_{d\,rji} = Tar_d S_i,$$
$$E\left(C_{rep\,rji}\right) = Tar_{rep} E\left(t_{rji}\right), \qquad (10)$$
$$\sigma^2\left(C_{rep\,rji}\right) = \left(Tar_{rep}\right)^2 \sigma^2\left(t_{rji}\right),$$

where Tar_d is the tariff of delivery of one unit to the repair center, S_i is the length of the delivery route of the unit to the repair center, Tar_{rep} is repair procedures tariff, $E\left(C_{rep\,rji}\right)$ and $\sigma^2\left(C_{rep\,rji}\right)$ are the expected value and variance of random duration of repair of the r-th unit in the repair center.

Based on the available information about the moments $E\left(C_{rji}\left(n_{rji}/T_\Sigma\right)\right)$ and $\sigma^2\left(C_{rji}\left(n_{rji}/T_\Sigma\right)\right)$ and the assumption about the Gaussian nature of the total costs for the repair of the r-th unit, we can calculate the threshold value $C_{rji\,th}\left(n_{rji}/T_\Sigma\right)$ for a given probability level θ of resource fund sufficiency, i.e

$$P\left(C_{rji}\left(n_{rji}/T_\Sigma\right) \leq C_{rji\,th}\left(n_{rji}/T_\Sigma\right)\right) \geq \theta.$$

During determining the total costs of repair resources for a set of failed structural units, it is necessary to use appropriate probabilistic characteristics that are designed to estimate the failure flow parameters of faulty units of individual aviation radio equipment, individual airports, etc.

The considered approach to determining the expected value and variance of resource costs can be generalized to the case when there are several repair centers. For example, consider the case of an organizational structure that has two repair centers. At the same time, we consider the r-th unit of the j-th equipment type in the i-th airport. At the same time, there are two aggregates of structural units, the repair of which is carried out in different repair centers. We believe that the statistical parameters of total repair costs in two repair centers are independent events, i.e.

$$E\left(C_{r,q}\left(n_{r,q}/T_\Sigma\right)\right) = E\left(C_{rji1}\left(n_{rji1}/T_\Sigma\right)\right) + E\left(C_{rji2}\left(n_{rji2}/T_\Sigma\right)\right), \qquad (11)$$

$$\sigma^2\left(C_{r,q}\left(n_{r,q}/T_\Sigma\right)\right) = \sigma^2\left(C_{rji1}\left(n_{rji1}/T_\Sigma\right)\right) + \sigma^2\left(C_{rji2}\left(n_{rji2}/T_\Sigma\right)\right). \qquad (12)$$

Each term in formulas (11), (12) is determined using formulas (6) – (8). Note that the given ratios can also be considered basic for other cases of analysis of the efficiency of repair processes, namely for different options for delivery of failed units, different values of tariffs for performing procedures in different repair centers, and others.

Let's consider a numerical example of applying the considered equations to analyze the efficiency of repair processes. This numerical example is associated with the r-th unit of the j-th equipment type in the i-th airport. The repair is carried out in one repair center.

During the observation interval, we have the probability mass function of the following type: $P\left(n_{rji} = 1\right) = 0.2$, $P\left(n_{rji} = 2\right) = 0.4$, $P\left(n_{rji} = 3\right) = 0.3$, $P\left(n_{rji} = 4\right) = 0.1$. Let random variable $C_{rep\,rji}$ is described by the probability mass function of following type: $P\left(C_{rep\,rji} = 1\right) = 0.4$, $P\left(C_{rep\,rji} = 2\right) = 0.3$, $P\left(C_{rep\,rji} = 3\right) = 0.2$, $P\left(C_{rep\,rji} = 4\right) = 0.1$. In this case $C_{d\,rji} = 5$.

Then expected values and variances will be

$$E(n_{rji}) = 2.3, \qquad \sigma^2(n_{rji}) = 0.81,$$
$$E(C_{rep\,rji}) = 2, \qquad \sigma^2(C_{rep\,rji}) = 1.$$

Taking into account equations (6) and (7), we will get

$$E\left(C_{rji}(n_{rji}/T_\Sigma)\right) = 2.3(2 \cdot 5 + 2) = 27.6.$$
$$\sigma^2\left(C_{rji}(n_{rji}/T_\Sigma)\right) = (2 \cdot 5 + 2)^2 \cdot 0.81 + (2.3)^2 \cdot 1 = 121.93.$$
$$\sigma\left(C_{rji}(n_{rji}/T_\Sigma)\right) = 11.04.$$

Determine conditional PDF for the random variable $C_{rji}(n_{rji}/T_\Sigma)$ in case of $n = 1, 2, 3, 4$ and randomized PDF $P\left(C_{rji}(T_\Sigma)\right)$. The content of conditional probability mass function is following

$$P(C_{rji} = 11|n = 1, T_\Sigma) = P(C_{rji} = 22|n = 1, T_\Sigma) = P(C_{rji} = 33|n = 1, T_\Sigma)$$
$$= P(C_{rji} = 44|n = 1, T_\Sigma) = 0.4.$$
$$P(C_{rji} = 12|n = 1, T_\Sigma) = P(C_{rji} = 24|n = 1, T_\Sigma) = P(C_{rji} = 36|n = 1, T_\Sigma)$$
$$= P(C_{rji} = 48|n = 1, T_\Sigma) = 0.3.$$
$$P(C_{rji} = 13|n = 1, T_\Sigma) = P(C_{rji} = 26|n = 1, T_\Sigma) = P(C_{rji} = 39|n = 1, T_\Sigma)$$
$$= P(C_{rji} = 52|n = 1, T_\Sigma) = 0.2.$$
$$P(C_{rji} = 14|n = 1, T_\Sigma) = P(C_{rji} = 28|n = 1, T_\Sigma) = P(C_{rji} = 42|n = 1, T_\Sigma)$$
$$= P(C_{rji} = 56|n = 1, T_\Sigma) = 0.1$$

The randomized probability mass function for total cost will be

$$P(C_{rji} = 11) = 0.08, P(C_{rji} = 12) = 0.06, P(C_{rji} = 13) = 0.04, P(C_{rji} = 14) = 0.02,$$
$$P(C_{rji} = 22) = 0.16, P(C_{rji} = 24) = 0.12, P(C_{rji} = 26) = 0.08, P(C_{rji} = 28) = 0.04,$$
$$P(C_{rji} = 33) = 0.12, P(C_{rji} = 36) = 0.09, P(C_{rji} = 39) = 0.06, P(C_{rji} = 42) = 0.03,$$
$$P(C_{rji} = 44) = 0.04, P(C_{rji} = 48) = 0.03, P(C_{rji} = 52) = 0.02, P(C_{rji} = 56) = 0.01.$$

For these values we can determine the moments:

$$E\left(C_{rji}(T_\Sigma)\right) = 27.6. \ \sigma^2\left(C_{rji}(T_\Sigma)\right) = 114.67. \ \sigma\left(C_{rji}(T_\Sigma)\right) = 10.7.$$

Comparing approximate and exact estimates of expected value, variance and standard deviation, the following conclusions can be made:

- the expected values in both cases are the same;
- the approximate estimate of the variance is overestimated by 6.3 percent compared to the exact estimate;
- the approximate estimate of the standard deviation is overestimated by 3.2 percent compared to the exact estimate.

The comparative analysis provides the ability to conclude that from an engineering point of view, the formula for approximate estimation of the expected values and standard deviation of the total repair costs allows calculating the numerical values of the moments with an acceptable error.

4. Results and discussions

The considered approaches to the analysis of the calculations of the numerical values of the efficiency indicators of the repair process can be presented in the form of a separate methodology. This technique can be used by operation system personnel or project organizations for:

- Periodic evaluation of the efficiency of the current repair system for the ARE.
- Development of proposals for the modernization of the current repair system for the ARE.
- Comparative analysis of the efficiency of options for new repair systems of the ARE.

It is advisable to use the following parameters as efficiency indicators:

- Expected value of total repair costs during a certain observation period for equipment in the specific airport and region served by the current repair system of the ARE.
- Expected value of the total repair costs during a certain observation period of the entire ARE fleet for the entire region served by the current repair system of the ARE.
- The standard deviation of total repair costs during a certain observation period for equipment in the specific airport and region served by the current repair system of the ARE.
- The standard deviation of the total repair costs during a certain observation period of the entire ARE fleet for the entire region served by the current repair system of the ARE.
- The threshold value of the total repair costs during a certain observation period for equipment in the specific airport, which corresponds to the probability of not exceeding the established threshold level.
- The threshold value of the total repair costs during a certain observation period of the entire ARE fleet for the entire region, which corresponds to the probability of not exceeding the established threshold level.

In this case, the entire region served by the current repair system of ARE contains a developed set of airports.

The methodology makes it possible to take into account the influence of ten main parameters on the efficiency indicators of ARE repair:

- The total number of airports that have equipment with the need of repair.
- The total number of equipment deployed at a separate airport.
- The length of the delivery routes of the failed units to the repair center from a specific airport.
- Different tariffs for delivery of units with failures to the repair center.
- Types of ARE (communication, navigation, surveillance).
- The amount of equipment of each type.

- The number of units included in the equipment of considered type.
- Expected value and standard deviation of recovery time of equipment units of a certain type.
- The failure rate of ARE equipment units of a certain type.
- Period of observation for the repair system of the ARE.

During the implementation and use of the methodology, it is necessary to:

- Inspect the researched repair system.
- Perform calculations of numerical values of efficiency indicators of the ARE repair system.

During the inspection of the repair system, it is necessary to perform an analysis of the location of ARE by airports and the location of repair centers, as well as to determine the numerical values of the parameters characterizing the ARE repair system.

During the analysis of the APE location, the following parameters are determined:

- The total number of airports hosting equipment that requires repair.
- The number of ARE located at a specific airport.
- Numbers of airports where repair centers are located.
- Schematic map of the location of repair centers and airports, where ARE requiring repair is located.
- The number of delivery routes of units with failures from the specific airport to the repair center.

When determining the numerical values of the parameters that characterize the ARE repair system, it is necessary to:

- Estimate the average failure rate for the r-th unit of the j-th equipment type in the i-th airport.
- Estimate the value of the tariff for one delivery operation in case of failure of the r-th unit of the j-th equipment type in the i-th airport.
- Estimate the amount of the initial tariff for performing unit repair procedures at one workplace of repair engineer in the repair center (the tariff is determined taking into account that the workplace provides nominal throughput).
- Estimate the amount of the actual tariff for performing unit repair procedures at one workplace of the repair engineer in the repair center based on the actual workload of the workplace.
- Estimate the expected value and standard deviation of recovery time for a particular repair center and for the r-th unit of the j-th equipment type in the i-th airport, compare these parameters, and decide on the feasibility of using the standard deviation as an indicator of efficiency.
- Calculate the length of the delivery route of the failed unit from the specific airport to the determined repair center.

5. Conclusions

The paper is devoted to issues of substantiation of the structure for the repair centers of aviation radio equipment within the limits of the specified region. The main attention is paid to the development of the methodology for evaluating the efficiency indicators of the repair process in the case of the arbitrary location of the repair centers.

The paper presents the step-by-step methodology for calculating statistical characteristics of operational costs spent during the repair process. The expected value, variance, and standard deviation can be determined using approximate and exact equations.

The results of numerical calculations give the possibility to conclude that formulas for approximate estimation of the expected values and standard deviation of the total repair costs allow calculating the numerical values of the moments with an acceptable error that does not exceed 7 % for a wide range of variation of initial parameters of operation process characteristics.

The results of the research can be used during the post-war reconstruction of the civil aviation infrastructure of Ukraine to ensure the efficiency of the operational processes of aviation radio equipment.

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