A method of cost-effective operation of equipment in the aviation enterprise with using intelligent technologies

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Abstract

Civil aviation enterprises usually spend significant financial resources to support the operation of aviation equipment. Most of these funds are related to the salary of the personnel of the operating companies, the purchase of auxiliary equipment for the operational processes, storage and transportation of spare parts of the equipment. These costs form the tariff rates for maintenance and repair procedures by the types of used equipment. In the general case, total operational costs and specific costs are determined by these tariff rates. Too frequent maintenance, on the one hand, leads to a high level of reliability, but, on the other hand, is characterized by significant operational costs. A small number of maintenance activities reduces the reliability of the equipment and is also characterized by high total costs due to a much higher repair tariff rate. In this context, the use of intelligent technologies in the management system of maintenance and repair processes for aviation equipment allows to improve the procedures for forming and making timely decisions. This paper considers the problem of determining the optimal time moment for maintenance carrying out in terms of minimizing operational costs. The problem is solved analytically, taking into account the stochastic model of changes in the diagnostic variable in the period immediately before the equipment failure. The obtained analytical relations are confirmed by statistical modeling.

Keywords

Intelligence technologies, aviation enterprise, operational cost optimization, equipment operation, maintenance, repair, data processing

1. Introduction

The protection of human life and material assets is the main task of civil aviation [1]. To achieve this task, a set of organizational, technical and regulatory factors has been developed to minimize the risks of aviation accidents associated with the acts of unlawful interference, serviceability and reliability of technical equipment, human factors, and others [2, 3].

Today, civil aviation is a system of interconnected systems aimed at ensuring the flight operations of aircraft. It has a hierarchical structure, which includes aircraft, equipment, resources, aviation enterprises, and others.

Modern intelligence technologies play a key role in optimizing processes at aviation enterprises. Due to the rapid development of the aviation industry, increasing efficiency and reducing costs are becoming a priority for aviation enterprises. The use of intelligent control systems allows automating routine processes, which significantly reduces the likelihood of human error and increases the accuracy of operations. These technologies also contribute to improved forecasting and planning, providing more accurate and timely decision-making.

It is worth noting that analytical tools based on artificial intelligence (AI) are capable of processing large arrays of data, identifying hidden patterns and trends, which contributes to the strategic development of enterprises. In addition, intelligent technologies can improve safety by monitoring and analyzing the technical condition of aircraft in real time. This allows for early detection of potential malfunctions and prevention of emergencies. The implementation of such

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solutions helps to increase the competitiveness of enterprises in the global market. In general, modern intelligent technologies are an integral part of the successful operation and development of aviation enterprises in the modern world.

The use of modern intelligent technologies in the system of maintenance and operation of aviation equipment is a promising area that, unfortunately, has not yet been sufficiently explored.

Despite the obvious benefits, such as improved diagnostic accuracy, fault prediction, and optimized maintenance, the lack of empirical data makes it difficult to implement intelligent systems in practice. This leads to the fact that aviation enterprises are forced to rely on traditional maintenance methods that are less efficient and more resource-intensive. In addition, insufficient attention to the integration of the new technologies can reduce the level of flight safety and reliability of aviation equipment. Further research is needed that would cover various aspects of the use of intelligent technologies, from data collection and analysis to real-life examples of their application in the aviation industry. This would allow for the development of clear recommendations and standards for aviation enterprises, especially in reducing the cost of operating equipment.

Thus, expanding research in this area is critical to improving the efficiency and safety of maintenance and operation of aviation equipment.

2. State of the art and the statement of the problem

Integration of modern management technologies allows automated monitoring of equipment condition, increasing diagnostic accuracy and timeliness of repairs. The use of analytical tools helps to predict and prevent possible malfunctions, which significantly reduces risks. In addition, optimized business processes contribute to the efficient use of resources and reduce maintenance costs. The implementation of the standards and regulations in maintenance processes ensures compliance with international safety requirements [4, 5].

The article [6] determines that intelligent technologies for managing the processes of maintenance and operation of airline equipment, which use artificial intelligence, automation, big data analysis and other advanced technologies for optimization, receive greater financial benefits than those that use traditional methods of equipment operation.

Improving the financial position of the airline company can be achieved through better quality of services, resource-saving methods, material and technical development, and social programs [7].

Paper [8] established that aviation enterprises that enter the market with innovative business processes and an appropriate competitive strategy have significant market advantages and can set their own rules with a strong competitive advantage over competitors.

An analysis of the literature in the field of aviation equipment operation shows that researchers are currently focused on the following problems:

1. Reliability analysis at the stages of operation beyond the determined useful life of the equipment [9, 10].
2. Development of intelligent data processing methods using artificial intelligence tools [11, 12].
3. Minimization of expendable resources [13, 14].
4. Synthesis and analysis of decision-making procedures regarding the condition of equipment and components of the operating enterprise [15, 16].
5. Optimizing the spare parts inventory and the organizational structure of their deployment [17, 18].
6. Optimization of operation processes [19, 20].

Civil aviation enterprises usually spend significant financial resources to support the operation of aviation equipment [21]. Most of these costs are related to the remuneration of the personnel of the operating companies, the purchase of auxiliary equipment for the operation processes, storage and transportation of spare parts of equipment. These costs form the tariff rates for maintenance C_M and repair C_R procedures by the type of used equipment [22, 23].

When solving the problem of minimizing operational costs, it is quite logical to choose the total operating costs C_Σ or average specific operating costs $E(C_\Sigma/T_\Sigma)$ per observation interval T_Σ as an indicator of efficiency [24, 25].

Average specific operational costs can be minimized based on the following considerations. Too frequent maintenance, on the one hand, leads to a high level of reliability, but, on the other hand, is characterized by high operational costs. A small number of maintenance activities reduces the reliability of the equipment and is also characterized by high total costs due to a much higher repair tariff rate. Therefore, the optimal number of maintenance procedures can be determined. This approach fits within the framework of the concept of preventive maintenance [26].

During the preventive maintenance, the decision to perform it is made on the basis of data processing using datasets on diagnostic variables of the equipment. We assume that these parameters are characterized by a stochastic model M_{DV} and the processing algorithms form a vector $\vec{A}$. We assume that the cost of implementing one processing procedure is spent with a tariff rate C_P. Equipment failure occurs when the values of the diagnostic variables exceed the operational tolerance v_O and the preventive maintenance is implemented when variables exceed the preventive tolerance v_M. The process of failure is characterized by a stochastic model M_F. In addition, a number of limitations may be imposed on the aviation company-operator, which are characterized by the set L. Therefore, the efficiency indicator can be represented as the functional dependence of the following form

$$E(C_\Sigma/T_\Sigma) = \Psi\left(M_{DV}, M_F, \vec{A}, C_M, C_R, C_P, v_O, v_M \middle| L\right). \tag{1}$$

The main task is to determine a preventive tolerance that minimizes the average specific operating costs, i.e.

$$E(C_\Sigma/T_\Sigma)_{optimal} = \min_{v_M} \Psi\left(M_{DV}, M_F, \vec{A}, C_M, C_R, C_P, v_O, v_M \middle| L\right). \tag{2}$$

Thus, the purpose of this paper is to optimize the operational costs of the aviation enterprise when monitoring the diagnostic variables of equipment. In this case, the main attention will be paid to the analytical solution of the optimization problem within the framework of the assumptions made about the models of the diagnostic variables, the model of failure occurrence and the adopted data processing algorithms.

3. Intelligence technologies during equipment operation

The use of intelligent technologies in the management system of maintenance and operation of equipment at aviation enterprises helps to increase productivity, reduce costs, and improve the overall competitiveness of the enterprise in the global market. The key opportunities for their application in the aviation sector are summarized in Table 1. In the context of the research problem, it is possible to identify the key advantages of using modern intelligent technologies in the management system of maintenance and operation of aviation equipment:

1. Because of the use of intelligent technologies (AI and big data analysis), it is possible to accurately predict possible failures and plan their elimination in time, which reduces equipment downtime and increases its availability.
2. Intelligent systems allow for efficient management of spare parts, rational allocation of personnel time, and minimization of maintenance costs.
3. With real-time monitoring and response systems, potential security threats can be quickly identified and timely remedial action can be taken.
4. Automation of routine tasks and the use of intelligent systems help free up personnel's time to perform more complex and strategic tasks, which increases their efficiency and job satisfaction.
5. The integration of various data and analytical tools allows to optimize the maintenance and operation schedule, coordinate the work of various departments, and minimize equipment downtime through optimal planning.

6. Failure prediction systems and regular monitoring of equipment conditions allow to timely detect and eliminate problems, which increases equipment availability.
7. The use of intelligent systems allows to efficient collect, process, and analyze operational data, which helps to improve reporting and make informed decisions.
8. Real-time monitoring and analysis of data allows to quickly identify problems and changes in the condition of the equipment, which can help to quickly respond and take the necessary measures to solve them [27–29].

Table 1
Possibilities of using modern intelligent technologies in the management system for maintenance and operation of aviation equipment

Areas of application	Characteristics of intelligent technologies
1. Fault prediction	1.1. AI. The AI algorithms can analyze historical data on equipment maintenance and operation to predict possible malfunctions. This allows to plan repairs in advance, reducing the aviation risks. 1.2. Big Data and analytics. Analyzing large arrays of data allows to identify patterns and trends that may indicate impending failures.
2. Real-time monitoring	2.1. Internet of Things. The sensors installed on equipment provide continuous data collection on its condition. This allows real-time monitoring of systems and prompt response to any deviations. 2.2. Cloud technologies. Data can be transferred to cloud storage, where it is processed and analyzed for immediate response.
3. Automation of business processes	3.1. Process robotization. These technologies can automate routine tasks, such as document management, processing spare parts orders, scheduling maintenance, and other operation processes. 3.2. Integrated management systems. The use of enterprise resource planning system can automate and coordinate all aspects of maintenance.
4. Improved training and support	4.1. Virtual and augmented reality. It can help to train personnel, to simulate real-life situations and practice maintenance skills without risking real equipment. 4.2. Intelligent learning platforms. AI-powered learning systems can adapt training programs to the individual needs of each employee.
5. Optimization of resources	5.1. Inventory optimization. AI and analytical tools help to optimize spare parts inventory management, reducing storage costs and preventing shortages of critical components. 5.2. Resource planning and allocation. Intelligent systems can automatically schedule and allocate personnel's work, ensuring optimal use of human resources.
6. Ensuring compliance with standards	6.1. Blockchain. The use of blockchain technologies to track the service history and origin of spare parts ensures transparency and compliance with international standards and regulations. 6.2. Automated reporting systems. It helps to ensure compliance with aviation regulatory requirements.
7. Improving customer experience	7.1. Intelligent platforms for customers. AI-powered systems can provide customers with information on the status of their equipment maintenance, predicted completion dates, and other important information in real time. 7.2. Personalized services. Using AI to analyze customer needs allows to provide personalized services and recommendations.

Thus, the introduction of modern intelligent technologies in the aviation equipment maintenance and operation management system is a critical step for airlines to improve the efficiency, safety and reliability of their operations, reduce costs and increase customer satisfaction with flight services.

4. Method of operational costs optimization

Let us consider the problem of optimizing operational costs for the case of monitoring the diagnostic variables of aviation equipment. To do it, we will accept a number of restrictions on the parameter models and the failure process:

1. One diagnostic variable is subject to monitoring. Let this variable be the voltage at a certain control point of aviation radio equipment.
2. Monitoring is performed discretely with a sampling interval of Δ and the cost of a single processing procedure C_P.
3. The diagnostic variable has two components: deterministic and random. The deterministic component has the form of a steady signal that corresponds to the standard initial value u_0. The random component is caused by the influence of thermal noise, instability of power supplies, and the presence of errors in measuring equipment.
4. The random component n_i of the diagnostic variable can be characterized by a normal distribution law with zero mathematical expectation and a given standard deviation σ.
5. The pre-failure state is characterized by a violation of the stationarity of the trend of the diagnostic variable change. The transition from the state of normal functioning to this state occurs at a random moment of time t_{BF}. The value of t_{BF} can be described by a uniform distribution law in the range of possible values $[t_{BF\,min};\ t_{BF\,max}]$.
6. The pre-failure state causes a linear change in the diagnostic variable over the time. The slope of the linear trend γ is random. The value of γ can be described by a uniform distribution law in the range of possible values $[\gamma_{min};\ \gamma_{max}]$.
7. Failures are independent, which does not require additional procedures for processing correlation dependencies [30, 31].
8. The duration of preventive maintenance is a deterministic value and is equal to τ.
9. After maintenance or repair, the value of the diagnostic variable will be equal to the value u_0.

Based on these assumptions, a mathematical model of the diagnostic variable can be written in a discrete form

$$u_i = u_0 + n_i + \tan(\gamma)(i - t_{BF})\phi(i - t_{BF}), \qquad (3)$$

where $\phi(i)$ is the step function.

To evaluate this model, regression analysis methods can be used, in particular those studied in [32–34].

For the cases when $i < t_{BF}$, the diagnostic variable will be described by a normal law with mean u_0 and standard deviation σ because of linear functional transformations. In the case of the pre-failure condition, taking into account the independence of the set of random variables n_i, t_{BF} and γ and using the methods of functional transformations, the probability density function of the diagnostic variable can be presented as follows

$$f(u) = \int\int \frac{f(n)}{\tan(\gamma)} f(t_{BF})\Big|_{t_{BF}=i-\frac{u-u_0-n}{\tan(\gamma)}} dn\,d\gamma. \qquad (4)$$

The efficiency indicator (1) can be written in the following form

$$E(C_\Sigma/T_\Sigma) = \frac{q_M C_M + q_R C_R}{\sum_{j=1}^{q_M} t_{M\,j} + q_M\tau + \sum_{j=1}^{q_M} t_{F\,j} + q_R t_R}, \qquad (5)$$

where q_M and q_R are the average number of maintenance and repair procedures per observation interval, $t_{M\ j}$ and $t_{F\ j}$ are the moments when the diagnostic variable exceeds the preventive and operational thresholds, t_R is the average repair duration.

In this view, it can be assumed that failure will occur when there is insufficient time to perform preventive maintenance in the case if the diagnostic variable changes from the preventive to the operational threshold. To solve the problem (2), we use model (3) for the moments of time $t_{M\ j}$ and $t_{F\ j}$, resulting in

$$t_{M\ j} = \frac{v_M - u_0}{\tan(\gamma)} + t_{BF} - \frac{\widetilde{n_\iota}}{\tan(\gamma)}, \tag{6}$$

$$t_{F\ j} = \frac{v_O - u_0}{\tan(\gamma)} + t_{BF} - \frac{n_i}{\tan(\gamma)}, \tag{7}$$

where $\widetilde{n_\iota}$ is the error value of the measuring equipment at the moment of exceeding the preventive threshold.

The maximum time resource for failure elimination and preventive maintenance carrying out will be determined as

$$t_{max\ j} = t_{F\ j} - t_{M\ j} = \frac{v_O - v_M + \widetilde{n_\iota} - n_i}{\tan(\gamma)}. \tag{8}$$

Let's assume that the monitoring uses equipment of a high accuracy class, then $\sigma \ll 1$. Then formula (8) will be simplified

$$t_{max\ j} \approx \frac{v_O - v_M}{\tan(\gamma)}. \tag{9}$$

To find the estimates q_M and q_R we first determine the probability density function for $t_{max\ j}$. To do this, we write the inverse function to (9)

$$\gamma = \arctan\left(\frac{v_O - v_M}{t_{max\ j}}\right). \tag{10}$$

In this case, the Jacobian of the transformation is equal to the modulus of the derivative of function (10) and is equal to

$$J = \left|\frac{d\gamma}{dt_{max\ j}}\right| = \frac{v_O - v_M}{t_{max\ j}^2 + (v_O - v_M)^2}. \tag{11}$$

Therefore

$$f(t_{max\ j}) = \frac{1}{\gamma_{max} - \gamma_{min}} \frac{v_O - v_M}{t_{max\ j}^2 + (v_O - v_M)^2}. \tag{12}$$

The average number of maintenance and repair procedures is determined from density (12) by determining the integral from zero to τ and the integral from τ to infinity. As a result of solving the equations, we can get the estimates of the form

$$q_M = \frac{q_\Sigma}{\gamma_{max} - \gamma_{min}} \left(\frac{\pi}{2} - \gamma_{min} - \arctan\left(\frac{t_{max\ j}}{v_O - v_M}\right)\right), \tag{13}$$

$$q_R = \frac{q_\Sigma}{\gamma_{max} - \gamma_{min}} \left(\arctan\left(\frac{t_{max\ j}}{v_O - v_M}\right) - \frac{\pi}{2} + \gamma_{max}\right), \tag{14}$$

where q_Σ is the average total number of maintenance and repair procedures.

After using the operations of averaging, finding the statistical characteristics of the tangent of the random slope of the linear trend and using equations (13) and (14), the observation interval (numerator in equation (5)) can be presented as follows

$$T_\Sigma = q_\Sigma \left(a_1 + a_2 v_M + a_3 \arctan\left(\frac{t_{max\ j}}{v_O - v_M}\right) + a_4 v_M \arctan\left(\frac{t_{max\ j}}{v_O - v_M}\right)\right), \tag{15}$$

where a_1, a_2, a_3, a_4 are the values determined using the initial parameters

$$\begin{cases} a_1 = \dfrac{t_{BF\,min} + t_{BF\,max}}{2} - \\ -\dfrac{u_0 \ln\left(\dfrac{\sin\gamma_{max}}{\sin\gamma_{min}}\right) + \dfrac{\pi}{2}\tau - \gamma_{min}\tau + \left(\dfrac{\pi}{2} + \gamma_{max}\right)\left(t_R - + \dfrac{v_O \ln\left(\dfrac{\sin\gamma_{max}}{\sin\gamma_{min}}\right)}{\gamma_{max} - \gamma_{min}}\right)}{\gamma_{max} - \gamma_{min}}, \\ a_2 = \dfrac{\dfrac{\pi}{2} - \gamma_{min}}{(\gamma_{max} - \gamma_{min})^2} \ln\left(\dfrac{\sin\gamma_{max}}{\sin\gamma_{min}}\right), \\ a_3 = \dfrac{v_O \ln\left(\dfrac{\sin\gamma_{max}}{\sin\gamma_{min}}\right) + t_R - \tau}{(\gamma_{max} - \gamma_{min})^2}, \\ a_4 = \dfrac{1}{(\gamma_{max} - \gamma_{min})^2} \ln\left(\dfrac{\sin\gamma_{max}}{\sin\gamma_{min}}\right). \end{cases} \quad (16)$$

If we introduce additional values a_5 and a_6 of the type

$$\begin{cases} a_5 = \dfrac{C_R\left(\gamma_{max} - \dfrac{\pi}{2}\right) - C_M\left(\dfrac{\pi}{2} - \gamma_{min}\right)}{(\gamma_{max} - \gamma_{min})^2}, \\ a_6 = \dfrac{C_R - C_M}{\gamma_{max} - \gamma_{min}}, \end{cases} \quad (17)$$

then we obtain the final equation for the efficiency indicator (5) in the form of average total specific costs

$$E(C_\Sigma/T_\Sigma) = \frac{a_5 + a_6 \arctan\left(\dfrac{t_{max\,j}}{v_O - v_M}\right)}{a_1 + a_2 v_M + a_3 \arctan\left(\dfrac{t_{max\,j}}{v_O - v_M}\right) + a_4 v_M \arctan\left(\dfrac{t_{max\,j}}{v_O - v_M}\right)}. \quad (18)$$

The last step of the calculation is to analyze function (18) for the presence of a minimum with respect to the preventive threshold v_M. The analysis showed that this dependence has one minimum. The complex nature of formula (18) necessitated the use of numerical optimization methods to find the optimal preventive threshold.

The flowchart of proposed method is shown in Figure 1.

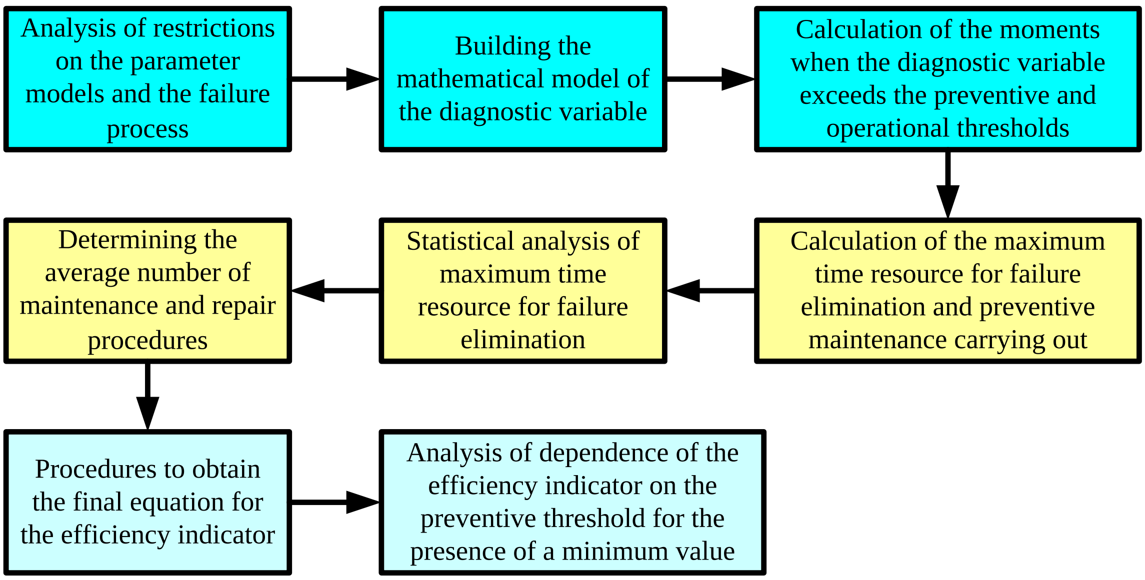

Figure 1: The flowchart of proposed method.

5. Results and discussions

For the practical testing of the proposed method of optimizing the operational costs of the aviation enterprise, statistical modeling was carried out. The primary data for modeling were obtained by analyzing statistical reports and activities of three aviation enterprises:

- ZEFKO UKRAINE LLC.
- PE "TRANS LOGISTICS".
- PJSC "DHL International Ukraine" [35–37].

The central repair center for spare parts and equipment is located at a long distance from the enterprises, which indicates a rather expensive and lengthy delivery of units with operational equipment failures. Maintenance procedures were carried out at the airport, which makes it much less expensive compared to repairs.

At the initial stage of the simulation, realizations of one diagnostic variable in the form of a 220 V supply voltage were obtained for 10000 repetition epochs. An example of changing the diagnostic variable is shown in Figure 2.

The graph in Figure 2 was obtained for the initial data:

- Nominal value of the supply voltage $u_0 = 220$ V.
- Operational thresholds $v_O = \{176; 264\}$ V.
- Preventive thresholds $v_O = \{198; 242\}$ V.
- Standard deviation of noise $\sigma = 3$ V.
- Distribution parameters for the slope angle: $\gamma_{min} = \frac{\pi}{9}$, $\gamma_{max} = \frac{\pi}{3}$.
- Distribution parameters for the moment of transition to the state before failure: $t_{BF\,min} = 30$, $t_{BF\,max} = 80$.
- The sampling interval is equal to one unit of time.

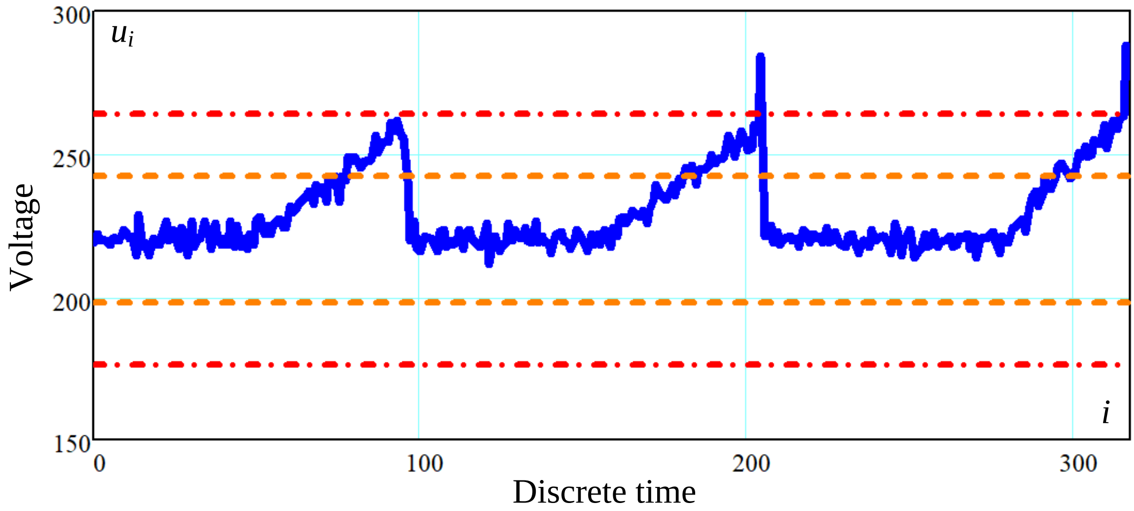

Figure 2: The example of diagnostic variable change before failure.

In Figure 1, we have one failure elimination when the voltage value does not exceed the operational threshold in the deterioration state, and two failures when this threshold is reached.

The durations of threshold crossings are also random variables. Figure 3 shows a histogram of frequencies for the moments of crossing the operational threshold.

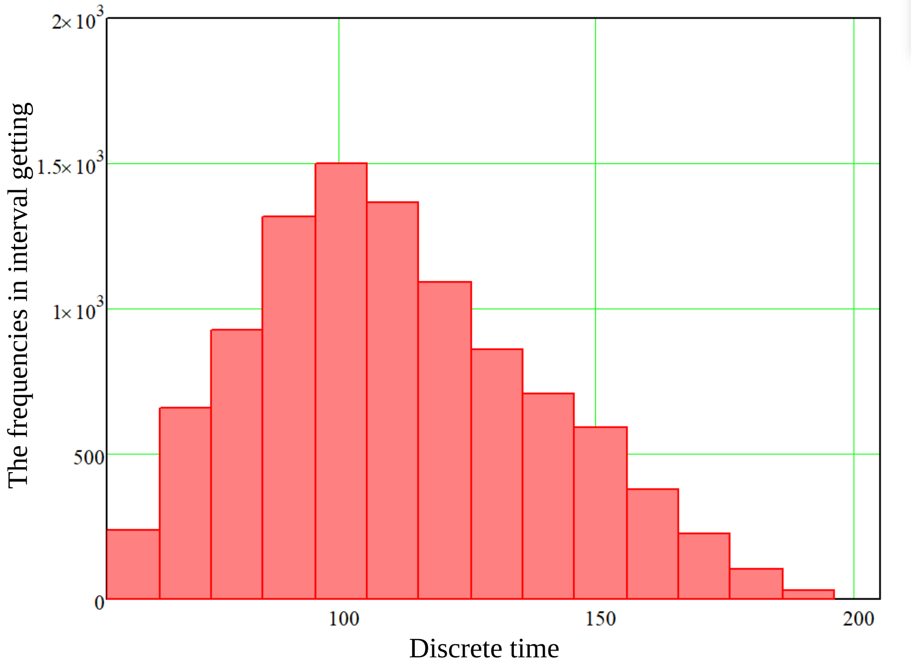

Figure 3: The histogram of time moments of operation threshold intersection.

The nature of the dependence of the statistical distribution in Figure 3 corresponds to the failure model and can be characterized by asymmetric laws, such as Rayleigh, Weibull, Birnbaum-Saunders, inverse Gaussian, and others. To determine the optimal preventive threshold, the Monte Carlo method was used for such initial data:

- The cost of a single processing procedure $C_P = 0.01$ USD.
- Cost of maintenance $C_M = 250$ USD.
- The cost of repair $C_R = 10000$ USD.
- Duration of maintenance $t_M = 24$ hours.
- Duration of the repair $t_R = 72$ hours.

The simulation results are shown in Figure 4.

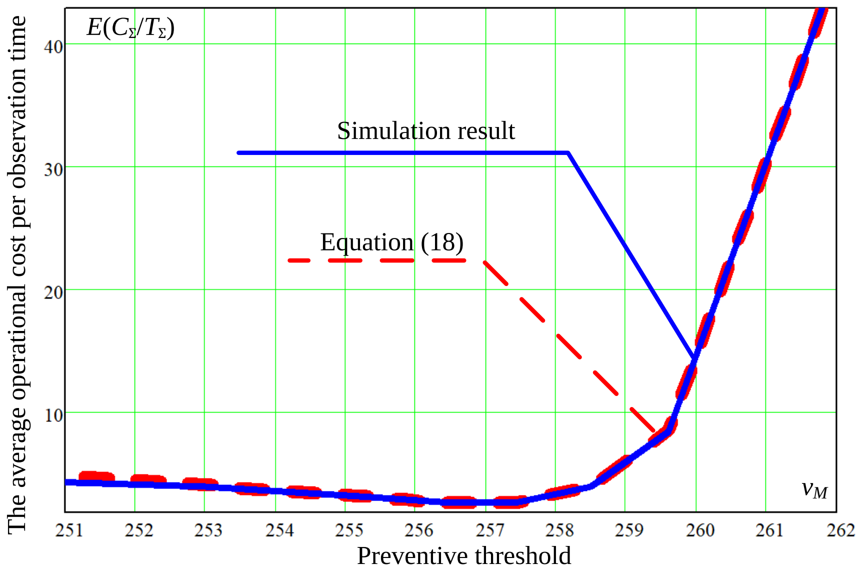

Figure 4: The average operational cost per observation time.

Figure 4 shows that the simulation results coincide with the analytical calculations. The minimum points on both graphs also coincide. The optimal value of the preventive threshold, which corresponds to the minimum operational cost, for the determined initial data is 257.48 V. The results of calculations and statistical simulation demonstrate the feasibility of the proposed approach for optimizing operational costs not only for aviation enterprises, but also in other industries.

6. Conclusions

Thus, the use of modern intelligent technologies in the management system for the maintenance and operation of aviation equipment is very appropriate and promising in the practice of an aviation enterprise. The introduction of intelligent technologies will allow aviation companies to optimize costs, reduce equipment downtime and increase its availability. In addition, they provide improved data management, which contributes to more efficient decision-making and resource planning. Intelligent technologies help to ensure sustainable improvement and innovation in the management system, which allows airlines to provide high quality service and remain competitive in the modern world of the aviation industry. This paper considers the problem of determining the optimal frequency of preventive maintenance in terms of minimizing operational costs. The problem is solved analytically, taking into account the stochastic model of changes in the diagnostic variable in the period immediately before the equipment failure. The obtained analytical equations are confirmed by statistical simulation. The results of the study can be used during the launching new aviation enterprises specialized on maintenance and operation and improve the management of production processes for existing ones.

Future scientific research will be aimed at developing a maintenance system with an adaptive preventive threshold, the value of which will be adjusted to the current trends in the diagnostic variables of aviation equipment.

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References

[1] S. K. Cusick, A. I. Cortes, C. C. Rodrigues, Commercial Aviation Safety, 6th. ed., McGraw-Hill Education, New York, 2012.

[2] Doc 9859, Safety Management Manual. International Civil Aviation Organization, Montreal, 2018.

[3] I. V. Ostroumov, N. S. Kuzmenko, Risk analysis of positioning by navigational aids, in: Proceedings of Signal Processing Symposium (SPSympo), IEEE, Krakow, Poland, 2019, pp. 92–95. doi: 10.1109/SPS.2019.8882003.

[4] A. Derkach, Application of modern information technologies in enterprise reengineering in conditions of digitalization, Science and perspective 9 28 (2023) 39–52.

[5] D. V. Medynskyi, Optimizing the provision of technological processes of ground maintenance of aircraft by aviation ground equipment to prevent malfunctioning situations at the airport, Academic notes of TNU named after V.I. Vernadsky, Series: Technical sciences 32 71 (2021) 113–122.

[6] A. Regattieri, A. Giazzi, M. Gamberi, R.Gamberini, An innovative method to optimize the maintenance policies in an aircraft: General framework and case study, Journal of Air Transport Management 44-45 (2015) 8–20. doi: 10.1016/j.jairtraman.2015.02.001.

[7] Z. Poberezhna, Comprehensive assessment of the airlines' competitiveness, Economic Annals-XXI 167 (2017) 32–36. doi: 10.21003/ea.V167-07.
[8] Z. Poberezhna, Comprehensive approach to the efficiency assessment of the business model of the aviation enterprise based on business process innovation, Eastern-European Journal of Enterprise Technologies 5 (2021) 44–57. doi: 10.15587/1729-4061.2021.243118.
[9] M. Modarres, K. Groth, Reliability and Risk Analysis, CRC Press, Boca Raton, 2023.
[10] O. Solomentsev, M. Zaliskyi, O. Zuiev, Estimation of quality parameters in the radio flight support operational system, Aviation 20 3 (2016) 123–128. doi: 10.3846/16487788.2016.1227541.
[11] M. Gopal, Applied Machine Learning, McGraw Hill Education, India, 2018.
[12] I.V. Ostroumov, N.S. Kuzmenko, Accuracy improvement of VOR/VOR navigation with angle extrapolation by linear regression, Telecommunications and Radio Engineering 78 15 (2019) 1399–1412. doi: 10.1615/TelecomRadEng.v78.i15.90.
[13] T. Nakagawa, Maintenance Theory of Reliability, Springer-Verlag, London, 2005.
[14] O. Solomentsev, M. Zaliskyi, T. Herasymenko, O. Kozhokhina, Yu. Petrova, Efficiency of operational data processing for radio electronic equipment, Aviation 23 3 (2019) 71–77. doi: 10.3846/aviation.2019.11849.
[15] O. Holubnychyi, et al., Self-organization technique with a norm transformation based filtering for sustainable infocommunications within CNS/ATM systems, in: I. Ostroumov, M. Zaliskyi (Eds.), Proceedings of the 2nd International Workshop on Advances in Civil Aviation Systems Development. ACASD 2024, volume 992 of Lecture Notes in Networks and Systems, Springer, Cham, 2024, pp. 262–278. doi: 10.1007/978-3-031-60196-5_20.
[16] O. M. Tachinina, O. I. Lysenko, S. O. Ponomarenko, I. V. Alekseeva, Conceptual proposals for the creation of a fully reusable light-class aerospace system in Ukraine, in: Proceedings of IEEE 6th International Conference on Methods and Systems of Navigation and Motion Control, IEEE, Kyiv, Ukraine, 2020, pp. 85–88. doi: 10.1109/MSNMC50359.2020.9255504.
[17] A. Anand, M. Ram, System Reliability Management: Solutions and Techniques, CRC Press, Boca Raton, 2021.
[18] O.V. Solomentsev, M.Yu. Zaliskyi, O.V. Zuiev, M.M. Asanov, Data processing in exploitation system of unmanned aerial vehicles radioelectronic equipment, in: Proceedings of IEEE 2nd International Conference Actual Problems of Unmanned Air Vehicles Developments (APUAVD), IEEE, Kyiv, Ukraine, 2013, pp. 77–80. doi: 10.1109/APUAVD.2013.6705288.
[19] H. Ren, X. Chen and Y. Chen, Reliability Based Aircraft Maintenance Optimization and Applications, Academic Press, 2017.
[20] O. Solomentsev, et al., Efficiency analysis of current repair procedures for aviation radio equipment, in: I. Ostroumov, M. Zaliskyi (Eds.), Proceedings of the 2nd International Workshop on Advances in Civil Aviation Systems Development. ACASD 2024, volume 992 of Lecture Notes in Networks and Systems, Springer, Cham, 2024, pp. 281–295. doi: 10.1007/978-3-031-60196-5_21.
[21] D. Galar, P. Sandborn, and U. Kumar, Maintenance Costs and Life Cycle Cost Analysis, CRC Press, Boca Raton, 2017.
[22] A. K. S. Jardine, A. H. C. Tsang, Maintenance, Replacement, and Reliability: Theory and Applications, CRC Press, Boca Raton, 2017.
[23] T. Nikitina, et al., Method for design of magnetic field active silencing system based on robust meta model, in: S. Shukla, H. Sayama, J.V. Kureethara, D.K. Mishra (Eds.), Data Science and Security. IDSCS 2023, volume 922 of Lecture Notes in Networks and Systems, Springer, Singapore, 2024, pp. 103–111. doi: 10.1007/978-981-97-0975-5_9.
[24] I. V. Ostroumov, N. S. Kuzmenko, Compatibility analysis of multi signal processing in APNT with current navigation infrastructure, Telecommunications and Radio Engineering 77 3 (2018) 211–223. doi: 10.1615/TelecomRadEng.v77.i3.30.
[25] D. J. Smith, Reliability, Maintainability and Risk. Practical Methods for Engineers, 10th. ed., London, Elsevier, 2021.

[26] I. Gertsbakh, Reliability Theory: with Applications to Preventive Maintenance, Springer, New York, 2005.
[27] E. Rogers, Diffusion of Innovations, 5th. ed., Free Press, New York, 2003.
[28] H. Taherdoost, A review of technology acceptance and adoption models and theories, Procedia Manufacturing 2 (2018) 960–967. doi: 10.1016/j.promfg.2018.03.137.
[29] S. Lippert, H. Forman, Utilization of information technology: Examining cognitive and experiential factors of post-adoption behavior. IEEE Transaction on Engineering Management 52 3 (2005) 363–381. doi: 10.1109/TEM.2005.851273.
[30] O. Solomentsev, M. Zaliskyi, Correlated failures analysis in navigation system, in: Proceedings of IEEE 5th International Conference on Methods and Systems of Navigation and Motion Control (MSNMC), IEEE, Kyiv, Ukraine, 2018, pp. 41–44. doi: 10.1109/MSNMC.2018.8576306.
[31] I. V. Ostroumov, N. S. Kuzmenko, Accuracy assessment of aircraft positioning by multiple radio navigational aids, Telecommunications and Radio Engineering 77 (8) (2018) 705–715. doi: 10.1615/TelecomRadEng.v77.i8.40.
[32] J. Al-Azzeh, A. Mesleh, M. Zaliskyi, R. Odarchenko, V. Kuzmin, A method of accuracy increment using segmented regression, Algorithms 15 378 (2022) 1–24. doi: 10.3390/a15100378.
[33] Y. Averyanova, et al., Turbulence detection and classification algorithm using data from AWR, in: Proceedings of IEEE 2nd Ukrainian Microwave Week (UkrMW), IEEE, Kyiv, Ukraine, 2022, pp. 518–522. doi: 10.1109/UkrMW58013.2022.10037172.
[34] T. Nikitina, et al., Algorithm of robust control for multi-stand rolling mill strip based on stochastic multi-swarm multi-agent optimization, in: S. Shukla, H. Sayama, J.V. Kureethara, D.K. Mishra (Eds.), Data Science and Security. IDSCS 2023, volume 922 of Lecture Notes in Networks and Systems, Springer, Singapore, 2024, pp. 247–255. doi: 10.1007/978-981-97-0975-5_22.
[35] ZEFKO UKRAINE LLC (financial statements 2020-2023), 2023. URL: https://clarity-project.info/edr/35894081/finances?current_year=2023.
[36] PE “TRANS LOGISTICS” (financial statements 2020-2023), 2023. URL: https://clarity-project.info/edr/34307753/finances?current_year=2023.
[37] PJSC "DHL International Ukraine" (financial statements 2020-2023), 2023. URL: https://clarity-project.info/edr/22925230/finances?current_year=2023.