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ESTIMATION OF QUALITY PARAMETERS IN THE RADIO FLIGHT SUPPORT OPERATIONAL SYSTEM

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Abstract. The paper considers the structure of the operational system of radio equipment, determines the procedures related to the estimation of the quality parameters in the radio flight support operational system, using the ready-to-operate factor and the probability of no failure operation in a finite time interval, and shows the analytical ratios for the probability density function (PDF).

Keywords: operational system, radio flight support, the probability of no failure operation in a finite time interval, ready-to-operate factor, estimation.

1. Introduction

The ground facilities of radio flight support equipment play an important role in the process of providing regularity, safety and efficiency to civil aviation entities. The operational stability of these facilities is supported with the help of the radio flight support operational system. The information signals in the operational systems are generally random. In order to solve practical problems and to modernize the operational system, generalized quality parameters are usually applied. These parameters are used to calculate the risks of air navigation service, the threshold characteristics of radio flight support facilities, etc.

The quality parameters of the radio flight support system include:

1) ready-to-operate factor;
2) operative factor;
3) technical applicability factor;
4) non-operative factor;
5) system integrity;
6) continuity of functioning, etc.

The initial data required to calculate the quality parameters are statistical data, including the operating time to a failure and the recovery time for radio support flight facilities. The analysis of some of the references to this article (Nakagawa 2005; Smith 2005) showed that proper attention has not been paid to the determination of the probability density function regarding the parameters given above.

2. Problem statement

2.1. Generalized structure of the operational system

The operational system is a set of products, operational facilities, executers, technological processes and the documentation that establishes the rules for their interaction in order to effectively fulfill operational tasks. The operational facilities include buildings, equipment (including tools), stands, devices, spare parts and raw materials necessary for operation. The operating system is a service type system, which is characterized by the flow of incoming and outgoing requests. The incoming flow of requests $\vec{З}_{\text{вх}}$ includes separate tasks and requirements for them, for instance, a task of transmitting information on-board.

The processing of requests is performed according to a specific technology which is implemented in separate elements (technological systems) of the air transport system (ATS). The analysis of the air transport system shows that some technological systems (TS) interact with each other on the basis of the maintenance principle (Kulyk *et al.* 2011). An example of the interaction of some of the technological systems in the air transport system concerning the radio flight support (RFS) is shown in Figure 1.

Figure 1 shows the flow of incoming requests $\vec{\text{A}}_{\text{IF}}^{(1/3)}$ from TS 1 to TS 3, incoming requests $\vec{\text{A}}_{\text{IF}}^{(3.1/3.2)}$ from TS 3.1 to TS 3.2, and incoming requests $\vec{\text{A}}_{\text{IF}}^{(3.2/3.3)}$ from TS 3.2 to TS 3.3. In order to describe the requests, it is possible to apply the demand vector $\vec{\gamma}$. This vector characterizes the requests by temporal demands (parameter description vector $\vec{T}$), spatial demands (parameter

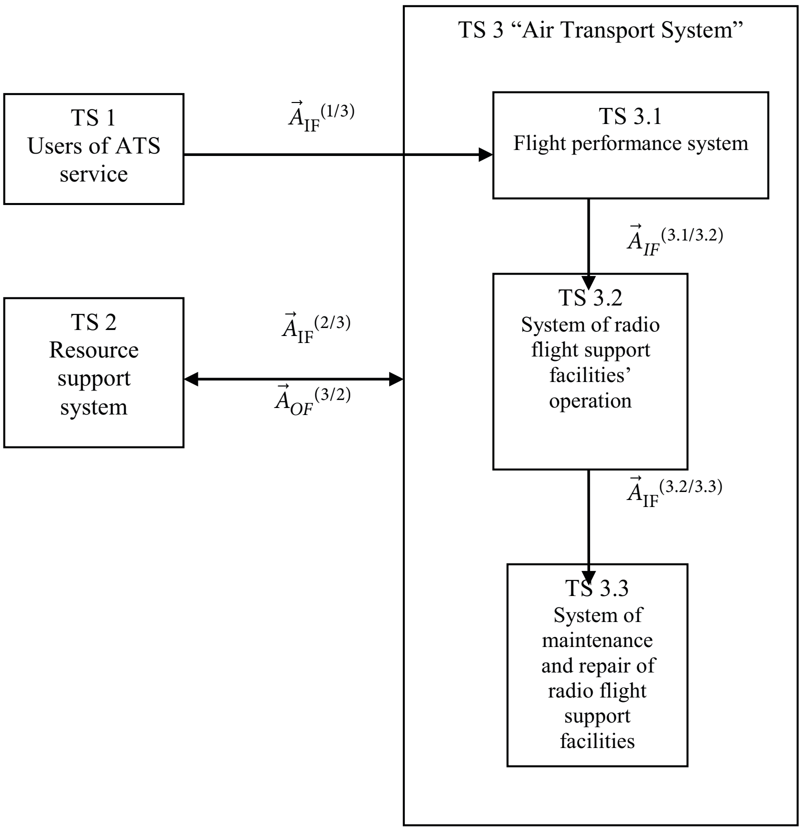

Fig. 1. Generalized structural diagram of the interaction between the technological systems in the ATS

description vector $\vec{L}$) and informational demands (parameter description vector $\vec{I}$). Generally, the numerical values of the components of the outgoing request vector $\vec{\gamma}$ differ from the numerical values of the components of the incoming requests vector $\vec{\gamma}$ because of failures or damages in products and systems, the random nature of the operational conditions, etc. As a result, the following equation can be obtained:

$$\vec{A}_{IF}^{(1/3)}(\vec{a}(\vec{L};\vec{T};\vec{I})), \vec{A}_{OF}^{(3/1)}(\vec{a}'(\vec{L};\vec{T};\vec{I}));$$

$$\vec{A}_{IF}^{(3.1/3.2)}(\vec{a}(\vec{L};\vec{T};\vec{I})), \vec{A}_{OF}^{(3.2/3.1)}(\vec{a}'(\vec{L};\vec{T};\vec{I})).$$

To adequately describe any TS, the following components of the generalized $TS(\cdot)$ operator ought to be determined:

- the list of system elements, the description of which is given by the operator $\vec{\text{El}}(\cdot)$;
- the organizational structure of these elements, the description of which is given with the help of the generalized operator $\overline{\text{Str}}(\cdot)$;
- system functioning conditions, the description of which is given with the help of the generalized operator $\vec{C}ond(\cdot)$;
- resource supply, using the generalized operator $\vec{R}es(\cdot)$;
- regulatory and administrative documentation, the description of which is given with the help of the generalized operator $\vec{R}d(\cdot)$;
- informational resources, the description of which is given with the help of the generalized operator $\vec{\text{I}}\text{r}(\cdot)$;
- technological processes, using the generalized operator $\vec{TP}(\cdot)$;
- operational facilities, the description of which is given with the help of the generalized operator $\vec{\text{O}}\text{m}(\cdot)$, including buildings and constructions (generalized operator *Bu*), means of the technological equipment (generalized operator *Mte*), which consist of the main technological equipment and technological tools.

The generalized operator for the TS $3.2(\cdot)$ is described as follows:

$$\text{TS } 3.2(\dot{O};\vec{A}_{IF}^{(3.1/3.2)}(\vec{\gamma});\vec{A}_{OF}^{(3.2/3.1)}(\vec{\gamma}')\,/$$

$$\overline{\text{Str}}(\vec{\text{El}});\vec{\text{O}}\text{m}(\vec{\text{M}}\text{te},\vec{\text{B}}\text{u});\vec{\text{T}}P;\vec{\text{I}}\text{r};\vec{C}ond;\vec{\text{R}}\text{e}s;\vec{\text{R}}\text{d}).$$

Having set the parameters included in the description of the random generalized $\text{TS}(\cdot)$ operator, it is possible to observe the changes in the states of the system, specifically its phase states $\vec{S}t(T)$ in time.

According to reference Dhillon 2006, it can be presumed that the main components of the operational system are as follows:

- requests to be processed;
- structural elements of the operational system and their organizational structure;
- technological processes;
- executors (engineering personnel maintaining radio flight support facilities);
- operational facilities;
- administrative regulatory documentation;
- onsumables;
- informational resources;
- operational conditions (climatic conditions, electromagnetic compatibility).

The effectiveness of the operational system functioning can be studied considering two aspects. The first aspect is related to the impact of the risk on radio flight support facilities and the stability of the air navigation service system functioning. Another aspect of effectiveness is related to the minimization of the costs spent on radio flight support facilities.

To carry out a quantitative evaluation of the radio flight support operational system functioning, it is necessary and possible to use the generalized reliability parameters, i.e. the probability of no failure operation in a finite time interval, and the ready-to-operate factor, etc. (Nechval *et al.* 2000). Actually, these parameters are random values which ought to be determined and fully characterized in the form of the probability density function.

2.2. Main statistical characteristics of the probability of no failure operation in a finite time interval

It is known that the probability of no failure operation in a finite time interval $P(t)$ means that no failure will occur if certain conditions in a given interval of time or within specific operating time t exist. Generally, the initial data for the calculation of the reliability indicators is the statistical data on the operating time t_i and recovery time τ_i for the radio flight support facilities. The information pertaining to the time between failures can be comprehensive for calculating the probability of no failure operation in a finite time interval. According to Kulyk *et al.* (2011), the case of exponential operating time between failures is believed to be most repetitive. The probability of no failure operation in a finite time interval is determined by the following ratio:

$$P(t) = e^{\frac{-t}{\hat{T}_0}}, \tag{1}$$

where $\hat{T}_0$ is the evaluated operating time between failures.

$$\hat{T}_0 = \frac{1}{n}\sum_{i=1}^{n} t_i .$$

This value corresponds to the gamma distribution, which is described as follows:

$$f(x) = \frac{n}{\Gamma(n)T_0}\left(\frac{nx}{T_0}\right)^{n-1} e^{-\frac{nx}{T_0}},\ x \geq 0, \tag{2}$$

where n is the number of failures which is used in the evaluation of the operating time between the failures; T_0 is the mathematical expectation of the operating time between failures; the $\Gamma(n)$ is a complete gamma function.

The probability density function (PDF) of no failure operation in a finite time interval is calculated according to the following ratio:

$$f(t,P) = f(x)\left|\frac{dx}{dP}\right|\Bigg|_{x=x(P)}. \tag{3}$$

The inverse function of the ratio (1) and its derivative are described as follows:

$$x(P) = -\frac{t}{\ln P}, \tag{4}$$

$$\frac{dx}{dP} = \frac{t}{P\ln^2 P}. \tag{5}$$

Applying formulas (2) and (5) to expression (3) and taking into account expression (4), we derive the following equation:

$$f(t,P) = \frac{n}{\Gamma(n)T_0}\left(-\frac{nt}{T_0\ln P}\right)^{n-1} e^{\frac{nt}{T_0\ln P}}\frac{t}{P\ln^2 P}.$$

After simplification, we obtain the final expression for the PDF of no failure operation in a finite time interval:

$$f(t,P) = \frac{n^n t^n}{P\Gamma(n)\left(T_0\right)^n\left|\ln^{n+1} P\right|} e^{\frac{nt}{T_0\ln P}}, \quad 0 \le P \le 1. \tag{6}$$

The theoretical PDF and the results of statistical modeling for the values of initial parameters $T_0 = 100$, $n = 5$, $t = 5$ are shown in Figure 2.

The nomograms for the PDF of no failure operation in a finite time interval (for the case $T_0 = 100$, $n = 5$) for different time intervals t are shown in Figure3.

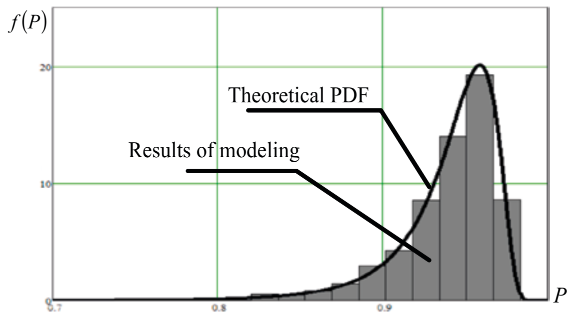

Fig. 2. Theoretical PDF and the results of statistical modeling

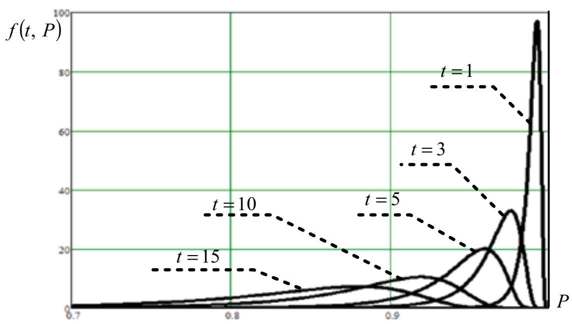

Fig. 3. Nomograms for the PDF of no failure operation in a finite time interval

Considering the case of normal operating time between failures, the probability of no failure operation in a finite time interval and the evaluated operating time between failures are calculated as follows:

$$P(t) = 1 - \frac{1}{\sigma\sqrt{2\pi}}\int_0^t e^{\frac{-(t-\hat{T}_0)^2}{2\sigma^2}}dt; \tag{7}$$

$$f(x) = \frac{\sqrt{n}}{\sigma\sqrt{2\pi}} e^{\frac{-n(x-T_0)^2}{2\sigma^2}}, \quad x \ge 0. \tag{8}$$

The exponent of equation (7) is placed in a Taylor series (to simplify calculations, only first two components of the series are taken) as follows:

$$6\sigma^2 t - t^3 + 3t^2 x - 3tx^2 + x^3 = 6\sigma^3\sqrt{2\pi}(1-P).$$

Upon solving this equation with respect to value x, the following equations are obtained:

$$x(P) = t + \sqrt[3]{6\sigma^3\sqrt{2\pi}(1-P) - 6\sigma^2 t}; \tag{9}$$

$$\frac{dx}{dP} = \frac{-2\sigma^3\sqrt{2\pi}}{\sqrt[3]{\left(6\sigma^3\sqrt{2\pi}(1-P) - 6\sigma^2 t\right)^2}}. \tag{10}$$

Applying formulas (8) and (10) to expression (3) and taking into account expression (9), we obtain the following:

$$f(t,P) = \frac{2\sigma^2\sqrt{n}}{\sqrt[3]{\left(6\sigma^3\sqrt{2\pi}(1-P) - 6\sigma^2 t\right)^2}} e^{\frac{-n\left(t+\sqrt[3]{6\sigma^3\sqrt{2\pi}(1-P)-6\sigma^2 t}-T_0\right)^2}{2\sigma^2}}, \quad 0 \le P \le 1.$$

2.3. Main statistical characteristics of the ready-to-operate factor

The ready-to-operate factor K_A under the random distribution of no-failure operation time T_0 and recovery time T_R is equal to the ratio between the mean time of no-failure operation and the mean recovery time, which is described as follows:

$$K_A = \frac{T_0}{T_0 + T_R}. \tag{11}$$

The revised calculation of the ready-to-operate factor allows designing complex systems more accurately, in order to implement preventive measures, to reasonably introduce additional elements, etc. In addition, there is a possibility to optimize the number of these elements and a more effective way to organize the maintenance of the investigated objects. The ready-to-operate factor $\hat{K}_A$ is estimated with the help of the following equation:

$$\hat{K}_A = \frac{\hat{T}_0}{\hat{T}_0 + \hat{T}_R}, \tag{12}$$

where $\hat{T}_0$ and $\hat{T}_R$ are the evaluated mean operating time between failures and system recovery.

The following equation shows the PDF of the ready-to-operate factor in the case of exponential distributions of the operating time between failures T_0 and recovery time $\hat{T}_R$:

$$f(\hat{K}_A) = \frac{\frac{T_R}{T_0}\Gamma(2n)\left(\frac{T_R}{T_0}\hat{K}_A\left(1-\hat{K}_A\right)\right)^{n-1}}{\Gamma^2(n)\left(1-\left(1-\frac{T_R}{T_0}\right)\hat{K}_A\right)^{2n}} \quad \text{when}$$

$$0 \le \hat{K}_G \le 1, \qquad (13)$$

where n is the number of system failures in the observed time interval, $\Gamma(n)$ is the complete gamma function, a is the normalizing factor:

$$a = \left(\int_0^1 \frac{\frac{T_R}{T_0}\Gamma(2n)\left(\frac{T_R}{T_0}x(1-x)\right)^{n-1}}{\Gamma^2(n)\left(1-\left(1-\frac{T_R}{T_0}\right)x\right)^{2n}}dx\right)^{-1}. \qquad (14)$$

If $T_0 = T_R$, the evaluation of the ready-to-operate factor is submitted to the beta distribution:

$$f(\hat{K}_A) = \frac{\Gamma(2n)}{\Gamma^2(n)}\left(\hat{K}_A\left(1-\hat{K}_A\right)\right)^{n-1} \quad \text{when}$$

$$0 \le \hat{K}_A \le 1. \qquad (15)$$

The average value of this estimation is described as $m_1(\hat{K}_A) = 0{,}5$, which is stable; consequently, the dispersion is described as follows:

$$\mu_2(\hat{K}_A) = \frac{1}{4(2n+1)}. \qquad (16)$$

Figure 4 shows the results of the modeling for the case of exponential distributions of the operating time between failures and recovery time under the condition that $T_0 = 10$, $T_R = 1$, $n = 50$.

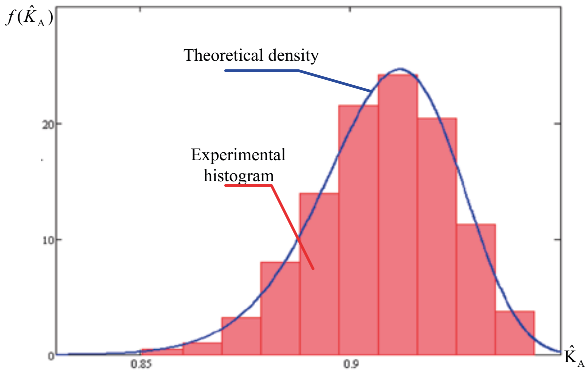

Fig. 4. PDF and histogram of the ready-to-operate factor estimation for the case of exponential distribution of the operating time between failures and recovery time

The probability density function of the ready-to-operate factor estimation for the case of exponential distribution of the mean operating time between failures T_0 and stable recovery time T_R is shown in the following equation:

$$f(\hat{K}_A) = \frac{n\frac{T_R}{T_0}\left(n\frac{T_R}{T_0}\hat{K}_A\right)^{n-1}}{\Gamma(n)\left(1-\hat{K}_A\right)^{n+1}}e^{-\frac{n\frac{T_R}{T_0}\hat{K}_A}{1-\hat{K}_A}} \quad \text{when}$$

$$0 \le \hat{K}_A \le 1. \qquad (17)$$

The results of the modeling for this case ($T_0 = 10$, $T_R = 1$, $n = 50$, $N = 500$) are shown in Figure 5.

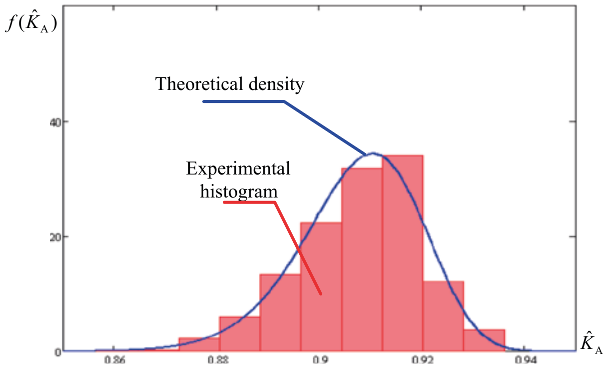

Fig. 5. PDF and histogram of the ready-to-operate factor estimation for the case of exponential distribution of the mean operating time between failures and a stable recovery time

Figure 6 shows the probability density function of the ready-to-operate factor estimation for the case of normal distribution of time between failures and recovery time under parameters $T_0 = 10$, $T_R = 1$, $n = 50$, and mean-square deviation $\sigma_0 = 0{,}2T_0$, ó$_R = 0{,}2T_R$.

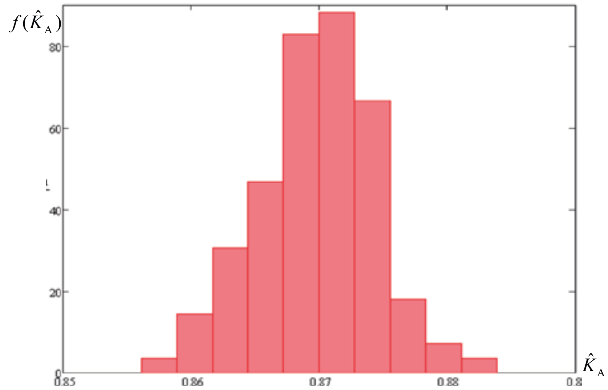

Fig. 6. Histogram of the ready-to-operate factor estimation for the case of normal distribution of operating time between failures and recovery time

Considering the case when the ready-to-operate factor estimation is carried out with one failure and one recovery of the system (where $n = 1$) and taking into account formulas (13) and (14), the PDF of the estimation is calculated as follows:

$$f(\hat{K}_A) = \frac{\frac{T_R}{T_0}}{\left(1-\left(1-\frac{T_R}{T_0}\right)\hat{K}_A\right)^2} \text{ when}$$

$$0 \le \hat{K}_A \le 1. \tag{18}$$

The modeling results are given in Figure 7 ($T_0 = 10$, $T_R = 1$, $n = 1$, $N = 500$).

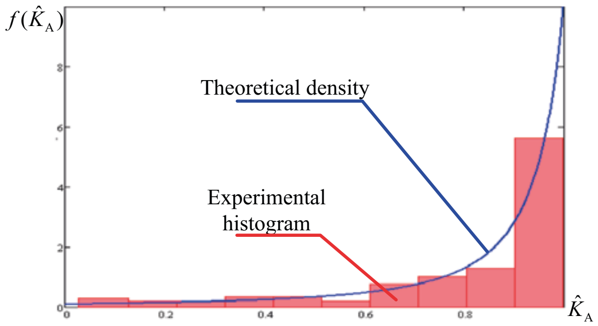

Fig. 7. PDF and histogram of the ready-to-operate factor estimation for the case $n = 1$

If the operating time between failures is equal to the recovery time ($T_0 = T_R$ та $n = 1$), the estimation of the ready-to-operate factor is carried out according to the following equation:

$$f(\hat{K}_A) = \begin{cases} 1, \text{ if } 0 \le \hat{K}_A \le 1, \\ 0, \text{ if } \hat{K}_A \le 0 \text{ або } \hat{K}_A \ge 1. \end{cases} \tag{19}$$

The modeling results under the condition that $T_0 = T_R$ and $n = 1$ are provided in Figure 8.

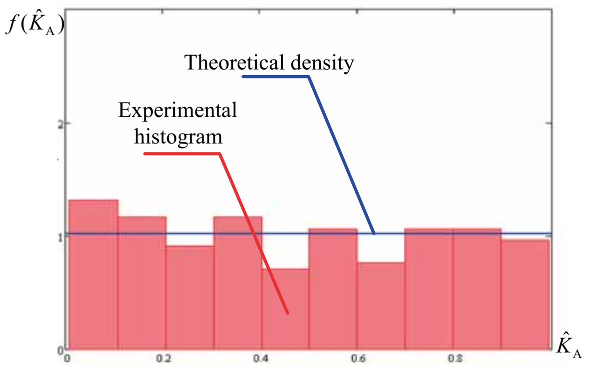

Fig. 8. PDF and histogram of the ready-to-operate factor estimation for the case $T_0 = T_R$ and $n = 1$

3. Conclusions

The analytical ratios obtained during the study are in good compliance with the modeling results. This fact confirms the accuracy of these ratios. The research results can be used in the design and modernization of radio flight support facilities.

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