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INFORMATIONAL AND FUNCTIONAL RELIABILITY MODEL FOR AIR NAVIGATION SYSTEM OPERATOR

Abstract

As shown in this paper, reliability of equipment and reliability of operator due to psychophysiological factors cannot be considered separately. This paper deals especially with air navigation system operator reliability. So the main goal was to create the operator's reliability model. As a result the information functional reliability model for the air navigation system operator has been created. This model takes into account dynamic of error changing, depending on the loading of the operator. It allows to solve the problem of determining the reliability of operator in normal and special flight conditions.

INTRODUCTION

The air traffic control system is an ergonomic system that includes as elements hardware and operators who interact with it. Nowadays the air traffic is a complicated task related to the account of the human factor, organizational factors. It aim is minimizing the occurrence of negative processes such as aviation accidents and incidents.

As known, all hardware systems include both machines and staff who interact with them. Thus, experts should analyze both these elements in assessing the reliability. So, reliability of equipment and reliability of operator due to psychophysiological factors cannot be considered separately.

The adding of some new characteristic to the reliability evaluation reduces its value if only it does not indicate constantly reliable system's item. If reliability estimation considers only factors that characterize the failure of equipment without staff actions, it is assumed that the operator's actions is described as flawless (the probability of operator failure equal R (t) = 1,00). It is well known fact, that the reliability of operator's actions is definitely lower than would be required in the ideal cases. Therefore, this should be taken into account by estimation of operator's characteristics. Otherwise, the estimations are wrong.

Large numbers of equipment failures that occur due to the fault of operator indicates that it influences a lot to the system reliability. The failures frequency caused by operator is 20 to 95% of all failures described in the documentation. Therefore, the failure rate list based on only hardware doesn't take into account important characteristic which influences on system reliability [1].

Actions of air navigation system's (ANS) operator and his ability to make decisions quickly and accurately depends not only the air traffic control system's capacity, but also flight safety in general.

Eurocontrol's statistics indicate that according to the way of arising, all operator errors can be divided to: perception and vigilance - 32%, skill's memory - 9%, long-term memory - 1%, planning and decision making - 53%, the reaction - 5%. That is why it is necessary to optimize operator's actions depending on the type of tasks.

The operator is a more complex system than any machine that works or will be made in the future. Currently any machine is not able to substitute the human-operator, even if it is able to fully duplicate the work of the senses and the nervous activity of human, such as sensing, recognition and decision-making [2]. The operator is less stable compared with the machine. A significantly greater number of factors are influencing him. His actions depend on the physiological state, the level of fatigue, effects of surrounding stimuli (e.g. noise), duration of training, incentives and other factors [3].

However, operator's actions can be estimated as the equipment functioning. This can be performed by using input and output parameters. It gives the opportunity for engineers and experts in the field of engineering psychology to create algorithms for identifying the characteristics of man and machine, and to use the same mathematical tools in the research of man and machine.

During the creation of a model which could predict the reliability and level of risks for ANS operator that are connected with the performance of his duties, it is necessary to take into account following: model should be flexible and able to be integrated into the structure's reliability of ANS. But also should avoid some lacks: necessity of usage the large and mixed expert groups and depending on their perception of the problem; weak link between success and rejection of action; the use of outdated models of errors' distribution, such as exponential, gamma model; unreported changes of the error's dynamic which depends on operator loading; difficulty obtaining analytical relationships.

Based on this it is possible to formulate basic limits and requirements for creation the information and functional model of reliability (IFRM) for operator ANS (Fig. 1)

1. RATIONALE FOR THE USE OF DECOMPOSITION ELEMENTS OF INFORMATION AND FUNCTIONAL MODEL OF THE AIR NAVIGATION SYSTEMS OPERATOR RELIABILITY

Taking into account the complexity of operators work, ANS structure and it is the number of elements, it is necessary to use the decomposition principle for IFRM creation. It should be based on a structural model of the operator's action reliability.

At calculating of reliability characteristics, two assumptions are using:

- the entire system and any element of it can only be in one of two possible states - working or non-working,
- elements's error are independent of each other.

In theory, these assumptions allow to perform the calculation of infallibility any system for as iteration of all possible combinations of states elements, determination of probability for each of them and summation of probabilities workable states of the system.

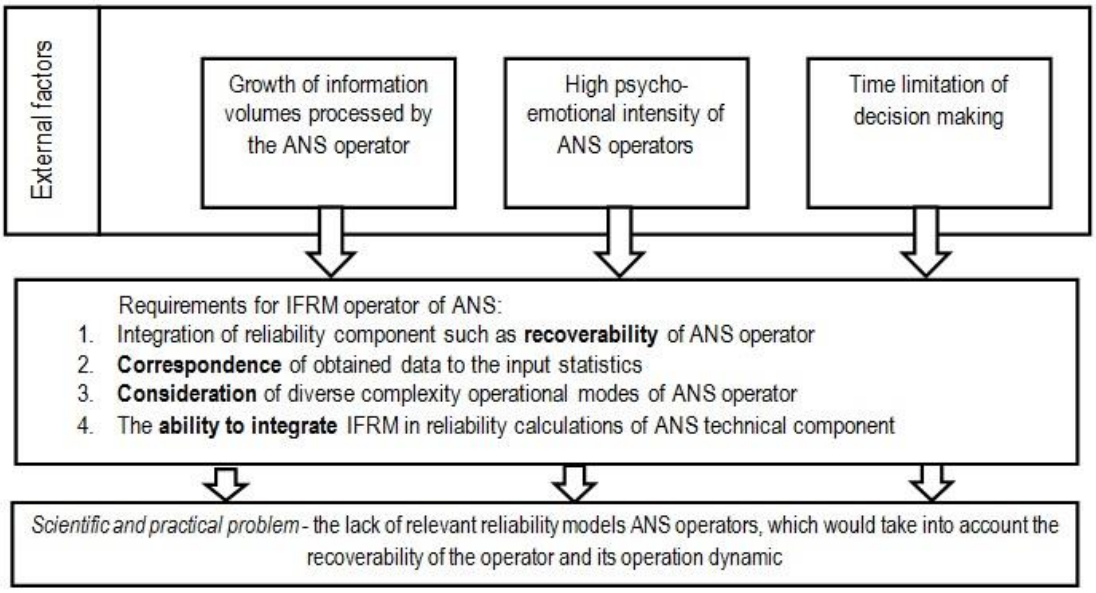

Fig. 1. *Requirements for information and functional reliability model of air navigation systems operator*

This method is practically universal and can be applied in the computation of any structures. However, if there are a large number of elements of M system, this method is impractical because of the large amount of computing: when M = 10 the number of possible states of the system is 1024, with M = 20 greater than 106 [4].

Thus, in practice, more efficient and economical methods of computation are used. These methods do not use the big amount of computation. The possibility of their use is associated with the decomposition of the system, thus methods allocate simple parts in a complex system. However, these parts are functionally integrated pieces (structural reliability models (SRM).

Exactly usage of the decomposition principle of the complex structure allows solving the problem of analytical estimation of ANS operator reliability according known characteristics of reliability of its components.

SRM is a graphical representation of the usable system's states and shows the logical association of elements required for its performance according to a given algorithm.

The opportunity to develop an efficiency condition of selected items is the criterion for combining multiple factors of the SRM system.

The ability to develop mathematical expression based on unique efficiency condition of all items that are a function of the reliability scheme allows creating the communication part. It expresses the dependence the refusal characteristics of the part of a structure from indicators of reliability its elements. Thus, quantitative assessment of the reliability fragment structure of the system [5] can be extracted.

An example, the communication function can be composed as follows:

$$R_C(t) = \Psi\left[R_1(t), R_2(t), \ldots, R_M(t)\right]$$

where $R_i(t), i \in \overline{1, M}$ - given reliability characteristics of the elements; $\Psi[\cdot]$- communication function indicator uptime fragment structure with indicators of reliability of elements; *M* - the number of elements in the SRM.

2. CONNECTION FUNCTION'S FEATURES IN THE STRUCTURE WITH SERIES ELEMENT CONNECTION

Structural reliability model with series connection of all elements is a prototype for systems, where system loses a usable state in case of error at least one of its constituent elements.

Let us consider the structure provided by M elements on fig. 2 a.

Every i-th element of the system has two possible random events:

- Event Ai - functional state of the i-th element; the probability of this event (probability of error-free operation of i-th element Ri (t)) is given;
- Event $\overline{A_i}$ - failure state of i-element is followed [4]:

$$P(\overline{A}_i) = F_i(t) = Q_i(t) = 1 - R_i(t)$$

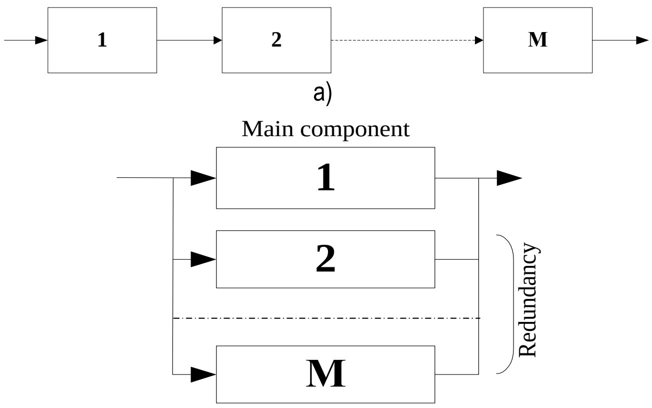

Fig. 2. *SRM: a) serial connection of elements;* b) with parallel connection of elements.

The structural formula for the event A (functional state of the ANS operator in general) is:

$$A_S = A_1 \cdot A_2 \cdot \ldots \cdot A_n = \prod_{i=1}^{M} A_i$$

Based on multiplication theorem of probability that are independent on random events the probability of a system failure is following:

$$R_S(t) = R\left(A_S\right) = \prod_{i=1}^{M} R\left(A_i\right) = \prod_{i=1}^{M} R_i(t)$$

3. CONNECTION FUNCTION'S FEATURES IN THE STRUCTURE WITH PARALLEL ELEMENT CONNECTION

The rule of structural elements redundancy is used by organizations with parallel element connection. One element from any is considered as main, all other parts are redundant. The number of redundant elements determines the backup multiplicity. To get an analytic function of system with parallel element connection the fig. 2. b) should be seen.

Efficiency condition for system with parallel element connection is shaped as follows: the system considered usable until at least one element is workable [4].

Let us consider the failure of the element as simple event and system failure – complex event. In this example, the theorem of probabilities multiplication is applied. In case of independence for failures the probability of error-free operation is:

$$R_S(t) = 1 - Q_S(t) = 1 - \prod_{j=1}^{r+1}\left(1 - R_j(t)\right)$$

To determine the elements of structural reliability for ANS operator, let us consider components of its reliability (Fig. 3).

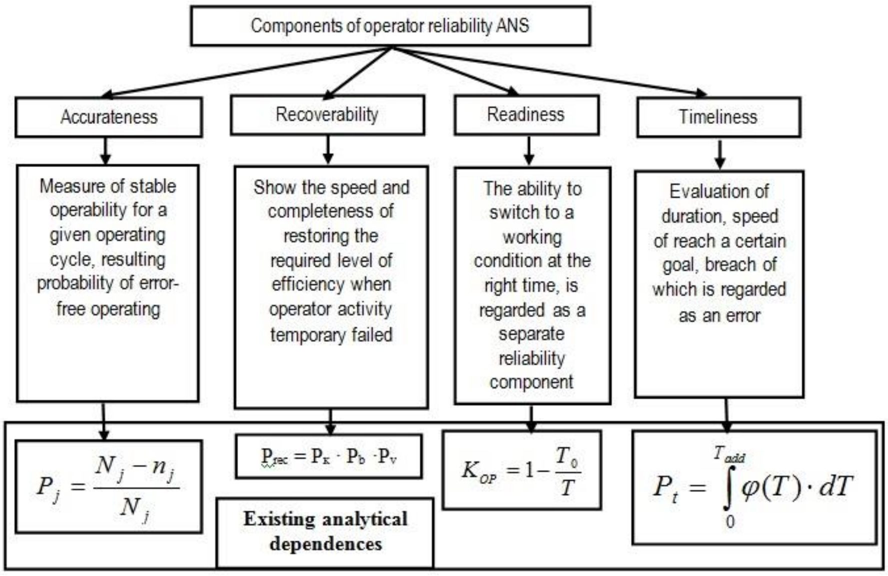

***Fig. 3**. Components of ANS operator reliability and principles of reliability calculations*

By analogy with the reliability of technical systems where one of the leading indicators of reliability is the probability of failure of the system, index of probability of failure for operator will be used for operator reliability estimation. The probability of failure for operator R (t) characterizes by the degree of ANS operator efficiency during duty cycle.

The probability of ANS operator failure is probability of the fact that during definite time failure of the operator had not taken place.

The probability of ANS operator failure R (t) is computed utilizing the methods of decomposition information and functional dependence associated with a compulsory feature of commands and instructions that operator executes.

Recoverability in IFRM was taken into account by using a diffusion nonmonotonic model of the failure distribution as a prototype distribution model for ANS operator errors.

$$R(t) = \Phi\left(\frac{\alpha - t}{\beta \cdot \sqrt{\alpha \cdot t}}\right) - \exp\left(\frac{2}{\beta^2}\right) \cdot \Phi\left(\frac{\alpha + t}{\beta \cdot \sqrt{\alpha \cdot t}}\right) \quad (1)$$

where α is the mean operation time to the first failure, β is the variation coefficient of an operator's performance to the failure,
Φ(•) – Laplace integral function.

Readiness and timeliness will be considered as components of creating safety structure for ANS operator, namely professional reliability

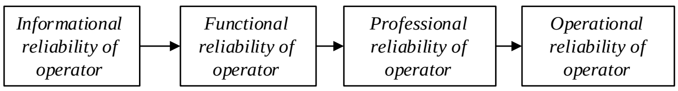

***Fig. 4** Components of creating safety structure for ANS operator*

When quantitative estimation is performed reliability should be considered of as series links of informational, functional, professional and operational components of the one physical system. The ANS operator in this case is such system [6]. In a system with consecutive structure, the ANS operator's error is reason that leading to failure of the physical system as a whole. Based on that, the probability of structural error free operation of operator of air navigation systems can be represented as:

$$R_{st}(t) = R_{\inf}(t) + R_f(t) + R_{prof}(t) + R_{op}(t) \quad (2)$$

where $R_{st}(t)$, $R_{\inf}(t)$, $R_f(t)$, $R_{prof}(t)$, $R_{op}(t)$ probability of error-free operation of operator of air navigation systems: structural, professional, operational, informational, and functional, respectively [8].

The total reliability of ANS operator, using given structure and values of reliability for all elements is limited as the structural reliability of the operator.

Note, that if the probability of no-failure operation R (t) of one link in this structure is equal to R (t) = 1, then actually it is equivalent that link will be removed from the structure (2).

Based on this, definition four groups ANS operator reliability should be used (Fig. 5).

Functional reliability of operator of the air navigation system is the property of operator of air navigation system functional systems to ensure dynamic stability in the performance of professional tasks for a certain time and with a given quality. The concept of functional reliability deals with the nature of human adaptation to the energy control process of the object.

Operational reliability of operator of the air navigation system is the ability to keep working capacity under the normal conditions in the working environment for a certain period.

Information reliability of operator of the air navigation system is the correct flow of information processes in a given time period under the given external conditions. Elements, such as deficiency of time, information overload, high rate of information flow, cause mental stress and disrupt the process of data exchange with the control scheme, resulting in decreased information reliability of operator and reliability of the completely energetic system.

Professional reliability of operator of the air navigation system is the inerrant and timeliness of the air navigation system operator of achieving a specific goal under the given conditions in the interaction with the hardware and other professionals under condition of correct perform regulations. The primary reason for the decrease of professional reliability of operator of the air navigation system is the ignorance of the basic jobs of instructions or professional activity and unwilling to perform them [7].

Taking into account these expressions for no-fail ANS operator's actions, it is possible to determine the general structural expression.

$$R_{CT}(t)=\left[(1-\prod_{e=1}^{l}(1-R_e(t))\right]\cdot\left[(1-\prod_{f=1}^{m}(1-R_f(t))\right]\cdot \left[\prod_{i=1}^{b}R_i(t)\cdot(1-\prod_{i=1}^{d}(1-R_i(t))\right]\cdot\left[\prod_{n=1}^{k}R_n(t)\right] \quad (3)$$

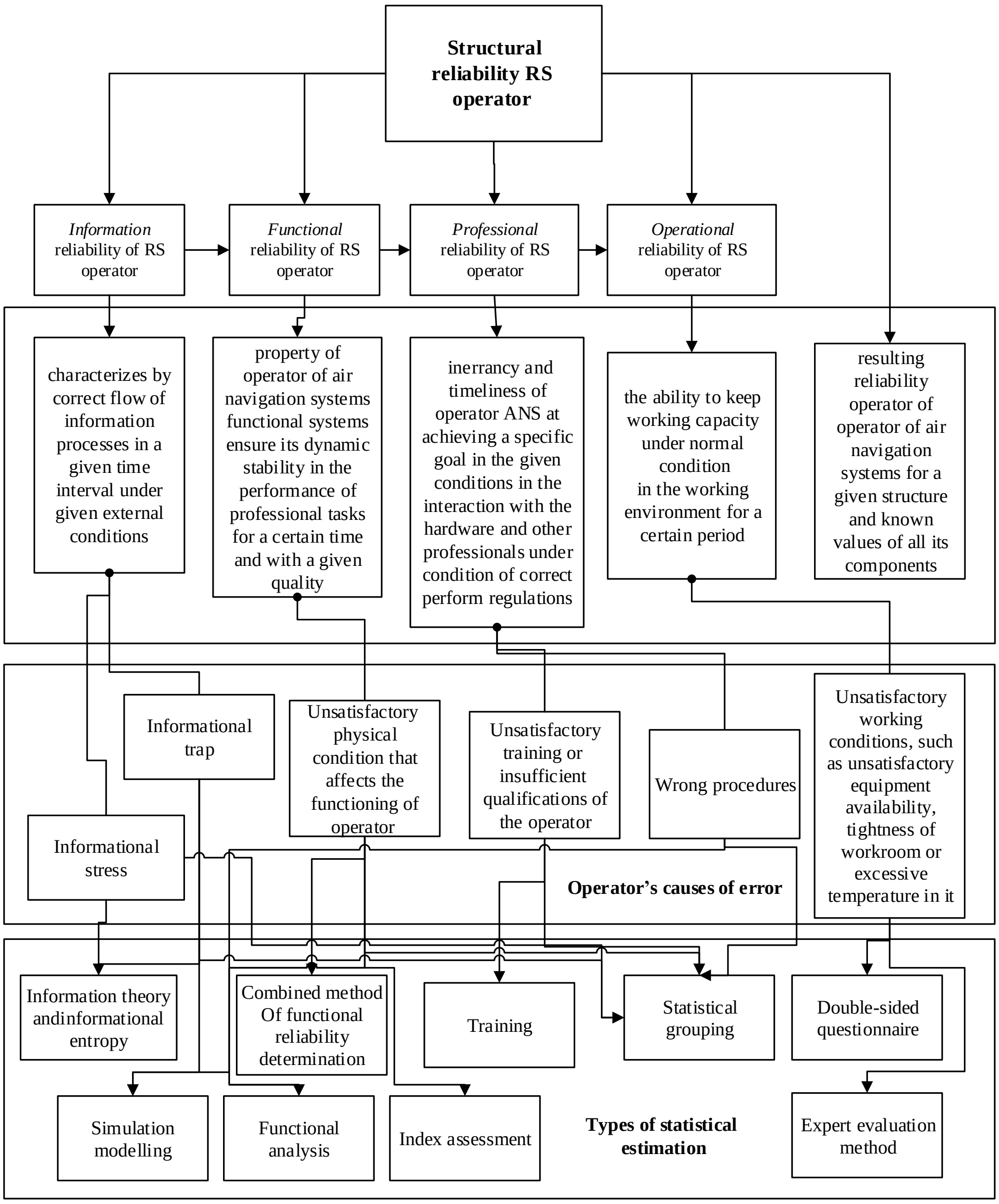

Fig. 5. *IFRM structure of ANS operator, reasons of his errors and methods of its estimation*

Considering that the probability of the no-failure ANS operator's action (R (t)) is a diffusion nonmonotonic model of error distribution and using analytical dependence (1), we obtain IFRM for ANS operator:

$$R_{CT}(t)=\left[\left[\left\{1-\prod_{e=1}^{l}\left(1-\left(\frac{\alpha_e - t}{\beta_e\cdot\sqrt{\alpha_e\cdot t}}\right)-\exp\left(\frac{2}{\beta_e{}^2}\right)\cdot\Phi\left(\frac{\alpha_e+t}{\beta_e\cdot\sqrt{\alpha_e\cdot t}}\right)\right)\right\}\right]\right.$$

$$\left[\left\{1-\prod_{f=1}^{m}\left(1-\left(\frac{\alpha_f - t}{\beta_f\cdot\sqrt{\alpha_f\cdot t}}\right)-\exp\left(\frac{2}{\beta_f{}^2}\right)\cdot\Phi\left(\frac{\alpha_f+t}{\beta_f\cdot\sqrt{\alpha_f\cdot t}}\right)\right)\right\}\right]\cdot$$

$$\cdot\left[\begin{array}{l}\prod_{i=1}^{b}\left(\frac{\alpha_i - t}{\beta_i\cdot\sqrt{\alpha_i\cdot t}}\right)-\exp\left(\frac{2}{\beta_i{}^2}\right)\cdot\Phi\left(\frac{\alpha_i+t}{\beta_i\cdot\sqrt{\alpha_i\cdot t}}\right)\cdot\\ \left\{1-\prod_{i=1}^{d}\left(1--\left(\frac{\alpha_i - t}{\beta_i\cdot\sqrt{\alpha_i\cdot t}}\right)-\exp\left(\frac{2}{\beta_i{}^2}\right)\cdot\Phi\left(\frac{\alpha_i+t}{\beta_i\cdot\sqrt{\alpha_i\cdot t}}\right)\right)\right\}\end{array}\right]\cdot$$

$$\left[\prod_{n=1}^{k}\left(\frac{\alpha_n - t}{\beta_n\cdot\sqrt{\alpha_n\cdot t}}\right)-\exp\left(\frac{2}{\beta_n{}^2}\right)\cdot\Phi\left(\frac{\alpha_n+t}{\beta_n\cdot\sqrt{\alpha_n\cdot t}}\right)\right]$$

Using the dependence above mentioned and based on the input statistics, it is possible construct a histogram of operator’s error probability density (Fig.6) that can be used to predict operator error at a certain point.

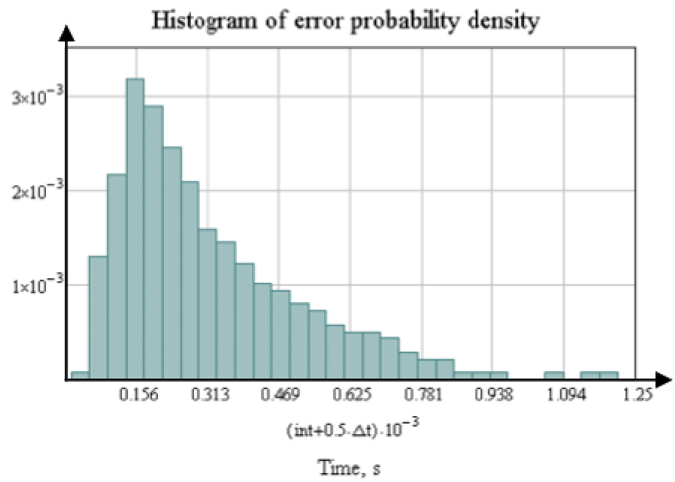

Fig.6 *Histogram of operator’s error probability density*

CONCLUSIONS

The analysis of existing models of operator’s reliability has been performed. It showed that they are fragmentary and do not take into account the possibility of operational estimation of reliability indicators for ANS operated as a part of technical system, use outdated models of error distribution, do not take into account ability to recover operator after errors.

The information and functional reliability model for the air navigation system operator has been created. This model, unlike the existing ones, takes into account dynamic of error changing, depending on the loading of the operator. It allows solving the problem of determining the reliability of operator in normal and special flight conditions. IFRM is relevant model and allows taking into account important component - recovering operator after errors. In addition, it uses the fact that errors of ANS operator cannot have uniform distribution low.

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INFORMACYJNY I FUNKCJONALNY MODEL NIEZAWODNOŚCI OPERATORA SYSTEMU NAWIGACJI LOTNICZEJ

Streszczenie

W artykule zwrócono uwagę na niezawodność sprzętu i niezawodność operatora, które ze względu na czynniki psychofizjologiczne nie mogą być rozpatrywane oddzielnie. Problem ten jest szczególnie istotny w aspekcie niezawodności operatora systemu nawigacji lotniczej, dlatego głównym celem pracy było stworzenie modelu niezawodności operatora. W efekcie, stworzono funkcjonalny model niezawodność operatora systemu nawigacji lotniczej, który uwzględnia dynamikę zmian błędu w zależności od obciążenia operatora. Model pozwala rozwiązać problem określania niezawodności operatora w normalnych i specjalnych warunkach lotu.

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