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METHODOLOGY FOR REDUCING THE NEGATIVE IMPACT OF NON-CONFORMANCE IN TECHNICAL PERSONNEL ACTIVITY IN THE SYSTEM OF CONTINUING AIRWORTHINESS OF AIRCRAFT

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ABSTRACT

This paper presents a mathematical model for managing the human factor in the system of continuing airworthiness. The model is based on the entropy evaluation of deviations in technical personnel activities, such as errors and violations recorded during maintenance operations. Using 10 years of statistical data from the "Safety" automated control system on Tu-154 aircraft maintenance (1995–2005), over 100 individual deviations were analyzed and grouped into 20 complex indicators. These were further consolidated into five generalized factors reflecting key areas of organizational performance. Entropy measures were then used to rank these factors according to their contribution to risks affecting continuing airworthiness. The outcome of this analysis is the development of a Human Factor Control System (HFCS) for application within an Maintenance and Repair Organization, ensuring the required level of continuing aircraft airworthiness. The HFCS provides a structured framework for prioritizing management actions, particularly under conditions of limited organizational resources.

Keywords

continuing airworthiness; human factor; non-conformance; aircraft maintenance; entropy; resource management.

1. INTRODUCTION

Airworthiness is a measure of an aircraft's ability to operate safely in compliance with established requirements and standards, as confirmed by the appropriate documentation [1–6]. Airworthiness is ensured at the design stage of the aircraft through the required series of bench, flight, and certification tests [7], and during serial production across all stages of aircraft manufacturing [7]. Continuing airworthiness is maintained throughout the aircraft's operational use and maintenance

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[8–11]. This is one of the key responsibilities of engineering and technical personnel during maintenance activities.

However, for various reasons, maintenance work may involve violations or errors in the application of regulatory and technical documentation, which can compromise both airworthiness and flight safety [10]. Analysis of such "non-conformances" in personnel activities reveals their wide variety, differing in nature and external manifestations [12, 13, 14]. This diversity significantly complicates effective problem-solving.

In this context, the development and implementation of Maintenance Resource Management (MRM) programs into maintenance practice has shown promise [15]. Practical applications of these programs are discussed in [16, 17–25]. The first MRM program designed specifically for maintenance specialists was launched in 1989. The need to manage team resources among technical specialists became especially clear after the Aloha Airlines accident on 28 April 1988, when responsibility was shifted from an individual mechanic to the entire maintenance system [17, 26].

Nevertheless, the absence of organized support initially hindered the program's practical effectiveness. This led to strategic changes and the introduction of second-generation programs, which emphasized personal communication – such as focus groups tailored to technical specialties – rather than impersonal classroom training. Yet, these efforts also proved largely ineffective. The emergence of third-generation programs, however, enabled the identification of the main causes of maintenance errors. Since 1994, this list of causal factors has been incorporated into all MRM programs implemented in North America [7].

However, an effective methodology for managing the human factor in the aircraft maintenance system for continuing airworthiness is currently virtually nonexistent. From a theoretical perspective, the SHEL model is considered the most advanced [27]. The practical basis for such studies relies on statistics of "non-conformance" (violations and errors) in technical personnel activities. To obtain the necessary information, the authors used various sources, including the Federal Aviation Administration system – the Aviation Safety Information Analysis and Sharing System (ASIAS). This system integrates various accident databases, such as the Aviation Safety Reporting System (ASRS) [28], the National Transportation Safety Board (NTSB) database [9, 29], and the ACS "Safety" database covering the period from 1985 to 2020.

Issues related to the organization and technology of continuing airworthiness have also been discussed in the works of numerous researchers [13, 30]. Analysis of these sources from different perspectives shows that the human factor in the aircraft maintenance system has been actively studied over the past 10–25 years, and that the methods proposed partially address these problems. The methodological recommendations presented by these and other authors are based on the principles of a systems approach to continuing airworthiness, involving a series of successive stages.

One advantage of these methods is the use of schemes for examining the structure, characteristics, and features of aircraft operation, as well as for identifying factors that affect airworthiness. These approaches draw on various scientific disciplines – including mathematical statistics, probability theory, reliability theory, engineering psychology, and aviation ergonomics.

This article presents a mathematical model based on ranking probability indicators that characterize the negative impact of "deviations" in technical personnel activities (errors and violations during aircraft maintenance) on airworthiness, using entropy assessment. The model makes it possible to define the main directions of Maintenance Resource Management within the continuing airworthiness system. The method has been tested through the processing of statistical data on "deviations" in technical personnel activities, taken from the ACS "Safety" database over a 10-year period during the operation of Tu-154 aircraft [31].

2. HUMAN FACTOR MANAGEMENT MODEL (HFMM)

Based on the systems approach [16], the developed model is presented as a multidimensional system consisting of a set of subsystems and elements that interact functionally. Their purpose is to collect information on "non-conformance" (violations and errors) in aviation technical personnel activities, process and analyze this information, and use the results to develop control actions aimed at reducing their negative impact.

In developing the "non-conformance" model, quality is assessed using indicators adopted in Qualitology [32]. Control actions are presented in the form of generalized indicators F_i, where $i \in \{1, 2, \ldots, n\}$. Each F_i includes a number of complex indicators K_{ij}, where $j \in \{1, 2, \ldots, m\}$, grouped according to logically similar reasons for the occurrence of "non-conformance". In other words, each F_i has its own "set" of j-th complex indicators.

Quantitatively, each K_{ij} is evaluated as the probability of repeated identical instances of a specific "non-conformance," denoted as private (single) k-th indicators X_{jk}, where $k \in \{1, 2, \ldots 1\}$. These represent recorded specific cases of non-conformance (errors or violations) in the activities of technical specialists over a given period of time.

Thus, the structure of the control actions F_i is represented as a three-level model (see Fig. 1). The lower level – of Specific Factors (SF) – includes recurring private indicators, the frequency of which is recorded over a given period. The next level – of Complex Indicators (LCI) – consists of the indicators K_{ij}. The upper level – the set of Control Actions (CA) – represents the quantitative values that are the objective of this model, as they cannot be measured directly.

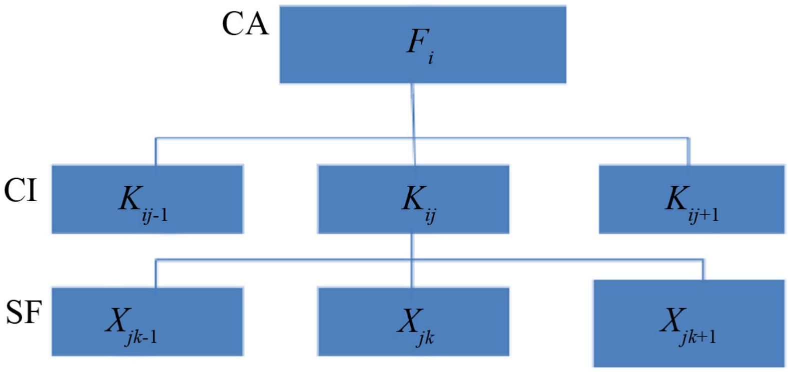

Fig. 1. Three-level model for determining control actions in the Human Factor Control System (HFCS). CA: Control Actions level; CI: Complex (probabilistic) Indicators level; SF: Recorded Specific Factors of "non-conformance" in staff activity.

The set of generalized indicators $F_i(t)$ in the Human Factor Control System (HFCS), which define the main areas of work to reduce the negative impact of the human factor, is given as:

$$\{F_1(t), F_2(t), \ldots F_n(t)\}. \tag{1}$$

From the theory of complex systems, it is known that if various types of influences – control actions $U(t)$ or environmental factors $V(t)$ – act on a system at random moments in time, its state $X(t)$ begins to change, and uncertainty exists until a new, stable state is established. If the system is observed during this period (i.e., some of its parameters are recorded), the degree of uncertainty is reduced or completely removed. As is well known, the measure of uncertainty in a complex system is characterized by entropy, $N(x)$:

$$N(x) = \sum P(x_i)\log_2 P(x_i) \tag{2}$$

If we consider a system state that, before the impact of random influences, was characterized by the probability $P(x_i)$of the parameter values (x_i), and that after some time following the impact is characterized by $P_k(x_i)$, then the amount of information obtained as a result of observation during this interval is equal to:

$$J(x_i) = \log_2 \frac{P_h(x_i)}{P(x_i)} \tag{3}$$

The connection between successive events $X_{(k\text{-}1)}$ and X_k can be estimated using correlation functions or conditional entropy. In our case, the latter will be applied. Since we are considering entropy in the context of information theory, we follow the convention in the literature and denote it by the symbol H [33]:

$$H\left(\frac{X_k}{X_{k-1}}\right)=\sum_{i=1}^{n}P(X_i)\sum_{j=1}^{m}P({X_j}/{X_i})\log P({X_j}/{X_i}) \qquad (4)$$

Where:
m – the number of states X_j associated with the appearance of states X_i,
$P(X_j/X_i)$ – the probability of state X_j occurring, given that state X_i has already occurred.

The use of entropy is one of the most promising approaches in modeling complex stochastic systems, particularly for risk ranking and for identifying priority measures to reduce risks – which is the main objective of this study x23, x24. Based on this, we use the entropy values of the generalized indicators $H(F_i)$ to rank risks associated with "non-conformance" in technical personnel activities:

$$H(F_i)=\sum_{i-n}^{j}P(K_{ij})\log_2 P(K_{ij}) \qquad (5)$$

Where:
$P(K_{ij})$ – the probability of a specific type of deviation in personnel activities, recorded over a certain period (specific factors),
$H(F_i)$ – the entropy level of the generalized factor, representing the i-th control object in the HFCS.

Thus, we have obtained a mathematical model of human factor management. The effective use of this model requires a careful approach to selecting both the composition and the number of indicators that determine the control actions F_iand the probabilistic values K_{ij} of the recurring individual indicators X_{jk} (see Fig. 1). Since the variety of possible "non-conformance" cases allows for their classification with different levels of detail and across different categories – in other words, at varying levels of generalization – a certain degree of logical expertise is required. This task can be carried out either by qualified specialists or through an expert survey, depending on the status and capabilities of the maintenance organization.

The next step in applying the model is to determine the entropy of the generalized factors F_i, using expression (3), and to rank them according to the quantitative values obtained. This ranking reflects the negative impact of personnel violations and errors on the process of maintaining aircraft continuing airworthiness. The highest entropy value indicates the area of greatest management priority for addressing human factor issues with maintenance personnel.

3. TESTING THE MODEL

The proposed model was tested using data on cases of "non-conformance" in technical personnel activities from the "Safety" automated control system database, covering a 10-year period of Tu-154 aircraft operation (1995–2005) [31]. The total number of non-conformance cases (specific indicators X_{jk}) recorded by personnel exceeded 100, which, after analysis, were grouped into 20 complex indicators K_{ij}. The probabilities of their occurrence were calculated over the study period. Using an automated expert system [34, 35], these complex indicators were further combined into five generalized factors F_i (see Fig. 1):

- F_1 – Improvement of personnel management organization in aircraft maintenance
- **F_2 – Enhancement of management organization within the operational circuit of aircraft maintenance in the airline's network**
- F_3 – Improvement of quality control in aircraft maintenance
- F_4 – Enhancement of professional training and discipline of technical personnel
- F_5 – Improvement of technical personnel efficiency in working with modern diagnostic and control equipment

The percentage distribution of complex indicators included in each of the generalized factors is presented in Table 1.

Table 1: Percentage distribution of non-conformance in the activities of technical personnel.

F_1	F_2	F_3	F_4	F_5
21.5%	16.2%	22.9%	25.1%	14.3%

The complex indicators K_{ij} included in each generalized factor F_i share a common logical feature. For example, the generalized factor F_1 includes five complex indicators K_{ij}, as shown in Table 2.

Table 2: Complex indicators K_{ij} included in the generalized factor F_1.

K_{11}	Violations and erroneous actions during aircraft maintenance procedures
K_{12}	Allowing personnel to work without the necessary training
K_{13}	Use of non-certified tools by personnel
K_{14}	Performance of work by personnel without appropriate authorization (not specified in licenses)
K_{15}	Releasing an aircraft for operation with malfunctions not listed in the relevant documents (MMEL and MEL)

Their diversity indicates that these violations arise from deficiencies in the overall organization of work within Maintenance and Repair Organizations (MRO). This conclusion is supported by the fact that all logically related complex indicators listed above manifest systematically, as evidenced by the significant proportion of violations and errors (21.5% of the individual indicators). Ineffective organization of maintenance operations within the technical department can, for example, result in personnel being allowed to work without proper briefing or certification, or in the use of uncertified tools, which in turn provokes violations and errors during maintenance procedures. Similar logical chains connect other specific indicators grouped into complex indicators, which are then consolidated into the generalized factors F_2, F_3, F_4, and F_5.

The next step in applying the model involved calculating the entropy values of the generalized factors F_i using equation (6), and ranking them according to their quantitative values in terms of the negative impact of personnel violations and errors on continuing airworthiness. The ranking results are presented in Table 3. The highest entropy value indicates the area requiring the most immediate managerial attention when working with personnel on these issues.

Table 3: Ranking of Control Actions.

F_i	F_1	F_2	F_3	F_4	F_5
$H(F_i)$	5.16	3.49	2.47	2.32	1.54

As a result, we established a well-founded sequence of control actions to prevent the loss of aircraft airworthiness due to violations and errors by technical personnel during maintenance. The highest priority was assigned to improving the organization of aircraft maintenance operations within MROs. The second priority concerned strengthening management practices for maintenance across the airline's route network. The third was the enhancement of maintenance quality control. The fourth focused on improving the professional training and discipline of technical personnel. Finally, the fifth priority involved increasing personnel effectiveness when working with modern diagnostic and control equipment.

Together, these five factors define the Human Factor Control System (HFCS) for use within a Maintenance and Repair Organization, ensuring the required level of continuing airworthiness of aircraft.

4. CONCLUSION

This paper has developed and tested an entropy-based mathematical model for managing the human factor in aircraft maintenance as part of the system of continuing airworthiness. By processing long-term statistical data on deviations in technical personnel activities, the model identified and ranked key factors that contribute to violations and errors, thereby providing Maintenance and Repair Organizations (MROs) with a structured decision-making tool.

The application of this model requires a careful approach to selecting both the composition and the number of indicators that define the control actions F_i and the probabilistic values K_{ij} of the recurring partial indicators X_{jk} (see Fig. 1). This necessity arises from the wide variety of possible "non-conformance," which can be classified with different levels of detail and categorization – that is, with varying degrees of generalization. Such classification requires a certain level of expertise in logical analysis. Depending on the status and capabilities of the maintenance organization, this task can be carried out either by qualified specialists or through expert surveys.

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