Reliability assessment of the organizational system functioning with self-checking of subjects on watch

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Abstract. A notion has been formed that nowadays there is no any description of periodical self-checking procedures providing proper and high level reliability in organizational systems. Such reliability of any ship's control organizational system depends on the choice of type of check or self-checking of "human errors", caused by the navigational situation dynamics. It has been shown that such procedures must make it possible to check the quality either of the whole organizational system at a certain period or on the basis of the chosen period of such a system check to define the moments when it is rational to carry out self-checking of its certain subjects. It has been shown that one of the principles when making up the self-checking procedures should be either the use of information about the organizational system work or restrictions imposed on this system work which will complicate the use of the received results in practice. The problem which has been studied – to find an optimal global period of subjects self-checking in the organizational system of keeping watch which would meet the specified conditions and provide minimum to the accepted criterion. It has been suggested to connect the reliability growth of the correct organizational system functioning with the development of the main characteristics of the procedure providing the periodical subjects self-checking. At that, as it is shown in the illustrative example to this article the received results can be easily used in practice.

1. Introduction

Nowadays the dynamism of navigational area parameters reached such a level at which it has become above "human element" capability of the situational dynamism perception. For example, the shortterm memory volume and the information processing capability of "a human element" on bridge watch have become so low that already they do not correspond to up-to-date controlling practicalities as to providing safety of navigation. That is why the reliability and correctness of any ship's control organizational system functioning in condition of present dynamics of navigational situations development depend on both the use of expert systems and on possible use of check and self-checking procedures for wrong or nonworking decisions of "a human element" [1].

The choice and the decision-making, and also the assessment of these decisions lead to the appearance of additional forms of management activity in the organizational systems. So, a person making decisions (PMD) is to assess an average time during which this person will have persistence of thinking and moreover, to define the average time limit after which PMD performing control functions will start loosing his capability to control dangerous navigational or operational situation [1].

When significant persistence of thinking in decision-making and also the choice of wrong and nonworking decisions, resulting in dangerous navigational situations, appear in organizational systems of
ship's safety control, it is rather important to develop dynamic models of PMD behavior [8]. These very models allow us to develop self-checking procedures of subjects united in organizational systems and to assess the reliability of the correct functioning of both watch-keeping part and the whole system as well.

2. Formulation of problems and the choice of method for their solving

Let the bridge watch be irredundant organizational system consisting of \( n \) social elements connected by functional duties for providing safety of navigation. When fulfilling their functional duties each of \( n \) subjects carry out self-testing of these actions [6]. The process of self-testing of each \( i \in \{n\} \) subject is a periodical process and is characterized by frequency: the self-testing period \( \nu_i \) or its phase \( \tau_i \). During some subject's self-testing in organizational system a complete check of his duties fulfillment is carried out while in the organizational system itself no essential change of its condition takes place.

Besides, let time spent on one self-testing operation of \( i \) subject be equal to value \( b_i \). Time distribution functions of the subjects' error-free work in the organizational system obey the representative law with parameters \( \lambda_1, \lambda_2, \ldots, \lambda_n \), respectively [5]. The subjects of the watch-keeping system are considered to be trained enough and reliable, and the self-testing procedures to be carried out quickly enough so that during the time taken for self-checking of one or several subjects the reliability of the correct functioning of each member of the bridge watch, and therefore of the whole organizational system, practically doesn't change.

The assessment of the organizational system functioning reliability depends on periods and phases during which the watch-keepers carry out the procedure of self-checking [9]. Then the first problem can be formulated: to determine such periods or phases for self-checking of watch officers from the organizational system so that the reliability of the correct system functioning was not less than the given \( I_0 \) while the time spent on carrying out the procedure of self-checking was minimum. However after solving this problem, during the procedures of self-checking carried out by watch officers the "strict" bilateral requirements may appear to the realization accuracy of self-checking phases due to apprehension of infeasible reduction of the correct organizational system functioning reliability.

Taking into account such a feature of the problem we will formulate it this way: to find such periods of self-checking of subjects from watch-keeping personal so that with any periods of checking \( \tau_i (i = 1, n) (0 \leq \tau_i \leq \nu_i) \) the reliability of the correct system functioning was not less than the given \( I_0 \) while the time spent on carrying out the procedure of self-checking was minimum. At the same time the prohibition of simultaneous self-checking of two or more persons from the bridge watch personal will create additional restriction to decision being made and the following command. However for practically important cases when the watch-keeping personal self-checking period considerably exceeds the time of the whole checking procedure this condition can be ignored and as a rule can be satisfied by means of the appropriate phase choice [10]. In any case under the terms of formulated assumptions, time separation of watch-keeping personal self-checking is only possible at the expense of negligible deviations of these checks frequencies.

We pass on to formal solving of the formulated problem [3]. Let the reliability state of correct functioning in the watch-keeping organizational system as a function of the reliability of correct functioning of certain specialists be determined by the following equality

\[
I(t) = \prod_{i=1}^{n} I_i(t).
\]  

(1)

Besides, let the time intervals of reliable work of certain subjects in the organizational system obey the exponential distribution law. Then with some margin we can assume that the minimum reliability value of a certain subject correct functioning in the organizational system during quantum of time \([0, t]\) will be equal to

\[
\min I_i(t) = \exp(-\lambda_i \nu_i)
\]  

(2)
If we further require the following inequality form to be satisfied
\[ \prod_{i=1}^{n} \min I_i(t) \geq I_o, \tag{3} \]
then, it is obvious that with any phase relations in the process of self-checking the condition written in the following form will be realized
\[ I(t) = \prod_{i=1}^{n} I_i(t) \geq \prod_{i=1}^{n} \min I_i(t). \]

At the same time from relations (2) and (3) we can get the following inequality
\[ \prod_{i=1}^{n} \exp \{- \lambda_i \nu_i \} \geq I_o, \]
and from this inequality immediately follows a relation of the form
\[ \sum_{i=1}^{n} \lambda_i \nu_i \leq \ln 1 / I_o. \tag{4} \]

Here a special emphasis should be made that the procedure on organization of self-checking process of subjects in the watch-keeping organizational system carried out under conditions of essential shortage of time must have minimum relative loss of time which more generally can be estimated this way
\[ y = \sum_{i=1}^{n} b_i / \nu_i. \tag{5} \]

Hereby, finally we have an extremum problem – to find such global periods of subjects' self-checking \( \nu_1, \nu_2, \ldots, \nu_n \), which would satisfy the relation (4) and provide minimum to the expression (5).

Further we will assume that there are no any additional considerations as to the choice of the global period of check. The self-checking realization carried out by subjects of the watch-keeping organizational system may appear unduly complicated. In this case it is reasonable to think of some requirements simplifying the organization of self-checking in present conditions of the organizational system operation which with a negligible deviation from optimum would provide these or those appropriate ratios of periods [4]. The conditions of the following type can be an example of such requirements: ratio of any two periods must be an integer, ratio of any two periods must be multiple of integral power of two, the global period duration must be multiple of the specified value or an integer less than the specified value.

In this work we consider the condition presenting the restriction of the global period duration from above.

Let the global period of self-checking of subjects included into elementary set of the organizational system be not more than maximum possible one [7]. Then this condition can be satisfied by correcting periods of self-checking in different ways. It is natural that the method of correction by which the increase of time required for self-checking will be minimum one is considered to be the best. Thereby, one more problem can be formulated: to find
\[ \theta < \max_i \nu_i \tag{6} \]
and such values of \( \nu_i' \leq \nu_i \), so that the quantity \( \theta / \nu_i' \) was integer for all \( i \), and the form
\[ y' = \sum_{i=1}^{n} b_i / \nu_i \]  

had minimum value.

So, one more problem has been formulated – to find optimum global period for subjects' self-testing in the watch-keeping organizational system which would satisfy ratio (6) and provide minimum to expression (7).

3. Solution of the formulated problems
The first problem has analytical solution. So by method of full mathematical induction, considering numerical order of \( n \) values, the following solution form can be found

\[ \nu_i = (b_i / \lambda_i)^{1/2} /\left[\left(\ln 1 / I_0\right) / \left(\sum_{i=1}^{n}(b_i / \lambda_i)^{1/2}\right)\right] \]  

And in accordance with this solution the minimum of the objective function (5) will be determined this way

\[ y_{\min} = \left(\sum_{i=1}^{n}(b_i / \lambda_i)^{1/2}\right)^2 / \ln 1 / I_0. \]

Consequently, to maintain the reliability state of the organizational system functioning with subjects' self-checking at the given points of time it is required to work out and use a check procedure with cyclical recurring topology [2]. In practical use of this procedure the period of self-checking may appear to be unacceptably long. If the value \( \theta \) of the self-checking period is specified (determined by the system working cycle, determined by the procedure), it is necessary to correct the self-checking period \( \nu_i \) of \( i = 1, n \) subjects from the watch-keeping personal calculated by expression (8). We will require that the state of reliability of the correct functioning of each subject in the organizational system was not decreased by such correction. Then the correction of \( \nu_i \) periods can be carried out only by reducing these values. The corrected values of the self-testing periods can be found by the formula

\[ \nu_i^* = \theta / \left(-E\left(-\theta / \nu_i\right)\right) \]  

where \( E(x) \) – is the function of Entier (the greatest integer) and the dependence \(-E(-x)\) signifies rounding toward the greatest integer.

The solution of the second problem can be formulated in an algorithmic form. When forming the algorithm of getting minimum of the discontinuous function \( y(\theta) \) it is necessary to use two following properties of the optimum global self-checking period. Firstly, let for some, even one \( i \in \{1, 2, \ldots, n\} \)

\[ \theta = k \nu_i \]  

where \( k \) is an integer. Secondly, let the ratio of the form be met

\[ \max_i \nu_i < \theta \leq \max_i \nu_i. \]

Than the algorithm of getting the optimum global self-checking period will be an enumeration of the finite number of a number axis points satisfying the specified properties.

The algorithm of getting the optimum global self-checking period can be described with the help of the following sequence of actions:

- to find the maximum self-checking period among all self-checking periods of subjects in the organizational system calculated by means of expression (8) provided
\[ \nu^* = \max_i \nu_i; \]

- to define values of function \( y(\theta) \) in points \( \theta = k \nu_q \), at that, in those points for which the following ratios will be met

\[ \frac{1}{2} \nu^* < k \nu_q < k \nu^* \leq \nu^*(q = 1, 2, \ldots, n), \]

and then to find value

\[ \min_q y \]

among all calculated values of function \( y(\theta) \);

- to equate the value of the argument \( \theta \) as an optimum global period \( \theta_{\text{opt}} \).

Hereby, the solutions of the formulated above problems both in analytical and algorithmic forms let us find either the corrected self-checking period or to define the optimum global self-checking period of subjects in organizational system of keeping bridge watch.

4. Illustration of the received results and their practical application

Let's consider the simplest reliability assessment example of correct functioning of the organizational system singled out from the bridge watch. Let this organizational system consist of three subjects, united by internal and external communications. According to the results of previous operation the subjects of organizational system have the following reliability characteristics [1]: probability of errors in navigational information perception \( \lambda_1 = 0.002 \text{ 1/hour} \), \( \lambda_2 = 0.003 \text{ 1/hour} \), \( \lambda_3 = 0.001 \text{ 1/hour} \) with the self-checking procedure duration: \( b_1 = 0.01 \text{ hour} \), \( b_2 = 0.02 \text{ hour} \), \( b_3 = 0.03 \text{ hour} \), respectively. The required reliability of the singled out organizational system correct functioning is equal to \( I_0 = 0.99 \).

For the given initial data the self-checking periods of each subject can be calculated by formula (8):

\[ \nu_1 = 1.3 \text{ hour}, \nu_2 = 1.3 \text{ hour}, \nu_3 = 3.2 \text{ hour}. \]

With such self-checking periods the minimum relative time spent on carrying out the procedures will be equal to \( y_{\min} = 0.029 \) or will make up only 2.9% of the total time of the organizational system functioning.

If we further choose

\[ \max_i \nu_i = 3.2 \text{ hour}, \]

then, using the generalization of expressions (7) and (8) in the form

\[ y'(\theta) = \left( -1 / \theta \right) \sum_{i=1}^{n} b_i E \left( - \theta / \nu_i \right) \]

the values of \( y(\theta) \) can be calculated in points

\[ y(2.6) = 0.034, \quad y(3) = 0.033, \quad y(3.2) = 0.037 \]

and finally to find

\[ \min_i y = 0.033, \]

that gives \( \theta_{\text{opt}} = 3 \).

Further normalizing the periods of the self-checking procedure we will get respectively \( \nu_1 = 1 \text{ hour}, \)
$v_2 = 1.5 \text{ hour, } v_3 = 3 \text{ hour}$ and so the actual time spent on the self-checking procedure will increase by 0.4%.

5. Conclusion

Nowadays there are no any recommendations how to develop methods (procedures) of periodical self-checking for providing the required and high level characteristics of reliability in the organizational systems. Such procedures must enable monitoring either the quality of the whole organizational systems at certain periods or on the basis of the chosen period of check of such a system to define the moments when it is reasonable to carry out the self-checking of its certain subjects. However one of the main disadvantages of such procedures may be either incomplete information about organizational system work or too large restrictions imposed on this system work which would complicate the use of the received results in practice.

According to this work the increase of the correct system functioning reliability is connected with the development of main characteristics of the procedure on providing periodical self-checking of subjects in the organizational system, at that as it is shown in the illustrative example, the results received can easily be used in practice on board ships of shipping companies.

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