Ergonomics of Cyberspace. Mathematical Modeling to Create Groups of Operators for Error-Free and Timely Implementation of Functions in a Distributed Control System

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Abstract. The problem of designing group activities of operators in distributed information environments is considered. An optimization model is proposed for choosing the option of assigning functions to a group of operators for the basic model of the algorithm for executing an application in the form of an event graph. The model can be used in decision support systems by the operator-manager of critical control systems.

Keywords: Ergonomics, Cyberspace, Human-Operator, Human-Machine, Reliability, Modeling, Cybersecurity, Control System, Critical System.

1 Introduction

Fundamental changes in computer control tools and methods [1] for complex distributed objects, such as energy systems, oil and gas transportation systems, transport and research systems [2-5], training systems [6-9] have fundamentally changed the work of people in distributed information environments. The technology of interaction between operators and control objects through complex information models has changed and become more complicated [1, 10]. The share of group activities has increased when operators jointly implement the specified control technologies, despite the fact that they may be located at a great distance from each other [1, 10]. With the increase in the technical and organizational complexity of such ergatic control systems, the cost of operator's errors, failures and malfunctions of information technology equipment also increases [1, 2, 10, 11]. With the introduction of computer-aided decision support methods and artificial intelligence, the role of a person does not decrease, but also increases significantly [1, 3, 10], especially in the context of combating cybercriminals and various cyber-attacks on information systems [12].

2 Problem Statement

The main goal of the ergonomic support of complex control systems is to minimize the risks caused by the erroneous actions of people-operators [3, 10, 13-16], by taking into account engineering-psychological and ergonomic restrictions, the individual characteristics of operators and by "adapting" technology to a person [16-18].

In recent years, emphasis from studying and solving problems of the so-called "physical" ergonomics (anthropometric, physiological, etc. problems) shifted to solving problems of providing cognitive comfort for operators and tasks of "organizational" ergonomics [2, 3, 11, 16-18]. This implies the taski of determining the number of personnel, the qualifications of people, the distribution of functions between operators and the design of methods for interaction between operators. This task of the prompt organization of operator interaction is especially acute in cases related to non-standard or emergency situations, as well as in the tasks of managing security incidents. The operator-manager, who takes over the organization of the elimination of the problem situation, must quickly distribute the functions between individual operators. In this case, the requirements [18-20] should be taken into account:

- Maximizing the probability of error-free execution of the application (elimination of the problem situation);
- Restrictions on the timing of activities;
- Opportunities for organizing joint activities (forming a team or group of operators compatible with each other): technologically (means of labor, communication channels, information models, etc.) [18-20]; psychologically [25-27]; other.

Various network methods can be used to simulate the activities of operators, e.g.[13, 21]; but the most convenient tool is a functional network (FN) [18-20], which allows not only description of the activity but also evaluation of its reliability characteristics. To assess the reliability of the activity, mathematical models and a software-modeling complex were developed [22-24], and a number of optimization tasks were solved, including distribution of functions between operators .However, the issues of organizing group activities are not fully resolved in the ergonomics of automated control systems [24-27]. In this regard, the objective of this work is to determine the problem of forming a group of compatible operators working in a single information space, who are assigned to perform discrete algorithmic activities to execute applications arriving at random times (with the distribution of individual operations between specific operators) in order to maximize the probability of error-free execution under constraint on mathematical expectation of runtime.

3 Results

3.1 The principle of formalizing the problem situation of group activity optimization

The principle of formalizing the problem situation of group activity optimization:

- Describe in natural language the sequence of work to complete the application.
- Following the identified logic, develop a FN model that describes the activities for the implementation of the application (work schedule).
- Make the transition from the work graph to the event graph (as events we use events consisting in the fact that some operation was performed correctly or performed with some violation (Fig. 1demonstrates an example of the transition from the work graph to the event graph).
- Considering the possibility of alternative assignments of operators to separate operations (with different probabilities of transition from state to state and different runtime characteristics), build on the basis of an event graph a model of semi-Markov decision-making process (SMDMP) for assigning operators to perform individual operations (taking into account their compatibility in a group).
- Formalize the optimization problem for SMDMP.

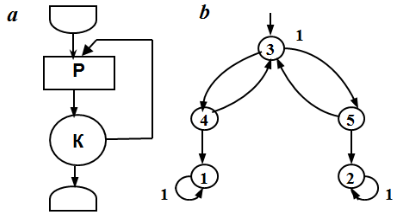

Fig.1. An example of the process model for implementing the simplest application: *a* - work graph; *P* - work operation; *K* - operation control; *b* – graph of events [18,25].

3.2 Model for designing group activities

Let us select the absorbing vertices among the SMDMP vertices. Let the vertices 1,2,...,r_l are the vertices with acceptable outcomes. For non-absorbing vertices, we define the probabilities of finding the process in these initial states: $a=(a_{r+1},a_{r+2},\ldots,a_n)$, so that

$$\sum_{i=r+1}^{N} a_i = 1, \quad (1)$$

where N is the number of states, r is the number of absorbing states.

We assume that K is the set of all operators. K_0 is the cardinality of K. At each vertex i there can be K_i of alternative assignments. Each variant is associated with a set of transitions from vertex i to vertex j when choosing the k-th solution, $k\epsilon K_i$, with corresponding probabilities and transition times.Thus, the k-th solution corresponds to the assignment of the operator $k\epsilon K_i\epsilon K$ to the stage of the technological process, which corresponds to state i of the SMDMP. $P_{ij}^{(k)}$ is the probability of the transition of the process from state i to state j when choosing the k-th alternative. Where in:

$$\sum_j p_{ij}^{(k)} = 1 \, at \ all \ i \ and \ all \ k \in K_i \quad (2)$$

$T_{ij}^{(k)}$ is the average time of transition from state i to state j when choosing the k-th alternative. Then the average time of the i-th work with the k-th solution, $T_i^{(k)}$, is defined as:

$$T_i^{(k)} = \sum_j P_{ij}^{(k)} * T_{ij}^{(k)} \quad (3)$$

It is necessary to maximize P_r- the probability of absorption in the r-state (or in states of the r-type):

$$P_r = \sum_l \sum_{i=r+1}^{N} \sum_{k \in K_i} P_{i r_l}^{(k)} * x_i^{(k)} \quad (4)$$

Here $x^{(k)}_i$ defines a solution: $x^{(k)}_i>0$ if the k-th alternative is selected at the i-th vertex, and $x^{(k)}_i=0$, if another solution is chosen. It is also necessary: introduce Boolean variables $\delta^{(k)}_i$ (to ensure the uniqueness of solutions and the formation of conditions for the dependence of the vertices: here k is the operator, i is vertex of the SMDMP).

Let's make the matrix [Qmj] consisting of zeros and ones and each row of which determines one of the possible groups ("teams") of operators for joint work in the information space. The number of matrix rows is the number of possible groups, the number of matrix columns is K_0. We can formalize our task as follows:

$$P_r^m = \sum_l \sum_{i=r+1}^{N} \sum_{k \in K_i} P_{i r_l}^{(k)} x_i^{(k)} \rightarrow \max \quad (5)$$

$$\sum_{k \in K} x_j^{(k)} - \sum_{i=r+1}^{N} \sum_{k \in K} P_{ij}^{(k)} x_i^{(k)} = a_j,\ j = r+1, r+2, ..., N \quad (6)$$

$$\sum_{i=r+1}^{N} \sum_j \sum_{k \in K_i} P_{ij}^{(k)} T_{ij}^{(k)} x_i^{(k)} \le T_0 \quad (7)$$

$$\sum_{k \in K_i} \delta_i^{(k)} q_{mk} = 1,\ at\ all\ i \quad (8)$$

$$\delta_l^{(k)} = \delta_v^{(k)} = ... = \delta_n^{(k)},\ at\ all\ k \in K \quad (9)$$

$$x_i^{(k)} - M\delta_i^{(k)} \le 0,\ at\ all\ i\ and\ all\ k \in K_i \quad (10)$$

$$x_i^{(k)} - w\delta_i^{(k)} \ge 0,\ at\ all\ i\ and\ all\ k \in K_i \quad (11)$$

$$\sum_{j=1}^{r} \sum_{i=r+1}^{N} \sum_{k \in K_i} P_{ij}^{(k)} x_i^{(k)} = 1 \quad (12)$$

$$x_i^{(k)} \ge 0,\ at\ all\ i\ and\ all\ k \in K_i. \quad (13)$$

Here M and w are a very large and very small numbers.

This task can be easy solved in the environment of any decision support system.

4 Conclusion

The share of group operator activity is growing sharply in modern management systems. The reliability of control processes substantially depends on the optimality of the distribution of functions between individual operators. The proposed model of organizing group activities takes into account the reliability and time characteristics of the operators, their compatibility with each other and maximizes the probability of error-free execution of tasks, entering the system. The development was tested during the practical design and operation of control systems for various purposes and can be recommended for building decision support systems for operators of control systems.

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