Improvement for ergonomic quality of man-machine interaction in automated systems based on the optimization model

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***Abstract*—A mathematical model of optimization of the man-machine system by the description of the functional algorithm in a form of an event graph was worked out.**

***Keywords*—automated system; man-machine system; ergonomics; interaction; optimization; reliability; infallibility; human factor.**

I. Introduction

Last years are characterized by a rapid change in the nature of automated technology management [1-3]:

- distributed information systems became widely spread;
- the number of operators, working simultaneously in single information space, has increased;
- the requirements for the efficiency of making decision are increasing;
- hierarchical management stipulated an increase of the role and responsibility of management operators;
- the necessity to take into account working conditions at the operator's workplaces has increased;
- the multivariance of technologies for the implementation of functions, ways of performing of individual operations, assigning operators to applications (transactions) has increased;
- the cost of errors is increasing.

In spite of the enormous achievements in the field of automation, it is impossible to exclude a person from management of complicated systems [1-3].

Paradoxically, but the role of the man-operator not only diminished, but it has even increased. 80% of accidents in production systems of different types, more than 64% of accidents in the marine fleet and 80% in aviation are caused by man-operator errors [1-3].

In fact, the purpose of every research in the field of designing of man-machine systems (MMS) is to reduce the mistaken reactions of man-operator [1-5].

The achievements of many researchers of the human factor, aimed at ensuring accuracy, are most successfully integrated in the functional-structural theory (FST) of ergotechnical systems of the school of Professor A.I. Gubinsky [1].

These models are based on the structure of algorithms for the functioning (AF) of MMS and probabilistic characteristics of the operations of these algorithms.

Developed within the framework of the FST schools, the Professor Gubinsky A.I. models stand out from many others by:

- focus on quantitative assessment;
- possibility of reduction ("folding") of the AF model with simultaneous calculation of the pragmatic AF parameters;
- computer-oriented dependencies.

The objectives of this work are:

- the development of the approach to the solution of the optimization problem of the AF MMS;
- the substantive analysis of the tasks facing the designers of automated systems for using the model to improve the efficiency of automated control of complex systems.

II. Exposition

A. Development of requirements for the model

The optimization model should:

- allow to choose the variants to implement the algorithms of performing activity of various types irrespective of a subject area and the maintenance of carried out actions and operations;

- be computer-oriented
- allow for the simple realization on common software without the long-term training of ergonomists;
- allow for the creating of a library of standard models for the optimization of the most common types of relationships between AF operations;
- be compatible with the procedures of calculating the initial data for optimization and the guides on the performance characteristics of common actions and operations by ACS operators when realized on a computer.

In view of the fact that the latest most modern environment for modeling MMS has been determined the Excel environment, in which it was developed an information system focused on the evaluation of the performance indicators of AF FS implementation, spreadsheets are also chosen as the most convenient environment for solving the optimization problem.

B. *Development of the AF model initial for optimization problem statement*

The functioning of the system can be formulated in the form of a work graph and an event graph.

The work graph represents a logic model of an interaction of the AF operation recorded with the help of special symbols (functionaries, i.e., operations: working procedures, control of functioning, control of efficiency, alternative, etc. [4]).

The event graph is a secondary one and based on the works graph.

"Events" reflect the consequences of performing of AF "works", for example:

- “free-error performing of a work operation",
- "performing of a work operation with an error".

An example of the transition from the work graph to the event graph is shown on Picture 1, where the following designations are introduced:

P_i – work operation with number *i; K* – performance control operation;

$B^1_i(B^0_i)$ – probability of error-free (erroneous) performance of the operation with the number *i*;

K^{11} – the probability of recognizing that the error-free performance of a work operation is error-free;

K^{00} – the probability of recognizing that the erroneous performance of a work operation is erroneous;

$K^{01}=1-K^{00}; K^{10}=1-K^{11}$.

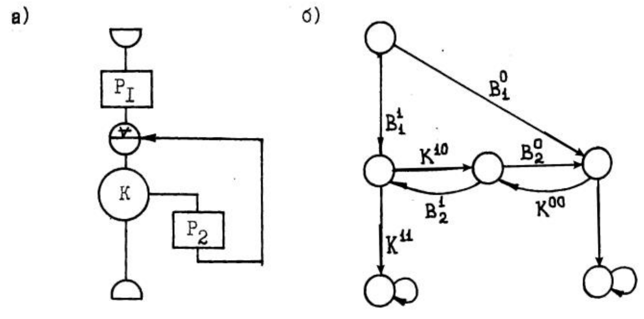

Fig. 1. The example of a transition from work graph to the event graph: a) work graph; b) event graph.

C. *Optimization model on the "events" graph*

The use of the work graph for the ergonomist-designer is more convenient and visual, but it is possible to put the optimization problem on it only for particular cases (as a rule, for AF of a sequential type).

In this connection we will develop an optimization model on the "events" graph, which is a semi-Markov process (SMP).

The problem can be reduced to the problem of ensuring the maximum probability of absorption into a given state s, which, for example, corresponds to the event "error-free execution of AF".

On the event graph, we will assign our absorption state to each variant of the end of the operation accordingly, for example, "error-free execution of AF" or "execution of an AF with an error".

The vertices, which correspond to the absorption states, are numbered by the first *r* natural numbers (*r* is the number of absorbing vertices of the SMP).

For initial vertices, which are numbered by numbers from the numerical sequence after the first *r* absorbing vertices, it is necessary to specify a vector of initial probabilities, that is, the probability of finding the system in the initial states at the corresponding vertex of the event graph:

$$a = (a_{r+1}, a_{r+2}, ..., a_m), \sum_{i=r+1}^{m} a_i = 1$$

Let us introduce the following variables and designations: P^k_{ij} – the probability of the transition of the SMP from the vertex *i* to the vertex *j* in the *k*-th method of performing the work;

N – the total number of vertices, of which the first *r* – the absorption vertices ;

$\overline{t_i^k}$ – the mathematical expectation of the random variable of process length of stay at the vertex *i* when choosing the *k*-th solution;

$\overline{u_i^k}$ – the mathematical expectation of resource consumption when the process is at the vertex *i* and the *k*-th solution is chosen;

T_0 – the limitation on AF execution time;

U_0 – the restriction on resource consumption for the implementation of AF;

x^k_i – the variable that characterizes the choice of the solution: $x^k_i>0$ if for *i*-th vertex is chosen *k* solution, otherwise *i* is equal 0;

K_l – the set of admissible solutions in the *l*-th vertex.

In such conditions, the problem is formulated as follows:

$$\begin{cases} \sum\limits_{i=r+1}^{N} \sum\limits_{k\in K_i} P_{is}^k x_i^k \to \max & (1) \\ \sum\limits_{i=r+1}^{N} \sum\limits_{k\in K_i} x_i^k \overline{t_i^k} \le T_0 & (2) \\ \sum\limits_{i=r+1}^{N} \sum\limits_{k\in K_i} x_i^k \overline{u_i^k} \le U_0 & (3) \\ \sum\limits_{k\in K_i} x_j^k - \sum\limits_{i=r+1}^{N} \sum\limits_{k\in K_i} x_i^k p_{ij}^k = a_j,\ j=\overline{r+1,N} & (4) \\ x_j^k \ge 0; \quad j=\overline{r+1,N}; \quad k\in K_j & (5) \\ \sum\limits_{k\in Kj} \delta_j^k = 1 & (6) \\ x_j^k - M\delta_j^k \le 0,\ j=\overline{r+1,N}; k\in K_j & (7) \\ \delta_l^k = \delta_m^k = \ldots = \delta_n^k,\ k\in K_l; & (8) \end{cases}$$

where *l,m,…,n* – dependent states which correspond to one AF operation (there may be several vertices on the event graph of one operation and it is obvious that identical decisions must be taken for them) or to the different operations that must be performed in the same way;

δ^k_j – a boolean variable (it takes the value 0 or 1);

M – a sufficiently large number.

The conditions (6) and (7) are required to find the unique solution at the vertex where the only one way of performing the operation is admissible. As in the ACS in each particular operation mode, each operation can be performed only in the one way, and change of the way is possible only when another mode has been chosen and for each mode it is necessary to build the appropriate AF, we will use only a pure strategy. So, the restriction of type (6) and (7) shall be introduced for all vertices. The restriction (8) is required for choosing the same solutions in dependent states.

The convenience of the model (1) – (7) is that the problem is reduced to the problem of linear programming, which can be solved with the help of any software package focused on this problem.

D. Approbation

We carried out wide approbation of models of this type in different software environments, including: MS Excel; Matlab.

The model has been used many times in solving problems of ergonomic design:

- Call-centers [5]
- Systems which provide access to Internet resources [6]
- Flexible manufacturing systems [7]
- Outsourcing campaign management systems [8-9]
- Management of the main gas pipeline [10-11]
- Settlement centers [12]
- e-learning [13-14]
- Production processes of machine-building enterprises [15-16], chemical industry enterprises [17].
- And etc.

E. Analysis of the problems of the ergonomic management of the optimization model.

In the process of the development of the arrangements for ergonomic quality assurance programs of automated systems it is required to solve the following tasks [4]:

- Professional selection of operators
- Selection of the degree of automation
- Distribution of functions between operators
- Design of information models
- Design of working conditions at operator's workplaces
- Design of the activity algorithms.

So far the main problem of the designing and efficient operation of ACS is to take into consideration the whole complex of influencing factors, such as:

- Thus, today, the main problem of designing and efficient exploitation of automated systems is the problem of accounting the whole complex of influencing factors, such as:
- design features of workplaces, interface features;
- the intensity of activities,
- operator's functional state,
- the state of the environment,
- temporal conditions of activity,
- qualification of an operator,
- emotional condition,
- motivation,

- settings (for speed, response time, etc.)

It is clear that a change in the value of any of these factors leads to a change in the value of effectiveness of the AF.

However, analyzing the experience of using mathematical models of the type (1) – (8) in ergonomics, it is possible to make the conclusion that such an experiment takes place only within the framework of the scientific school "Efficiency, quality and reliability of ergotechnical systems of professor Gubinsky A.I. " [4–18]. Among such models there are the models for the design of activity algorithms [4,5,6,9,17], the distribution of functions between a human and automation [4], the distribution of functions among operators [4,7,11,12], etc

Obviously, the practice of ergonomic management rarely refers to models of the type (1) – (8) because of the "narrow interpretation" of the concept "the method of performing an operation" (from the set of K_l-admissible solutions at the l-th vertex – refer to tasks (1) – (8)). Traditionally in ergonomics such method is interpreted restrictively (for example, " to press the button" or " to toggle" or "to give a voice command")

In practice, the change of any parameter in the MMS leads to a change of the characteristics of the ways of operation performance. So, for example, if it is solved the problem of the design of working conditions at the operators' workstations is solved, then the reliability and time response characteristics of the operations performed at the corresponding work places are also changed accordingly.

Likewise there can be formed the variety of possible ways of the performing of operations taking into consideration the influence of all the above-mentioned influencing factors. And this is a combinatorial problem.

Evidently to overcome the obvious difficulties of applying optimization models in ergonomics it is required:

- to expand the interpretation of the concept of "the method of operation performance";
- to develop information technology to generate possible ways of performing operations based on a combination of possible MMS parameters.

Conclusion

It has been developed the mathematical model of the optimization of the human-machine system when describing the algorithm of functioning in the form of an event graph.

The optimization is reduced to the problem of linear programming.

The wide outreach of information technologies for solving linear programming problems makes this model quite a convenient tool for ergonomists and experts in the reliability of MMS.

The task of the subsequent widespread implementation of the optimization model in ergonomic management of automated systems is determined as the task of automatic generation of the alternatives for AF MMS operations with the determination of the appropriate reliability and time response characteristics.

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