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THE INFLUENCE OF AUTOMATIC CONTROL TECHNOLOGIES ON HUMAN ERRORS IN THE CENTRES FOR CONTROL AND MANAGEMENT OF AUTOMATED SYSTEMS

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Abstract. *In the paper, we have shown the results of the research on the human errors in the centers for control and management of air traffic, electro-energetic systems and mines with underground exploitation. The human errors were the result of inadequate situation awareness in the real-time systems, and they were conditioned by automation and computerization of those systems. The paper deals with the most recent approach in applying modern and intelligent control method, conditioned by the quick development of computer technology and machine intelligence. In the process of management, modern control use space state models, and the intelligent control systems are applied based on knowledge.*

Key Words: *Visualization, Intelligent Control, Computer-supported Cooperative Work, Human Errors*

1. INTRODUCTION

The term "automation" is defined in many ways in technical literature. Some people like to think of it as any implementation of a computer technology, particularly if it did not exist before. Other definitions are limited to computer systems that have certain degree of automation. In the field of an ergonomic design for control and monitoring of the automated systems, the most acceptable definition is: "the appliances or systems that realize (partially or completely) a function that was not performed before (partially or completely) by the human being" [1].

Advances in hardware and software offer promising opportunities for automating a greater range of information – processing, decision-making, and control functions than has been possible in the past. Along with these advances comes the question of the degree

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to which emerging hardware and software systems can be trusted to perform functions in a reliable and valid manner.

When the relationship between man and automation is studied, one should mention that, regardless of the fact that the implementation of automation has the function of supporting the human operator, it also has a negative influence on the operative activities.

This is conditioned by the greater demands of intellectual nature (observation, attention, awareness, memory, opinion, learning) in accordance with the sensory and mobility abilities of the human operator (sight, hearing, movements of the extremities, etc.), his biological mechanisms of the reciprocal connection (watchfulness, sleepiness, monotony), preventive protection from the homeostatic disorders in human organism (stress, strain, fatigue) and the level of accordance of the signaling and commanding devices with the operators. Because of these demands, the operator has to have high qualifications in organizing and managing informational-managerial systems in automated production, he has to be in optimal psycho-physical condition and endurance, he has to have neuropsychical and intellectual effectiveness, psychosomatic and emotional stability and professional motivation for such a responsible and intellectually hard work [2].

Researches have shown that in the great number of cases, automated systems prevent the operators from getting complete situation awareness, i.e. from understanding the situation fully and foreseeing future actions. That is why we should pay special attention to the design and implementation of these systems.

2. Control Technological Resources

In this paper we review and assess three technologies that relate to the functions of information acquisition, information distribution, the generation of alternative decision options, and options selection. These technologies are visualization and mental models, intelligent decision aiding and computer-supported cooperative work.

2.1. Visualisation and Mental Models

Visualization, the process of using a visual mental model, is perhaps the most important cognitive function the controller performs. Visual mental models are what we usually think of when we speak of mental models – we "see" them in our "mind's eye" (although musicians surely have auditory mental models, professional tasters surely have olfactory and gustatory models, etc.). Computerized automation can enhance visualization in many ways, which is the point of revisiting the topic of visualization there [3], [4].

As described earlier, the operator has a mental model of the physical surroundings stored in his memory. The process control room operator therefore has a more or less effective and useful model of the process under supervision stored in his brain's long-term memory. This mental model is updated continuously by interaction with the short-term memory and probably takes place at a subconscious level. It is also probable that things are brought to his attention by a lack of agreement between the updated model and the actual state of the process. When this occurs, conscious processing takes over and the operator starts to observe the process in order to analyze this lack of synchronization. As man's ability to process large amounts of information simultaneously is limited, he is dependent upon having some form of summary description of the process. The various possible methods for storing this mental model will be examined. The way in which the model of the physical reality is actually stored in the brain is not known. Based on the various methods of describing the process, however, we can make suppositions on the most suitable way to structure the process in the long-term memory. Through having a better idea of the way and form in which the mental model of the physical process is stored, it should be easier to specify the ways in which the various forms of display device should present the true status of the process to the operator.

Two main types of model may be used for the graphic description of a process: some type of physical presentation may be made, such as a component flow diagram; or a functional presentation of the process can be given. Singleton [5] used this basis for distinction. Ivergard [6] developed the method further in order to describe a process using different function flow diagrams.

Using this method, the starting point is general system goal. From this goal different sub-goals may be produced where each sub-goal consist of a function. The goals may be broken down to different degrees, thereby obtaining functions at different levels of detail. However, these functions must not be broken down in too much detail, as this causes the degree of abstraction to be lost, together with the ability to see the functions as a whole. Also, working with too many functions may make the model unusable. If the functions become too generalized there will be too many physical functions and human tasks, and it will thereby become of less practical use, for example, in fault analyses.

Rasmussen [7] produced an excellent review of many different types of conceivable models of how the operator could store structures of the physical process he is supervising. Rasmussen starts with taxonomy of model descriptions, and then describes the following models:

– Model of physical shape
– Model of physical function
– Model of functional structure
– Model of abstract function
– Model of functional meaning and objectives.

The first two are examples of what Ivergard [8] refers to as physical models. The others are examples of functionally oriented models. The model based on the functional structure is, in Ivergard's view, an intermediate between and functional description. The logical function flow diagram described under the heading of model of meaning and objectives by Rasmussen is that closest to the function flow diagram described by Ivergard. It is not thought that any further knowledge of the type of mental models used by operators exists. Rasmussen and his colleagues argue for some form of functional logical description method.

2.2. Intelligent Decision Aiding

The principal uses of intelligent computer-based decision-making systems include diagnosis, planning, decision aiding, intent inferencing, and training. They can be developed from a variety of sources, including highly structured written documents, such as military doctrine; knowledge elicitation methods used to create expert emulations; and algorithms that provide structures and strategies for learning by example or through neural networking. Although these systems may vary in underlying logic or structure most include both domain knowledge and procedures for operating on that knowledge.

In this paper we briefly review the technology of expert systems, intent inferencing systems, learning software, and blackboard systems. The current technology for expert, intent inferencing and blackboard systems require a programmer to make changes. Learning systems, in contrast, are designed to grow and add new knowledge through iterative operation.

Intelligent control or implementation of intelligent systems in the control process includes system control, examination of operational activities, computer technology implementation, artificial intelligence and basic characteristics of the process under control.

Most recent advances in computer technology, modern technology and machine intelligence, made a platform for new generation of industrial control, providing for sufficient economic use by means of integrated computer, information and management system implementation.

Control technology ranges from classical control to actual modern control, based on mathematical model and intelligent, knowledge-based control.

Modern control theory and technology develop quickly and are successfully implemented to the system identification, evaluation, and optimization, powerful and adjustable control, particularly to linear systems.

Computers and microprocessors are used as basic units in control industry, so that today, the main challenge the control unit is coped with, is not lack of reliable computers and their software environment to support modern control, but memorizing real and executive applicative software for control industry.

Most recent research and development in the field of artificial intelligence that includes knowledge management, sample recognition, not clear logics, neuron networks and learning by means of machines etc., provided great possibilities for solving problems of process systems control [9], [10].

2.3. Computer-supported Cooperative Work

Distributed networking capabilities plus advances in telecommunications multi-user applications, shared virtual environment technologies, and the like have created opportunities for users in the same of different locations engaged in interdepended activities to work together in a common computer based environment.

These capabilities have given rise to a relatively new interdisciplinary field of study known as computer-supported cooperative work (CSCW). Its goal is to use groupware technologies to facilitate communication, collaboration and coordination in accord with the users, organizational and social contexts. Research in this area takes into account situations, roles social interactions, and task interdependences among participants as a guide for CSCW system design, development, implementation and evaluation.

A primary concern of the work in CSCW is the development of methodologies to describe roles, relationships, and shared work procedures for coordination, cooperation, and communication.

A number of investigators [11], [12], [13], [14] have employed a variety of social research methods (ethnography, field experiments, replicated case designs, unobtrusive measures, and realistic laboratory studies) in efforts to develop the required social knowledge and incorporate it into design and implementation processes. Less progress has been made toward developing methods for evaluation.

3. The Results of the Research in the Control and Management Centers

Analyzing accidents and disasters, cases in which high levels of automation lead to the loss of situation awareness and, thus, to the operators` mistakes, were discovered. Situation awareness has a time and space component, and it takes some time for the operator to get the idea of the situation, i.e. to achieve the necessary level of situation awareness in order to handle the given tasks efficiently and safely [15].

The definition of situation awareness is: "Situation awareness includes perception of the elements of the surrounding in time and space, understanding their importance and projecting their status into near future", and it can be, hierarchically, divided into three levels:

- Perception of the elements in the surrounding (level 1), where the perception or observation is defined as immediate knowledge of the objects and phenomena on the basis of physical data and other cognitive processes. To achieve this level, one needs to observe status, characteristics and dynamics of the relevant elements from the surrounding.
- Understanding of the immediate situation (level 2), where one needs to understand the meaning of the elements stated in the above level in order to do the operator's tasks. Operator-beginner can have the same level of awareness when observing the elements in the surrounding, but he can have problems when it is necessary for those data to be integrated into a complex whole.
- Projection of the future state (level 3), where it is necessary to bring decisions about the future actions of the operator on the basis of the correct perception of the elements in the observed surrounding and their adequate integration.

Operator's complete situation awareness includes his judgment of the immediate and expected workload, as well as the image of the situation in the space he controls. Situation awareness is based on the use of knowledge gained by the recurrent situation evaluation. This situation awareness is not just a momentary image of the existing system status; it also serves to lead the process of developing and modifying the image that represents a time envelope comprising near past, present and near future [16].

Important tool for adequate control and management of different systems is a mental model that is actually imaginary representation of the functional connections in the automated system. It sustains the operative understanding of the system that is based on previous experience [17]. Mental model is a thinking model on the basis of which the operator foresees and expects future behavior of the system. It can also influence the operator's situation awareness that is going on and it can influence mental simulation of some (typically physical) connections when conceptually recognizing variables. It is possible to do the check "what will happen" (in the time when actual processes happen), if the operator is trained to use the mental model.

Experience shows that, when a real-time system is automated, there are failures in many cases because the operator does not fully understand how the system really works (his mental models are either wrong or incomplete) and he continues, out of safety, to work by earlier procedures, which causes serious managerial problems. The operator, who does not understand the new system and continues to work in the old way, allows for the control process to continue actually without control, and, thus, endangers functioning of the whole system and creates a real possibility for the accidents and disasters to happen. The following things are necessary to prevent this: first, better training of the operator, especially his cognitive level of understanding the algorithm and logic connections in the system which is more adequate than the influence only on the level of his skill, and second, enabling the operators to participate in the automation of the system, to participate in the installing and testing of the system, so that they can learn by themselves from the beginning [18].

One of the reasons for not trusting the automation is the operator's failure to understand the basic algorithms of the system and a poor mental model when the operator fails to understand truly the function of the automation, which makes him react in a totally unexpected manner.

Situation awareness is very important for successful accomplishment of tasks in the control centers and for managing different automated systems. What we know about this phenomenon up to know, points to several factors connected with the situation awareness, which are stated in some leading studies on the operative mistakes in these centers.

We will show here the results of the research on the common causes of the human errors (Table 1) conducted in NASA centers, centers for control and management of Electro-energetic Systems of Yugoslavia and centers for control and management of underground coal mines in Serbia.

Flight controllers were the initiators of 33 incidents (69% - of level 1, 19% - of level 2, 12% - of level 3). The most frequent cause for the mistakes of level 1 was the failure in monitoring data (51%); equally responsible for the mistakes of level 2 were the mistakes caused by incomplete and incorrect mental model and excessive relying on the expected values, and the mistakes of level 3 were caused by the exaggerated projection of the existing statistic trends.

They came to similar results in the research on mutual coordination of the operator and the informational-managerial devices in the controlling and managing centers [20], because the biggest cause of mistakes was a failure in monitoring data (63,16%). This was most often caused by the visual strain (57,89%), the speed of receiving information (21,05%), the distance from informational display (15,78%) and the language of informing (5,26%). However, somewhat different data are in the field of mistakes connected with the difficult data perception, because in these centers the percentage is somewhat bigger (15,78%), and the structure of these mistakes is made up of cleanness of the signs (36,84%), the quality of light (36,84%), the reflection of the video terminal (15,78%) and the blinking of the video terminal (10,52%).

Among the mistakes of level 2, the most common mistakes are made because of inadequate mental models, and their structure is as follows: difficulties in memorizing (42,11%), lack of attention (36,84%), anxiety (15,78%) and irritability (5,26%).

The most common mistakes in level 3 are made because of wrong anticipations caused, in this case, by models of evaluation (42,11%) and excessive relying on routines (15,78%).

Table 1. Representation of the causes of the human errors

Levels of errors	Errors	0 1 2 3 4 5 6 7 8 9 10
1.	Unsuccessful data monitoring	51 63,16 42,11
	Inaccessibility of data	18,2 5,26 21,05
	Memory mistake	18,2 10,52 15,78
	Difficult data perception	6,1 15,78 10,52
	Wrong data observation	6,1 5,26 10,52
2.	Incomplete mental model	22,2 21,05 26,33
	Inadequate data model	22,2 15,78 21,05
	Excessive relying on the expected values	22,2 36,84 42,11
	Other	33,3 26,33 10,52
3.	Excessive projection of statistic trends	33,3 36,84 42,11
	Wrong estimation of mathematical probability	33,3 33,3 26,33
	Other	33,3 29,86 31,56

Key:

Flight control **Electro-energetic Systems** **Coal mines with underground exploitation**

In 1999, Endsley and Kaber presented the results of the research on accidents that included the problems related with the awareness of the situation given in NASA researches (Aviation Safety Reporting System – ASRS) [19].

Human errors were also analyzed in the project "Research and development of the equipment and software for reengineering of monitoring, diagnostics, management and safety of working conditions in the underground coal mines". According to this research as well, the biggest cause for the mistakes of level 1 was unsuccessful data monitoring (42,11%), for the mistakes of level 2, it was relying on the expected values (42,11%), and for the mistakes of level 3, it was excessive projection of statistic trends (42,11%).

4. CONCLUSION

Advanced technologies related to control and management is all the more present in various industrial processes. In these processes it becomes more and more necessary to introduce automatic control and computers, as a support to system needs, that are controlled and managed and human factors in these. The needs refer to compensation of human shortcomings and adequate use of human potentials. The analyses approaches of modern and intelligent controls in this paper, contribute to quicker realization of these needs.

Reestablishing of even complete automation of the control and advancement tasks cannot eliminate the need of the operator to evaluate the awareness of the situations, because it is crucial for effective monitoring of the automated system and for the integration of the exit from the automated system with the other manual tasks. Operator has to have good situation awareness when he is in the role of observer, so as to see when the intervention is necessary.

As the automation considerably affects human characteristics, it is necessary to consider in great detail the way it is going to be introduced, because it makes considerable difficulties to the operator when forming higher levels of situation awareness (considering the situation and projecting future actions). This is conditioned by the following factors: decrease of watchfulness as a consequence of long monitoring, relaxation caused by the excessive trust in automation or lack of that trust, passive handling of the information which could make dynamic updating and integration of informing difficult, then changes in shape, form or complete loss of recurrent information and other disturbances which occur with many automated systems.

Many research projects on the characteristics of automation in the real-time systems have identified series of problems connected with the interaction between humans and automation, with potentially serious consequences on the security of the system. These observations are based on the research projects which include lab experiments, simulation examination and conceptual analysis, and many among them find the connection between human answers and mistakes of the automation, in the mistakes of the automated system itself, and also in the mistakes of the surrounding in which the system works. It is indisputable that the problems with automation do not occur only as a result of the malfunction of the automation, but also as a result of much complex influences of automation on the behavior of the humans-machines system.

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UTICAJ TEHNOLOGIJA AUTOMATSKE KONTROLE NA LJUDSKE GREŠKE U CENTRIMA ZA KONTROLU I UPRAVLJANJE AUTOMATIZOVANIM SISTEMIMA

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U ovom radu su prikazani rezultati istraživanja o greškama operatora u centrima za kontrolu i upravljanje vazdušnim saobraćajem, elektroenergetskim sistemima i rudnicima uglja sa podzemnom eksploatacijom, koje su nastale kao posledica neadekvatne svesnosti o situacijama koje su se realno u njima dešavale, a bile su uslovljene automatizacijom i kompjuterizacijom tih sistema. Rad je posvećen najnovijim pristupima u primeni modernih i inteligentnih metoda upravljanja uzrokovanim brzim razvojem kompjuterske tehnologije i mašinske inteligencije. U procesu upravljanja moderna kontrola koristi modele prostora stanja, a primenjeni inteligentni sistemi upravljanja zasnovani su na znanju.

Ključne reči: vizuelizacija, inteligentna kontrola, kooperativan rad podržan kompjuterom, ljudske greške