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HUMAN FACTOR INFLUENCE ON SYSTEMS MAINTENANCE OPERATIONS

Abstract: *The method of cause-effect diagram is used in the subject investigation to detect and systematize human factors (human errors) that affect the results performing for the mining machines maintenance operation, i.e. sources that cause a maintenance problem. Event Tree Analysis is used as additional method in regard to cause-effect diagram. This method described certain logical events which come from primary initial event – error of maintainer. Event tree is in the subject investigation developed in order to find modes for mitigation waste (injury), rather than prevent waste.*

Key words: Human factor, maintenance operation, human error cause, "Swiss chese" model, event tree, human reliability prediction.

INTRODUCTION

One of the most important problems in ensuring the systems reliability is the organization of preventive measures. Timely and useful, in depth and scope, measures of preventive character (maintenance measures) enable not only the reduction of exploitation cost, but also an improvement of technical characteristics of system equipment and an increase of its reliability and safety.

In accordance to complexity increase and price of systems, the cost to ensure support for its exploitation are also increased. For example, according to the data in [1], airline companies spend 25-30% of total exploitation cost for the maintenance and overhaul of the planes. According to the same source, the cost for the maintenance of transportation systems and mining machines are 14-25% of the annual purchasing expense. At the other hand, in many systems (for example, safety systems of power units as the power stations are), the maintenance represents a mean to provide safety, since it enables prevention of disastrous failure modes, i.e. failure modes that cause heavy accidents.

The increase of exploitation systems effectiveness is, therefore, related to the improvement of the maintenance concept. Considering the maintenance as a group of support operations for the working capability of the system equipment, it is possible to single out two maintenance aspects:

- review of the maintenance operations that are included in the maintenance tasks (for example, dismantling, cleaning, diagnostics, setting, assembling, control),
- conceptions, that assume general rules of control of system operational condition in the process of maintenance tasks.

THEORETICAL BASICS OF HUMAN FACTOR: DEFINITIONS AND CONCEPTIONS

Term "human factor" should be clearly and precisely defined, since the use of this phrase in speech is often understood as any other factor that relates to a human being. One of the definitions of human factor, accepted in the International Civil Aviation Organization (ICAO), proposed by Elvin Edwards reads: "Human factor is associated with the optimization of mutual relations between people and their work by systematic use of knowledge about man in the frame of system design" [1]. The objective of the work in the area of human factor is to provide successfulness of entire system, including its safety and efficiency, and also a normal subjective feeling of each individual. Professor Edwards stressed that, according to his notion, the word "people" includes persons of both sexes and characteristics of their behavior as individuals in a society., and the word "work" stands for expressing (manifesting) the people's need to be interconnected. Later, this definition included the question of the features of the interconnectivity of individuals, groups and organizations in which they belong, and also it included the aspects of the organization interconnectivity that make certain industrial branch [1]. The science of man, anthropology, study the personality and character of a man, his capabilities and limitations, as well as characteristics of individual and group behavior [2].

Integration of human factor in the stage of system design mean that the specialists determine the tasks and work method of man, as well as difficulties and limitations, when people that work in interconnected areas of engineer activities should make decisions. Information on human factor is used in a degree needed to solve real problems.

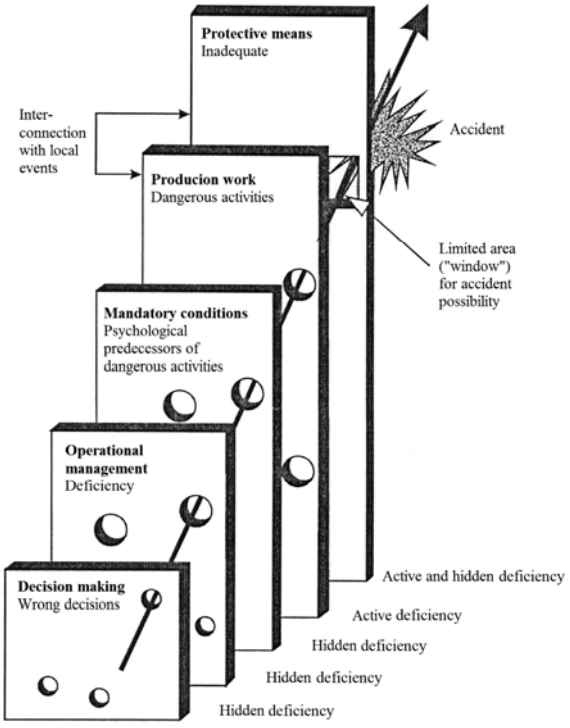
Therefore, human factor represents a science about people in certain circumstances in which they live and work, about their interconnectivities with machines,

procedures and environment, and also interconnectivity of people. In the industrial engineering, aspects of human factor touch a series of individual, medical and biological notions directed towards the optimization of exploitation, management and maintenance of technical systems.

MODEL OF HUMAN ERROR CAUSES: "SWISS CHEESE"

It is important to establish why errors occur, what are the causes that induce them, which factors contribute to their occurrence and to try to eliminate them. Accidents, by the rule, occur not as a result of individual error, but as a consequence of hidden, timely undetected damages and failure modes, that by accumulating may lead to undesirable event. This feature of accidents is described in a best way by "Swiss cheese" model, which is developed by James Reason [3], and which illustrates the role of man in technical systems accidents. If the condition of a technical system is presented in a shape of small piece of cheese with small holes, each hole corresponds to a hidden defect caused by the lack of production process or maintenance of the system. These failures may remain undetected many years. Hidden defects may also be the consequence of intentional activities, for example, intentional violation of maintenance rules in the form of omitted required controls and checks or execution of irregular assembly replacements.

Reason's model, which describes the accident causative conditionality, is shown on Figure 1. It shows various types of human "contributions" to the disruption of execution completeness of maintenance task.



Figue 1. *Model of accident cause, titled "Swiss cheese" [3]*

Reason's model, "Swiss cheese", explains in what way people add to the disruption of operational capabilities of complex interconnected technical systems and why accidents happened. Thanks to technological-technical progress and reliable protective measures, the cause of accidents are rarely the incorrect work of operational personnel or failure of the main equipment. On the contrary, they are the result of mutual actions of series of failure modes and defects, already present in certain technical system. Many of these failure modes cannot be easily detected, and their consequences cannot be immediately manifested.

In his book "Human error" [3], Reason considers a complex production system. One of the main elements of the system consists of individuals that **make decisions** (top level of management structure), who are responsible for performing the established objectives and for management of resources they have, to achieve safety and efficiency of the system operation. Second key element is **operational management**, i.e. individuals who execute decisions made by top management. In order to transform the decisions of the top management and work (procedures) of the operational personnel into effective and **productive work**, generated by an appropriate working force, certain **preconditions** have to be fulfilled. For example, certain equipment have to exist and to be reliable, work force has to be qualified, competent and interested (motivated), and working conditions – safe. Conclusive element – various types of **the protection at work** or precaution measures – usually is intended to prevent expected.

CAUSES OF PERSONNEL ERRORS DURING MINING MACHINES MAINTENANCE OPERATIONS

Investigation of causes of human errors during mining machines maintenance operations is performed by a team work in the regime of Brainstorming method. The team would have to act in accordance with all the recommendations for the organization of Brainstorming. The main recommendations are for: team composition, working way in the team, role of the team leader. The team generated ideas about causes of the maintenance problem that requires being resolved.

The rule, appropriate for making a starting (general) cause-effects diagram, which is applicable in most of real situations, is applied in the subject investigation. This rule anticipates that there always exist certain number of categories of possible causes to some consequences (undesirable results) of work process.

In resolving a particular maintenance problem, the investigation revealed the factors (causes) on which the undesirable result or consequence depends:

"*Human error with the highest degree of risk during performing of mining machine maintenance operations".*

The investigation firstly determined and separated five causes, in the sense as shown on Figure 2: lack of training, inappropriate information, lack of experience, carelessness, danger neglect.

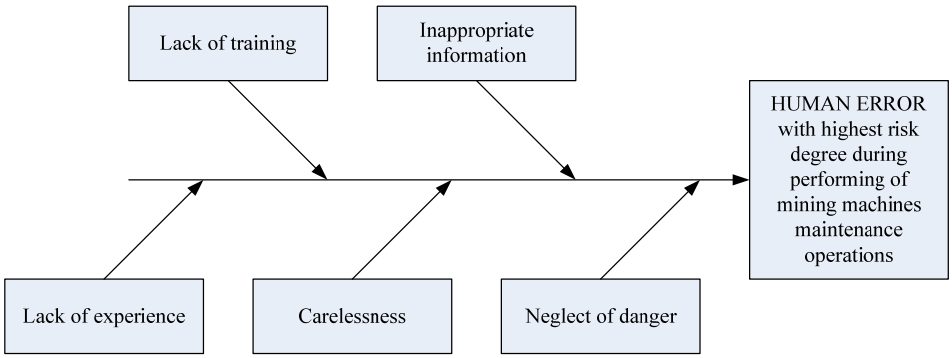


Figure 2. *Potential causes of human errors with the highest risk degree during performing of mining machines maintenance operations in the form of cause-effect diagram*

Investigations performed in the course of the subject work, have shown which types and causes of human errors have the highest risk degree at execution of corresponding maintenance operations of various mining machines, as: bucket wheel excavator, landfill machine, dumping machine, self-transporter bandwagon, dragline dredge.

Further solution of the subject problem in a qualitative way established the causes of the second and higher levels that generate the first level causes of human errors with the highest risk degree, during performing of mining machines maintenance operations.

HUMAN FACTOR INFLUENCE ON MINING MACHINES MAINTENANCE OPERATIONS

The maintenance task is executed by personnel specially trained for the maintenance and overhaul of the mining machines. However, this circumstance does not guarantee the provision of reliability and safety in exploitation of the complex system as he mining machines are. Even more, the analysis of the accidents causes, performed and published in [4], has shown that the role of human factor increases with the increase of technical system reliability and price increase of technological equipment. Regarding that, taking into account the errors of the personnel that executes the maintenance tasks operations, presents an actual problem at the safety analysis.

At the human factor analysis, relating to the problem of maintenance effect on the safety of a technical system, it is possible to single out the following typical errors of the personnel that executes the maintenance tasks [4]:

- error of omission, that occurs when a maintainer omits one or several maintenance operation,
- error in the maintenance operations order,
- error at selection,
- error of time,
- error that affects the maintenance quality.

For the mining machine that is in idle regime, the availability of the machine is affected by the errors connected to the short time that is assigned to the maintainer, so that he can't analyze the situation allowing an error to happen. For example, with the assigned time of 5 minutes for the analysis of a situation, the probability of error occurrence is 10^{-1}, and with 100 minutes for the analysis of the same situation, the probability of a error is equal to 10^{-4} [4].

Further qualitative analysis of the personnel influence on the probability for an error to occur during the maintenance is connected to the factors that affect the operational capability, among which we single out:

- inadequate workplace and equipment layout,
- bad environment conditions (for example, lighting),
- weakened control and so on.

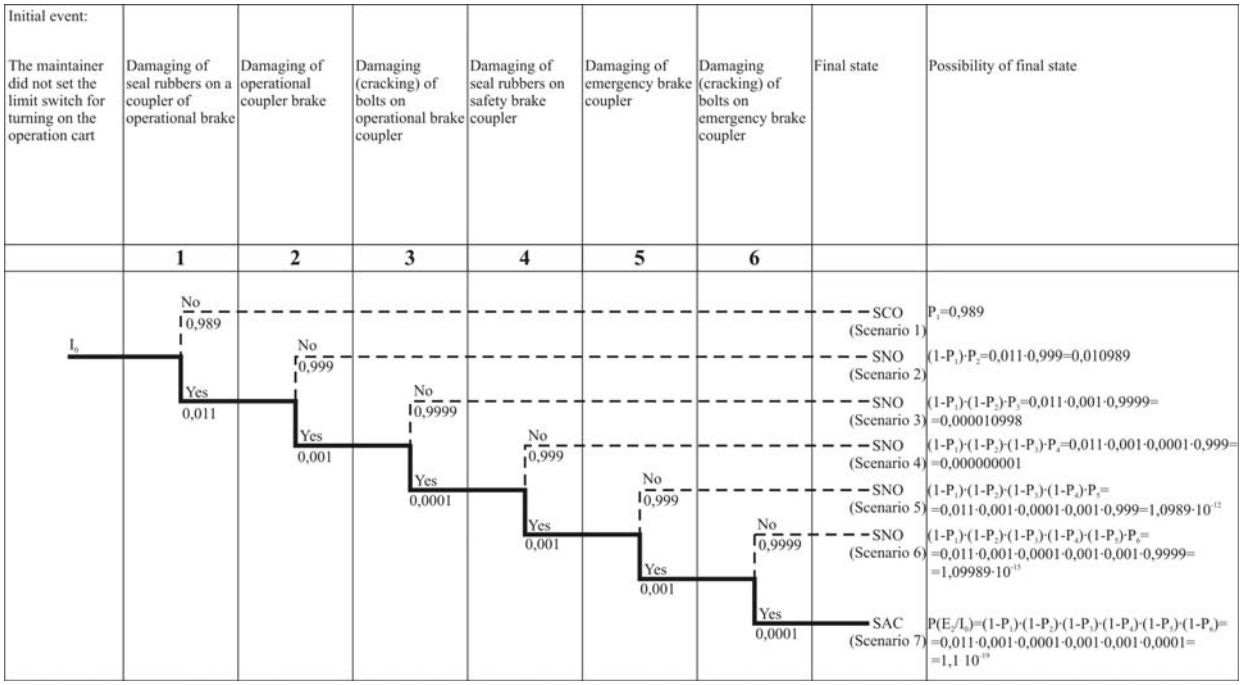
Distinctive factors that affect the operational capability are also the inner individual factors, characteristic for the maintainer, for example, the professional training (expertise education, qualification and competency), working motivation, stress, etc.

Safety analysis in the phase of mining machine exploitation is preformed primarily in the situation when accident had never happened. Damaging of the mining machine is caused by the undesirable event (type of operator error, type of maintainer error, failure mode of a mining machine item) with disastrous consequences, and when the accident occurs it is too late for the analysis. Therefore, the safety analysis of the mining machine should be performed preventively. There is no need for the history data of the mining machine to analyze the safety, as the case is for the analysis of the mining machines reliability. Therefore, the safety analysis enables the prognosis of undesirable events with catastrophic consequences, i.e. it serves for

the prognosis of generation of accident condition (State of Accident - SAC) of the mining machines.

In the investigation it is concluded that the safety criterion of the bucket wheel excavator SRs 1200x24/4x0(400 kW)+VR is an accident of the Mechanism for lifting the bucket wheel arrow, because in that case it causes the total damage of the whole excavator (bucket wheel excavator fall on a counterweight). The error modes of the maintainer are observed as the initial event in the analysis of the event tree, besides functional failures of the Mechanism items for lifting the rotor arrow, maintainer errors. The initial event - error modes of the maintainer, lead to the catastrophic accident (State of Accident - SAC) through the realization of scenario in the event tree, in the sense as shown in Figures 5.

The event tree for the initial event – error mode of maintainer: **The maintainer did not set the limit switch for turning on the operation cart,** is presented on Figure 3.



Legend:

No - undesirable event hasn't happened,

Yes - undesirable event has happened,

SCO - state of capability to operate,

SNO - state of noncapability to operate,

SAC - state of accident.

Figure 3. *Event tree for the initial event:*
"The maintainer did not set the limit switch for turning on the operational cart"

The probability of realization of scenario for state of accident (SAC) in the event tree on Figure 5:

$$P(E_2/I_0) = (1-P_1) \cdot (1-P_2) \cdot (1-P_3) \cdot (1-P_4) \cdot (1-P_5) \cdot (1-P_6) = 0{,}011 \cdot 0{,}001 \cdot 0{,}0001 \cdot 0{,}001 \cdot 0{,}001 \cdot 0{,}0001 = 1{,}1 \cdot 10^{-19}.$$

In certain cases, the safety analysis of systems, taking into account the maintenance, may require a quantitative estimation of human reliability that performs maintenance. Methodology of the quantitative analysis of human reliability is presented in reference [5].

MODEL FOR HUMAN RELIABILITY PREDICTION

In the course of many years the researchers of human factor have developed numerous mathematical models for the anticipation of human reliability. These models can be, directly or indirectly, used for the execution of various researches and reliability analysis.

On such a model represents the model of human reliability in static (invariable) environment (external conditions). This is a usable model for the anticipation of human reliability prediction in the area of continuous time in constant ambient (external conditions). Human reliability is expressed by formula:

$$R_h(t)=\exp[-\int_0^t \lambda_h(x)dx], \quad (1)$$

where:

$R_h(t)$ - particular value of human reliability (in time t) in an constant ambient,

$\lambda_h(t)$ - current human error rate.

In the expression (1), particular time until human mistake occur can be subjected to any continual statistic distribution in time (for example, exponential, Weibull, Gama).

CONCLUDING COMMENTS

Experience shows that the human errors are one of the main sources of many problems related to the reliability of mining machines. Generally speaking, the occurrence of human errors is caused by the actions as failure (omission, unsuccessful attempt) to execute a required function, wrong decision in a response on certain problem, performing of function that shouldn't be executed, unsuccessful in recognition (observation, revealing) of a dangerous condition that requires corrective measures, bad timing and bad response on unpredicted circumstances. Human errors can be classified in the following seven categories: working errors, maintenance errors, design errors, control errors, support errors, operation errors, production errors.

Some of the significant causes for the human errors are: badly designed equipment, inappropriate (insufficient) working surface, bad management, insufficient lighting of workplace, unfitting tool, overcrowded working surface, insufficient training, qualification or competency of personnel for the work, complexity of work, fatigue, badly written working and maintenance procedures, high noise level, poor motivation, high temperature in the workplace, poor verbal communication and inappropriate handling of equipment.

REFERENCES

[1] Human Factors in Aircraft Maintenance and Inspection, CAP 718, Documedia Solutins Ltd., Cheltenham, 2002, 51 p.

[2] Golubović Z.: Antropologija, Službeni glasnik, Beograd, 20007, 595 s.

[3] Reason J.: Human Error, Cambridge University Press, Cambridge, 1990, 302 p.

[4] Шабанов Г. П.: Количественная оценка деятельности человека в системах человек – техника, Машиностроение, Москва, 1983, 263 с.

[5] Dhillon B. S.: Mining Equipment Reliability, Maintainability, and Safety, Springer, London, 2008, 211 p.

BIOGRAPHY

Ljubiša Papić is a Professor and Head of the Department of Industrial and Systems Engineering at the Faculty of Technical Sciences Cacak at the University of Kragujevac, Serbia. He received PhD degree in Reliability Engineering from University of Novi Sad, Serbia. He is a Member of Russian Quality Problems Academy and Corresponding Member of Serbian Engineering Sciences Academy. His research topics are: reliability testing, failure analiysis, safety analysis, concurrent engineering. Professor Papic is director and founder the Research Center of Dependability and Quality Management (DQM Research Center), Prijevor, Serbia. He was a Visiting Professor at Ben-Gurion University of the Negev, Israel, at Valencia Polytechnic University, Spain and at Samara State Aerospace University, Russia.

UTICAJ LJUDSKOG FAKTORA NA ODRŽAVANjE SISTEMA

Ljubiša Papić

Rezime: *Metod uzročno-posledičnog dijagrama se koristi u predmetnom istraživanju za otkrivanje i sistematizaciju ljudskog faktora (ljudske greške) koje utiču na rezultate performansi održavanja mašina koje se koriste u rudarstvu, odnosno izvora koji izazivaju probleme u vezi sa održavanjem. Analiza stabla događaja se koristi kao dodatna metoda kod dijagrama uzrok-posledica. Ovom metodom se opisuju određeni logički događaji koji su prouzrokovani primarnim početnim događajem - greška održavaoca. Stablo događaja se razvija kako bi se pronašli načini za ublažavanje štete (povreda) a ne za sprečavanje štete.*

Key words: ljudski faktor, operacija održavanje, uzrok ljudske greške, model "švajcarski sir", stablo događaja, predviđanje ljudske pouzdanosti.