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RISK MANAGEMENT OF MACHINES IN OPEN PIT MINES

UPRAVLJANJE RIZIKOM MAŠINA U OTVORENIM RUDNIČKIM KOPOVIMA

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Abstract:

The phenomenon of risk should first be defined, and in order to be managed it is necessary to be measured. The measurement is necessary to determine the objectives to be achieved and the degree achievement of the objectives. Measurement can be qualitatively and quantitatively, based on statistics, the measurement of physical quantities, and the estimations given by experts. This paper deals with models of risk management of machinery of open coal mines, with special focus on human resource influence.

Izvod

Fenomen rizika treba najpre definisati, a da bi se njime upravljalo, potrebno ga je i meriti. Merenje je neophodno da bi se utvrdili ciljevi koji se žele postići i stepen ostvarenja ciljeva. Merenje može biti kvalitativno i kvantitativno, zasnovano na statistici, merenju fizičkih veličina, ili na procenama datim od stručnih lica. U ovom radu je prikazan model upravljanja rizikom mašina koje rade na površinskom kopu, sa posebnim osvrtom na uticaj ljudskog faktora.

INTRODUCTION

Risk is meant to contain the following three components: event, which carries a risk of a specific unwanted outcome (accidents causing certain amount of damage), probability of this event occurring and its significance (value, quantity and amount).

Consideration of risk (measuring, evaluation) represents the assessment of probability of the occurrence of events that carry with them risks and their effects. Damage is the unwanted consequence of one or more events (a series of accidents).

Probability represents the chance of an event happening during the expected time period or a conditional probability for an event to occur. Frequency represents a number of expected events per time unit. Risk is most often measured based on the aggregation of two values: the probability of the unwanted event occurring and its consequences.

A – unwanted event
$P = P^2(A)$ – probability
$C = C(A)$ – consequence
$R(A)$ – risk related to the event A
$R(A) = f(P,C) = P*C$

In case there are multiple unwanted events, $A_1, \ldots A_k$, then an aggregation of probabilities and consequences of every single one of them should be made and used to calculate the total risk.

$$Risk = f(P_1,\ldots P_k, C_1,\ldots C_K) = \Sigma_i P_i * C_i$$

RISK MANAGEMENT

Risk management includes the review of sources and causes of risks appearance; consideration of hypothetical negative consequences caused by a possible realization of a specific risk and the consideration of specific actions that will minimize the risk in question, /1-4/.

Normally, the process should start upwards, by defining for each working task, of the hazards and for each hazard of the risks related. Only after this hazard and risk identification phase (e.g. based on a checklist) the quantification can be initiated.

Methods for analyzing of potential hazards and risk assessment include: Preliminary potential hazards analysis (PHA?); Third party risk analysis; Hazard and Operability studies - HAZOP; Analysis of records; Failure Mode Effects Analysis - FMEA; "What if" method; "lean" method; Failure Tree Analysis - (FTA); FMEA (tools for assessment of ways and effects of potential failure modes of subsystems, assemblies, components or functions.

For the purpose of risk management, qualitative and quantitative methods are used. Qualitative risk analysis is the measure of risk or property value based on risk ranking or classification into descriptive categories such as low, medium, high, irrelevant, relevant, very important, etc. Qualitative analysis includes method for determining of priorities for further actions or planned reactions to risks. Companies can efficiently improve the performance of systems by focusing on high priority risks. Qualitative risk analysis evaluates the priority of identified risks using the probability of their occurrence and effects on the system.

Qualitative risk analysis je usually a fast and efficient way (that does not require high cost) to establish priorities and define the base for quantitative risk analysis, if necessary, and should be used throughout the entire lifespan of the systems in order to notice possible problems on time. Qualitative risk analysis uses results of risk management planning and risk identification process as input data, and can lead to quantitative risk analysis or direct planning of response to risk.

Quantification of risk emphasizes quantitative risks and provides methods for its assessments. Thereby, a limited number of consequences is taken into account, since only those consequences that can be quantified are considered. Statistical analysis and system analysis techniques are used. The drawback of this analysis is that it does not take into account the human factor.

Multiple methods of risk quantification can be encountered in practice. Each of them has its advantages and drawbacks. Figure 1 shows the method which uses calculation of FMEA Risk Priority Number (RMN):

RPN = Severity* × *Occurrence* × *Detection

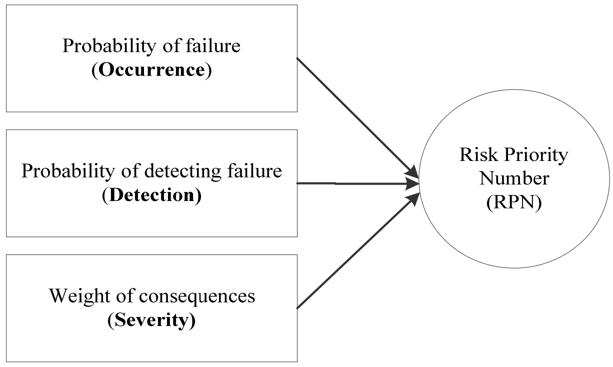

Figure 1. Risk Priority Number.
Slika 1. Stepen prioriteta rizika

Short-term risk management gives a list of potential failures and identifies the severity of their effects and in this way determines the priority of corrective actions. Long-term risk management develops criteria for planning of system testing; it provides the documentation for future reliability analysis in case of system design changes and provides the basis for maintenance planning. Risk management of systems is a continuous process, Fig. 2.

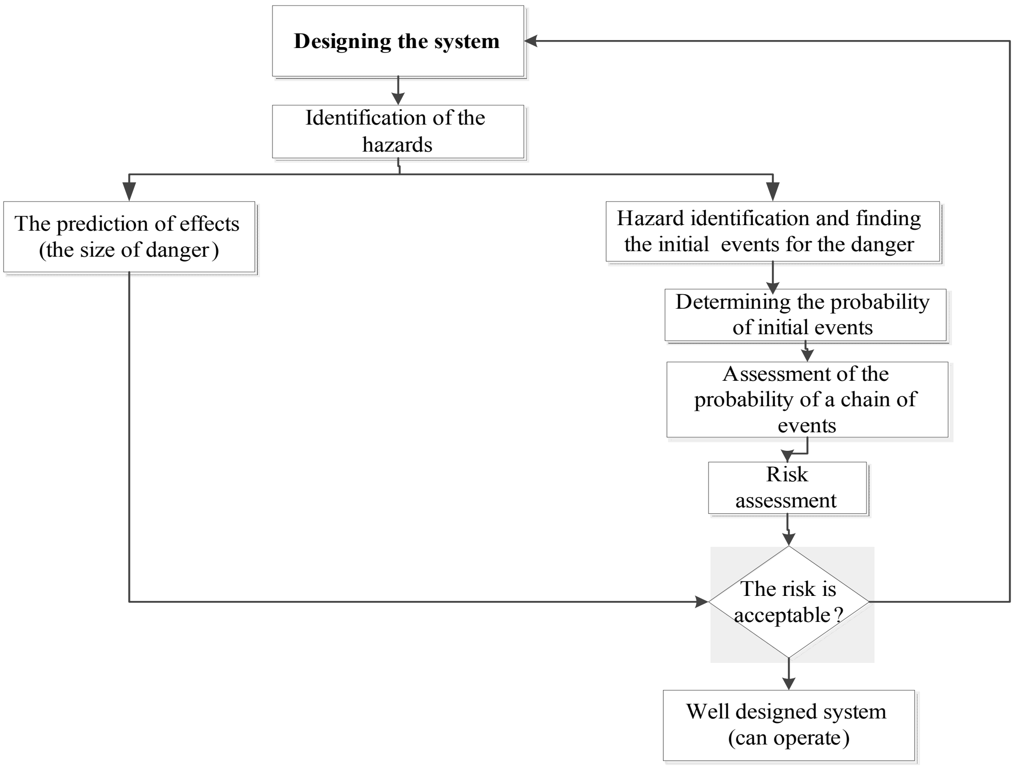

Figure 2. The risk of the system.
Slika 2. Shema rizika sistema

RISK MANAGEMENT IN OPEN PIT MINES

The plan of implementing the risk assessment process among other, includes the organization and coordination of risk assessment process implementation, the list of experts in risk assessment and the timelines, the ways of gathering documentation necessary for risk assessment, ways of gathering information for risk assessment from employees (work place surveys), consulting with employee representatives and informing them about the results of risk assessments and measures taken, other activities required for implementing, changing and adding to the risk assessment process.

During the identification of hazards and harms following is taken into account: routine and non-routine activities of the entire staff that has access to the work place (including negotiators and visitors), the human factor (behavior, abilities and other factors), working equipment, identified hazards and harms that originate from outside of the work place, and can have an unfavorable effect on work health and safety, hazards and harms occurring in the vicinity of the work place, due to work activities or materials, changes of management systems, including temporary ones, and their effect on operations/activities, processes, products/services and work place, obligations related to risk assessment and application of necessary management, data about previous incidents, accidents and emergency situations related to operations/activeties, processes, products /services and work place, including their adjustment to human abilities.

Re-examining of hazards and harms takes into account all changes in operations/activities of the mine and in the environment that could lead to increase or decrease of hazard levels (refitting of objects, installations, plants, changes in processes, technology, introducing of new processes, products/services, energy, changes in organization structure, laws and regulations, serious incidents, accidents, emergency situation, etc.). During the re-examining, checklists, interviews, measures, direct control, results of previous system management checks and other re-evaluations are used depending on the nature of the operation/activity being examined.

RISK MANAGEMENT OF MACHINES IN OPEN PIT MINES

Maintenance and life cycle of excavator units

The life cycle of machines includes the stages of design, manufacturing, delivery, commission, exploitation, revitalization and decommission. Duration of life cycle stages of a bucket wheel excavator, Fig. 3:

- 2 years for conceptual and preliminary design
- 1 year for detailed design
- 2 years for manufacturing, delivery and commission
- 30 years for exploitation until revitalization
- 1 year for revitalization
- 20-25 years for exploitation after revitalization and
- 0,5-1 year for decommission

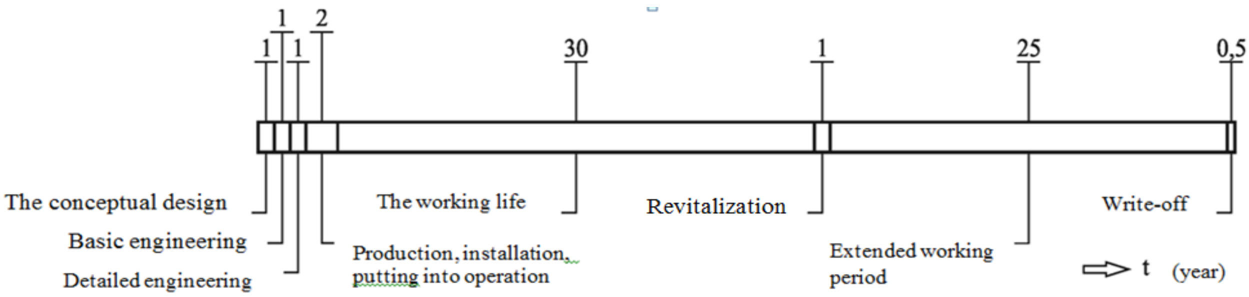

Figure 3. The life cycle stages of a bucket wheel excavator.
Slika 3. Faze radnog veka rotornog bagera

Determining of limitations of machines requires the analysis of data about the intended use of the machine and assumed misuses of machines during the stages of its life cycle, the analysis of qualifications and competence of machine operators, exposure of other individuals to the effects of machine's work, specific limitations (operator - machine, installing, maintenance), time limits (machine, service intervals) and environmental limitations (inside/ outside, dust, temperature, landslides).

Analysis of risk for machines in open pits

Identifying of hazards (dangers) represents the forming of a list of all hazards that may occur related to the intended use of the machine within individual subsystems and on the interface between the system and operator, which have to be identified and documented. Examples of hazards related to the use of machines include: potential mechanical hazards, potential electrical hazards, potential heat hazards, noise hazards, vibration hazards and radiation hazards.

Risk analysis includes risk assessments, i.e. assessment of maximum possible injuries/damages and the probability form them to occur and these are essential information typical for every risky situation. Risk diagrams and matrices are used in practice to display the risks of a dangerous situation.

Evaluation of risks is related to whether the safety goals have been fulfilled or not, i.e. if the probability for an incident to occur, along with the severity of its consequences, is at a satisfactory level.

If the risk of a dangerous event is not at the appropriate level, measures must be taken in order to reduce it, according to the methodology given in SRPS EN ISO 12100-1, Fig. 4.

APPLICATION OF RISK MATRIX ON MACHINE AND EQUIPMENT RISK MANAGEMENT

During the probability assessment, analysis of historical data is applied, when data about previous incidents exist, and evidence of previous malfunctions, types of damage/ failures, properties of relevant equipment and machines are taken into consideration.

Risk matrix can be modified and in that way used during the risk analysis in maintenance. The result of this analysis is the priority of maintenance which leads to a period during which the equipment needs to be repaired - failure. Table 1 shows the qualification of priorities. Potential consequences - same as in the "big-main" RAM matrix.

Instead of event frequency, failure probability is used - i.e. the expected period until the next failure, Table 2.

INFLUENCE OF PERSONNEL RELIABILITY ON EXPLOITATION SAFETY OF EXCAVATOR UNITS

Since man is the key element of the working process, every serious risk analysis includes the influence of the human factor. Analysis of open pit failures, Table 3, shows that the human factor is responsible for the largest percentage of them, because of both design flaws and machine operating and their maintenance.

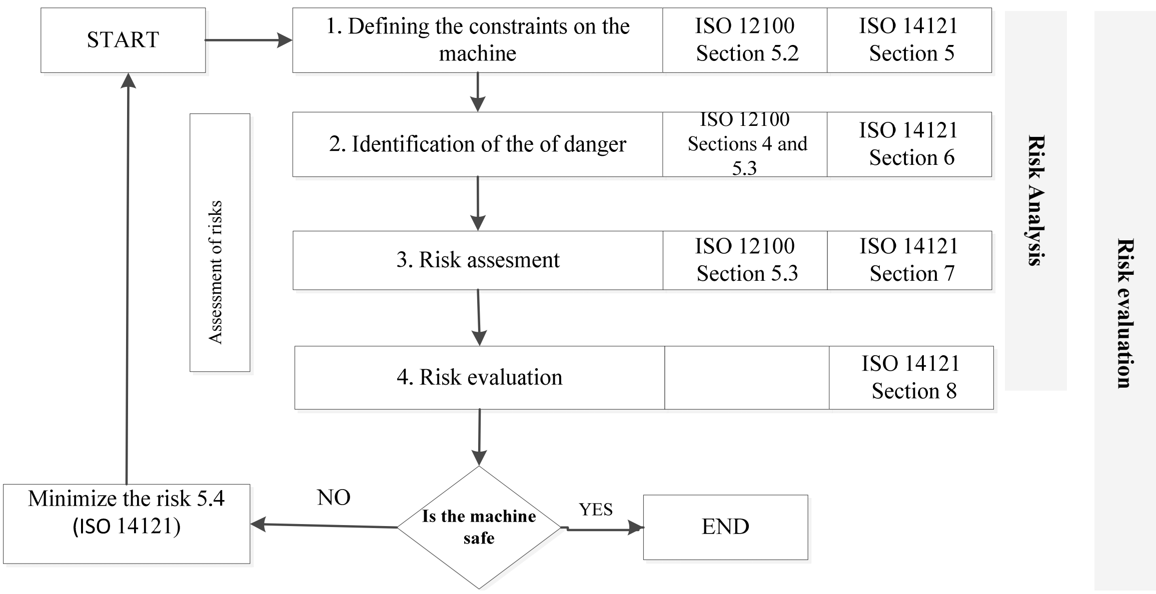

Figure 4. Risk management of machines.
Slika 4. Risk management of machines

Table 1. Priorities.
Tabela 1. Prioriteti

RAM:	Priority	Suggested time for completion of work
x	Reject the request	-
6	Normal priority	12 weeks
5	Normal priority	8 weeks
4	Normal priority	6 weeks
3	Normal priority	2 weeks
2	Emergency priority	1 week
1	Urgent priority	Immediately + overtime

The HRA (Human resource analysis) probability is calculated as:

$$\text{HRA} = \frac{\textit{Number of errors}}{\textit{Number of possiblities for making errors}}, \text{ and}$$

$$\text{Level of human error} = \frac{\textit{Number of errors}}{\textit{Total work duration}}$$

Instead of event frequency, failure probability is used - i.e. the expected period until the next failure, Table 2.

The example of bucket wheel excavator failure due to human error is shown in Figs. 5-6.

Table 2. Risk matrix.
Tabela 2. Matrica rizika

	Potential consequences				Failure probability				
	on humans	on property	on the environment	On reputation	A	B	C	D	E
					Over 18 months	3 to 18 months	2 weeks to 3 months	2 days to 2 weeks	Less than 2 days
0	No injury	No consequences	No consequences	No consequence	x	x	x	x	x
1	Slight injury	Slight consequences	Slight consequences	Slight consequences	6	6	5	4	3
2	Minor injury	Minor consequences	Minor consequences	Minor consequences	6	5	4	3	2
3	Severe injury	Severe consequences	Severe consequences	Severe consequences	5	4	3	2	1
4	Permanent disability	Significant consequences	Significant consequences	Significant consequences	4	3	2	1	1
5	Fatality	Huge consequences	Huge consequences	Huge consequences	3	2	1	1	1

Figure 5. Failure of SRs 1200 bucket wheel excavator failure due to human error, /5/.
Slika 5. Primer havarije rotornog bagera SRs 1200 usled ljudske greske, /5/

Figure 6. Failure of SchRs 630 bucket wheel excavator due to human error, /5/.
Slika 6. Primer havarije rotornog bagera SchRs 630 usled ljudske greske, /5/

Table 3. Structure of failure causes.
Tabela 3. Struktura uzroka loma

Failure cause	Failure share (%)
Difficult exploitation conditions	27
Design and assembly flaws	22
Operator errors	18
Maintainer errors	13
Material fatigue, equipment wear and corrosion	8
Inadequate design solution	7
Others	5

During the analysis of the human factor it is very important to determine the conditions in which the incident occurs (typical probability of human error is between 0.01 and 0.03) such as night shifts, or working on several things simultaneously, poor evaluations during design, human tendency to overestimating themselves, routine, poor communication, fatal combination of different reasons. Figure 7 shows the difference between the risk of occupational accidents and major disasters. It can be seen that the occupational accidents occur frequently, but their consequences are less severe. The most serious effects occur in the area of small probability.

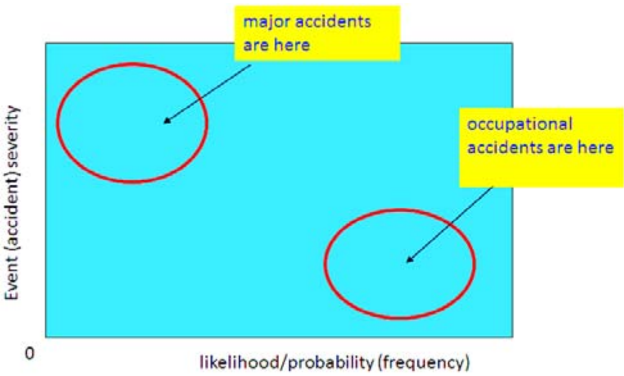

Figure 7. Professional and disasterous accidents.
Slika 7. Profesionalni i katastrofalni dogadjaji

RESPONSE TO A RISKY SITUATION

Risk management requires the defining of possible responses to a risky situation. These can include:

- Eliminating the possibility of an unwanted event occurring. Find the root causes of an unwanted event (Primary events; typical techniques: Failure Tree Analysis, Event tree analysis, preliminary hazard analysis, …)
- Reducing the probability of an accident occurring (technological improvements, ABS systems for vehicles, understanding of way, effects and consequences of failures, study the mechanics of flaws and errors spreading; understanding of processes; analysis of mechanics, effects and criticality of failures, …)
- Reducing the consequences in case of an accident (Firefighting systems, airbags, designer, enginner, decision maker's creativity, technological dependence.)
- Transferring or dividing of risks (insurance, risk dividing contract, health risks in medicine and pharmacy, e.g. surgery, testing of new medications; legal aspects, …)
- Accepting of (residual) risks - acceptance of risks that cannot be eliminated (relation to risks, costs-benefits analysis, risk-reward analysis, …)

CONCLUSIONS

Technological advancement and improved development of processes did not reduce the total amount of risks. Risk management requires the abandoning of old concepts based on planning and establishing of routine procedures for corrective maintenance and periodic preventive maintenance. Instead it relies on continuous learning and strengthening in terms of recognition and adequate response to risks.

A new concept of the risk management on machinery predicts involvement of all stakeholders in this process, through disciplined behaviour, predict possible failures and predictive maintenance, continuous learning and proactive maintenance and vigilance in situations when all seems well in order to achieve a new goal, which is based on maintaining safety.

New concepts of risk management demand constant alert and an active attitude toward risk.

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