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# Risk assessment model of mining equipment failure based on fuzzy logic

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ABSTRACT

The systematic maintenance of mining machinery and equipment is the crucial factor for the proper functioning of a mine without production process interruption. For high-quality maintenance of the technical systems in mining, it is necessary to conduct a thorough analysis of machinery and accompanying elements in order to determine the critical elements in the system which are prone to failures. The risk assessment of the failures of system parts leads to obtaining precise indicators of failures which are also excellent guidelines for maintenance services. This paper presents a model of the risk assessment of technical systems failure based on the fuzzy sets theory, fuzzy logic and min–max composition. The risk indicators, severity, occurrence and detectability are analyzed. The risk indicators are given as linguistic variables. The model presented was applied for assessing the risk level of belt conveyor elements failure which works in severe conditions in a coal mine. Moreover, this paper shows the advantages of this model when compared to a standard procedure of RPN calculating – in the FMEA method of risk assessment.



## 1. Introduction

Underground coal exploitation is one of the most difficult human occupations in technical aspect. It is coupled with high technological costs, high equipment prices and high risk to environment and labors. Unfortunately, mining operations are globally followed by high number of accidents (Retzer, 2014). Serbian coal mining is even more difficult because of high incorporation of manual labor and use of lightweight (handheld) equipment. Chain conveyors are used for the coal transport from the stopes. Belt conveyors are placed in the haulage drifts, usually several of them in a row, due to complex process of the underground mine development. Apart from gas and combustible coal dust, the biggest problem is the coal transport and hoist which include a lot of equipment that has had decades of machine hours already, but it hasn't been adequately and well maintained. Contrary to discontinuous transport systems, if there is a malfunction in one subsystem in a continuous transport, the entire system stops, causing unplanned production downtime. Because of that it is of high importance to constantly monitor risk levels. The ability to predict the failure of system parts by using modern methods and high-quality preventive maintenance reduces the possibility for the occurrence of unplanned downtime.

During the past twenty years, great attention was paid to the risk of technical systems failure. Moreover, the international and European standards were established, including the international standard IEC 300-3-9, which defines the risk analysis in technological systems. According to this standard, the risk is defined as the combination of frequency, probability and consequences of a specific dangerous situation or event, (IEC 300-3-9, 1995). An updated standard on risk management is ISO 31000 (2009) and according to this standard, the risk is defined as a chance that something will happen and that it will have an impact on a facility. The risk, based on the same standard, is presented as the combination of potential events and consequences associated with probability of its occurrence. The systematic use of information in order to identify the sources and to estimate the risk is defined as the risk analysis in ISO Guide 73, 2009. The explanation states that risk analysis provides the basis for assessing the risk level, the treatment and the acceptability of a risk. The information used can be historical data, theoretical analysis, expert opinions and the attitude of interested parties. The risk analysis of an identified risk event consists of determining the consequences and their probability, taking into account the existence or non-existence of an effective control. The consequences and their probabilities are then combined to determine the risk level. The risk analysis involves taking into consideration the causes and sources of risks, their consequences and

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the probability that there may be consequences, and the factors that influence the event. The event may have multiple effects and can affect the multiple objectives. The risk analysis usually involves the assessment of the range of potential consequences that may result from an event, a situation or a circumstance, as well as their associated probabilities, in order to measure the level of risk which is defined in IEC 31010/FDIS (2009).

Risk assessment is one of the methods providing necessary knowledge for failure prevention and failure impact mitigation. The failure of just one segment of the technologically linked system, like the belt conveyor haulage system in underground coal mines results in a set back or even total stop of production. Consequently, costs rise due to repair costs, lost time and productivity decrease. Considering the severity of mining technical systems elements failure consequences and their impact to the operation of the entire system it is almost essential to develop a model for reliable and timely identification of system's critical points. Such a model could provide possibility to preventively take appropriate organizational and technical measures in order to prevent failure or minimize the impact.

The risk of technical system failure is extremely important, especially if it is considered from the aspect of personnel safety and environmental safety. The risk assessment is of essential importance in underground coalmines where combustible coal dust and explosive gasses are constant safety threat and where adverse effects of failure can be a cause of major disaster. The review of available literature sources revealed that fuzzy approach to risk assessment for technical systems has not been applied in underground mining.

The idea of this paper is to establish the model for risk determination according to fuzzy sets theory utilization. The governing idea was to calculate risk in realistic conditions and to develop a model which would overcome the shortcomings of the conventional Risk priority number (RPN) method. Thereby the fuzzy sets were used to analyze severity, occurrence and detectability (partial indicators of risk) as well as for their integration into risk. The model can be used as effective tool for risk assessment related to any procedure in purchasing, operation or maintenance of the system, for prediction of adverse developments. Quality and functionality of the proposed model is shown in risk definition of mining machinery.

Since the research is still going on this phase was intended to compare traditional approach to risk level assessment upon the RPN (risk priority number) calculations with suggested model based on fuzzy sets and fuzzy logic. The comparability was achieved by analyzing the same risk indicators: severity, occurrence and detectability of potential failures.

The rest of paper is organized as follows: The risk and fuzzy logic literature review are shown in Section 2. Proposed fuzzy and traditional model for risk assessment are explained in Section 3. Using proposed model for risk assessment on mining machinery, results and comments are presented in Section 4, and conclusion and planes for future research are given in Section 5.

## 2. The literature review

Beside standard procedures in the failure mode and effects analysis (FMEA) method, the theory of fuzzy sets and fuzzy logic is also applied for risk assessment and reliability (Grassi, Gamberini, Mora, & Rimini, 2009; Zalewski, 2011; Zhang & Chu, 2011). The fuzzy sets theory was developed by Zadeh (1965), who is considered as the creator of the fuzzy logic theory by many authors.

Yang, Bonsall, and Wang (2008) presented the approach of the fuzzy rules based on Bayesian's system of conclusions for determination of the failure priority in the FMEA method. Their approach enables the subjective evaluation of the membership rate to be assessed as the consequent part of the rules for modeling of incompleteness which is taken into account in the development of the fuzzy rule base. Gargama and Chaturvedi (2011) proposed a fuzzy FMEA model for ranking the risk of failure, the model based on the degree of similarity and on the fuzzy rules base in order to overcome some of the limitations of traditional FMEA methods. Braglia, Frosolini, and Montanari (2003) suggested that the risk function should be associated with the normalized values of RPN, where the normalized RPN value represents the value RPN/1000. Guimaraes and Lapa (2007) defined the concept of fuzzy logical reasoning based on if–then fuzzy rules so as to determine a fuzzy RPN to have it compared with the traditional RPN on the example of a nuclear reactor cooling system.

Liu, Liu, and Liu (2013) did an analysis of 75 papers with the subject of risk assessment. The papers written in the period from 1992 to 2012 were analyzed. The fuzzy logic and the system of fuzzy rules and conclusions are the most used methodology in these papers. This fact only confirms the opportunities provided by this methodology: the imprecise linguistic data are the base for estimating the level of the risk of machine or technical system failure. The author pointed out the advantages and higher accuracy of fuzzy expert system over the "*non supportive and robust enough*" traditional approaches. The fuzzy sets theory, according to Ivezić, Tanasijević, and Ignjatović (2008), is used as an appropriate tool which works simultaneously with terms not precise enough and expressions that are difficult to be represented by numerical models, as well as with the strictly determined facts. Taking into account the reliability of indicators, the fuzzy set theory presents the possibility to calculate with the linguistic variables.

According to Bowles and Pelaez (1995), the fuzzy logic allows direct work with linguistic terms in the methods of risk assessing. In this way, the risk assessment based on fuzzy logic allows an analyst to assess the risk associated with failure modes. The application of fuzzy logic eliminates some of the computational problems associated with traditional method of ranking. Moreover, the priority to appropriate actions can be given, even if the basic scope of information is vague, ambiguous or imprecise. In their work, the authors described the use of fuzzy logic approach to determine the risk of failure in the application of FMECA, where they used linguistic terms to describe the occurrence, severity and detection. The connection between risk, occurrence, severity and possibility of detecting failure was defined by if–then base of fuzzy rules, which is developed based on the expert knowledge system. Pillay and Wang (2003) proposed the approach based on fuzzy rules, an approach which does not require an additional function for defining occurrence, severity and possibility of detecting failure. The proposed approach requires an assigned membership function for each of the three risk factors. Each type of failure is evaluated by the linguistic variables which represent the risk factors. By applying the fuzzy rule base, these three variables are integrated into multiplying of linguistic variables that represent the risk ranking for each type of failure. A similar methodology was also presented by Xu, Tang, Xie, Ho, and Zhu (2002) on the example of the diesel engine turbocharger.

The researches (Gargama & Chaturvedi, 2011; Grassi et al., 2009; Zalewski, 2011; Zhang & Chu, 2011), which were analyzed in this study applied the theory of fuzzy sets and fuzzy logic for risk and reliability assessments. The methodology was mainly used for the assessment of indicators in FMEA method. In addition, max–min composition of fuzzy sets of reliability and risk indicators was applied. Opposing to this traditional approach the study suggests that min–max composition is superior. Such a composition returns the worst of the best outcomes which is especially significant when variables related to negative events, such as risk, are calculated.