Analyses and algorithms of personnel safety in mines using event tree and Bayesian network method

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Abstract. Determination of the hazard index in ensuring the safety of personnel in underground mines requires a comprehensive approach. Different methods can be applied depending on the specifics and conditions of work. This article discusses event tree and Bayesian network methods as tools for systematic analysis and assessment of personnel safety risks. The event tree method allows the sequence of events that lead to certain outcomes to be ordered and visualised. Analysing this event tree can help identify critical points and determine likely ways to prevent accidents. The Bayesian grid method is a graphical model of the probabilistic relationships between different variables. When analysing personnel safety, the Bayesian grid method can take into account the probability of events, the factors affecting safety and their interrelationships. Key words: risk, algorithm, event tree, Petri net, Bayesian network, mathematical model, artificial intelligence, information system, monitoring system, conceptual model, function, heuristic algorithm.

1 Introduction

Injury prevention in the process of personnel work in underground mines remains one of the topical issues. Risk in risk prevention a number of scientists have proposed their own methods of risk assessment. The most common representation of risk assessment is to predict the probabilities of occurrence of detectable unforeseen events by formulating and analysing risks in the form of statistics based on information obtained with a high degree of accuracy [1,2,3] Bayes theorem-one of the basic theorems of elementary probability theory, which allows us to determine the probability of an event in the case of statistically related other events. In other words, using Bayes' formula, one can specify the probability of any event, taking into account both previously known data and new observational data.

The peculiarity of Bayes' theorem is that its practical application requires a large amount of computational work, so Bayes' formula was widely used in computer and network technologies only after the third information revolution. Today this method is widely used in machine learning and artificial intelligence technologies.

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2 Materials and methods

2.1 Bayesian network method

It is based on Bayesian statistics and models the probabilities of interrelated events, which can be useful in risk assessment in complex systems. The Bayesian grid method (BSM) is a statistical analysis technique used to model probabilistic relationships between random variables. It is based on Bayes' theorem, which allows the probability of events to be updated based on new data. Bayesian *networks* are graphical models in which nodes represent random variables and oriented edges between nodes represent probabilistic relationships between variables [4,5]. The use of Bayesian networks in underground mines allows more effective risk management, prediction of possible events and decision-making based on available data and data based on expert knowledge. The choice of a particular method depends on the characteristics of a particular mine site, its environment and the objectives of the risk assessment. Generally, using a combination of several methods provides a complete picture of the risks. These methods are as follows:

- Personnel safety assessment-we can model the probability of various safety events such as rock falls, gas releases and other emergencies due to accidents;
- Technical risk assessment-allows us to model the probability of equipment failures and technical malfunctions and determine the impact of changes in technical parameters in the mining and processing processes;
- Production performance forecasting-modelling the probabilistic performance of different levels of production and manufacturing;
- Resource management-assessing the likelihood and impact of energy, water and labour shortages. It plays an important role in developing strategies for optimal resource utilisation under changing conditions.

Suppose we are creating a Bayesian network model to simulate the risk of injury due to loss of balance while travelling in an underground mine. This our model will have the following variables, namely:

1. Probability of injury *(L):* L_{xn}, where X-order number of the employee (report card number), N-degree of injury (N={1,2,..., 10}) probability of loss of balance during movement.$L_{xn}(\overline{L_{x1}}, \overline{L_{x2}}, \dots, \overline{L_{x10}}) = 0$ when there's no chance of losing balance;

2. Experience of a current employee *(E):* $E_{rs}=1$ where r-discharge of the employee (r=0,1,..., 12), s-labour experience of the employee (s={1,2,...}) the employee has work experience in underground mine if $\overline{E_{x_{rs}}} = 0$ the employee has no experience of working in an underground mine. Each of the three variables can take only one of several possible values: ***T*** *(TRUE)* and ***F*** *(FALSE)*;

3. Status of a mine worker *(M): M=1* employee is not in the underground mine or M=0 employee is not in the underground mine;

Joint probability function. The model asks: "what is the probability that the employee is injured if the employee is in an underground mine? "let's see if it can give a probabilistic answer to questions such as" "why?" The joint probability condition of the function is as follows:

$$\mathrm{P}(L_{xn}, M, E_{rs}) = \mathrm{P}(L_{xn}|M, E_{rs}) * \mathrm{P}(M \mid E_{rs}) * \mathrm{P}(E_{rs}) \quad (1)$$

Based on this, "what is the probability that an employee will be injured if they are in an underground mine?" we can build the mathematical model (2) to be able to answer the question "why?"

$$\mathbf{P}(\boldsymbol{E_{rs}} = \boldsymbol{T} \mid \boldsymbol{L_{xn}} = \boldsymbol{T}) = \frac{\mathbf{P}(\boldsymbol{L_{xn}}=\boldsymbol{T},\boldsymbol{E_{rs}}=\boldsymbol{T})}{\mathbf{P}(\boldsymbol{L_{xn}}=\boldsymbol{T})} = \frac{\sum_{\boldsymbol{M}\in\{\boldsymbol{T},\boldsymbol{F}\}} \mathbf{P}\,(\boldsymbol{L_{xn}}=\boldsymbol{T},\boldsymbol{M},\boldsymbol{E_{rs}}=\boldsymbol{T})}{\sum_{\boldsymbol{M},\boldsymbol{E_{rs}}\in\{\boldsymbol{T},\boldsymbol{F}\}} \mathbf{P}\,(\boldsymbol{L_{xn}}=\boldsymbol{T},\boldsymbol{M},\boldsymbol{E_{rs}})} \quad (2)$$

The algorithm for assessing the probability of injury to personnel working in an underground mine based on Petri nets [6,7] is presented in Figure 1.

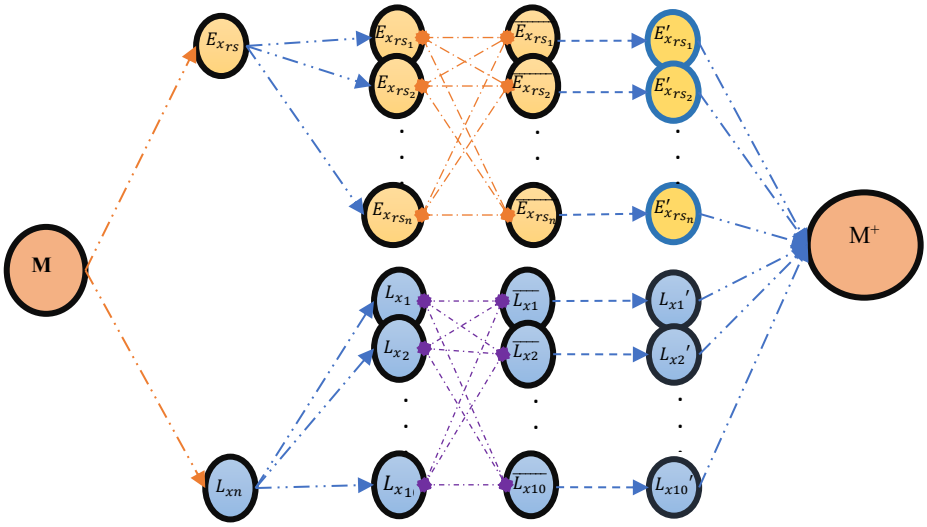

Fig.1. Algorithm for assessing the probability of injury to personnel working at an underground mine

There is $E'_{x_{rs}}$ - the resulting value of the probability that a worker has or does not have experience in underground mining.L'_{xn} - the final value of the probability that the worker will lose his balance while travelling through the underground mine. M^+ is the total sum of the probabilities of the outcome.

2.2 Event Tree Analysis method

It is a graphical method used to model a sequence of events and their possible outcomes under uncertainty. This method represents hazards in the form of a tree in which nodes represent events and branches represent outcomes. This system also helps to visualise and analyse the chain of events. This method can often be used in mining, nuclear power, aerospace and other industries where the evaluation of potential hazard impact of different events is important [8,9]. A conceptual model for assessing the impact of a potential hazard using the event tree method is shown in Figure 2.

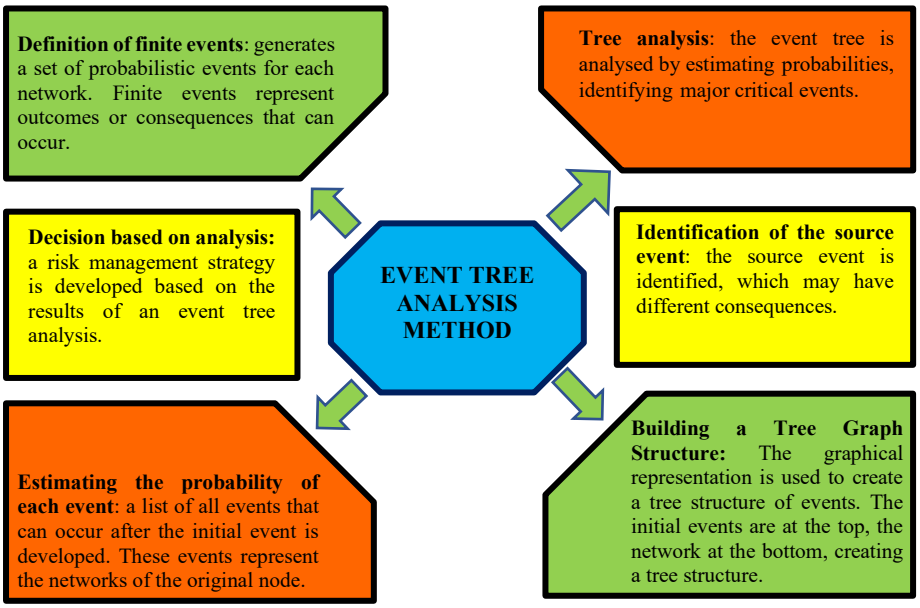

Fig. 2. Conceptual model for assessing the impact of a potential hazard using the event tree method.

The structural framework for assessing the impact of a potential risk using the event tree method provides a visual representation of the various potential outcomes and consequences associated with a particular event or risk [10,11]. Assuming that the event tree method is a systematic approach used in risk analysis to assess the sequence of events that may occur after a particular event, the structural framework for assessing the potential impact of a risk using the event tree method is shown in Figure 3.

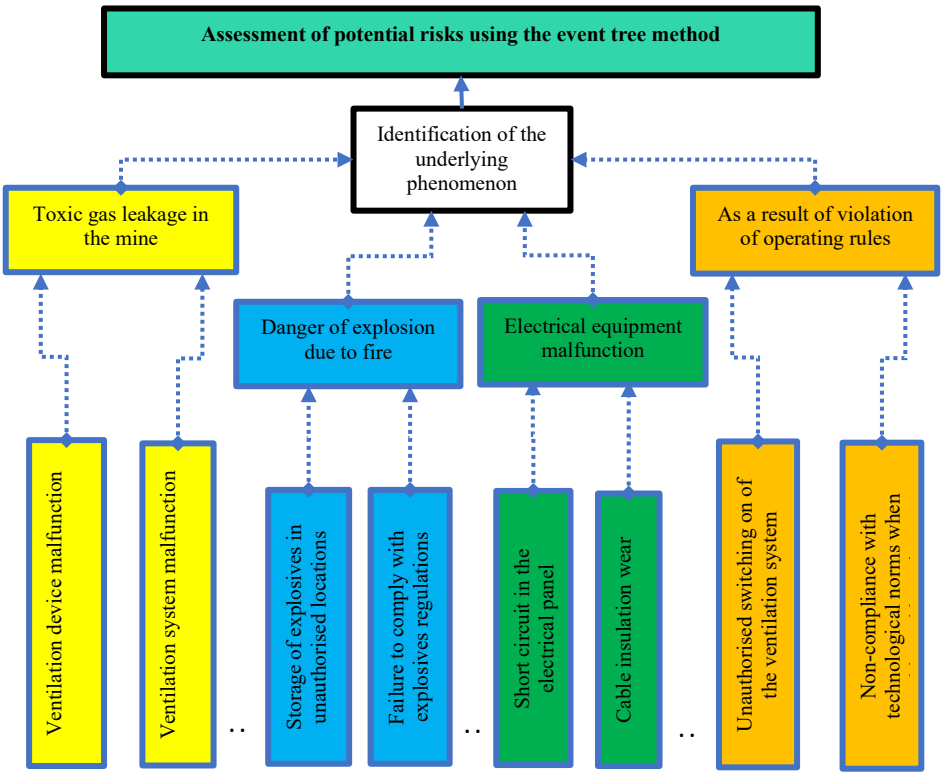

Fig. 3: Structure drawing of a potential hazard impact assessment using the event tree method

3 Results and discussion

At industrial enterprises there is a need to develop a software complex based on heuristic algorithms and an information system presented in a single, complete form as an auxiliary system in order to ensure labour safety of workers in the process of their activities [12,13]. In particular, the conceptual model of the information system for ensuring labour safety in the process of activity implementation by workers engaged in underground mining operations is presented in Figure 4 [14,15].

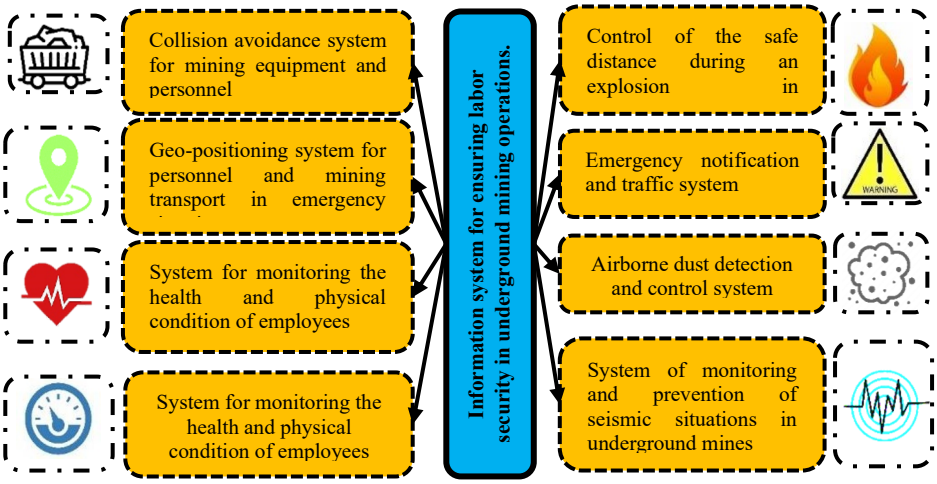

Fig. 4: Conceptual model of the information system for personnel labour safety at underground mines

In this research-based article, the main objective is to synthesise the results of the approach by systematically analysing personnel safety risks in underground mines [16,17]. Event tree and Bayesian network methods provide powerful tools for risk identification, probabilistic modelling and management. The results underlying the analysis and prediction of outcomes from these methods provide the basis for developing effective strategies to ensure employee safety and improve the working environment [18,19].

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