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Root Cause Analysis of Occurrence of Accident in Indian Underground Mines Using Bayesian Network

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ABSTRACT

The underground mining industry is one of the most hazardous industries since it has high rate of fatal and non-fatal accidents. These accidents often cause loss of life, money, machinery, and time that directly affect the production of the industry. Hence it is necessary to predict these accidents and their root causes to avoid accidents to improve the total safety of the mine using artificial intelligence tools. In this research work, Bayesian Network (BN) model is used to make a causal relationship between the root cause of accidents and their effects and some of the additional parameters that are responsible for the occurrence of an accident in underground mining industries. Whenever any evidence is identifiedthat is directly fed into the BN model and updates the conditional probability table (CPT). After that Bayesian inference is used to identify the most probable root cause along with the probability of the accidents in the mine. The predicting root cause gives them sufficient time to take some necessary action to eliminate the symptoms of the accident and to improve the safety of the mines.

KEYWORDS: Bayesian network, Bayesian inference, Underground mine accident, Root cause analysis, Netica

1. INTRODUCTION

An accident is defined as an unfavourable event that causes a period of disability, interruption of work scheduleor time loss that directly affects the production of the industries. Some the occurrence of accidents can cause loss of life, serious injury, machinery, and money that reduce the safety of the mining [1]. The mining industries are highly unsafe due to the high rate of fatal and non-fatal accidents [2]. In the case of underground mining fatalities rate and the number of accidents increase due to their work environments, improper lighting, toxic gases and geological disturbance [3]. In the Indian underground mining, the number of the person killed and injured from 1960 to 2022 is presented in figure 1. The data have been collected from the ENVIS centre of environmental problems of mining. It is observed that from Figure 1,there are 59 to 112 persons killed every four years and 18 to 53 peoplehave been seriously injured. To increase the safety of the Indian underground, the DGMS issued rules and regulations such as the Coal Mine Regulation 2017, the Mines Rule 1955, and the Mines Act 1952. The underground mining industry employs millions of miners and other workers, it is critical that personnel are kept informed about hazards and that proper precautions are taken to reduce risks.

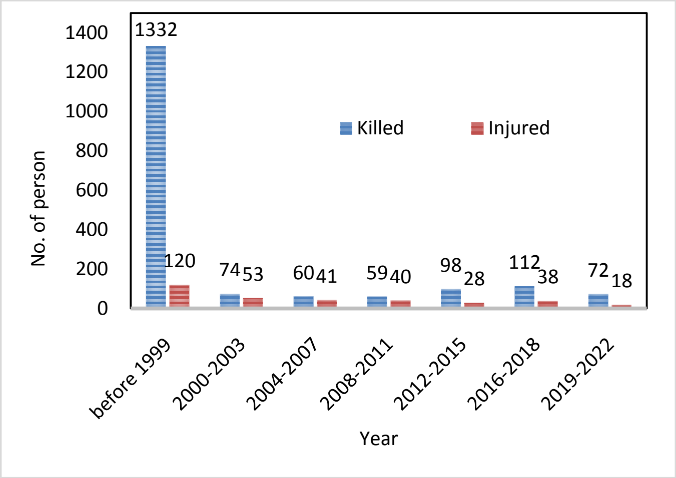

Figure 1: Trend of accidents (Persons killed and injured) in Indian underground mines from 1960 to 2022

The occurrence of accidents in any industry is caused by a series of risky events and it's by some of the specific causes or multiple root causes. Sometimes the root causes are natural and sometimesthey occur by the human mistake that not following the specific rule and regulations or improper monitoring. After identifying the root cause of the accident, the inquiry can be completed but analysis of these data playsan important role inthe future prediction of the root cause and its effect [3].

This paper develops the BN model to make the causal relationship between the root cause of the accident and its effect and some additional parameters that are responsible for the occurrence of an accident in underground mining industries. After developing the BN model fed the evidence and updates the conditional probability table (CPT). After that Bayesian inference is used to identify the most probable root cause along with the probability of the accidents in the mine. After identifying the root cause take the necessary action to eliminate the symptoms of the accident and improve the safety of the mines.

1.1 Introduction of Bayesian Network (BN)

A Bayesian network is a probabilistic inference network, which consists of nodes and a directional arrow [4].The nodes represent the random variables thatare connected with directional arrows that indicate their causal relationship between the variables [4,5]. The BN is also applicable in small data sets in the condition of uncertainty [6]. The BN based prediction model is applied in various fields such as fault diagnosis, reliability evaluation, medical treatment, and quality evaluation. The details about the BN networkare presented in sections 1.1.1 and 1.1.2.

1.1.1. Bayesian theorem and inference

If A_1 and A_2 are two random events with $P(A_2) > 0$, conditional probability is defined as:

$$P\left(\frac{A_1}{A_2}\right) = P\left(\frac{A_1A_2}{A_2}\right)$$

In which $P(A_1A_2)$ is called the joint probability and

$$P(A_1A_2) = P(A_2)P\left(\frac{A_1}{A_2}\right) = P(A_1)P\left(\frac{A_2}{A_1}\right)$$

Furthermore, supposing $A_{21}, A_{22}, \ldots A_{2n}$are a set of random variables. They satisfy the three of the following condition:

1. $\sum_{i=1}^{n} A_{2i} = S$, where S is a certain event.
2. They are mutually exclusive, and
3. $P(A_{2i}) > 0$, $i = 1,2,\ldots,n$, for any given event A_1

Then we have to calculate the marginal probabilityusing the following equation:

$$P(A_1 \mid A_{2i}) = \sum_{i=1}^{n} P(A_{2i})P(A_1 \mid A_{2i})$$

Therefore, the relationship between condition probability and marginal probability is given by the following equation:

$$P(A_{2i} / A_1) = P(A_1A_{2i}) / P(A_1) = \frac{P(A_{2i})P(A_1 / A_{2i})}{\sum_{i=1}^{n} P(A_{2i})P(A_1 / A_{2i})}$$

The Bayesian theorem describes how to calculate the posterior probability of the occurrence of an accident from prior probabilities of the root cause is known. The variables on the right-hand side of the equation represent the prior probabilities and the variable on the left of the equation represents the posterior probability of the occurrence of an accident using Bayesian inference.

1.1.2. Topological of Bayesian network

The strength of linkages between the variables is expressed using the conditional probability of a node given the set of its immediate parents.Figure 2 depicts a simple Bayesian network. The nodes with no input arrow or predecessor, such as A_1 and A_2, are known as root nodes.A_3 and A_4 are the immediate parent nodes of A_5, and they are also the child nodes of A_2 [6].

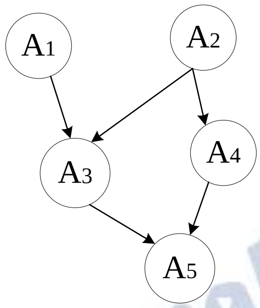

Figure2:A simple Bayesian network

1.1.3. Independence assumption and inference of BBN

The first assumption of the BN, all of the root nodes are independent of one another. The probability relationship for the two root nodes is presented as $P(A_1A_2) = P(A_1)P(A_2)$ as shown in figure 2. The secondly, assumption if two nodes share one or more immediate parent nodes and there is no direct arrow connecting them, they are conditionally independent. i.e. $P(A_3/A_2A_4) = P(A_3/A_2)$ as shown in figure 2. The third assumption is that any non-root node is conditionally independent of its non-immediate parent nodes when the statuses of all its immediate parent nodes are knowni.e. $P(A_5/A_1A_3A_4) = P(A_5/A_3A_4)$ as shown in figure 2.The independence assumption not only simplifies the inference technique, but it also greatly reduces the prior probabilities necessary in the calculation, as seen in the following study.The joint probability distribution for the network presented in figure 2 can be calculated as follows:

$$P(A_1A_2A_3A_4A_5)=\prod_{i=1}^{5}P(A_i\,|\,A_1,A_{i-1})$$

$$=P(A_1)P(A_2\,|\,A_1)P(A_3\,|\,A_1A_2)P(A_4\,|\,A_1A_2A_3)P(A_5\,|\,A_1A_2A_3A_4)$$

The joint probability distribution can be further reduced if the independence assumption is used.

$$P(A_1A_2A_3A_4A_5)=\prod_{i=1}^{5}P(A_i\,|\,Pa_i)$$

$$=P(A_1)P(A_2)P(A_3\,|\,A_1A_2)P(A_4\,|\,A_2)P(A_5\,|\,A_3A_4)$$

The Pai (Parents of Xi) are all the immediate parent nodes of node Xi. For instance, the likelihood of variable of X_3 can be determined by:

$$P(A_3=True)=\sum_{A_1A_2A_4A_5}P(A_1,A_2,A_3=True,A_4,A_5)$$

Further, the conditional likelihood of variable A_3 given A_4 can be determined by:

$$P(A_3=True\,|\,A_4=True)$$
$$=\frac{P(A_3=True,A_4=True)}{P(A_4=True)}$$
$$=\frac{\sum_{A_1A_2A_5}P(A_1,A_2,A_3=True,A_4=True,A_5)}{\sum_{A_1A_2A_3A_5}P(A_1,A_2,A_3,A_4=True,A_5)}$$

Before executing mathematical operations on the table's elements, the calculation technique is to first determine the joint probability distribution table.In practice, Bayesian networks are calculated using inference methods [5].

2. LITERATURE REVIEW

In the previous research work, researchers use failure mode effect analysis (FMEA) to assign a risk score of the accident and based on these scores should take the action. There have been numerous risk assessment studies that have been assessed using BN or reviewed using expert opinions [7,8]. With the help of the BN model, identify the ship collision accidents and causing factors to make the probabilistic relationship between them [9]. Van der Gaag et al. created a BN with 70 variables to determine the features of the cancer disease [9]. The safety risk analysis on a building project uses expert judgementsusing prior eight ship accident data for developing the BN model [10].Gohar et al. describe the systematic review of the injuries that caused the loss of timein eight health and related databases [7].Kumar et al. conducted a retrospective review of mining accidents and certain error reduction measures, in underground mines after that calculated the human error rate and suggested prioritising modifying the work environment system and process design[8].Through the accident analysis pathway of the 24 Model and logical thought of why because analysis of 67 typical major accidents [11,12]. Jing et al. identified the root causes of typical coal mines accidents and emphasised the role of departments,supervision climate, safety participation andsafety communicationthat implementing the safety culture to reduce industrial accidents and improve the safety of the mines[13]. In this study, we, focus on analyzing the root cause of the accident using the BN model.

3. CASE STUDY AND DATA COLLECTION

In this study, wecollect the accident data from ENVIS Centre on Environmental problems of mining, which is hosted by the Indian Institute of Technology (ISM) Dhanbad. The recorded data of underground mines accident in India from 1960 to 2022 have been used for this study. The underground mine disasters are considered for the study. The collected accident data are categorized into three groups; Root cause, effect and additional parameter. The effects are categorized into the number of persons killed and the number of persons injured. The additional parameter is also considered such as mine type (either coal mine or metal mine) and season (summer, winter and rainy season). The root cause of the occurrence of accidents is categorized into eight different groups such as natural root cause, explosion, roof fall, blasting, inundation action, winding and rope haulage and reaming is categorised into other groups. The detailed classifications of root causes arefollowing

- Natural root cause: If accidents are caused by natural calamities without any man error are known as natural root causes. These natural root causes include accidents related to lightning (Li), landslides (LS), rockburst (RB) and air blasts(AB).
- Explosion: If accidents are caused by heavy explosions due to human errors or natural causes.Explosion accidents are caused due to friction (Fr), emission of gases (EG), improper dilution of gases (IDG) and spontaneous heating (SH).
- Roof fall: Accidents caused by the failure of the roof. The main causes for roof failure are improper supports in roof fall (ISRF), geological disturbances (GD), heavy blasting (HB), and failure of supports (FS).
- Blasting: using of unapproved explosives (UE), improper connections (IC), testing of misfires (TM), and improper charging of explosives (ICE).
- Side fall: improper supports inside fall (ISSF) and weak strata(WS).
- Inundation: Accidents caused by the overflow of water into the mines due to natural or human errors. The main causes for the occurrence of inundation are floods (FD), improper pumping and over seepage (IPOS) and collapse of a wall (CW).
- Winding & rope haulage: rope failure (RF), fall of material in shaft (FMS) and overwinding(OW).
- Other causes of mine accidents dueto electrical faults(EF), accidents between two trucks(ABTT), run over by vehicles (ROV) (including run over by trucks, run over by dumpers, run over by wheeled trackless, abnormal speed, run over by loading machines, hit by other machines), improper tension of conveyor (ITC) and over the speed of conveyor (OSC).

3.1 METHODOLOGY

The root cause, fatal accidents, injured accidents, and the day of the tragedy were all collected using ENVIS for the creation of a three-layer BN model.The collected information was transformed into categorised information.The categorical data is then put into Netica software, which establishes the causal links between the parameters.Each parameter in the BN model has its prior probability estimated.When evidence is found during a mining operation, it can be put into the BN model, which is based on historical data, and the Conditional Probability Table (CPT) can be updated. The flow chart of the proposed study work is shown in figure 3.

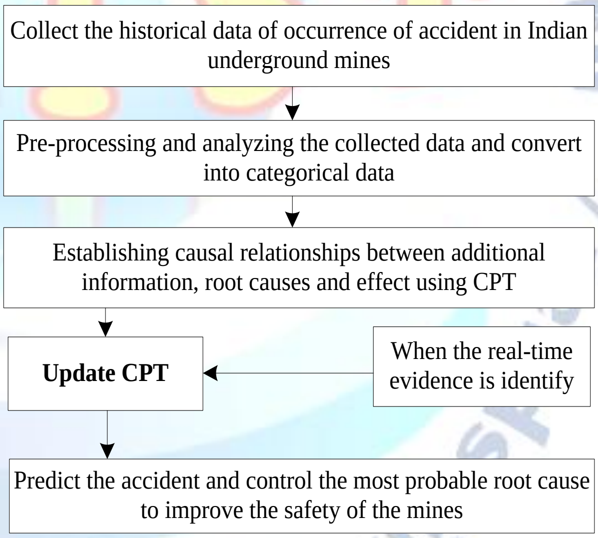

Figure 3. Flow chart of proposed research work

3.2 MODEL DEVELOPMENT:

The Bayesian inference model is built on the CPT using prior knowledge (prior probability) and then updated when further evidence is found using Netica software.

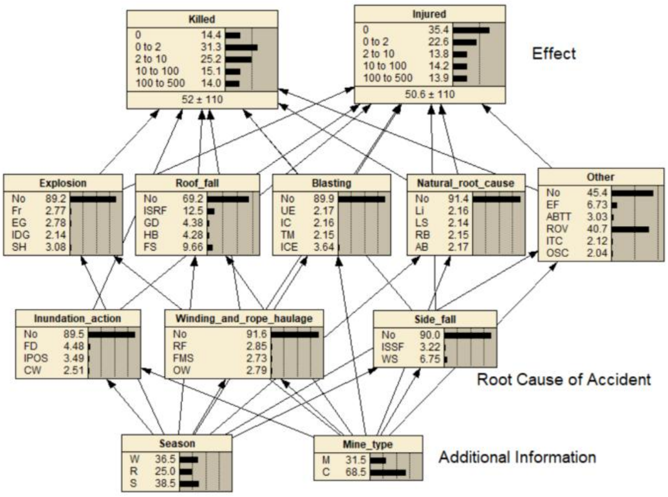

Figure 4: Bayesian inference model

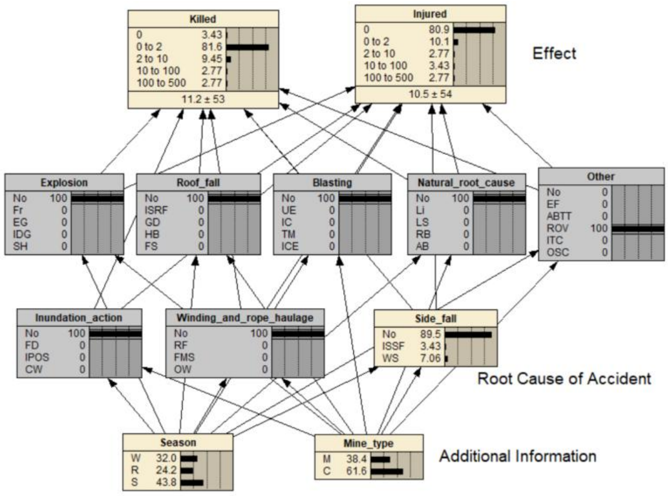

Figure 5: Updated BN model when the evidence ROV is identified

4. RESULTS

For this study the trend of occurrence of accidents is analyzed in Indian underground coal mines and metal mines, and developed the probabilistic relation between root cause and accident by using Bayesian network, most probable cause for each of the accident is calculated.

Considering one real-time evidence when the run of vehicle accident is identified, the change in posterior probability of the killed person in range 0 to 2 varies from 31.3 to 81.6 and injury person in range of 0 to 2 is 22.6 to 10.1, when these ROV accidents occur the fatality rate is more than the injury rate so these kinds of accidents should be considered as risky and these should be controlled and prevented. It is observed that the accidents caused by ROV are more in Indian underground mines. Even though the fatality rate caused by these accidents is low, the number of lives lost due to this accident is high so the safety measures should be increased in ROV departments by utilizing recent developments.

The fatality rate in the range of 2 to 10 is 25.2 to 9.45 and the injury rate is 13.8 to 2.77 so by this analysis, it can be described that the fatality range is less from 2 to 10 than the range of 0 to 2 but it has to be considered as the moderate range.

5. CONCLUSION

Despite a recent downward trend in the numbers of major accidents and causalities in mining enterprises, accident reoccurrence remains ongoing for the last two decades in the underground mining industry. Hence this study focus on predicting the most probable root cause of the occurrence of an accident in underground mining industries. This study first makes the casual relationship between root causes, effects and additional parameters to represent the probabilistic relationship between the parameter. When any evidence is identified that can be directly fed into the BN model estimate the posterior probability of the effect and root cause. In future, the model is flexible to add more parameters that give a more accurate root cause and their impact that increase the model accuracy. In future studies add more parameters to improve the prediction accuracy of the accidents that occur in the underground mines.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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