Application of Fuzzy Fault Tree Analysis on Risk Assessment of Hazards Related to Wire Cutting Machine in Kowsar Quarry Mines of Isfahan

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Abstract: Mining is among the most dangerous activities around the world, which is always associated with various incidents, injuries, loss of life, and property damage. There are many safety, health and environmental hazards in mining workplaces that neglecting them and not planning to control them can have irreparable consequences. Therefore, risk assessment is important in mines. The purpose of this study is to provide a model for analysis of hazards associated with wire cutting machine using fuzzy fault tree analysis in stone dimensional mines. In present research, after conducting studies and collecting information about causes of the risks associated with wire cutting machines, judging was done by relevant experts through questionnaires, and the risks associated with cutting wires were identified, then the causes of the hazards were derived and analyzed using fault tree analysis method. According to the tree model that was created with this method, fuzzy theory was used to weigh the root causes identified as “basic events” in order to eventually obtain probability of any basic events. Results showed that the highest probable intermediate events are respectively: hazards of maintenance, hazards of geological issues, and hazards of improper design; And the highest probable basic events are respectively: hazards of move and whipping caused by rupture of wires, hazards of diversion of wire cutters, and hazards of existing Lakarty (mud) inside stone blocks. Finally, considering control methods, an appropriate response to these risks is presented.

Keywords: Risk management, Fuzzy fault tree analysis, Dimensional stone mines, Wire cutting machine.

INTRODUCTION

Quarrying is one of the most dangerous types of mining. According to reports, coal mines and quarry mines have the highest rates of accidents compared to other mine types. So, reducing the risks in these mines is very important and leads to the development of production, and therefore, to the economic recovery.

The comprehensive assessment of incidents and their implications during mining process is vital for effective management, enhancement of safety and reduction of risks in these mines.

One of the methods that can be used to manage risks is the combined method of fault tree analysis with fuzzy theory. The purpose of this study is to assess risks of hazards associated with wire cutting machines in Iran quarry mines, using the combined approach.

Among different types of mining such as underground mining, surface mining, and quarrying, a bad record has been observed for high rates of accidents. Quarry mines have their own special events that have been studied by some researchers in Iran. In 2017, Dehghan and Sattari conducted a study to manage and analyze safety risks in quarry mines of Mahallat County using failure modes technique, and analyzed the effects. The hazards in these mines were identified and evaluated in 15 categories, 7 of which were identified as unacceptable and high-risk hazards (Dehghan and Sattari 2017, 33-42).

Considering previous works, current study aims to provide an approach for risk assessment. Evaluating the probability of occurrence of accidents and injuries with mathematical formulas provide a better understanding of the risks. This paper also shows how risk assessment can be used

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for understanding risk adjustments and therefore has a significant contribution to the reduction of risk in mines.

METHODS

Fault tree analysis method was first developed and used for reliability analysis by Watson in 1961 (Ericson 2005). The success of this method in identifying and eliminating system weaknesses has made it a powerful tool for evaluating and managing risks of complex systems (Hassl 1965). In this method, order of analysis is from whole system to the components. Analysis begins from the top event (whole), then the causative factors are identified in the structure of the fault tree as the intermediate and basic events (component), and problem analysis continues until it achieves the right level of detail. This method analyzes the root causes of events, graphically and accurately using symbols, and predicts the probability of occurrence of events (Ataei 2017, 133-137). Although all attempts have been made to identify the hazards of the wire cutting machines in quarry mines, some of the hazards or causes may not be identified and evaluated. In this research, various methods have been used to identify hazards, such as reviewing previous researches, interviewing experts, and using incident learning system forms from Iranian Mining Engineering Organization. Identified hazards associated with wire cutting machined were placed in the fault tree structure in 6 groups (Table 1 and Figure 1).

Table 1- Risks related to wire cutting machine in quarry mines

Event			Cause
Risks associated with wire cutting machine TE	Operator IE_1	Operator inadequacy and ignorance $IE_{1,1}$	Lack of training BE_1
		Lack of attention $IE_{1,2}$	Lack of training BE_2
	Geology IE_2	Unusual concentration of stress $IE_{2,1}$	Wire passed from rock block edges and rock discontinuities BE_3
		Faults, joints and cracks $IE_{2,2}$	Non recognition BE_4
		Dealing with a very hard layer $IE_{2,3}$	Non recognition BE_5
		Dealing with soft layer $IE_{2,4}$	Non recognition BE_6
	Designing IE_3		Failure to consider proper cutting height BE_7
			Too much pressure on wire (Tension devices) BE_8
			Sharp cutting angles BE_9
			Wide cutting angle BE_{10}
	Maintenance and repairing wire cutter IE_4		Erosion of the wire cutting B_{11}
			Damaged wire BE_{12}
			Diversion of wire cutter BE_{13}
			Soil and gravel existence in wire BE_{14}
			Fatigue due to wire bending stress BE_{15}
	Flying spring parts or active components of spring IE_5		Moving and whipping caused by rupture of wire BE_{16}
	Fall of Stone blocks while cutting IE_6		Lakarty (mud) existence inside the stone blocks BE_{17}

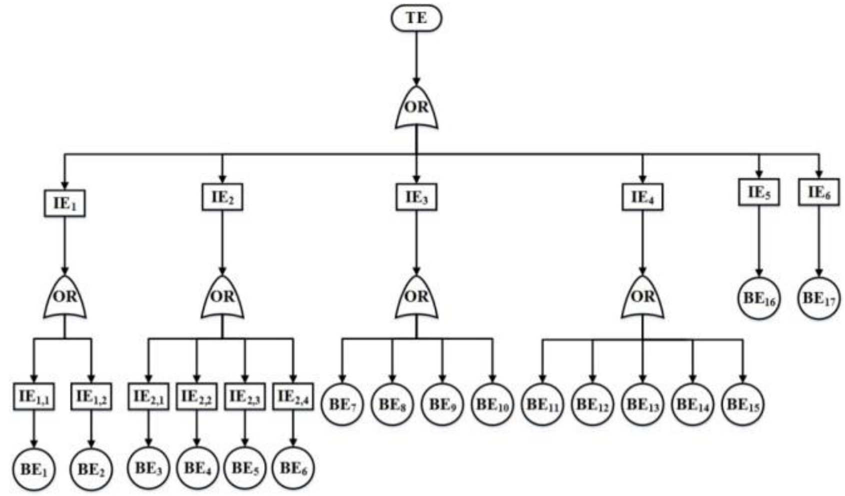

Fig.1 fault tree related to the wire cutting machine TE

In the 1st stage, experts with sufficient and up-to-date experience on the dangers of wire cutting machines in quarry mines are selected. They need to be familiar with the fuzzy fault tree analysis to get the most out of their views. In the 2nd stage, since these experts do not have the same importance weight, method of Lavasani and his colleagues was used (Lavasani et al. 2015, 732). The purpose of the fuzzification phase is to determine the probability of initial failure in the data in form of membership function of fuzzy numbers derived from linguistic terminology. In this study, a trapezoidal fuzzy number was used for collection and fuzzification of the views of experts (Table 2) about basic events, which are classified using linguistic term; very low (VL), low (L), medium (M), high (H), and very high (VH). An important point in the 3rd step is that an agreement can be reached after the process of collecting experts' opinions (Hsu and Chen 1996, 284). According to the equation provided by Clemen and Winkler, in order to reach a consensus among experts, the weight of each expert should be multiplied by his linguistic terms and shown as a trapezoidal fuzzy number $\widetilde{M} = (m_1, m_2, m_3, m_4)$ (Table 2) (Clemen and Winkler 1999, 189-192). In the 4th stage, after the consensus of experts, fuzzy numbers must be converted into definite numbers (Table 2), due to the large number of variables and extended calculation of fuzzy numbers. The formula developed by Sugeno was used for non-fuzzification (FPS) stage (Sugeno 1999). Then, in the 5th step, since the fault tree calculations are based on the probability of events (FP), the definite numbers obtained in the 4th step, should be converted from possibility mode to probability mode. Therefore, equations provided by Onisawa are used (Table 2) (Onisawa 1990, 270-272).

In the 6th step, after determining the probability of major events, the probability rate of the intermediate and top events must be calculated using the obtained information. Each fault tree contains a large number of cut sets that are unique for the top event (Table 3) (Lindhe et al. 2009, 1644). In the 7th stage, after calculating the probability of the top event, using the Fussell – Vesely equation, the importance of the minimum cut sets must be specified and ranked. Since events are identified considering reliability and risk, this numerical significance allows all top and intermediate events to be ranked (Table 3) (Wang, Zhang and Chen 2013, 1394). In the last step after risk assessment and ranking, it is necessary to take actions to control critical risks. So the risk control and response program is introduced. Risk response is one of the main components of risk management that can reduce negative risks or even increase positive risks.

Table 2 - Fuzzy number consensus of experts and results of calculations related to each of the major events

Rank	Importance	FP	FPS	Fuzzy numbers consensus experts				Number expert										Event
				m1	m2	m3	m4	10	9	8	7	6	5	4	3	2	1	
15	0.028	0.004	0.465	0.0316	0.0449	0.476	0.617	M	H	L	VL	H	M	L	VH	M	VL	BE_1
11	0.052	0.007	0.553	0.399	0.542	0.570	0.703	H	H	M	L	VH	M	L	VH	M	VL	BE_2
8	0.062	0.009	0.580	0.413	0.578	0.588	0.743	M	M	H	L	H	H	M	VH	M	L	BE_3
5	0.087	0.012	0.633	0.460	0.630	0.649	0.800	M	M	H	M	VH	M	M	VH	H	M	BE_4
13	0.044	0.006	0.528	0.363	0.525	0.544	0.686	M	M	L	H	VH	M	M	VH	L	L	BE_5
16	0.027	0.004	0.460	0.287	0.451	0.469	0.632	M	M	M	M	M	M	L	VH	L	VL	BE_6
14	0.044	0.006	0.528	0.371	0.518	0.547	0.680	H	VH	L	M	M	M	M	VH	VL	L	BE_7
9	0.058	0.008	0.0571	0.415	0.569	0.579	0.724	H	H	L	L	H	H	M	VH	L	M	BE_8
17	0.026	0.004	0.455	0.292	0.446	0.464	0.617	M	M	L	L	H	M	M	VH	VL	L	BE_9
10	0.054	0.008	0.0559	0403	0.558	0.566	0.713	M	H	L	M	H	H	L	H	VH	L	BE_{10}
7	0.075	0.011	0.611	0.451	0.601	0.627	0.768	H	M	M	VL	VH	H	H	M	VH	M	BE_{11}
4	0.090	0.013	0.638	0.496	0.627	0.658	0.775	H	VH	L	VL	VH	H	H	M	H	H	BE_{12}
2	0.099	0.014	0.654	0.484	0.654	0.654	0.823	H	M	H	M	H	H	H	M	M	H	BE_{13}
6	0.081	0.011	0.623	0.456	0.621	0632	0.786	M	H	M	H	H	VH	H	M	M	L	BE_{14}
12	0.043	0.006	0.527	0.367	0.520	0.529	0.690	H	H	M	L	H	H	M	M	L	VL	BE_{15}
1	0.107	0.015	0.666	0.515	0.656	0.686	0.812	H	VH	H	M	VH	H	H	M	VL	M	BE_{16}
3	0.097	0.014	0.650	0.490	0.646	0.671	0.801	M	VH	VH	H	H	L	H	M	M	M	BE_{17}

Table 3 - Rate of probability of intermediate and top events

Rank	Importance	FP	Event name	Event type	Event avatar
-	-	0.139	Hazards of wire cutting machine	top	TE
6	0.079	0.011	Operator	Intermediate	IE_1
2	0.216	0.031	Geology	Intermediate	IE_2
3	0.180	0.025	Designing	Intermediate	IE_3
1	0.380	0.053	Maintenance and repair	Intermediate	IE_4
4	0.107	0.015	Risk of throwing parts of the spring or active springs	Intermediate	IE_5
5	0.097	0.014	Falling Stone Block During Cutting	Intermediate	IE_6

FINDINGS AND ARGUMENT

To implement a combination of error analysis and fuzzy theory, first all the risks associated with the wire cutting machines that occur as the final event in quarry mines are considered and a questionnaire is prepared. So the most important hazards were detected and used as intermediate events of the fault tree. Then the causes of these hazards were first identified and ranked in form of intermediate and top events, with a top-down tree-like structure, and then used for calculating the probability of the final event.

Also, for preventing damage and injuries and increasing safety, the probability of risks occurrence must be reduced using control measures.

Based on the calculations made among the basic events, minimum cut sets of three hazard were identified as three critical path: moving and whipping caused by rupture of wire, diversion of wire cutters, and Lakarty (mud) existence inside the stone. With the following solutions, reliability of the system can be increased and probability of occurrence of the hazards is eliminated:

- To avoid flying spring parts or active components of spring, use plastic cutting wires instead of metal.
- Constant monitoring and reminding of the use of personal and group protection devices.
- Investigating before wire cutting process to make sure that there is no Lakarty (mud) inside the stone block in order to prevent the block from falling during cutting process.
- Among the intermediate events, minimum cut sets of hazards of maintenance and repair, geology, and false design were identified as three critical paths. With the following solutions, reliability of the system can be increased and probability of occurrence of the hazards is eliminated:
- A specialist must be used for correct and principled repairs.
- Proper design of wire cutting and its use must be taught to the operator.
- A geologist must be present in the area in order to accurately identify the cutting area.

CONCLUSIONS

Accidents and dangers occurring in quarry mines are the main problem of these mines that have adverse human and financial consequences. Therefore, identifying and managing hazards are essential to avoid these results, and necessary steps must be taken accordingly. This research has been carried out in stone quarry mines and it has combined fault analysis method with fuzzy theory to determine and rank cut assemblies; then control solutions have been introduced to increase reliability of the system and reduce system risks. This research, reviewing past researches and utilizing fuzzy theory, can successfully overcome the problem of ambiguity and inaccuracy caused by subjective information, and can provide a comprehensive assessment of the risks associated with a wire cutting machine in the form of a fault tree.

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