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Assessment and Management of Safety Risks through Hierarchical Analysis in Fuzzy Sets Type 1 and Type 2: A Case Study (Faryab Chromite Underground Mines)

Rudarsko-geološko-naftni zbornik
(The Mining-Geology-Petroleum Engineering Bulletin)
UDC: 622:08
DOI: 10.17794/rgn.2021.3.1

Original scientific paper

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Abstract
There is a high rate of casualty among miners in the world every year. One way to reduce accidents and increase safety in mines is to use the risk management process to identify and respond to major hazards in mines. The present study is an attempt to investigate the assessment and management of safety risks in Faryab chromite underground mines. In this paper, the method of AHP in type-1 and type-2 fuzzy sets is used for risk assessment. Upon studying two underground mines of Faryab chromite (Makran and Nemat), 45 hazards were divided into 9 groups, among which 7 main risks were eventually identified. The risk assessment showed that the most important hazards in the Nemat underground mine are the required airflow, the lack of proper scaling and post-blast scaling. Similarly, the assessment of hazards in the Makran underground mine showed that post-blast scaling, absence of proper scaling, and proper ventilation of dust, are the most important hazards. Finally, after detecting the causes of the accidents, based on the records of accidents at the mine safety, health, and environmental unit, technical personnel's descriptions, and similar risk projects, proper responses are prepared for each group of hazards.

Keywords:
safety risk; risk management; Faryab Chromite underground mines; fuzzy hierarchical analysis; fuzzy sets type-2

1. Introduction

Mines are one of the most dangerous workplaces. Health and safety standards vary depending on the status of the infrastructure, technology development and development priorities in this sector (**Mainardi, 2005**). Mine accidents have different causes and consequences, but the main concern is the casualties (**Kasap and Subaşı, 2017**). Despite the significant reduction in mine damages, accidents are still widespread in mining compared to other industries (**Komljenovic et al., 2008**) because in mining, there are always a variety of hazards. Risk assessment makes it possible to confront these risks (**Jikani et al., 2020**). Since current safety analysis tools have not been adequate for a systematic and dynamic safety risk assessment, new assessment methods seem necessary (**Zhang et al., 2006**). Multi-criteria decision-making techniques have been widely used to overcome a variety of problems in mining and mine processing (**Sitorus et al., 2019**). Analysis of accident data in mines is useful in identifying the main hazards of mining (**Tetzlaff et al., 2020**). The most important step in assessing occupational health and safety is to calculate the risk size and determine whether the risk is acceptable or unacceptable (**Kokangül et al., 2017**). One of the methods of risk assessment and risk grading is hierarchical analysis. One of the problems of using hierarchical analysis is the uncertainty in decision-making as caused by the quantitative and qualitative criteria (**An et al., 2011**). Nowadays, the use of fuzzy sets is more favored because of the ease of the decision-making process and the fuzzy nature of pairwise comparisons that has led to a reduction of decision uncertainty.

Due to the enormous economic and psychological burdens of risk-taking on various projects, the issue of risk assessment and management has received increasing attention worldwide. Also, different works done in this area have hosted many studies, some of which can be mentioned below. Mati et al. assessed the risk of miners' work casualties, their personal and workplace characteristics, and behavioral and polynomial models for measuring the hazards of threats to the miners who work in underground coal mines (**Maiti and Bhattacherjee, 1999**). Badri et al. proposed a new scientific and practical approach to risk management in mining projects based on a new concept called "hazard concentration" using multi-criteria analysis. Their study demonstrates the importance of using occupational health in all mining activities (**Badri et al., 2013**). Mardani et al. systematically reviewed the applications and methods available in fuzzy decision-making techniques from 1994 to 2014. They surveyed 403 published papers on fuzzy decision-making techniques in more than 150 journals (**Mardani**

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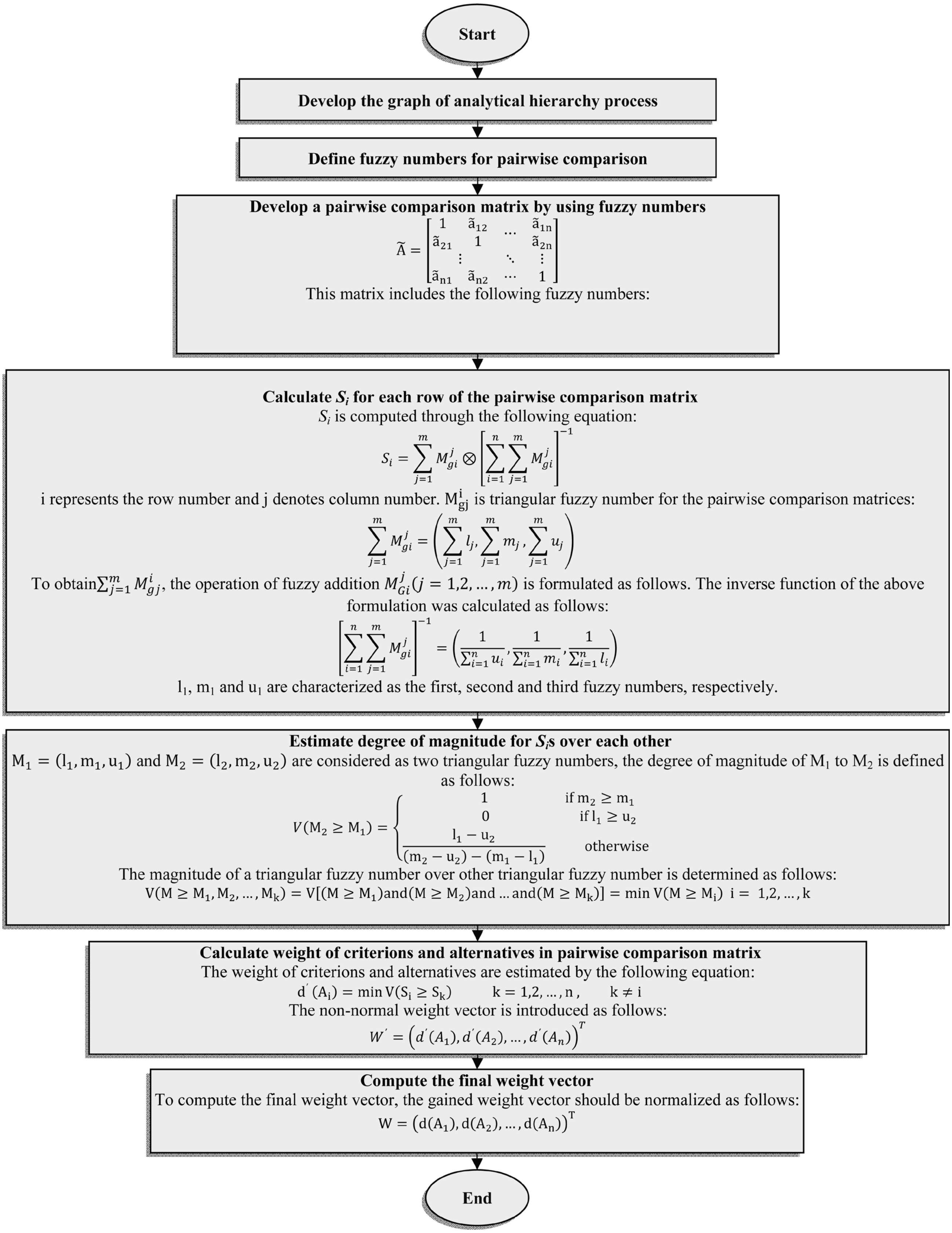

Figure 1: The FAHP method in type-1 fuzzy sets

et al., 2015). Haas et al. investigated the common methods for measuring individuals' performance in mining excavation to determine the value and capability of the methods in measuring individuals' health and safety per-

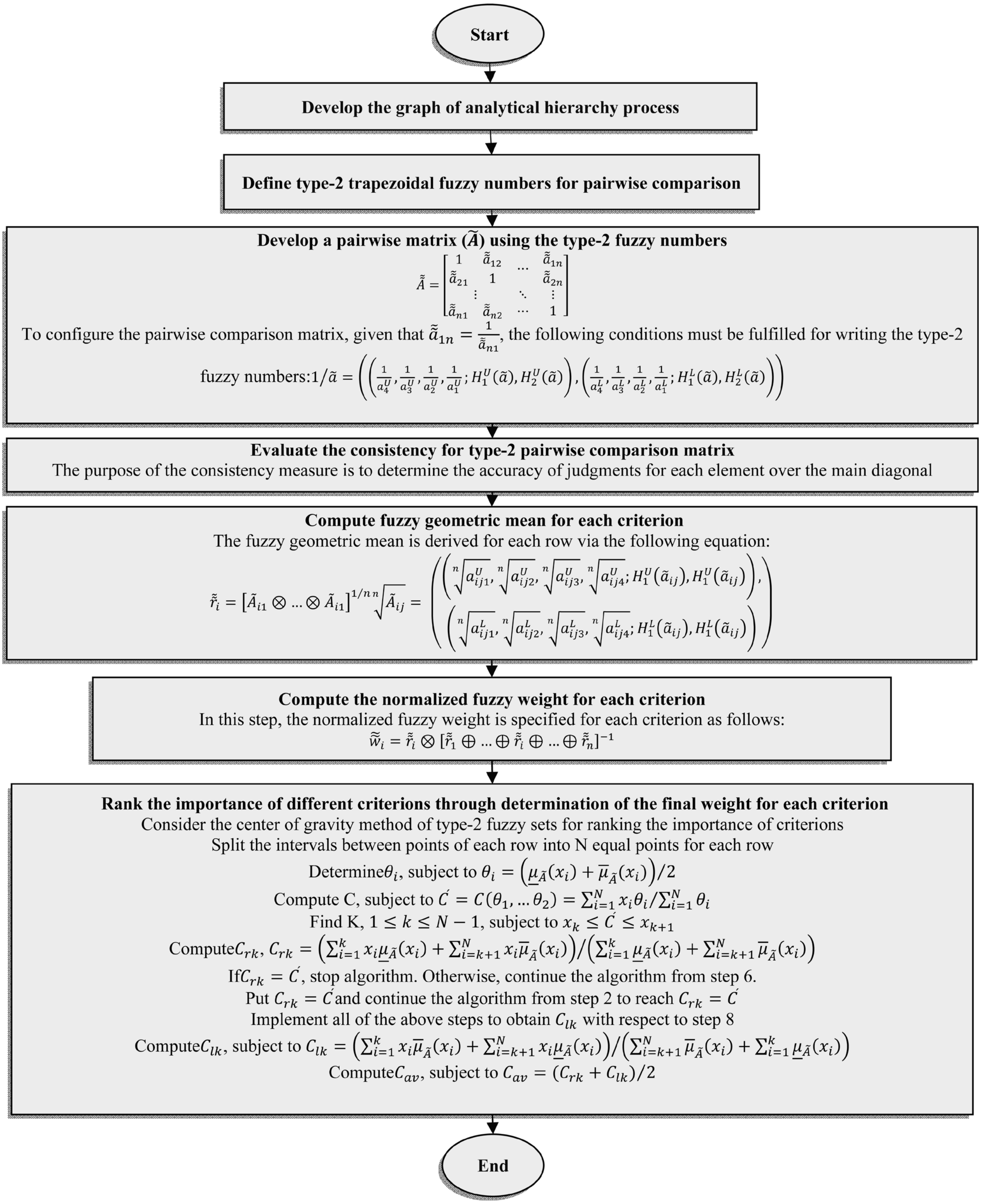

Figure 2: The FAHP method in type-2 fuzzy sets

Table 1: Four different occupational groups in Questionnaire No. 1

Occupational Groups	Number of persons
Service personnel	30
Technical personnel	18
Transport	11
worker	72

formance (**Haas and Yorio, 2016**). In a review paper, Kubler et al. assessed the FAHP method in the papers which were published between 2004 and 2016. In their review, they categorized articles by the topic, the year of publication, and the practical use of FAHP in those pa-

Table 2: List of main risks in two Makran and Nemat mines

Risk Groups	Title	Description
Geology	G_1	Roof-fall or wall-fall
	G_2	Natural or artificial surface ruggedness
	G_3	Falling down or slipping on steep slopes
	G_4	Water flow or leakage
	G_5	Tectonic conditions such as fault, joint, etc.
	G_6	Formation of dunite blocks and serpentinization
Drilling and Blasting	$D\&B)_1)$	Dust generation because of rock drilling and blasting
	$D\&B)_2)$	Scaling of rock after blasting
	$D\&B)_3)$	Inhalation of smoke and toxic gases produced by blasting
	$D\&B)_4)$	Remaining unexploded explosives in rock
Ventilation	V_1	The required air flow
	V_2	Air conditioning in terms of heat and cold
	V_3	Adequate ventilation for existing dust
Transportation	T_1	Adequate lighting in front of the locomotives
	T_2	Vehicle collision with people
	T_3	Vehicle collision with fixed objects
	T_4	Wagons have not properly been attached
	T_5	Overturn of vehicles
	T_6	Exceeding the speed limit of vehicles
	T_7	Breaking chain or failure of wagon's couplings
Support System	S_1	Incorrect scaling
	S_2	Unsuitable support devices
	S_3	Collapsing support system
Lighting	L_1	Inadequate illumination in working space
	L_2	Frazzle of illumination facilities
	L_3	Nonstandard distance between electrical cables and other facilities
	L_4	Installation electrical in humidity environment
	L_5	Avoiding the use of mining cables
Machines and Equipment	$M\&E)_1)$	Noises and vibrations caused by machineries and equipment
	$M\&E)_2)$	Tear of compressed air tube
	$M\&E)_3)$	Changing equipment conditions such as aging and undesirable performance
	$M\&E)_4)$	Inappropriate arrangement of equipment
	$M\&E)_5)$	Pressing people between machineries and equipment
	$M\&E)_6)$	Hitting people with vehicles
	$M\&E)_7)$	Impact of body with sharp edges
Rules and Regulation	$_1(R\&R)$	Equipped transportation machineries with safety equipment
	$_2(R\&R)$	Installation warning devices on the vehicles
	$_3(R\&R)$	Considering haul capacity for trucks
	$_4(R\&R)$	Surveying and inspection of equipment and machineries before beginning of the operation
	$_5(R\&R)$	Existence of shelter
	$_6(R\&R)$	Unavailability of personal protective equipment
Human cases and individual errors	$_1(H\&E)$	Existence of musculoskeletal problems
	$_2(H\&E)$	Psychological factors such as: hard working conditions, non-payment of salaries
	$_3(H\&E)$	Human errors
	$_4(H\&E)$	Inappropriate working situation

Table 3: The sub-criteria set for each group of risks in underground mines

Group of risks	Terms of criteria	criteria	sub-criteria	Group of risks	Terms of criteria	criteria	sub-criteria
Geology	G	C_1	C_{11}	Lighting	L	C_6	C_{61}
			C_{12}				C_{62}
			C_{13}				C_{63}
			C_{14}				C_{64}
			C_{15}				C_{65}
			C_{16}				
Drilling and Blasting	(D&B)	C_2	C_{21}	Machines and Equipment	(M&E)	C_7	C_{71}
			C_{22}				C_{72}
			C_{23}				C_{73}
			C_{24}				C_{74}
Ventilation	V	C_3	C_{31}				C_{75}
			C_{32}				C_{76}
			C_{33}				C_{77}
Transportation	T	C_4	C_{41}	Rules and Regulation	(R&R)	C_8	C_{81}
			C_{42}				C_{82}
			C_{43}				C_{83}
			C_{44}				C_{84}
			C_{45}				C_{85}
			C_{46}				C_{86}
			C_{47}				
Support System	S	C_5	C_{51}	Human cases and individual errors	(H&E)	C_9	C_{91}
			C_{52}				C_{92}
			C_{53}				C_{93}
							C_{94}

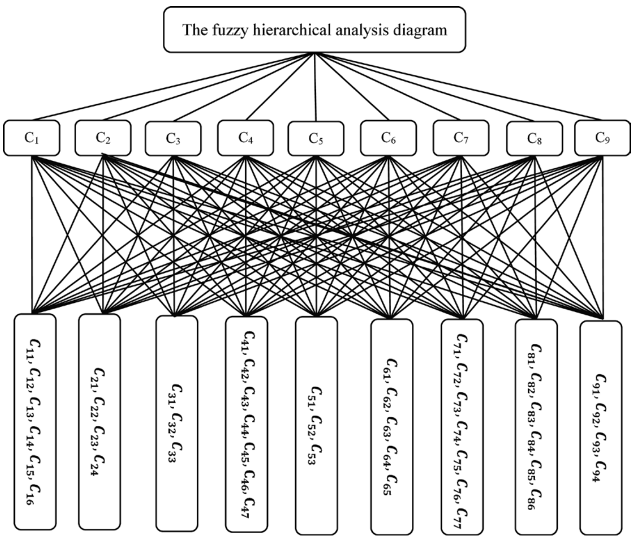

Figure 3: The hierarchical analysis diagram for Faryab Chromite Underground Mines

pers. Their findings suggest that FAHP is primarily used in manufacturing and industry (**Kubler et al., 2016**). Kasp et al. used the hierarchical analysis method to measure the mine accidents in the Turkish coal sector during 2005-2010. They found landslides as the greatest danger in open-pit mines. They also found out that the most threatened occupational groups were inexperienced and unskilled workers, and the most common occupational hazards were landslides and falls in mines (**Kasap and Subaşı, 2017**). Gaurina and Novak used preliminary risk assessment to identify risks of CO_2 leakage from the injection zone and through wells by quantifying hazard probability (likelihood) and severity to establish a risk-mitigation plan and to engage prevention programs (**Gaurina M. and Karolina N. M., 2017**). Tripathy et al. investigated the safety hazards in India's underground coal mines. They created a database that can help to better manage decisions to identify the most important hazards (**Tripathy and Ala., 2018**). Zečević evaluated the risk of potable water supply in the area of amphibious military operation (**Zečević, 2019**). Gul et al. examined the occupational hazards in an underground copper and zinc mine. Their findings show that fuzzy approach solutions can be used to classify hazards at different levels (**Gul et al., 2019**). Kiani et al. assessed the risk of blasting in open pit mines using the FAHP method (**Kiani et al., 2019**). Sakhno et al. analyzed the available approaches which are used to determine risks of injures of miners and developed a new method to assess risks of roof fall (**Sakhno et al., 2020**). Yari et al. pro-

Table 4: Pairwise comparison matrix of C_1 criteria in the Nemat underground mine (main sample)

The opinions of the first expert							The opinions of the second expert						
1	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	2	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}
C_{11}	1	9	9	9	1	8	C_{11}	1	9	9	9	8	0.2
C_{12}	0.11	1	0.12	0.12	0.11	0.11	C_{12}	0.11	1	0.12	0.12	0.14	0.14
C_{13}	0.11	8	1	0.2	0.12	0. 2	C_{13}	0.11	8	1	0.2	0.2	0.11
C_{14}	0.11	8	5	1	1	1	C_{14}	0.11	8	5	1	1	0.14
C_{15}	1	9	8	1	1	6	C_{15}	0.12	7	5	1	1	0.2
C_{16}	0.12	9	5	1	0.17	1	C_{16}	5	7	9	7	5	1
The opinions of the third expert							The opinions of the fourth expert						
3	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	4	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}
C_{11}	1	9	0.25	7	6	8	C_{11}	1	7	7	0.2	0.17	0.14
C_{12}	0.11	1	0.12	0.14	0.12	0.17	C_{12}	0.14	1	4	0.14	0.17	0.14
C_{13}	4	8	1	7	0.12	0.12	C_{13}	0.14	0.25	1	0.17	0.14	0.14
C_{14}	0.14	7	0.14	1	0.12	0.12	C_{14}	5	7	6	1	7	7
C_{15}	0.17	8	8	8	1	0.12	C_{15}	6	6	7	0.14	1	6
C_{16}	0.12	6	8	8	0.12	1	C_{16}	7	7	7	0.14	0.17	1
The opinions of the fifth expert							The opinions of the sixth expert						
5	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	6	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}
C_{11}	1	8	7	8	5	6	C_{11}	1	7	5	5	0.33	7
C_{12}	0.12	1	0.2	4	0.14	0.2	C_{12}	0.14	1	5	3	0.33	0.14
C_{13}	0.14	5	1	5	0.14	0.17	C_{13}	0.2	0.2	1	7	0.33	0.17
C_{14}	0.12	0.25	0.2	1	0.17	0.17	C_{14}	0.2	0.33	0.14	1	5	0.2
C_{15}	0.2	7	7	6	1	7	C_{15}	3	3	3	0.2	1	0.2
C_{16}	0.17	5	6	6	0.14	1	C_{16}	0.14	7	6	5	5	1

The opinions of the seventh expert						
7	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}
C_{11}	1	6	6	6	4	4
C_{12}	0.17	1	0.5	2	0.25	0.25
C_{13}	0.17	2	1	2	2	2
C_{14}	0.17	0.5	0.5	1	0.5	0.5
C_{15}	0.25	4	0.5	2	1	2
C_{16}	0.25	4	0.5	2	0.5	1

Table5: Final comparison pairwise matrix for criteria C_1 in the Nemat underground mine (main example)

	C_{11}			C_{12}			C_{13}			C_{14}			C_{15}			C_{16}		
C_{11}	1	1	1	6	7.9	9	0.25	6.18	9	0.2	6.3	9	0.17	3.5	8	0.14	4.76	8
C_{12}	0.11	0.13	0.17	1	1	1	0.12	1.44	5	0.12	1.36	4	0.11	0.18	0.33	0.11	0.16	0.25
C_{13}	0.11	0.70	4	0.2	4.49	8	1	1	1	0.17	3.08	7	0.12	0.44	2	0.11	0.42	2
C_{14}	0.11	0.84	5	0.25	4.44	8	0.14	2.43	6	1	1	1	0.12	2.11	7	0.12	1.30	7
C_{15}	0.12	1.53	6	3	6.29	9	0.5	5.5	8	0.14	2.62	8	1	1	1	0.2	4.2	8
C_{16}	0.12	1.83	7	4	6.43	9	0.5	5.93	9	0.14	4.16	8	0.12	1.6	5	1	1	1

posed a comprehensive model for evaluating occupational and environmental risks of dimensional stone mining (**Yari et al., 2020**).

According to the explanations given above and the importance of safety in mines, in this paper, an attempt is made to examine the safety risk assessment and management of underground mines in Faryab Chromite through the hierarchical analysis method in Fuzzy Type-1 and Type-2.

2. Data & Method

In this section, we examine the concepts and steps of risk management as the first stage in performing and pre-

Table 6: the value of S_i, weight of criteria (d) and final weight of criteria (W) in final pairwise comparison matrix (main example)

S_i	l_i	m_i	u_i	$d\ (C_i)$	Value	$W\ (C_i)$	Value
S_{C11}	0.0479	0.3832	2.9876	$d_{(C11)}$	1	$W_{(C11)}$	0.190
S_{C12}	0.0097	0.0552	0.6060	$d_{(C12)}$	0.6298	$W_{(C12)}$	0.120
S_{C13}	0.0106	0.1310	1.3529	$d_{(C13)}$	0.8380	$W_{(C13)}$	0.159
S_{C14}	0.0108	0.1568	1.9166	$d_{(C14)}$	0.8919	$W_{(C14)}$	0.169
S_{C15}	0.0306	0.2736	2.2548	$d_{(C15)}$	0.9526	$W_{(C15)}$	0.181
S_{C16}	0.0363	0.2709	2.1984	$d_{(C16)}$	0.9503	$W_{(C16)}$	0.181

Table 7: The results of FAHP type-1 method in the Nemat underground mine

Geology	$W_{(C11)}$	$W_{(C12)}$	$W_{(C13)}$	$W_{(C14)}$	$W_{(C15)}$	$W_{(C16)}$	
	0.190	0.120	0.159	0.169	0.181	0.181	
Drilling and Blasting	$W_{(C21)}$	$W_{(C22)}$	$W_{(C23)}$	$W_{(C24)}$			
	0.229	0.274	0.250	0.247			
Ventilation	$W_{(C31)}$	$W_{(C32)}$	$W_{(C33)}$				
	0.349	0.318	0.333				
Transportation	$W_{(C41)}$	$W_{(C42)}$	$W_{(C43)}$	$W_{(C44)}$	$W_{(C45)}$	$W_{(C46)}$	$W_{(C47)}$
	0.142	0.147	0.138	0.144	0.143	0.146	0.140
Support	$W_{(C51)}$	$W_{(C52)}$	$W_{(C53)}$				
	0.343	0.337	0.320				
Lighting	$W_{(C61)}$	$W_{(C62)}$	$W_{(C63)}$	$W_{(C64)}$	$W_{(C65)}$		
	0.200	0.194	0.204	0.205	0.197		
Machines and Equipment	$W_{(C71)}$	$W_{(C72)}$	$W_{(C73)}$	$W_{(C74)}$	$W_{(C75)}$	$W_{(C76)}$	$W_{(C77)}$
	0.143	0.143	0.139	0.138	0.147	0.145	0.144
Rules and Regulation	$W_{(C81)}$	$W_{(C82)}$	$W_{(C83)}$	$W_{(C84)}$	$W_{(C85)}$	$W_{(C86)}$	
	0.168	0.164	0.165	0.169	0.166	0.167	
Human cases and individual errors	$W_{(C91)}$	$W_{(C92)}$	$W_{(C93)}$	$W_{(C94)}$			
	0.237	0.263	0.259	0.241			

Table 8: The results of FAHP type-1 method in the Makran underground mine

Geology	$W_{(C11)}$	$W_{(C12)}$	$W_{(C13)}$	$W_{(C14)}$	$W_{(C15)}$	$W_{(C16)}$	
	0.219	0.102	0.213	0.020	0.221	0.225	
Drilling and Blasting	$W_{(C21)}$	$W_{(C22)}$	$W_{(C23)}$	$W_{(C24)}$			
	0	0.476	0.154	0.370			
Ventilation	$W_{(C31)}$	$W_{(C32)}$	$W_{(C33)}$				
	0.349	0.298	0.353				
Transportation	$W_{(C41)}$	$W_{(C42)}$	$W_{(C43)}$	$W_{(C44)}$	$W_{(C45)}$	$W_{(C46)}$	$W_{(C47)}$
	0.144	0.147	0.136	0.143	0.143	0.144	0.144
Support	$W_{(C51)}$	$W_{(C52)}$	$W_{(C53)}$				
	0.374	0.336	0.290				
Lighting	$W_{(C61)}$	$W_{(C62)}$	$W_{(C63)}$	$W_{(C64)}$	$W_{(C65)}$		
	0.201	0.203	0.208	0.204	0.184		
Machines and Equipment	$W_{(C71)}$	$W_{(C72)}$	$W_{(C73)}$	$W_{(C74)}$	$W_{(C75)}$	$W_{(C76)}$	$W_{(C77)}$
	0.123	0.138	0.098	0.072	0.205	0.188	0.176
Rules and Regulation	$W_{(C81)}$	$W_{(C82)}$	$W_{(C83)}$	$W_{(C84)}$	$W_{(C85)}$	$W_{(C86)}$	
	0.135	0.172	0.161	0.181	0.170	0.181	
Human cases and individual errors	$W_{(C91)}$	$W_{(C92)}$	$W_{(C93)}$	$W_{(C94)}$			
	0.199	0.271	0.269	0.261			

Table 9: The final weight of each group of risks in the Nemat and Makran underground mines

Nemat underground mine									
$W(C_i)$	$W_{(C1)}$	$W_{(C2)}$	$W_{(C3)}$	$W_{(C4)}$	$W_{(C5)}$	$W_{(C6)}$	$W_{(C7)}$	$W_{(C8)}$	$W_{(C9)}$
Value	0.109	0.112	0.122	0.105	0.121	0.105	0.115	0.101	0.109
Makran underground mine									
$W(C_i)$	$W_{(C1)}$	$W_{(C2)}$	$W_{(C3)}$	$W_{(C4)}$	$W_{(C5)}$	$W_{(C6)}$	$W_{(C7)}$	$W_{(C8)}$	$W_{(C9)}$
Value	0.093	0.203	0.160	0.047	0.175	0.046	0.062	0.060	0.154

Table 10: The interval linguistic variables scales of FAHP type-2 method (**Kahraman et al., 2014**)

Linguistic variables	Trapezoidal Interval Type-2 fuzzy scales
Absolutely Strong (AS)	(7,8,9,9;1,1), (7.2,8.2,8.8,9;0.8,0.8)
Very Strong (VS)	(5,6,8,9;1,1), (5.2,6.2,7.8,8.8;0.8,0.8)
Fairly Strong (FS)	(3,4,6,7;1,1), (3.2,4.2,5.8,6.8;0.8,0.8)
Slightly Strong (SS)	(1,2,4,5;1,1), (1.2,2.2,3.8,4.8;0.8,0.8)
Exactly Equal (E)	(1,1,1,1;1,1), (1,1,1,1;1,1)

senting the risk management process. Finally, the general steps of risk management in underground mines of Faryab chromite are presented.

2.1. Risks and Risk management

Different definitions are offered for risk in different studies. According to the latest Project Management Guide published by the Institute (PMI), risk is: "… an uncertain event or condition that, if it does occur, can present a positive or a negative effect on one or more of the project objectives" (**Kerzner, 2017**). Risk assessment and risk management are currently central to national approaches to the analysis and management of many issues (**Liu et al., 2019**). Risk management refers to coordinated activities to guide and control the organization in response to the risk (**Domingues et al., 2017**). There are different approaches to manage risks, however, all of these approaches contain one key process, consisting of three key elements: identification, evaluation and risk response (**Mahdevari et al., 2014**).

Table 11: First expert's judgment of C_1 criteria base on the type-2 trapezoidal fuzzy numbers for the Nemat underground mine

U							L						
	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}		C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}
C_{11}	1	0.11	0.11	0.11	1	0.11	C_{11}	1	0.11	0.11	0.11	1	0.11
	1	0.11	0.11	0.11	1	0.11		1	0.11	0.11	0.11	1	0.11
	1	0.14	0.14	0.14	1	0.14		1	0.14	0.14	0.14	1	0.14
	1	0.17	0.17	0.17	1	0.17		1	0.17	0.17	0.17	1	0.17
C_{12}	7	1	6	6	7	7	C_{12}	7.2	1	6.2	6.2	7.2	7.2
	8	1	7	7	8	8		8.2	1	7.2	7.2	8.2	8.2
	9	1	9	9	9	9		8.8	1	8.8	8.8	8.8	8.8
	9	1	9	9	9	9		9	1	9	9	9	9
C_{13}	7	0.11	1	3	6	3	C_{13}	7.2	0.11	1	3.2	6.2	3.2
	8	0.11	1	4	7	4		8.2	0.11	1	4.2	7.2	4.2
	9	0.14	1	6	9	6		8.8	0.14	1	5.8	8.8	5.8
	9	0.17	1	7	9	7		9	0.17	1	6.8	9	6.8
C_{14}	7	0.11	0.14	1	1	1	C_{14}	7.2	0.11	0.14	1	1	1
	8	0.11	0.17	1	1	1		8.2	0.11	0.17	1	1	1
	9	0.14	0.25	1	1	1		8.8	0.14	0.25	1	1	1
	9	0.17	0.33	1	1	1		9	0.17	0.33	1	1	1
C_{15}	1	0.11	0.11	1	1	0.11	C_{15}	1	0.11	0.11	1	1	0.11
	1	0.11	0.11	1	1	0.14		1	0.11	0.11	1	1	0.14
	1	0.12	0.14	1	1	0.2		1	0.12	0.14	1	1	0.2
	1	0.14	0.17	1	1	0.25		1	0.14	0.17	1	1	0.25
C_{16}	6	0.11	0.14	1	4	1	C_{16}	6.2	0.11	0.14	1	4.2	1
	7	0.11	0.17	1	5	1		7.2	0.11	0.17	1	5.2	1
	9	0.12	0.25	1	7	1		8.8	0.12	0.25	1	6.8	1
	9	0.14	0.33	1	8	1		9	0.14	0.33	1	7.8	1

Table 12: The fuzzy geometric mean for each row (C_1 criteria) in the Nemat underground mine (the main example)

U	$\tilde{\tilde{r}}_{C11}$	2.153	2.520	3.227	3.571
	$\tilde{\tilde{r}}_{C12}$	0.236	0.261	0.358	0.427
	$\tilde{\tilde{r}}_{C13}$	0.421	0.468	0.668	0.798
	$\tilde{\tilde{r}}_{C14}$	0.548	0.627	0.859	0.971
	$\tilde{\tilde{r}}_{C15}$	1.272	1.509	2.095	2.364
	$\tilde{\tilde{r}}_{C16}$	1.131	1.315	1.816	2.043
L	$\tilde{\tilde{r}}_{C11}$	2.217	2.575	3.170	3.520
	$\tilde{\tilde{r}}_{C12}$	0.238	0.264	0.356	0.423
	$\tilde{\tilde{r}}_{C13}$	0/425	0.480	0.660	0.788
	$\tilde{\tilde{r}}_{C14}$	0.555	0.633	0.838	0.962
	$\tilde{\tilde{r}}_{C15}$	1.314	1.556	2.048	2.334
	$\tilde{\tilde{r}}_{C16}$	1.160	1.339	1.778	2.018

2.1.1. Identification of risk

There are many instruments and approaches to identify hazards, but identifying all hazards is always difficult. Therefore, different methods should be used to identify risks. The most common methods of risk identification include: document review, observation and inspection, brainstorming, Delphi method, interview, checklist and scenario analysis (**Rout and Sikdar, 2017**).

2.1.2. Risk Analysis and Assessment

It is time consuming and cost ineffective to investigate all the risks identified in a project. Thus, different identified risks must be prioritized. In this paper, a hierarchical analysis in fuzzy sets and fuzzy type-2 is used to evaluate and prioritize the identified hazards. The steps of the FAHP method in fuzzy type-1 and type-2 are shown in **Figures 1** and **2** (**Chang, 1996**) and (**Kahraman et al., 2014**).

2.1.3. Response to Risk

The strategy used in response to risk includes various aspects such as: risk transfer, risk avoidance, risk reduction or acceptance. In other words, in response to risk, measures are taken to reduce the occurrence probability of an event or its effect resulting from a risk or a combination of both. Risk response measures are classified

Table 13: The normalized fuzzy weight of C_1 criteria in the Nemat underground mine (the main example)

U	$\tilde{\tilde{W}}_{C11}$	0.374	0.376	0.357	0.351
	$\tilde{\tilde{W}}_{C12}$	0.041	0.039	0.040	0.042
	$\tilde{\tilde{W}}_{C13}$	0.073	0.070	0.074	0.078
	$\tilde{\tilde{W}}_{C14}$	0.095	0.094	0.095	0.095
	$\tilde{\tilde{W}}_{C15}$	0.221	0.225	0.232	0.232
	$\tilde{\tilde{W}}_{C16}$	0.196	0.196	0.201	0/200
L	$\tilde{\tilde{W}}_{C11}$	0.375	0.376	0.358	0.350
	$\tilde{\tilde{W}}_{C12}$	0.040	0.039	0.040	0.042
	$\tilde{\tilde{W}}_{C13}$	0.0720	0.070	0.075	0.078
	$\tilde{\tilde{W}}_{C14}$	0.094	0.093	0.095	0.096
	$\tilde{\tilde{W}}_{C15}$	0.222	0.227	0.231	0.232
	$\tilde{\tilde{W}}_{C16}$	0.196	0.195	0.201	0.200

Table 14: The total weight of C_1 criteria in the Nemat underground mine (the main example)

U	$\tilde{\tilde{W}}_{C11}$	0.02419	0.02479	0.02398	0.02422
	$\tilde{\tilde{W}}_{C12}$	0.00265	0.00257	0.00266	0.00289
	$\tilde{\tilde{W}}_{C13}$	0.00473	0.00461	0.00496	0.00541
	$\tilde{\tilde{W}}_{C14}$	0.00616	0.00617	0.00638	0.00659
	$\tilde{\tilde{W}}_{C15}$	0.01430	0.01484	0.01557	0.01603
	$\tilde{\tilde{W}}_{C16}$	0.01270	0.01294	0.01349	0.01386
L	$\tilde{\tilde{W}}_{C11}$	0.02424	0.02494	0.02383	0.02398
	$\tilde{\tilde{W}}_{C12}$	0.00260	0.00255	0.00267	0.00288
	$\tilde{\tilde{W}}_{C13}$	0.00465	0.00465	0.00496	0.00537
	$\tilde{\tilde{W}}_{C14}$	0.00607	0.00613	0.00630	0.00655
	$\tilde{\tilde{W}}_{C15}$	0.01436	0.01507	0.01539	0.01590
	$\tilde{\tilde{W}}_{C16}$	0.01268	0.01297	0.01337	0.01375

into different forms. Briefly, risk response is divided into four sections: risk avoidance, risk transfer, risk reduction and risk acceptance (**Karnik and Mendel, 2001**).

3. Safety Risk Assessment and Management in Fryab Chromite Underground Mines

In this section, the risk management steps at Fryab chromite underground mines are presented. First, the area and mines are introduced, and then the risk assessment process which was carried out is presented.

3.1. Faryab and the geology of the area

The Faryab mining area is about 600 square kilometres located between Kerman and Hormozgan provinces. Faryab region is an ophiolite complex massif, known as the Sorkhband Belt. The rocks and constituents of this complex include: "dunite, chromite deposits, olivine-bearing clinopyroxinite masses and dikes, olivine-bearing dikes and websterite." This complex consists of an upper and lower part. Faryab chromite deposits are the largest chromite deposits in Iran, with an estimated reserve of 30 million tons with an economic grade of Cr2O330% (**Delavari et al., 2016**). At present, only two underground mines (Makran and Nemat) are being exploited separately in this mineral reserve.

Table 15: The Final weights C_1 criterion

$\tilde{\tilde{W}}_{Ci}$	Value
$\tilde{\tilde{W}}_{C11}$	0.363
$\tilde{\tilde{W}}_{C12}$	0.044
$\tilde{\tilde{W}}_{C13}$	0.075
$\tilde{\tilde{W}}_{C14}$	0.095
$\tilde{\tilde{W}}_{C15}$	0.226
$\tilde{\tilde{W}}_{C16}$	0.197

3.2. Risk and Risk Management in Faryab Open Chromite Mines

According to the initial investigation, 125 hazards were identified through the employment of three main methods of observation (observation and inspection of mines), interview (interview with miners) and review of mine accident documents. The identified hazards were divided into 9 groups (geology, drilling and explosion, ventilation, transportation, maintenance, lighting, machinery, rules and regulations, and individual errors). Then, Questionnaire No. 1 was prepared to determine the most important hazards. It was distributed among 131 individuals with four different occupational groups in the mine (see **Table 1**).

A survey of the views of 131 people in two Makran and Nemat mines, and the statistical analysis of their responses based on 35% Paratto analysis (to determine at least three risks for each group in forming a pairwise comparative matrix in the fuzzy hierarchical analysis method), indicated that only 45 of the 125 risks were identified as the main risks. Questionnaire No. 2 was presented to 11 members of technical staff in the open

Table 16: The results of FAHP type-2 method for the Nemat underground mine

Geology		$W_{(C11)}$	$W_{(C12)}$	$W_{(C13)}$	$W_{(C14)}$	$W_{(C15)}$	$W_{(C16)}$
		0.363	0.044	0.075	0.095	0.226	0.197
Drilling and Blasting				$W_{(C21)}$	$W_{(C22)}$	$W_{(C23)}$	$W_{(C24)}$
				0.097	0.533	0.190	0.181
Ventilation					$W_{(C31)}$	$W_{(C32)}$	$W_{(C33)}$
					0.551	0.138	0.312
Transportation	$W_{(C41)}$	$W_{(C42)}$	$W_{(C43)}$	$W_{(C44)}$	$W_{(C45)}$	$W_{(C46)}$	$W_{(C47)}$
	0.117	0.204	0.084	0.138	0.144	0.223	0.090
Support					$W_{(C51)}$	$W_{(C52)}$	$W_{(C53)}$
					0.468	0.350	0.182
Lighting			$W_{(C61)}$	$W_{(C62)}$	$W_{(C63)}$	$W_{(C64)}$	$W_{(C65)}$
			0.160	0.098	0.308	0.327	0.106
Machines and Equipment	$W_{(C71)}$	$W_{(C72)}$	$W_{(C73)}$	$W_{(C74)}$	$W_{(C75)}$	$W_{(C76)}$	$W_{(C77)}$
	0.116	0.114	0.074	0.050	0.259	0.211	0.176
Rules and Regulation		$W_{(C81)}$	$W_{(C82)}$	$W_{(C83)}$	$W_{(C84)}$	$W_{(C85)}$	$W_{(C86)}$
		0.193	0.131	0.108	0.238	0.149	0.180
Human cases and individual errors				$W_{(C91)}$	$W_{(C92)}$	$W_{(C93)}$	$W_{(C94)}$
				0.109	0.474	0.234	0.183

mines in two groups (safety and production engineers). They were asked to indicate the significance of each item identified in group 9 according to **Table 2**.

It is quite time consuming and cost ineffective to investigate all the identified risks individually. Prioritizing the risks through risk assessment makes it easy to identify the type of risk response. Hence, the different risks identified in the Faryab chromite underground mines were prioritized.

3.2.1. Risk Assessment of Faryab Chromite Underground Mines Using Fuzzy Hierarchical Analysis Type-1

In the first step, prior to drawing and presenting a fuzzy hierarchical analysis diagram according to **Table 3**, the identified risk groups were specified in terms of criteria and sub-criteria. In the second step, the fuzzy hierarchical analysis diagram was drawn (see **Figure 3**).

At step 3, the triangular fuzzy numbers were defined as follows (**Saaty., 1988**):

- absolute importance is equal to 9;
- very important is equal to 7;
- important is equal to 5;
- poor importance is equal to 3;
- equal importance is equal to 1.

A pairwise comparison matrix for each group was formed according to the opinions of 7 experts (see **Tables 4** and **5**). To avoid verbosity, only the comprehensive pairwise comparison matrix for the geology group and all steps of the fuzzy type-1 hierarchical analysis method for this group (main sample) are presented here. For the other groups, the results of assessment are presented in the form of final weights of the criteria.

At step 4, S_i was calculated for the pairwise matrix rows of each risk group. Then, the magnitude of S_i was calculated relative to each other. In addition, the weights of the criteria and options in the paired comparison matrix for each criterion were calculated separately (for the main sample) according to **Table 6**.

According to the above procedure, the steps of type-1 fuzzy analytic hierarchy process were followed for all criteria and groups in the Faryab chromite underground mines. The results of this method can be seen in **Tables 7** to **9**.

Table 17: The results FAHP type-2 method for the Makran underground mine

Geology		$W_{(C11)}$	$W_{(C12)}$	$W_{(C13)}$	$W_{(C14)}$	$W_{(C15)}$	$W_{(C16)}$
		0.211	0.050	0.173	0.036	0.243	0.286
Darling and Blasting				$W_{(C21)}$	$W_{(C22)}$	$W_{(C23)}$	$W_{(C24)}$
				0.052	0.539	0.095	0.314
Ventilation					$W_{(C31)}$	$W_{(C32)}$	$W_{(C33)}$
					0.198	0.087	0.715
Transportation	$W_{(C41)}$	$W_{(C42)}$	$W_{(C43)}$	$W_{(C44)}$	$W_{(C45)}$	$W_{(C46)}$	$W_{(C47)}$
	0.317	0.183	0.142	0.094	0.103	0.096	0.065
Support					$W_{(C51)}$	$W_{(C52)}$	$W_{(C53)}$
					0.565	0.272	0.163
Lighting			$W_{(C61)}$	$W_{(C62)}$	$W_{(C63)}$	$W_{(C64)}$	$W_{(C65)}$
			0.157	0.202	0.278	0.225	0.138
Machines and Equipment	$W_{(C71)}$	$W_{(C72)}$	$W_{(C73)}$	$W_{(C74)}$	$W_{(C75)}$	$W_{(C76)}$	$W_{(C77)}$
	0.043	0.155	0.054	0.035	0.299	0.238	0.175
Rules and Regulation		$W_{(C81)}$	$W_{(C82)}$	$W_{(C83)}$	$W_{(C84)}$	$W_{(C85)}$	$W_{(C86)}$
		0.096	0.128	0.092	0.266	0.115	0.303
Human cases and individual errors				$W_{(C91)}$	$W_{(C92)}$	$W_{(C93)}$	$W_{(C94)}$
				0.076	0.385	0.304	0.235

Table 18: The final weight of each group of risks based on FAHP type-2 method for the Nemat and Makran underground mines

Makran underground mine									
$W(C_i)$	$W_{(C1)}$	$W_{(C2)}$	$W_{(C3)}$	$W_{(C4)}$	$W_{(C5)}$	$W_{(C6)}$	$W_{(C7)}$	$W_{(C8)}$	$W_{(C9)}$
Value	0.067	0.104	0.247	0.061	0.213	0.059	0.123	0.045	0.081
Nemat underground mine									
$W(C_i)$	$W_{(C1)}$	$W_{(C2)}$	$W_{(C3)}$	$W_{(C4)}$	$W_{(C5)}$	$W_{(C6)}$	$W_{(C7)}$	$W_{(C8)}$	$W_{(C9)}$
Value	0.049	0.332	0.143	0.020	0.201	0.024	0.036	0.028	0.168

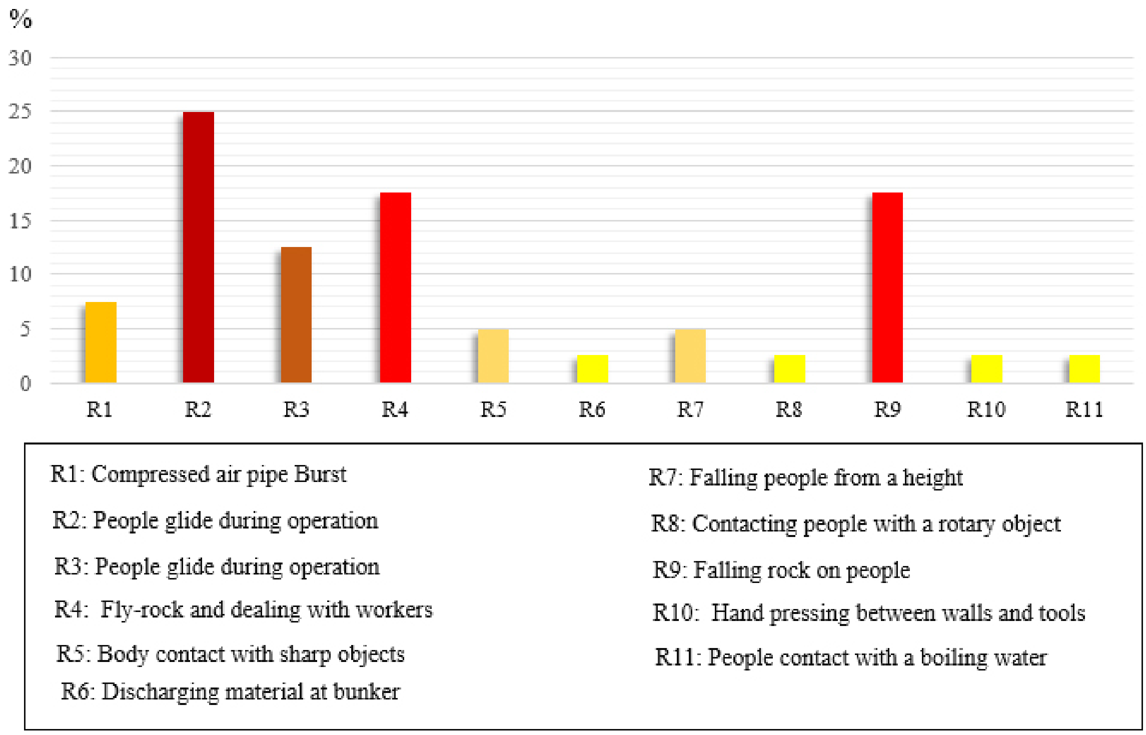

Figure 4: Available mine accident documents in the Faryab Chromite mines

3.2.2. Risk Assessment Using Type-2 Fuzzy AHP

In the first step, instead of drawing a hierarchical analysis diagram, the diagram was used in the fuzzy hierarchical analysis method. In the second step, fuzzy numbers of type-2 trapezoid were defined. In this section, for pairwise comparisons using trapezoidal numbers of type-2, the values determined according to the response of each expert were used. The numbers are set according to **Table 10**.

In the third step, like, the geological hazards of the Nemat underground mines were identified quite like the fuzzy hierarchical analysis method (main sample). Different steps of the hierarchical analysis method in Type-2 fuzzy sets were followed based on the data of this example. To avoid redundancy, **Table 11** is used to form a pairwise comparison matrix (First Expert's Score for C1 Criterion in Underground Mines Based on Type II Trapezoidal Fuzzy Numbers).

In step 4 of adjustment (adjustment is meant to determine the scoring accuracy of each element relative to the original diameter), the fuzzy pair-type comparison matrix of type II (First expert's score for C1 criterion in open pit mines based on type II trapezoidal fuzzy numbers) was investigated. At this stage, the adjustment check of each decision was verified, and the validity of the values over each other with respect to the original diameter was specified. In step 5, the fuzzy geometric mean for each raster was determined according to the following relation (see **Table 12**).

The sixth step was to calculate the normalized fuzzy weight for each criterion according to the following relation (see **Table 13**). After determining the weight of the sub-criteria, the total weight of each sub-criterion was calculated by multiplying the weight of the geological sub-criteria by the weight of criterion C1 (see **Table 14**).

In step 7, the importance of different criteria was ranked by determining the final weight of each criterion. To rank the importance of different criteria, the center of gravity method was used in accordance with **Figure 2**. Finally, the normalized weights for each of the sub-criteria were calculated for C1 criterion (see **Table 15**).

According to the above procedure, the steps of the hierarchical analysis method in Type-2 fuzzy sets were followed for all criteria and groups in Faryab chromite underground mines. The output of this method is presented in **Tables 16** to **18**.

3.2.3. Comparison of FAHP method in Fuzzy Type-1 and Type-2 Sets

To compare these two methods, first, based on Pareto analysis, the most important group of hazards were set to have 35% of the final score of each hazard.

The most important risks in each group were determined in terms of the weighted average of the highest and the lowest risk weights, resulting in a better categorization of hazards. Besides, rating hazards and comparing them with mine accidents result in ease of understanding, and high accuracy of the evaluation method and its consequences (see **Figure 5**)

A comparison of these two methods indicates that in the hierarchical analysis method in type II fuzzy sets, the uncertainty is eliminated better and more properly than

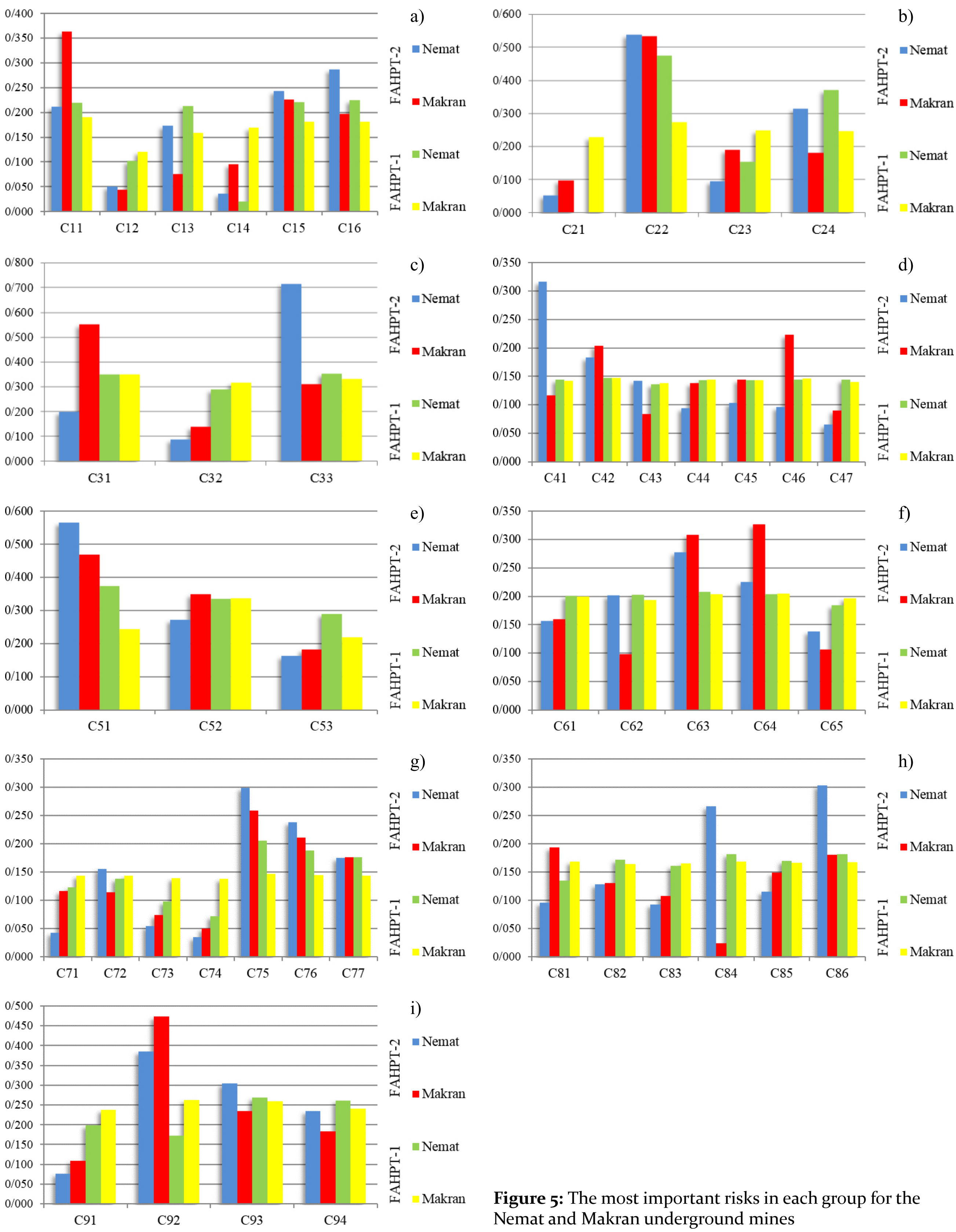

Figure 5: The most important risks in each group for the Nemat and Makran underground mines

through the fuzzy hierarchical analysis method. It can easily be seen and noted by comparing **Figure 5** of the C21 criterion. The hierarchical analysis method in fuzzy sets of type 2 criteria with higher scores are more weighted than criteria with lower scores, which makes it easier to make decisions in the assessment process. It was found that the implementation of the hierarchical analytic method in type-2 fuzzy sets has both advantages

Table 19: Response to risks in Faryab Chromite underground mines

Risk title	Weight of sub-criteria	Response to Risks
Adequate ventilation of existing dust	0.715	Applying suitable fans and avoiding the use of a shotcrete device for concrete spraying.
Incorrect scaling	0.565	Direct inspection and supervision for scaling process and employing expert crews.
The required air flow	0.551	Modification of ventilation system in the maingate and development of a periodical inspection plan for various places from ventilation point of view.
Scaling after blasting	0.539	Provide a checklist for regular inspection of scaling after each blasting.
Psychological parameters such as hard working conditions and non-payment of salaries	0.474	Providing normal working conditions, along with timely payment of salaries.
Roof-fall or wall-fall	0.363	Direct surveillance of geological conditions in high risk extraction sites.
Not-rigid support devices	0.350	Replacement of worn-out support system in high risk places.
Installation of electrical enclosure in humidity environment	0.327	Installation of power substations using permanent concrete platforms in air-dry places.
Ignoring to adhere the standard distances between electrical cables and other facilities	0.308	Providing proper distance between electrical cables and installed equipment with respect to the existing standards.
Human errors	0.304	Holding permanent workshops, application of supervision checklists, supervision and considering penalties for work offenders.
Unavailability of personal protective equipment	0.303	Equipping various sections of mine with personal protective equipment.
Pressing people between machineries and equipment	0.299	Holding training courses for newcomers.
Formation of dunite blocks and serpentinization	0.286	Using suitable support system in high risk sites and prevention of weathering the dunite zone.
Surveying and inspection of equipment and machineries before beginning of the operation	0.266	Development of permanent monitoring system for inspection of equipment and machineries prior to beginning of the operation.
Tectonic conditions such as fault, joint, etc.	0.243	Identify high risk and downfall points and direct monitoring of these points.
Vehicle collision with people	0.238	Highlighting the high risk places through signboard, warning signs and holding training courses for individuals.
Exceeding the speed limit of vehicles	0.223	Installation of signboards and warning signs across the roads, especially in the high risk sites, as well as development of regulations and continuous supervision.
Inhalation of smoke and toxic gases produced by blasting	0.190	Modification of ventilation system in maingate and application of personal protective equipment.
Getting stuck body with sharp edges	0.176	Holding training courses for individuals and use of personal protective equipment.
Overturn of vehicles	0.144	Installation of signboard and warning signs in high risk places and their regular supervision.
Wagons have not properly been attached	0.138	Monitoring wagons' situation, its operability and specifying the wagons location.
Transportation machineries are being equipped with the safety equipment	0.131	Development of permanent supervision plan for inspection of equipment. It is done to ensure that they are equipped with safety equipment.

and disadvantages as compared to type-1 fuzzy analytic method.

The advantages of the FAHP type-2 method:

- more precision for calculations rather than similar methods;
- ease of decision-making based on the type of evaluation;
- applying the weight of each criterion on its sub-criteria;
- it is possible to estimate the weight of criteria based on sub-criteria up to N steps;
- elimination of uncertainty with respect to the method of determining final weight for each criterion.

3.2.4. Comparison of FAHP method in Fuzzy Type-1 and Type-2 Sets with Mine Accident Data

To determine the accuracy of the calculations and to validate the results of the risk assessment, the results of the risk assessment were examined with the mine accident documents available in the Faryab Chromite Mines Safety and Environment Unit as seen in **Figure 4**. By comparing **Figure 4** with **Tables 16** to **18**, it can be concluded that most of the accidents are within the identified hazards through risk assessment. The risk assessment of each group of hazards was evaluated separately. In this section, according to the descriptions recorded by the Safety, Health and Environmental Unit of the mine, as recorded after the event, the major causes of each event were identified according to the identified hazard group.

Figure 5 shows the importance of each of the sub-criteria for the Nemat and Makran mines. By comparing section, *a* to *i* in this figure, one can see the superiority of fuzzy hierarchical analysis in type-2 fuzzy sets over type-1 fuzzy. The high accuracy of the calculations in the fuzzy type-2 analytic hierarchy process compared to the type-1 fuzzy is easily observable. In the fuzzy type-2, the calculations' accuracy is higher because the scope of the evaluation is wider (see section *a* to *i*). In the fuzzy type-2 hierarchical analysis method, unlike fuzzy type-1, where all criteria are uniform and close to another (For example, compare the sub-criteria C_{33} with C_{32} in section c). In the fuzzy type-2, The difference between the weights of the criteria is better shown (for example, compare the weight of sub-criterion C_{11} with sub-criterion C_{12} in section *a*), and it makes decision easier. Another advantage of the hierarchical analysis of type-2 is the accurate weighing of criteria. In section *b* the final value of C_{21} sub-criterion in Fuzzy Type-1 and Type-2 are 0 and 0.052, respectively. In decision-making, a zero value means that the option is not important, according to the experts' ratings.

3.2.3. Response to Risks

In this section, the responses to the identified risks, according to experts and similar projects, are presented in **Table 19**. In **Table 19**, the response to each risk is prioritized by the importance of each of the sub-criterion from highest to lowest. The division is done accorded by the weight of sub-criteria. For example, sub-criterion C_{33} with a weight of 0.715 is more important than sub-criterion C_{44} with a weight of 0.131. The red box in this table are high risk parameters and the yellow box are low risk parameters.

4. Conclusion

Safety risk assessment is one of the most effective ways to reduce hazards in mines. The most important way to reduce accidents and increase safety is to use the risk management process to identify and respond to significant hazards in mines. The present study is an attempt to investigate the assessment and management of safety risks in Faryab chromite underground mines. In this paper, the method of AHP in type-1 and type-2 fuzzy sets were used for risk assessment. Upon studying two underground mines of Faryab chromite (Makran and Nemat), 45 hazards were divided into 9 groups, among which 7 main risks were eventually identified. Based on the results, the most important hazards in the Nemat underground mine are the required airflow (0.715), incorrect scaling (0.565), and post blast scaling and the required airflow (0.551 respectively. Similarly, the assessment of hazards in the Makran underground mine showed that scaling after blasting (0.539), psychological parameters such as hard working conditions and non-payment of salaries (0.474), roof-fall or wall-fall (0.363) and not-rigid support devices (0.350) were the most important hazards.

Also, a comparison of method Fuzzy Type-1 and Type-2 sets indicates that in the hierarchical analysis method in type II fuzzy sets, the uncertainty is eliminated better and more appropriately than through the fuzzy hierarchical analysis method. In the AHP type-2 fuzzy, the criteria with higher values have more weight than criteria with lower values, which makes it easier to make decisions in the assessment process. In the fuzzy type-2, the calculations' accuracy is higher because it is possible to estimate the weight of criteria based on sub-criteria up to N steps. Finally, according to the mine conditions and the experts, descriptions, review of similar projects and accident documents in the mine safety, health and environmental unit, the proper risk response is applied for each hazard. Also, in this study, some disadvantages of the fuzzy type-1 hierarchical analysis method compared to the fuzzy type-2 are introduced. The use of the method fuzzy type-2 is recommended to carefully classify hazards before starting the assessment because this makes calculations easier.

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SAŽETAK

Procjena i upravljanje sigurnosnim rizikom uporabom hijerarhijske analize neizravnoga skupa podataka tipa 1 i 2, primjer podzemnoga rudnika kromita Faryab

Godišnja stopa smrtnosti rudara u svijetu vrlo je visoka. Jedan od načina smanjivanja rizika, odnosno povećanja sigurnosti rudarenja, jest upravljanje takvim rizikom i prepoznavanje glavnih opasnosti. U radu je prikazano istraživanje takve procjene u podzemnome rudniku kromita Faryab. U ocjenjivanju rizika uporabljene su metode AHP-a na neizravnim skupovima podataka tipa 1 i 2. Izučena su dva podzemna radilišta u spomenutome rudniku (Makran i Nemat). 45 opasnosti podijeljeno je u 9 skupina sa 7 temeljnih rizika. Najveća opasnost na radilištu Nemat jest protok zraka te ocjena primjerenoga izvlačenja jalovine, posebice nakon miniranja. Vrlo slična procjena načinjena je i za radilište Makran. Nakon otkrivanja uzroka nesreća, na temelju evidencije nesreća u jedinici za sigurnost, zdravlje i zaštitu okoliša, opisa tehničkoga osoblja i sličnih projekata rizika, pripremaju se odgovarajuće reakcije za svaku skupinu opasnosti.

Ključne riječi:
sigurnosni rizik, upravljanje rizikom, podzemni rudnik kromita Faryab, neizravna hijerarhijska analiza, neizravni skup tipa 2

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