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Identification and Ranking of Factors Affecting the Emission of CO Gas in Karkar Coal Mine

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ABSTRACT

Karkar coal mine is one of the largest mines in Afghanistan, where mining has been ongoing since 1938. Throughout its operational history, the Karkar mine has experienced unfortunate incidents caused by the release and explosion of gases, resulting in substantial financial and human losses. Carbon monoxide gas is one of the primary factors contributing to accidents in the Karkar mine. This research includes literature reviews, field data collection using the CEM CO-181 model gas meter, and statistical calculations employing Shannon entropy and PROMETHEE methods. Initially, the concentration of CO gas was measured in ventilation tunnels, development, and excavation areas. Extraction workshops of the Karkar coal mine were monitored at different working times. Subsequently, 26 cases that may contribute to a reduction in accidents were used as effective criteria, and 9 cases were identified as influential factors on CO emissions through the distribution of questionnaires and interviews with recognized experts. The final weights of twenty-six effective criteria on the emission of CO gas were calculated based on the Shannon entropy method. As a result, the criterion of consumed oils, with a final weight of 0.1790, was ranked first, while the criterion of lack of experience, with a final weight of 0.1065, was ranked last. The influential factors have been ranked based on the amount of net flow and the PROMETHEE method. Consequently, the factors of mining fire and coal dust explosion ranked first and last, respectively, with net flows of 0.55 and -0.84. The remaining factors are positioned according to their net flow rates and have varying effects on the emission of CO gas.

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INTRODUCTION

Since Afghanistan is rich in mineral resources and has large mines, coal mines also form a significant part of these mineral resources. Karkar coal mine is one of the biggest coal mines in Afghanistan, including the rich coal field of Pol-e-Khomri (Wnuk 2016). This mine is located in Baghlan province, 12 km northeast of Pol-e-Khomri city, which is separated from the

Chimney coal mine by an extensive tectonic fracture. The size of the Karkar mine area is 0.95 km in the longitudinal direction and 0.8 km in the downward direction (Mir Fakhreddin, 2011).

Carbon monoxide (CO) is a colorless, odorless, and tasteless gas whose specific gravity is 0.97 times that of air; therefore, it is almost the same as air (Dey and Dhal 2019). The CO gas is highly toxic and causes death in minimal percentages. This is because CO mentioned has a tendency to combine with blood hemoglobin (250-300) times more than oxygen has to combine with hemoglobin (Jasani 2015), so no matter how low the amount of CO gas is, some of it still enters the blood. And as a result of combining with hemoglobin, it forms carboxyhemoglobin (Siddiqui, 2020).

When 70-80% of hemoglobin combines with CO, the blood is almost saturated with CO, which causes death (Widdop 2002). In general, it can be said that if the percentage of CO is less than 0.1%, then there is no side risk in a short period, but the amount of 0.1% causes headaches and minor poisoning. An amount of 0.15-0.20% may produce dangerous poisoning (Rahilly and Mandell 2009). 20-30 minutes of breathing in the air where the amount of CO is around 0.50% will lead to death, and if its amount reaches 1%, it will cause immediate death of people (Dear 2014). According to the safety regulations of the former Soviet Union, the amount of CO gas in the air of mines should be less than 0.0016%. However, the United States' regulations have set their limit at 0.01%. The most important sources of CO gas production are mine fires, coal oxidation (Wojtacha-Rychter and Smoliński 2020), the explosion of explosives, and the operation of locomotives and diesel engines. In addition, if the amount of coal remains inside the holes, it will turn into carbon monoxide due to incomplete combustion (Madani, 2018).

Considering the number of accidents caused by the emission of CO gas and the financial and life losses in the Karkar mine, the idea of evaluating the factors of the said gas emission has been created. Since no research has been done on any of the mines, evaluating CO gas in the mentioned mine is urgently needed. Investigating how the amount of CO gas in the Karkar mine causes accidents is more important. Because it is possible to make a pathology in the field and make the people who interact with it aware, the number of accidents caused by the mentioned gas can be reduced.

Since CO is one of the poisonous and deadly gases in the Karkar coal mine, it has always caused the poisoning and death of workers in the mine. And still, most of the accidents recorded during the lifetime of the mentioned mine are due to CO emissions. This problem has persisted and has not yet been resolved, which always causes financial losses (coal fire, mining equipment fire, loss of coal ready for extraction, stoppage of production, and daily operating costs while the mine is not producing). It brings life (poisoning and death of workers) to the mining processes. Therefore, research on the factors affecting the emission of this gas is more important.

Gases form large volumes in coal-bearing layers and are considered one of the dangerous phenomena in mining processes (Xu et al., 2023). All the mines, in the early stages of formation, place some gases in the seams, holes, and voids on the floors, and during drilling and extraction, these gases are emitted in different forms. The gases in the coal seams in the Karkar coal mine are standard and constantly emitted from the coal seams and nearby stones during drilling and extraction. No research has been done to identify factors affecting the emission of CO gas in the mentioned mine. Still, some standards have been defined regarding the amount of carbon monoxide gas in underground mines, which is included in Table 1.

Table 1. Permissible limit of carbon monoxide gas in the air of underground mines according to concentration and contact time (Siddiqui 2020)

Country	Condition	Allowed size	
		Percent	PPM
United States of America	8 hours of continuous work	0.005	50
	Short term call up to 15 minutes	0.04	400
Russia	8 hours of continuous work	0.0016	16
Spain	8 hours of continuous work	0.005	50
South Africa	8 hours of continuous work In the gold mine	0.01	100
Australia	8 hours of continuous work	0.003	30

Past studies have been conducted based on the needs of the respective societies in the respective countries. However, in Afghanistan, especially the Karkar coal mine, no extensive research has been done regarding all types of gases. A few studies have been done concerning Karkar coal mine (Assessment of methane gas in Karkar mine, ventilation study of Karkar mine, and USGS report regarding the mining situation in Karkar mine and some reports of other institutions). Still, no research has been done on carbon monoxide gas. This research is based on detailed studies and measurements of CO gas from all exploratory and extraction tunnels, and its essential purpose is to identify the influential factors and determine their position on the emission of CO gas using Shannon entropy and Promethee methods, which is a rare and different research from the past.

METHODS & MATERIALS

In this research, after a literature review and field studies, questionnaires were first designed in the form of Shannon's entropy method 26 items were given as effective criteria, and 9 items were given as influential factors on carbon monoxide emission(Aziz and Rahmatzai, 2024). The distribution of questionnaires for experts is based on the requirements of field and specialization, which includes Karkar coal mine engineers and mining engineering elites. The experts' judgment was made based on the numbers defined in Table 2. Then, the criteria weights were determined based on the results of the questionnaires and the steps of Shannon's entropy method in Excel. In the next stage, the second questionnaire was designed using the Promethee method to obtain the influential factors' position, which experts judged based on the numbers defined in Table 5. According to the weights of the criteria, which are the results of the Shannon entropy method and the results of the questionnaires in the Promethee method, the ranking of the influential factors has been done. Since every research has a structure, the structure of this research also includes a regular and understandable structure, which is arranged in the form of a flowchart, which is drawn in Fig 1, to explain further the topic of the general structure of the research.

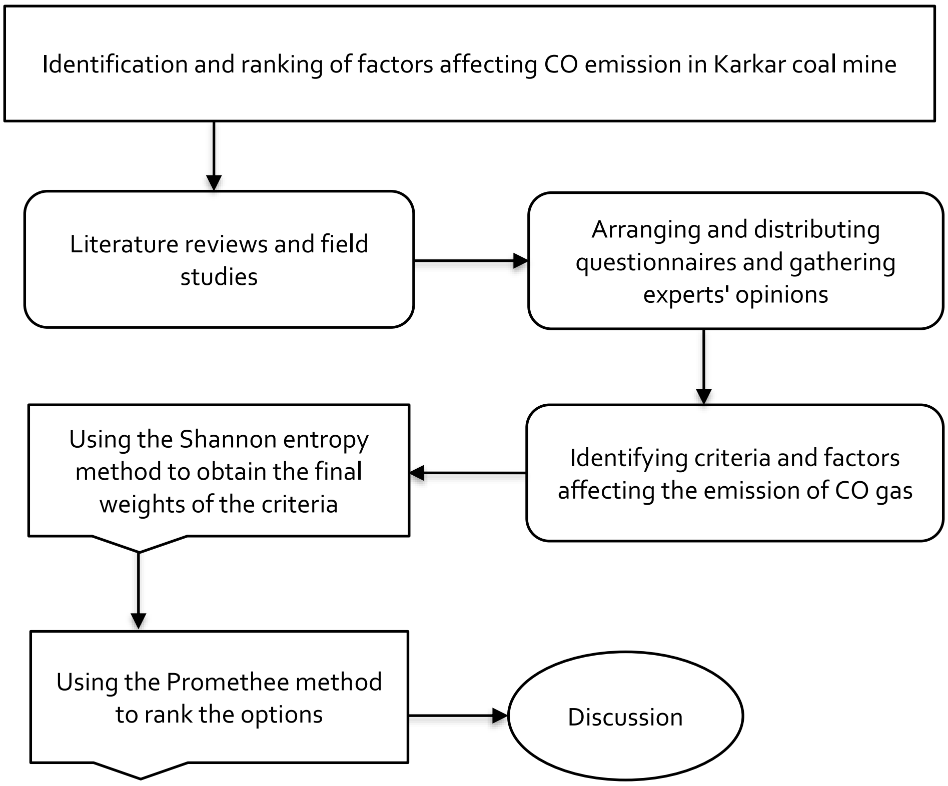

Fig 1. General flowchart of research

Determining the weights by the Shannon entropy method

The entropy method is one of the multi-criteria decision-making methods for calculating the weight of the criteria, which requires the formation of a criteria-option matrix(Yue 2017). The mentioned method was presented in 1974 by Shannon and Weaver(Lotfi and Fallahnejad 2010). Shannon showed that events with a high probability of occurrence provide less information, and conversely, the lower the likelihood of an event, the more information it provides. Shannon's entropy method is one of the multi-criteria decision-making methods, and in this research, its non-fuzzy type is used to obtain the weights of the criteria.

Questionnaires were arranged in the form of Shannon's entropy method to obtain the weights of the practical criteria on the emission of CO gas in Karkar coal mine, and experts were interviewed. According to the steps of Shannon's entropy method, in this research, questionnaires were first arranged in the form of factors and criteria influential on the emission of CO gas in the Karkar coal mine. Then, 150 mining experts and engineers were interviewed. According to the problems and limitations of the research, only 10 of the questionnaires were selected as samples, and their results were examined. Questionnaires are arranged in the form of 9 factors (options) and 26 effective criteria on the emission of CO gas in the Karkar coal mine, and a sample of the questionnaire is explained in Table 1 of

Appendix 1. To obtain the final weights of the criteria, a weight is usually assigned to each criterion so that the sum of the criteria weights is equal to one. Various methods have been defined to determine the criteria weights, including the entropy method, the Linmap method, the eigenvector method, and the least squares method(Gu 2017). This research used the Shannon entropy method to obtain the final weights of the criteria, which is explained below.

To determine the final weights of the criteria according to the steps of Shannon's entropy method, quantitative numbers were first defined to evaluate the importance of the requirements compared to the options (factors), which are included in Table 2. The membership function of small numbers is also shown in Figure 2. Then, the arrangement and distribution of questionnaires and interviews with experts were made; based on their results, the decision matrix was formed according to Relation 1, and Table 2 is included in Appendix One.

Table 2. Quantitative numbers to evaluate the importance of criteria compared to options

Explanatory phrases	Degree of importance
Very unimportant	0.00
Relatively unimportant	0.50
Equal importance	1.00
Relatively importance	1.50
Highly importance	2.00

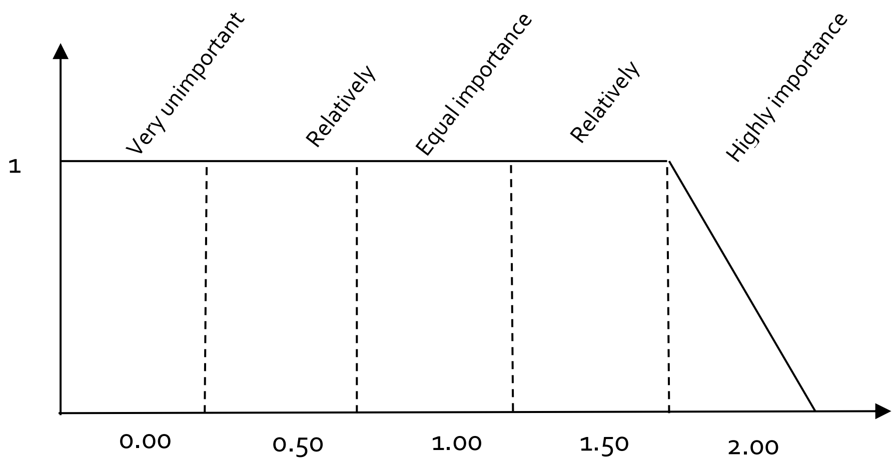

Fig 2: The membership function of quantitative numbers to evaluate the importance of criteria

$$X = \left[X_{ij}\right]_{n\times m} = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1m} \\ X_{21} & X_{22} & \cdots & X_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ X_{n1} & X_{n2} & \cdots & X_{nm} \end{bmatrix} \qquad 1$$

After forming the decision matrix based on the results of the questionnaires, the decision matrix has been normalized based on Equation 2. To normalize the decision matrix, it is necessary to divide the values of each column of the decision matrix by the total number of its columns and write it as a new value in the normalized matrix. The normalized matrix is included in Table 3 of Appendix 1.

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}} \qquad 2$$

Entropy (E_j), degree of deviation (d_j) and normalized weight (w_j) of each criterion are calculated based on relations 3, 4, and 5, which includes table 3, and k is obtained as a constant value of E_j For all criteria from relation 6 to be made, the k price equals 0.455 according to the number of indicators (factors).

$$E_j = -K \sum_{i=1}^{m} P_{ij} \times L_n P_{ij} \qquad i = 1.2. \ldots\ldots m \qquad 3$$

$$d_j = 1 - E_j \qquad 4$$

$$W_j = \frac{d_j}{\sum_{i=1}^{m} d_j} \qquad 5$$

$$k = \frac{1}{\mathrm{Ln}\,(n_i)} \qquad 6$$

Table 3. Entropy (E_j), degree of deviation (d_j) and normalized weight (w_j) of criteria

	Criteria	E_j	d_j	w_j
1	A1	0.963	0.037	0.013
2	A2	0.888	0.117	0.042
3	A3	0.922	0.078	0.028
4	A4	0.973	0.027	0.010
5	B1	0.936	0.064	0.023
6	B2	0.935	0.065	0.024
7	B3	1.005	-0.005	-0.002
8	C1	0.961	0.039	0.014
9	C2	0.664	0.336	0.123
10	C3	0.800	0.200	0.072
11	D1	0.700	0.300	0.109
12	D2	0.631	0.369	0.134
13	D3	0.631	0.369	0.134
14	E1	1.075	-0.075	-0.027
15	E2	0.922	0.078	0.082
16	E3	0.785	0.0215	0.078
17	F1	0.949	0.051	0.018
18	F2	0.740	0.0260	0.094
19	F3	0.906	0.094	0.034
20	G1	0.882	0.118	0.043
21	G2	0.885	0.115	0.042
22	H1	1.035	-0.035	-0.013
23	H2	1.123	-0.123	-0.044
24	I1	0.987	0.013	0.005
25	I2	0.837	0.0163	0.059
26	I3	1.110	-0.110	-0.040

Recently, the final weight of the criteria (W_j^0) has been calculated according to the degree of deviation and the relative weight of the criteria according to equation 7, and the results are included in Table 5. In the mentioned relationship (λ_j) is a remarkable weight that is defined for each criterion in advance.

$$W^0{}_j = \frac{\lambda_j \ W_j}{\sum_{j=1}^{m} \lambda_j W_j} \qquad 7$$

Ranking of influential factors by using the Promethee method

In this section, by using the output data from the Shannon entropy method and by ordering and distributing the questionnaires in the form of the Promethee method, the ranking of the factors affecting the emission of CO gas using the Promethee method, which is one of the multi-criteria decision-making methods, is done The ranking of factors affecting the emission of CO gas in Karkar coal mine has been done based on the net flows that are carried out by the Promethee method.

This method was designed by Vinck & Brans in 1982 and developed by her colleagues in 1994 (Liang, Fu, and Garg 2024). This method is a multi-criteria decision-making (MCDM) method (Taherdoost 2023) based on comparing one option. The PROMETHEE[1] method uses definite numbers to rank the options from best to worst (Brans, Vincke, and Mareschal 1986). To use this method in solving the problem, the following must be specified by the decision maker (Zhang et al., 2023):

1. Essential indicators in the issue
2. Weight of indicators
3. The influence of the indicator on the problem should be such that if the corresponding indicator has a negative effect, it should be reduced, such as in terms of cost.
4. Choosing the preferred pattern from the six main patterns
5. Decision matrix that includes options and indicators and their corresponding data (Behzadian, M; Kazemzadeh, R B.; Albadvi, A.; Aghdasi, 2010).

This method can be named (the structural preference ranking method for maximum valuation), which, as its name implies, tries to approach it structurally and use the actual values of the criteria for evaluation (Vinodh and Jeya Girubha 2012). To rank the options first, similar to Shannon's entropy method, it is necessary to organize questionnaires in the form of a parametric method and to interview experts to gather the views and opinions of experts and specialists. After arranging and distributing the questionnaires, 150 experts were interviewed. The judgment of the experts was based on the pre-defined range of numbers, which is included in Table 4, and the membership function of the Promethee method is explained in Fig 3. A sample of questionnaires is also presented in Table 4 of Appendix 1.

Table 4: The range of quantitative numbers defined for valuing the options concerning the criteria

Explanatory phrases	Auxiliary numbers
Very much	4
much	3
medium	2
Low	1
very Low	0

[1] *Preference Ranking Organization Method for Enrichment Evaluation*

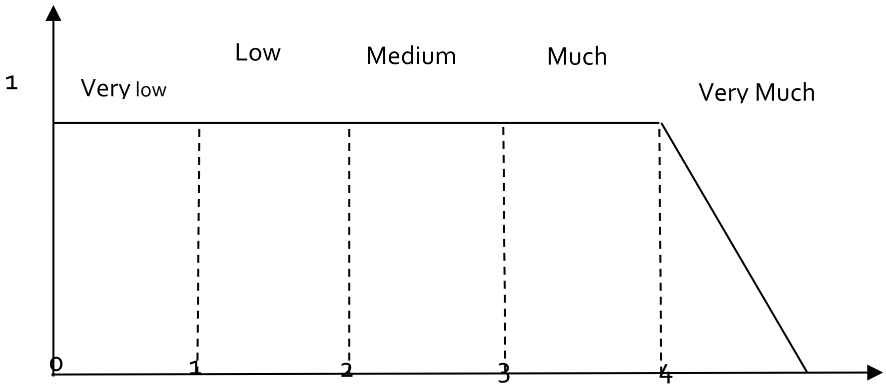

Fig 3. The membership function of quantitative numbers to value the options compared to the criteria

After interviewing the experts and collecting their opinions, the decision matrix was formed based on the results of the questionnaires and the steps of the Promethee method, which includes Table 5 of Appendix 1. Then, the difference between each option and other options was calculated according to the criteria, which was omitted due to the larger volume.

The options (factors) ranking has been done based on net flow. The positive and negative flows of the alternatives were calculated according to the results of the method and the use of relations 8 and 9. Then, the options' net flow (total flow) was computed using relation 10, followed by ranking the influential factors. Based on the amount of net flow, which is included in Table 6.

$$\forall x \in A \to \varphi^{+} = \frac{\sum \pi(a.x)}{n-1} \quad 8$$

$$\forall x \in A \to \varphi^{-} = \frac{\sum \pi(x.a)}{n-1} \quad 9$$

$$\forall x \in A \to \varphi(x) = \varphi(x)^{+} - \varphi(x)^{-} \quad 10$$

FINDINGS AND DISCUSSION

Since this field-statistical research was done using new statistical methods (Shannon entropy and Promethee), it brings many results. First, the questionnaires were organized in the form of Shannon's entropy method to obtain the weights of the practical criteria for the emission of CO gas in Karkar coal mine, and experts were interviewed. According to the steps of Shannon's entropy method, in this research, questionnaires were first arranged in the form of factors and criteria influential on the emission of CO gas in the Karkar coal mine. After the distribution, 150 mining experts and engineers were interviewed. According to the problems and limitations of the research, only 10 of the questionnaires were selected as samples, and their results were examined. Questionnaires are arranged in the form of 9 factors (options) and 26 effective criteria on the emission of CO gas in the Karkar coal mine, and a sample of the questionnaire is explained in Table 1 of Appendix 1. Shannon's entropy method was used to calculate the final weights of the criteria, and according to the steps of the mentioned method, the final weights of the criteria were calculated and included in Table 5.

Table 5. The final weights of the criteria according to the defined relative weights

Criteria	A_1	A_2	A_3	A_4	B_1	B_2	B_3	C_1	C_2	C_3	D_1	D_2	D_3	E_1	E_2	E_3	F_1	F_2	F_3	G_1	G_2	H_1	H_2	I_1	I_2	I_3
w_s	0.040	0.080	0.070	0.060	0.060	0.030	0.050	0.020	0.010	0.020	0.010	0.020	0.030	0.060	0.050	0.020	0.020	0.010	0.050	0.030	0.040	0.060	0.040	0.050	0.010	0.060
$\tau_j w_j$	0.0005	0.0034	0.0020	0.0006	0.0014	0.0007	-0.0001	0.0003	0.0012	0.0014	0.0011	0.0027	0.0040	-0.0016	0.0014	0.0016	0.0004	0.0009	0.0017	0.0013	0.0017	-0.0008	-0.0018	0.0002	0.0006	-0.0024
w_{sj}	0.0238	0.1512	0.0880	0.0264	0.0633	0.0315	-0.0042	0.0125	0.0543	0.0647	0.0485	0.1193	0.1790	-0.731	0.0630	0.0697	0.0165	0.0420	0.0762	0.0575	0.0743	-0.0344	-0.0793	0.0105	0.0264	-0.1065

In the second part, to receive net flows and ranking options, the questionnaires are organized using the Promethee method, which includes Table 4 of Appendix 1. 150 experts were interviewed; among them, 10 cases were selected as samples, and the rest of the calculations were based on them. According to the results of the questionnaires and the final weights of the criteria, which were calculated using the Shannon entropy method, as well as the steps of the Promethee method, first the positive flow and the negative flow, and in the next step, the net flow of options was calculated. The results of the Promethee method indicate that among the 9 candidate options as influential factors on the emission of CO gas, the option of mining fires with a net flow of 0.55 is in the first rank. The option of coal dust explosion with a net flow of -0.84 is ranked last, And the rest of the factors are placed in different positions according to the amount of their net flows, which is explained in Table 6 and Figure 4.

Table 6. Ranking of factors based on net flow

options (factors)	**Characteristics of factors**	**positive flow**	**Negative flow**	**Net flow**	**rank**
Mine fires	A	-0.59	-1.14	0.55	1
Coal oxidation	B	-0.35	-0.63	0.28	5
Explosion Materials Explosives	C	-0.08	-0.56	0.48	4
Working of locomotives and diesel engines	D	-0.66	0.07	-0.73	8
Rock explosion	E	0.64	0.14	0.50	3
Coal dust explosion	F	1.08	1.92	-0.84	9
Methane gas explosion	G	0.67	0.94	-0.27	6
Mining in abandoned places	H	-0.69	-1.22	0.53	2
Irregular mining system	I	-0.02	0.48	-0.50	7

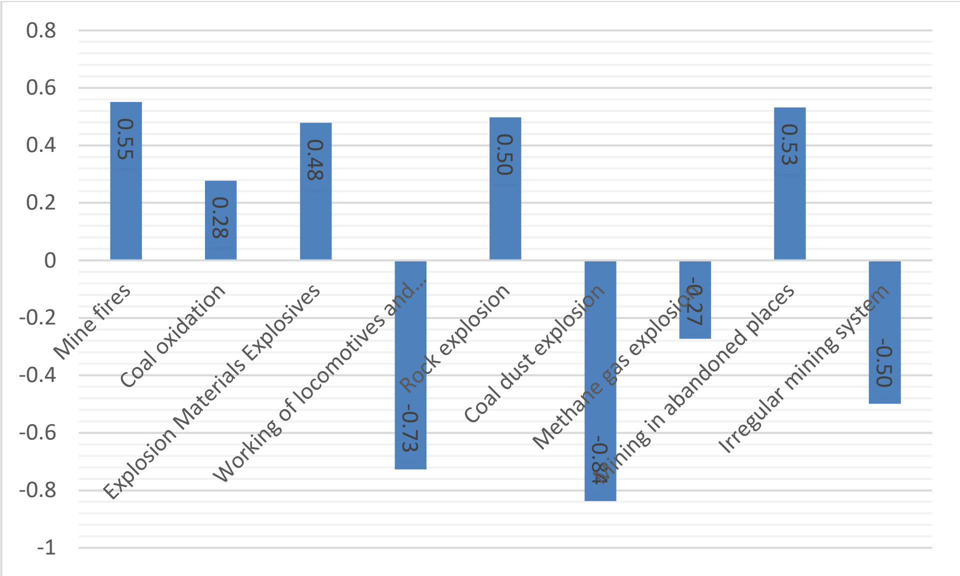

Fig 4. The effect of factors on the emission of carbon monoxide gas based on net flow

According to the ranking table of options and calculations, the Karkar coal mine is one of Afghanistan's old and worn-out mines, and all its coal fields have been mined. Therefore, mine fires constitute a significant part of mining challenges and are always active in the mentioned mine, causing financial and human losses and being one of the primary sources of CO gas production. From there, mining in the Karkar coal mine is done in abandoned areas, which have been oxidized due to extensive fractures and porosity. As a result, the oxidation of the mentioned materials emits large volumes of CO gas in the tunnels, which causes mining challenges and is one of the essential factors in the amount of CO gas emission.

DISCUSSION

The factors of mineral fires with a net flow rate of 0.55 are in the first rank of the effects on CO gas emissions. This indicates that the Karkar coal mine is one of the most dangerous mines from the point of view of fire, which is based on the fractures of the floors due to previous mining and the self-combustion properties of coal. Mining fires in the mentioned mine started working continuously with the entry of oxygen in the seam and voids. After going through the stages of the process, the fire is activated and emits CO gas, which causes poisoning and death of mine workers.

Karkar coal mine is one of the country's most prominent and old mines and has been going on for a long time. The areas explored in the past have been thoroughly mined, and the work is ongoing in abandoned places. As a result of mining, fractures, and pores have been reopened, and oxygen enters the seams due to the coal oxidation process; some gases are emitted in the space of the tunnels, which causes partial and dangerous poisoning. Therefore, the mining factor in abandoned fields is ranked second with a net flow rate of 0.53. Rock explosion is another factor that directly affects the instantaneous emission of CO gas. As a result, the amount of gases in the mine increases immediately. Since this factor mainly occurs in young mines and non-extracted layers under the intense pressure of the earth's layers and the mines' depths, it has a lower net flow in the Karkar coal mine, which does not have the above conditions.

Options of coal dust explosion and the work of locomotives and diesel engines in this research have less net flow because there has been no incident of coal dust explosion in the Karkar mine for several years. There has always been controversy about the phenomenon of dust in mines, and ways to prevent and reduce dust are active in mining programs. On the other, locomotives and diesel engines have not been used in the Karkar coal mine for a long time, and the smoke produced as a result of the operation of these machines is the main factor in the amount of CO gas emission that is not emitted either. Therefore, these factors have an insignificant net flow in this research.

CONCLUSION

Since this research is based on statistics and numbers and the use of Shannon entropy and Promethee methods, the following can be stated as conclusions:

According to the measured results of the concentration of CO gas in the extraction tunnels of the Karkar coal mine and comparing it with the international standards, we conclude that the extraction tunnels are in a dangerous and illegal condition due to the vital need to Air supply is necessary for diluting CO gas.

From Shannon's entropy method, it can be concluded that the criteria of the type of fuel used with a final weight of 0.1790, spontaneous combustion with a final weight of 0.1512, and the kind of fuel with a final weight of 0.1193 are among the items that are the first, second and third highest respectively. They have a share in the emission of CO gas. Also, the criteria of lack of experience with a final weight of 0.1065, lack of a development plan with a weight of 0.0793, and depth of the mine with a final weight of 0.0731 are among the items that respectively have the lowest share in the amount of CO gas emission in Karkar mine.

The ranking of options has been done based on the number of net flows as a result of factors such as mining fires with a net flow of 0.55 in the first place, mining in abandoned places with a net flow of 0.53 in the second place, rock explosion with a net flow rate of 0.50 in the third place, explosion materials explosives with a net flow rate of 0.48 in fourth place, coal oxidation with a net flow rate of 0.28 in fifth place, methane gas explosion with a net flow rate of -0.27 in sixth place, irregular mining system with flow rate Net - 0.50 in the seventh place, the work of locomotives and diesel engines with a net flow rate of - 0.73 is in the eighth place and the coal dust explosion factor with a net flow weight of - 0.84 is in the last rank of the effects on the emission of carbon monoxide gas.

Since the Karkar underground coal mine is one of the oldest mines, all the areas have been explored and mined, and mining is now going on in abandoned places; mining fires are part of the daily work of this mine. Also, the extracted regions are not blocked in their basic form, and oxygen quickly penetrates the abandoned places, which causes mine fires with external impulses. Since mine fires involve different stages, including the oxidation of coal, ignition, and the creation of long flames in this mine, the building emits carbon monoxide gas in all stages. Hence, mine fires are the first option with the highest net flow rate.

Due to the drilling and mining workshops of Karkar, coal is constantly sprayed with water, and most of the work points are located in the second layer, where the moisture level is higher. Due to the amount of dust collected in the mentioned mine, fortunately, there has been no coal dust explosion in the Karkar coal mine for several years. It should also be remembered that the amount of CO gas emitted from excavation and destruction of layers of coal dust particles is insignificant compared to mining fires; therefore, the cause of coal dust explosion has a smaller share of the emission of the mentioned gas.

Conflict of Interest: The authors declare no conflict of interest.

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Appendix 1:

Table 1: The structure of the questionnaire in the Shannon entropy method to determine the final weights of the criteria

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Options/criteria	**Physical and mechanical properties (A_1)**	**Internal combustion (A_2)**	**Mine ventilation methods (A_3)**	**Mining method(A_4)**	**Improper ventilation (B_1)**	**Preparation methods (B_2)**	**Increase mining time (B_3)**	**Explosive material type (C_1)**	**presence dust in holes (C_2)**	**Incomplete detonation of explosives (C_3)**	**Fault in the locomotive (D_1)**	**Type of fuel (D_2)**	**Type of oil used (D_3)**	**mine depth (E_1)**	**Earth pressure (E_2)**	**Cortical inclination angle (E_3)**	**Size of coal dust (F1)**	**Dimensions of coal dust(F_2)**	**Coal specifications (F_3)**	**Accumulation of methane gas (G_1)**	**Spark or Flame (G_2)**	**Lack of mining facilities and equipment (H_1)**	**Lack of development and monitoring plan (H_2)**	**Demand excess production (I_1)**	**Lack of governance and law enforcement (I_2)**	**Lack of scientific and practical experiences (I_3)**
Mine fires (A)																										
Coal oxidation(B)																										
Explosion Materials Explosives(C)																										
Working of locomotives and diesel engines(D)																										
Rock explosion(E)																										
Coal dust explosion(F)																										
Methane gas explosion(G)																										
Mining in abandoned places(H)																										
Irregular mining system(I)																										

Table 2: Decision matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Options/criteria	A_1	A_2	A_3	A_4	B_1	B_2	B_3	C_1	C_2	C_3	D_1	D_2	D_3	E_1	E_2	E_3	F_1	F_2	F_3	G_1	G_2	H_1	H_2	I_1	I_2	I_3
A	2.0	2.0	2.0	2.0	2.0	1.7	2.0	0.7	0.7	1.7	0.5	0.5	0.5	1.7	1.2	1.0	1.2	0.7	2.0	1.2	1.4	1.5	2.0	1.5	1.0	1.5
B	1.7	2.0	2.0	2.0	2.0	1.5	2.0	0.5	1.0	1.0	0.5	0.5	0.5	1.4	1.5	1.0	0.9	1.0	1.4	1.0	1.4	1.5	2.0	1.0	1.0	1.5
C	0.8	0.5	0.5	0.5	0.5	0.5	0.5	2.0	1.5	1.0	0.5	0.5	0.5	1.0	0.5	0.5	1.0	0.5	0.5	0.5	1.7	0.5	1.0	0.5	0.5	1.5
D	0.5	0.5	1.2	0.5	1.5	0.5	0.5	1.0	0.5	0.5	2.0	2.0	2.0	1.0	0.5	1.0	0.5	0.5	0.5	0.5	0.5	1.0	1.0	1.5	0.5	1.5
E	1.8	0.5	0.7	1.5	1.0	1.7	2.0	1.0	0.5	0.5	0.5	0.5	0.5	2.0	2.0	1.7	1.0	0.5	1.5	0.5	0.5	1.5	2.0	1.5	0.5	2.0
F	1.7	1.7	2.0	1.2	1.7	1.0	1.0	1.2	0.5	1.5	0.5	0.5	0.5	1.7	1.2	0.5	2.0	2.0	1.7	1.0	2.0	1.5	1.5	1.0	1.0	1.5
G	1.2	2.0	2.0	1.2	1.7	1.0	1.0	1.2	0.5	1.5	0.5	0.5	0.5	1.7	1.2	0.5	1.5	1.5	1.5	2.0	2.0	1.5	1.5	1.0	1.0	1.5
H	0.9	0.7	0.5	1.2	0.5	1.5	2.0	2.0	0.5	0.5	1.0	0.5	0.5	1.5	1.0	0.5	1.5	0.5	0.5	2.0	0.5	2.0	2.0	2.0	2.0	1.5
I	0.9	0.7	0.5	1.7	0.5	1.5	2.0	2.0	0.5	0.5	1.0	0.5	0.5	1.5	1.5	1.5	1.5	0.5	1.0	1.5	0.5	2.0	2.0	2.0	1.7	1.7
$\sum P_{ij}$	**11.6**	**10.6**	**11.4**	**11.9**	**11.5**	**11.0**	**13.0**	**11.7**	**6.2**	**8.5**	**7.0**	**6.0**	**6.0**	**13.6**	**10.7**	**8.2**	**11.1**	**7.7**	**10.6**	**10.2**	**10.6**	**13.0**	**15.0**	**22.0**	**9.2**	**14.2**

Table 3: Normalized matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Options/criteria	A_1	A_2	A_3	A_4	B_1	B_2	B_3	C_1	C_2	C_3	D_1	D_2	D_3	E_1	E_2	E_3	F_1	F_2	F_3	G_1	G_2	H_1	H_2	I_1	I_2	I_3
A	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.1
B	0.1	0.2	0.2	0.2	0.2	0.1	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1
C	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.1
D	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.2	0.2	0.2	0.2	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.1
E	0.2	0.0	0.1	0.1	0.1	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.1	0.0	0.1	0.0	0.0	0.1	0.2	0.1	0.0	0.2
F	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.2	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1
G	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1
H	0.1	0.1	0.0	0.1	0.0	0.1	0.2	0.2	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.2	0.0	0.2	0.2	0.2	0.2	0.1
I	0.1	0.1	0.0	0.1	0.0	0.1	0.2	0.2	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.2	0.2	0.2	0.1	0.1

Table 4: The structure of the questionnaire in the Promethee method to determine the weights of the options

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Options/criteria	Physical and mechanical properties (A_1)	Internal combustion (A_2)	Mine ventilation methods (A_3)	Mining method(A_4)	Improper ventilation (B_1)	Preparation methods (B_2)	Increase mining time (B_3)	Explosive material type (C_1)	presence dust in holes (C_2)	Incomplete detonation of explosives (C_3)	Fault in the locomotive (D_1)	Type of fuel (D_2)	Type of oil used (D_3)	mine depth (E_1)	Earth pressure (E_2)	Cortical inclination angle (E_3)	Size of coal dust (F1)	Dimensions of coal dust(F_2)	Coal specifications (F_3)	Accumulation of methane gas (G_1)	Spark or Flame (G_2)	Lack of mining facilities and equipment (H_1)	Lack of development and monitoring plan (H_2)	Demand excess production (I_1)	Lack of governance and law enforcement (I_2)	Lack of scientific and practical experiences (I_3)
Mine fires (A)																										
Coal oxidation(B)																										
Explosion Materials Explosives(C)																										
Working of locomotives and diesel engines(D)																										
Rock explosion(E)																										
Coal dust explosion(F)																										
Methane gas explosion(G)																										
Mining in abandoned places(H)																										
Irregular mining system(I)																										

Table 5: Decision matrix based on the results of the questionnaires and the steps of the Promethee method

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Options/criteria	A_1	A_2	A_3	A_4	B_1	B_2	B_3	C_1	C_2	C_3	D_1	D_2	D_3	E_1	E_2	E_3	F_1	F_2	F_3	G_1	G_2	H_1	H_2	I_1	I_2	I_3
function type	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
threshold of indifference (q)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
threshold of superiority (p)	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Max/Min	min	min	min	min	min	max	max	max	max	min	max	max	max	min	max	max	max	max	min	max	max	min	min	max	max	max
Weight criteria	0.0238	0.1512	0.0880	0.0264	0.0633	0.0315	-0.0042	0.0125	0.0543	0.0647	0.0485	0.1193	0.1790	-0.731	0.0630	0.0697	0.0165	0.0420	0.0762	0.0575	0.0743	-0.0344	-0.0793	0.0105	0.0264	-0.1065
A	1.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.03	3.03	0.00	0.00	0.00	0.00	0.00	0.00	2.00	2.35	2.17	2.17	3.00
B	1.00	0.00	0.00	0.00	0.00	0.00	0.00	2.95	1.87	3.07	0.00	0.00	0.00	2.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	2.05	2.00	1.87	2.38
C	2.64	0.00	0.00	0.00	0.00	0.00	0.00	3.27	3.25	3.27	0.00	0.00	0.00	2.00	2.00	0.00	0.00	0.00	0.00	0.00	2.66	2.00	2.26	2.00	2.00	3.67
D	2.69	0.00	3.00	2.88	3.09	1.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	2.00	1.00	0.00	0.00	0.00	0.00	0.00	2.00	2.08	2.08	2.08	3.89
E	3.18	0.00	1.28	3.27	1.12	3.27	3.27	4.00	1.00	3.00	0.00	0.00	0.00	4.00	4.00	4.00	0.00	0.00	3.18	2.30	0.00	2.14	2.00	2.23	2.23	3.09
F	3.89	3.00	3.00	3.00	3.00	2.00	1.00	3.00	4.00	3.00	0.00	0.00	0.00	2.00	2.00	1.00	4.00	4.00	4.00	4.00	3.00	2.00	2.00	2.00	2.00	4.00
G	3.00	3.00	2.00	2.00	2.00	1.00	0.00	3.00	2.00	1.00	0.00	0.00	0.00	2.00	1.00	2.00	2.00	1.00	1.00	4.00	4.00	1.00	2.00	0.00	2.08	3.89
H	1.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.26	2.26	0.00	0.00	0.00	0.00	0.00	0.00	2.26	3.27	2.26	2.00	3.00
I	2.00	2.00	2.00	3.00	2.08	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	3.00	3.00	0.00	0.00	2.00	0.00	0.00	2.00	3.00	3.00	2.00	3.00