A Model to Determine the Number of Rescue Brigades in Underground Mines using the Risk Factor Approach*

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Abstract

Mine rescue practices have seen significant improvement over the century. There have been developments in breathing apparatus, safe havens, rescue capsules, rescue simulators, underground communication technology, and training for rescue brigades. Most countries practice a mine-owned rescue system and the number of rescue brigades required in a mine is country-specific and determined by the mining regulations of the host country. A review of mining regulations globally shows that the number of brigades required in a mine depends solely on the number of people employed underground. For ages, this has been the only criterion used to determine the number of rescue brigades required in a mine. This criterion is not appropriate since there are other vital factors which must be taken into account. Considering the nature, complexity and innovations in mining operation currently, this paper considers eleven (11) factors that influence the number of rescue brigades in a mine. These eleven (11) factors were subjected to focus group discussions, the Classical Analytical Hierarchy Process, and the Fuzzy Analytical Hierarchy Process to establish seven (7) vital factors with weights more appropriate for determining the number of rescue brigades required in a mine. The results show that the number of rescue brigades required in a mine depends on: the safety culture of the mine; the number of people employed per shift; the resourcefulness of the rescue team; the number of active mines in the mine; the level of mechanisation of the mine, the mining depth; and the nearness and responsiveness of sister rescue teams. A novel model called the Yenzanya Model has been derived for determining the number of rescue brigades for underground mines as a contribution to science. This should be adopted by mine regulators to determine the number of brigades required for mining projects.

Keywords: Mine Rescue, Rescue Brigade, Risk Factors, Yenzanya Model

1 Introduction

Mine Rescue practices have existed for over a century (Anon., 2008a). Previously, mine rescue was a haphazard effort by volunteers who happened to be at the mine site at the time of the incident to save, salvage equipment and men as well as restore mining operations and its environment. These volunteers risked their lives to explore and rescue victims; sometimes got injured or died due to a lack of formal rescue training (Anon., 2008a). The US Bureau of Mines on July 1, 1910 established an act of congress to reduce fatalities in the mining industry; hence mine rescue was then formed. The objectives of mine rescue are basically to save the lives of victims and prevent damage to properties and the environment (Anon., 2008a). Mine rescue objectives have not changed since its inception. Nowadays, rescue operations are highly organised in both underground and surface mines, non-mining industries and communities (Yenzanya and Amegbey, 2018). Emergency preparedness is now factored into mine design and planning and this is backed by Mining Regulations. Emergency management is focused on putting up effective and efficient systems that can detect, control and prevent conditions that initiate accidents.

Mine rescue in Ghana started in the early 1960s by the then Ashanti Goldfields Cooperation now AngloGold Ashanti, Obuasi Mine. The Company took the initiative to train employees who could rescue and recover trapped miners. By the early 1980s, the training had become an integral part of the mine. Currently, there are records of rescue brigades in all the large-scale underground mining projects in Ghana. In Ghana, the rescue brigades are charged with additional responsibilities as follows (Yenzanya and Amegbey, 2018): training employees on the use of breathing apparatus; conducting fire evacuation drills at the various sections of the mine; training employees on emergency procedures and basic firefighting; inspecting, testing and installing fire hydrants, fire extinguishers, and fire alarms

Selecting the required number of rescue brigades for a mine differs across countries because there are no standard criteria tied to the number of rescue contingents. As a result, the number of rescue brigades differs across mines irrespective of the number of employees. Table 1 contains a summary of the various models used by different countries to determine the number of rescue brigades in their mines.

From Table 1, while the Czech Republic requires 5% of the employees to be part of the rescue brigade, the Ireland republic requires 2%. Also, South African regulations require one rescue brigade for 100 employees while Ghanaian regulations require at least 3 brigades for the same 100 employees.

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Table 1 Determination of the Number of Rescue

Country	Number of People (x)	Rescue Brigade(s) Required
Czech Republic (Lehnen *et al.*, 2013)	Total employees	5%
Ireland (Lehnen *et al.*, 2013)	Total employees	2%
US (Anon., 1977)	Total employees	At least 2
India (Anon., 1985)	100	At least 1
	>500	1 additional personnel for every hundred employees
South Africa (Anon., 2008b)	100-1100	At least 1
	1100<x<3600	At least 2
Ghana (Anon., 2012)	<50	At least 1
	150<x<500	At least 3
	500<x<2000	At least 4
	>2000	At least 5

Globally, the number underground employees have been used as the only criterion to define the number of rescue brigades required in mine. While the criterion has been useful to emergency response management for over a century now, it does not consider any form of risk associated with the mining operations. Over the years, experience has shown that the number of rescue brigades depends on a lot of factors other than the number of underground employees alone. The criterion does not justify whether the number of rescue brigades established in a mine is sufficient because there are other factors needed to be considered such as:

(i) the nature of the mine;
(ii) the mining technique; and
(iii) available process plants and other surface facilities

Since the current criteria does not consider other factors of the mine, there is a gap. To fill this gap, this research used risk analysis of the entire mine operations to determine the required number of rescue brigades.

2 Resources and Methods Used

2.1 Study Area

Ghana, West Africa, is the research location. Ghana is a Sub-Saharan African developing country. It has a rich mining history reaching back to the 15th century. The country is located in the centre of the West African coast, bordered by three French-speaking countries: Burkina Faso to the north, Togo to the east, and Côte d'Ivoire to the west. The Gulf of Guinea and the Atlantic Ocean lay to the south. Ghana has nearly the same land area as the United Kingdom, with a total land area of 238 699 km^2. Its southernmost point, Cape Three Point, is located at 4 30'N. The country stretches inland for approximately 670 km from this point to 11 N. The greatest distance is approximately 560 km and is located between longitudes 3 15'W and 1 12'E. The Greenwich Meridian, which runs through London, also runs through the industrial enclave of Tema in Ghana's Greater Accra Region (Kumi-Boateng *et al.*, 2015). Fig. 1 is a map showing the study area.

Ghana has seen lots of benefits from mining since colonial days and these benefits range from employment, royalties, foreign aid, taxes, to scholarships. The mining sector currently contributes approximately 41 percent of total exports earnings, 14 percent of total tax revenues, and 5.5% of Ghana's gross domestic product (GDP). The production of gold in Ghana has been the backbone of Ghana’s economy and the single most foreign income earner for the nation. Averagely, Ghana produces 179 000 000 kg of gold every year (from 1990 to 2019). In 2019, Ghana was reported to be the largest producer of gold (130 000 000 kg) followed by South Africa (Anon., 2020a). Mining employs 2% of the country’s population in both the large and small scale sectors. The large scale mining sector in Ghana consists of a bauxite mine, a manganese mine, six (6) underground gold mines and seven (7) surface gold mines. These mines cluster around the southwestern part of Ghana. There are many small-scale gold mines and quarries scattered all over the country.

This research was limited to large scale underground mining where mine rescue operations are highly organised. The large scale underground mines in Ghana include: Chirano Gold Mines Limited (CGML); Newmont Ahafo Mine (NAM); Mensin Gold Mine (MGM), AngloGold Ashanti - Obuasi Mine (AGA-Obuasi); Future Global Resources - Prestea Underground Mine (PUG); and Golden Star Resources - Wassa Underground Mine (WUG). All these mines practice mine-owned rescue systems where they have established mine rescue brigades on site for emergency management. The locations of these large-scale underground mines is shown in Fig. 1.

Fig. 1 Location of Large-Scale Underground Mines in Ghana

2.2 Data Collection

Primary data was used for this research. It was collected between 2017 and 2021. The data was collected from mine rescue instructors, rescue coordinators, rescue attendants, rescue team members, mine safety managers, shift bosses, mine captains, underground mine managers, mine inspectors, ventilation experts, and mine planners. These individuals have either work directly or indirectly with the mine rescue teams and they constitute the subject matter experts for this research.

A focus group is a method of data collection in both private and public organisations (Parker and Tritter, 2006) and has been employed mostly by social scientists for the past 70 years (Merton and Kendall, 1946; Merton *et al.*, 1956). The method has wide applications in customer satisfaction, research on sensitive topics, questionnaire survey formulation, development of teaching materials and promotion development (Parker and Tritter, 2006). It has commonly been used as a tool to explore topics which has little information available (Parker and Tritter, 2006). The method generates large pools of data as compared to other face to face contact methodologies between researchers and participants (Parker and Tritter, 2006). Focus groups are gathering people in an interactive setting to discuss specific topics with the aim of drawing personnel experiences, expertise, beliefs and perspectives. These could take place in a room or online video conference led by a trained moderator or facilitator where participants feel comfortable airing out their feelings and opinions about the subject (Nyumba *et al.*, 2018; Anon., 2020b). The method deals with some selected group of individuals other than the statistical representative sample of a population. The composition of the focus group depends on the objective or purpose of the research.

Generally, focus group methodology is made up of four (4) steps: research design, data collection, analysis and reporting of results (Morgan *et al.*, 1998). Identification of the group is the difficult part since it depends on the synergistic relationship with the participants to generate data. The researcher acts as the facilitator or moderator of discussion between participants i.e., between himself/herself and the participants. A purposive sample is usually better since the method relies on the ability and capacity of the participant to provide the relevant information (Morgan, 1988). Feedbacks from focus groups are from the participants' own words and voice and the approach uncover ideas the researcher may not come across but are important to the research. Despite some setbacks associated with the method, it is widely accepted and established for use in social science research because it helps us to understand and also enhances our use of Analytical Hierarchy Process (AHP) as a research method.

Using a focus group approach, rescue teams in some selected underground mines were invited to form groups of experts to brainstorm and discuss the possible factors that could influence the number of rescue teams required for a mining project. Fig. 2 is a picture of a session during a focus group discussion with one of the rescue teams. The factors that influence the number of rescue teams for a mining project were identified through the focus group sessions organised.

Fig. 2 Focus Discussion Sessions

The factors identified were then streamlined by the mine rescue instructors, rescue coordinators, mine managers and mine inspectors to arrive at a final set of factors. The final set of factors were then used to design a questionnaire which served as input for the ranking process in order of importance. There were 30 questionnaires issued, and 24 were retrieved. The experts applied a pairwise comparison of the streamlined factors against each other. The responses from the experts were then analysed using the Classical Analytical Hierarchy Process (AHP) and the Fuzzy AHP which are examples of Multi-Criteria Decision-Making Methods (MCDM).

2.3 Multi-Criteria Decision-Making Methods

MCDM are mathematical models that help to take decisions in scenarios where the possible alternatives are evaluated over multiple and conflicting criteria (Ceballos, 2016). There are many MCDM in literature and they include:

i. Preference Ranking Organisation Method for Enrichment Evaluation (PROMETHEE) (Brans *et al.*, 1985);
ii. ELimination Et Choix Traduisant la Realité (ELECTRE) (Roy, 1968);
iii. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Hwang and Yoon, 1981);
iv. the Analytic Hierarchy Process (AHP) (Saaty, 1980); and
v. VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) (Opricovic and Tzeng, 2004).

Analytical Hierarchy Process (AHP)

The AHP is a robust and flexible MCDM tool for dealing with complex decision problems. Human beings have varying responses to different situations. AHP was developed to enable people to tell how much one element dominates the other with respect to a given property. This allows one to tell how much, more one element dominates the other with respect to a given property. In comparison analysis, sometimes the contact could be so great that no scale value could be assigned with confidence in most situations. An easy way to compare them is to put them on a fixed scale. A scale of 1 to 9, to measure the comparison has been proposed (Saaty, 1987). AHP works in the following steps: defining alternatives, defining the problem and criteria, establishing priority among criteria using pair-wise comparison, check consistency, and get the relative weight.

Saaty (1980) calculates a consistency ratio (CR) to check the probability that the ratings are randomly generated. The CR is defined by Eqs. (1) and (2).

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RCI}} \quad (1)$$

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1} \quad (2)$$

where *CI* represents the consistency index, *RCI* represents the random consistency index (which is obtained from the random consistency index table proposed by Saaty (1987). Since the *CR* value is smaller than 0.1, the inconsistency is acceptable. A matrix with a *CR* value greater than 0.1 should be re-evaluated, and the process repeated until the CR is less than this threshold. λ_{max} is the principal eigenvalue of the matrix; *n* is the number of factors.

Fuzzy Analytical Hierarchy Process (FAHP)

Fuzzy set theory has been widely employed in conjunction with AHP because it allows the decision maker to make an interval judgement while also taking uncertainty or fuzziness into account. It is well-suited to handling decision-making problems involving subjective judgments and is currently one of the most used MCDM strategies (Basim and Alsyouf, 2003). The research combines fuzzy logic with AHP. This combination enables us to deal with qualitative criteria that are unclear, imprecise, and uncertain. Three FAHP methods are available: Van Laarhoven and Pedrycz (1983), Buckley (1985), and Chang (1996). The Buckley (1985) method was adopted for this study because it has the following advantages: it is easy to extend to the fuzzy case; computational easiness; and it guarantees a unique solution. Buckley (1985) method has the following disadvantages: the computational requirement is quite high; and it derives fuzzy weights and requires defuzzification.

Buckley (1985) invented the geometric mean method to extend the AHP to the case of linguistic variables. The steps for the geometric mean method of Buckley (1985) are summarised as follows:

Step 1: The fuzzy pairwise comparison matrix *D_* = [a_{ij}] is constructed as

$$\tilde{D} = \begin{bmatrix} (1,1,1) & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & (1,1,1) & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & (1,1,1) \end{bmatrix} \quad (3)$$

where $\tilde{a}_{ij} \times \tilde{a}_{ji} \approx 1$ and $\tilde{a}_{ij} \cong w_i/w_j$, $i, j = 1,2,\ldots,n$.

Step 2: The fuzzy geometric mean value for each criterion is computed as

$$\tilde{r}_i = (\tilde{a}_{i1} \times \tilde{a}_{i2} \times \ldots \times \tilde{a}_{in})^{1/n} \quad (4)$$

Step 3: The fuzzy weight of each criterion is calculated as

$$\tilde{w}_i = \tilde{r}_i \times (\tilde{r}_1 + \tilde{r}_2 + \ldots + \tilde{r}_n)^{-1} \quad (5)$$

These risk factors were used to formulate a questionnaire and a sample of the retrieved questionnaire processed in the expert choice software has been presented.

3 Results and Discussion

3.1 Background of Respondents

The background of the respondents for this study was collected for the following areas: years of experience, level of education, and whether they were in mine rescue. The results have been presented in Figs. 3 to 6.

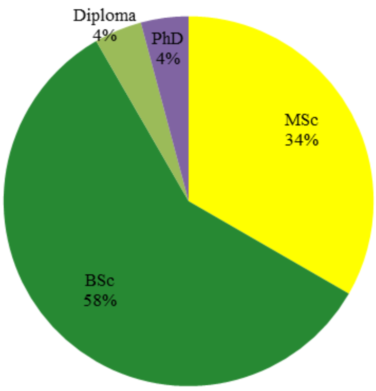

Fig. 3 Level of Education by SMEs

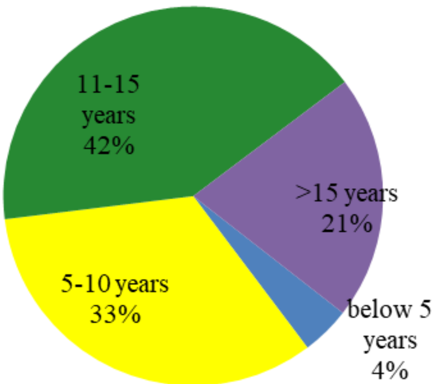

Fig. 4 Years of Mining Experience by SMEs

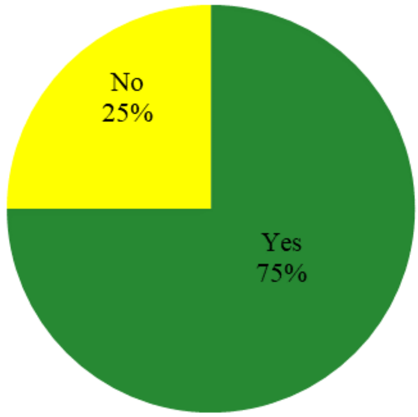

Fig. 5 Rescue Member

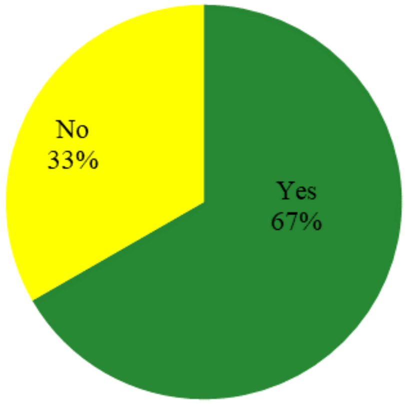

Fig. 6 Active Rescue Member

From Fig. 3, the educational level of the Subject Matter Experts (SMEs) shows PhD (4%), Diploma (4%), MSc (34%), BSc (58%). From the results, all the respondents are literate, with 96% having at least a Bachelor's degree. From Fig. 4, it can be seen that at least 63% of the respondents have at least 10 years of experience in mining, with only 4% having less than 5 years' experience. Those who have 5-10 years of experience were 33%. From this, the SMEs have varying levels of experience in the mining industry. SMEs were asked if they had been members of the mine rescue team in their participation in active rescue service and the results are shown in Fig. 5. Fig. 5 indicates that 75% have been members of rescue services while 25% have not. Those who had not been members of the rescue team were identified as safety managers and some mine regulators, where a mine rescue ticket certificate is not a prerequisite for their office positions. In Fig. 6, 67% of the SMEs are still active in mine rescue operations, while 33% of them have retired from active mine rescue operations.

3.1 Risk Factors

From the focus group sessions, the SMEs identified eleven (11) risk factors that could possibly influence the number of rescue brigades required in a mine. The factors are:

(i) Maximum number of people employed per shift;
(ii) Life of the mine;
(iii) Depth of the mine;
(iv) Level of mechanization;
(v) Safety culture of the employees;
(vi) Location and distance between surface facilities of the mine;
(vii) Responsibilities of the rescue team;
(viii) Budget for emergency management;
(ix) Availability of sister rescue teams;
(x) Mode of entry into the mine i.e. shafts, ramps; and
(xi) Maximum active workings.

These eleven factors were refined and concised by experts into seven (7) as follows:

(i) Number of Workers per Shift;
(ii) Level of Mechanisation of the Mine;
(iii) Safety Culture of the Mine;
(iv) Mining Depth;
(v) Nearness and Responsiveness of Sister Rescue Teams;
(vi) Distance between Operating Mines/Surface Facilities;
(vii) Resourcefulness of Rescue Team;

These risk factors were used to formulate a questionnaire and the responses were separately processed in expert choice software. In this research, AHP was implemented through three main stages: as shown in Eqns (3) to (5) (Saaty, 2001). A questionnaire that had a consistency ratio of more than 0.1 was rejected, and SMEs were asked to refill it. The expert choice software was used to reduce the inconsistence ratio and over assigned judgments were reassigned. A sample of the process questionnaire in Expert Choice Software is presented in Fig. 7. From Fig. 7, it can be seen that the judgement of the SME has been entered and the entry in red is the inverse of the judgment, while the entry in black indicates that the factor in the column is more important than the factor in the row. In Fig 7, it is seen that the judgement of the individual indicates that the number of employees per shift is more important than the level of mechanisation of the mine. The consistency index is indicated at the bottom of the table as 0.02, which is less than 0.1 as required by the methodology of Saaty.

The entries of each questionnaire were run through Eqs (1) to (5) supra using Microsoft Excel, and the respective ranking of each SME judgment was obtained. The final weighting was defuzzified by normalisation of the weight for each risk factor obtained. The weights for each of the 24 questionnaires were averaged and the results have been presented in Fig. 8. From Fig. 8, it can be seen that the factors were ranked according to the following order:

(i) Safety Culture of the Mine;
(ii) Number of Employees per Shift;
(iii) Resourcefulness of the Rescue Team
(iv) Number of Active Mines within the Mine and other Facilities e. g. process plant
(v) Level of Mechanisation of the Mine
(vi) Mining Depth; and
(vii) Nearness and Responsiveness of Sister Rescue Teams.

These risk factors were therefore selected, classified and standardised into three levels of risk, namely, low, median and high risk. The classification and standardization of the risk factors is shown in Table 2.

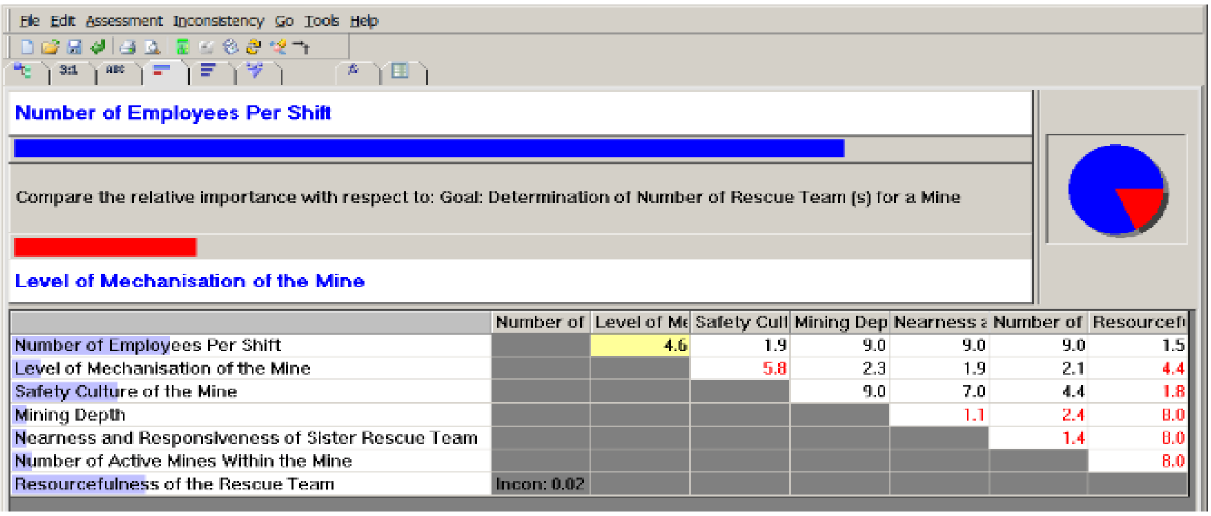

Fig. 7 Questionnaire Processing with Expert Choice Software

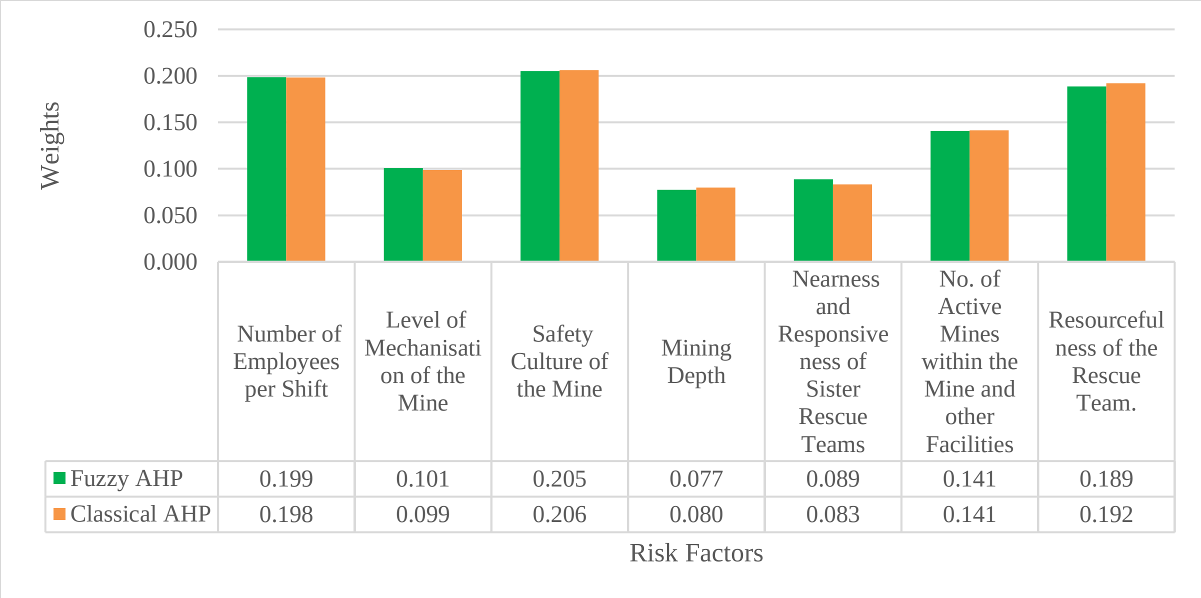

Fig. 7 Classical AHP and Fuzzy-AHP Weights

Table 2 Risk Factors and their Risk Levels

Risk Levels	**Low**	**Median**		**High**	
	1	2	3	4	5
Number of people Employed per shift	<51	51-150	151-500	501-2000	>2000
Safety Culture	Integrated	Interdependent	Independent	Dependent	Reactive
Level of Mechanisation	Full Automation	Semi Automation	Mechanised	Semi-Mechanised	Conventional
Mining Depth;	<200	201 m – 300 m	301 m – 400 m	401-500	>500
Nearness and Responsiveness of Sister Rescue Teams;	< 13 min	13 - 20 min	21 - 30 min	>31 – 60 mins	>60 mins
Number of Active Mines within the Mine and other Facilities; and	1	2	3	4	5 or more
Resourcefulness of the Rescue Team.	Robots for Mine Rescue	Rescue Capsules, Rescue Van, mobile rescue station	Breathing Apparatus for all Team members. Fully stocked refuge chambers	With Breathing Apparatus for First Team only	Volunteers and Without Breathing apparatus

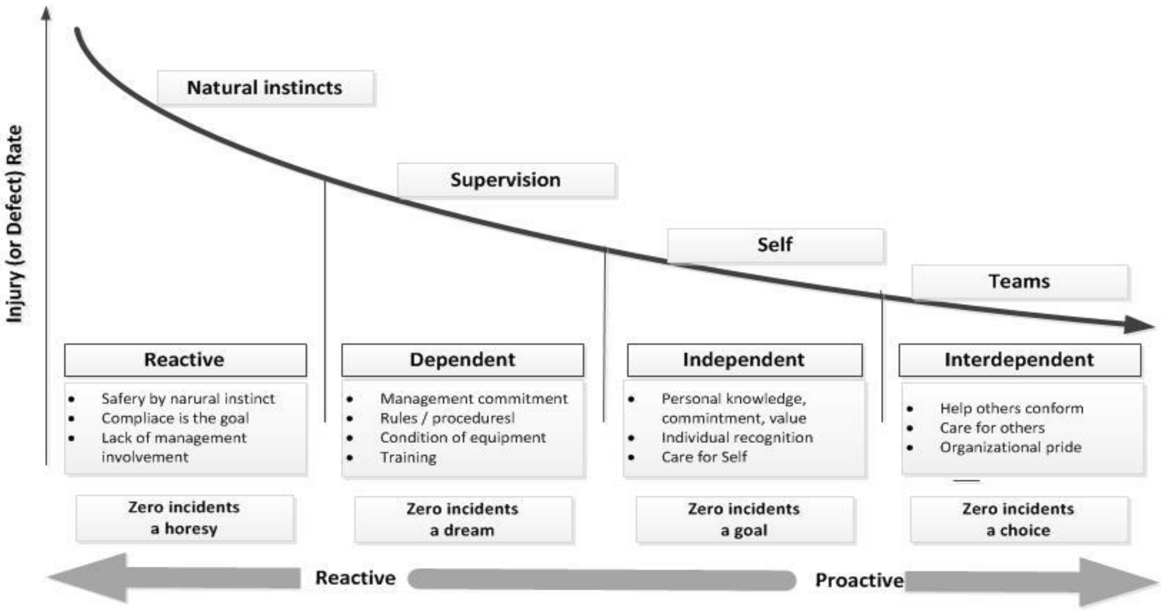

Fig. 8 DuPont Bradley Curve (Source: Jasiulewicz-Kaczmarek *et al.*, 2015)

Table 3 Processing of Questionnaires in ExcelFAHP

FACTOR	MINE A	MINE B	MINE C
Number of Employees per Shift	152	91	160
Level of Mechanisation of the Mine	Mechanised	Mechanised	Semi-Mechanised
Safety Culture of the Mine	Dependent	Independent	Reactive
Mining Depth	800 (m)	465 (m)	300 (m)
Nearness and Responsiveness of Sister Rescue Teams	45 mins	> 2hrs	> 2hrs
Number of Active Mines within the Mine and other Facilities e.g. process plant and	5	3	5
Resourcefulness of the Rescue Team.	Breathing Apparatus for all team members	Breathing Apparatus for all team members	No Breathing Apparatus for Rescue Men

Table 4 Processing of Questionnaires in ExcelFAHP

FACTOR	MINE A	MINE B	MINE C
Number of Employees per Shift	5	2	2
Level of Mechanisation of the Mine	3	3	4
Safety Culture of the Mine	2	3	5
Mining Depth	5	4	3
Nearness and Responsiveness of Sister Rescue Teams	4	2	5
Number of Active Mines within the Mine and other Facilities e.g. process plant	4	3	5
Resourcefulness of the Rescue Team	3	3	5
RESULTS	3.54	2.80	4.21

As a result, these risk indicators were chosen, categorised, and standardised into three risk levels: low, median, and high risk. The classification and standardisation of the risk factors are shown in Table 2. Classification of the number of employees per shift was adopted from the Minerals and Mining (Health, Safety and Technical) Regulation of Ghana (see Table 1) while the safety culture of the mine was modified after the DuPont Bradley curve as presented in Fig. 8.

3.2 Proposed Model for Determining Number of Rescue Brigade

From the questionnaire, the factors that influence the number of mine rescue teams in a mine and their respective weights (in brackets) are as follows:

i. Safety Culture of the Mine (0.225);
ii. Number of Employees per Shift (0.194);
iii. Resourcefulness of the Rescue Team (0.177)
iv. Number of Active Mines within the Mine and other Facilities e.g. process plant (0.146);
v. Level of Mechanisation of the Mine (0.097);
vi. Mining Depth (0.082); and
vii. Nearness and Responsiveness of Sister Rescue Teams (0.079);

These factors with their weights were used to derive a model for predicting the number of rescue teams required in a mine. The model is called the Yenzanya Model. The weights are treated as constants established for the Ghanaian underground mines in the Yenzanya Model. Yenzanya model for determining Number of Rescue Brigades (NRB) required in a mine is presented in Eq. 6:

$$NRB = 0.225(SC) + 0.194\,(ES) + 0.177(RR) + 0.146(NA) + 0.097(LM) + 0.082(MD) + 0.079(NR) \quad (6)$$

where,

SC = the Safety Culture of the Workers
ES = Number of Employees per Shift
RR = the Resourcefulness of the Rescue team
NA = the number of Active Mines within the Mine
LM = Level of Mechanisation of the Mine
MD= Mining Depth
NR=Nearness and Responsiveness of Sister Rescue Teams

3.3 Application of the Yenzanya's Model in Ghanaian Mines

The Minerals and Mining (Health, Safety, and Technical) Regulation (L.I. 2182) is used to determine the number of rescue teams required for mining projects in Ghana. The criteria used by this regulation (L.I. 2182) have been presented in Table 1 *supra*. To compare the output of the model with that of L. I. 2182, three underground mines were selected for case studies: Mine A; Mine B, and Mine C. Information was gathered from the three mines using the classification and standardization of risk factors presented in Table 2. The risk level of each risk factor for each mine has been presented in Table 3. From Table 3, it can be seen that Mine A is a mechanised mine with 152 employees. Its safety culture level is classified as dependent using the modified DuPont Bradley Curve. The mine has five portals and a mining depth of 800 m. The nearest sister rescue team is a 45-minute drive away. The mine has provided all rescue team members with breathing apparatus. All this information was compared with the risk levels in Table 2. The risk levels are selected based on these entries, and the results are entered into the model. The results have also been presented in Table 4. A similar exercise was carried out in mines B and C as well, and the results are also in Table 4. The number of rescue teams determined by the model was compared to one proposed by the L.I. 2182 and the result is presented in Figure 8. From Fig. 8, The L.I. 2182 for Mine A and LI 2182 require at least 3 teams, while the proposed model requires 3.54 teams (approximately 4 teams) and the rest (Mine B and C) are presented in Fig. 8.

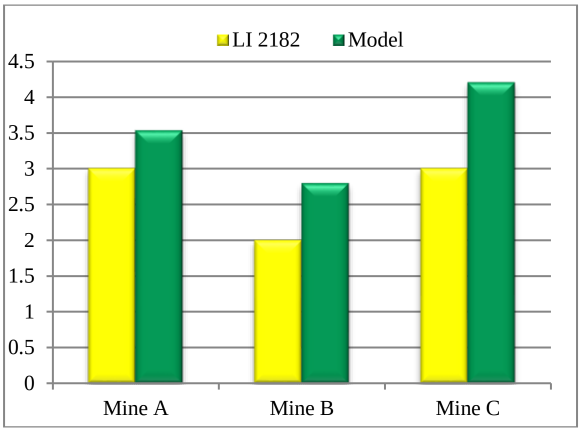

Fig. 9 L.I 2182 and the Propsed Model for Mines A, B and C

4 Conclusions and Recommendations

The study has established the factors that influence the number of rescue brigades required in underground mines. The factors include: safety culture of the mine; number of employees per shift; resourcefulness of the rescue team; number of active mines within the mine and other facilities, e.g., process plants; level of mechanisation of the mine; mining depth; and nearness and responsiveness of sister rescue teams. By using these factors, a novel model called the Yenzanya Model has been derived for determining the number of rescue brigades required in underground mines as a contribution to science. This should be adopted by mine regulators to determine the number of brigades required for mining projects.

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