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Evaluation of Factors Influencing Rock fragmentation by Blasting using Interrelations Diagram Method

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Abstract

Purpose: The purpose of this study is to develop an interrelations diagram for the factors affecting rock fragmentation by blasting and to determine their theoretical percentage contribution to rock fragmentation by blasting

Methodology: In order to develop an interrelations diagram for factors affecting rock fragmentation by blasting, first, factors that affect rock fragmentation by blasting were identified through literature review. Secondly, uncontrollable factors whose influencing factors are difficult to pin point where group into three major categories of hardness factor, joints and in-situ block size. Thirdly, the cause and effect relationship between al factors affecting rock fragmentation were identified. The factors affecting rock fragmentation by blasting were then arranged in an orderly fashion and the arrows indicating the direction of influence were drawn among them. The arrows entering and leaving each factor were counted and count value for each factor was used to calculate the theoretical percentage contribution for each factor.

Findings: Based on the Interrelations Diagram method, the top four influential controllable parameters towards rock fragmentation are Burden with 12%, Blasthole diameter with 9%, Powder factor with 7% and Delay timing with 7%. The most influential uncontrollable parameter towards rock fragmentation is Hardness Factor with 4%. It was further revealed that Controllable factors are more influential toward rock fragmentation by blasting than uncontrollable factors. This can be seen from the cumulative percentage contribution of 90% for controllable factors compared to cumulative percentage contribution of 10% for uncontrollable factors.

Unique contribution to theory, practice and policy: Application of the interrelation diagram gives insight on how factors affecting rock fragmentation by blasting are generally interrelated and identifies the theoretical percentage contributions of factor towards influencing rock fragmentation by blasting

Keywords: *Rock fragmentation; Interrelation Diagrams; Blasting*

1.0 INTRODUCTION

Rock blasting, in mining operations, is used to fragment hard rock masses to obtain valuables and separate them for further processing. Therefore, rock blasting affects the efficiencies of all the subsequent downstream processes. Efficient rock blasting is still the most cost- effective method for rock mass breakage in many if not all mining operation (Roy et al, 2016). An efficient blasting operation should result in increased equipment productivity and safety while reducing the associated environmental effects (Sastry and Chander, 2012). The most common economic issues associated with poor rock fragmentation include increased re-handling costs for oversize rocks, increased rock handling equipment’s operational and maintenance costs and increased processing costs. Obviously, for a mining operation to become more competitive by reducing its operational costs, an optimal rock fragmentation distribution should result from its blasting operation.

A well-designed blast should take into account the geological factors of the rock mass in order to efficiently utilize the explosive energy generated by the detonation of explosive in a blast hole. This should be so in order to obtain optimum rock fragmentation. There are many ways in which fragmentation can be optimised. The common fragmentation optimisation opportunities include; better digging and bucket fill factors, potential to produce better priced end product, reduction in material losses (more saleable product), reduction in blast induced damage and consistent crusher throughput and power draw. Rock fragmentation by blasting depends on factors that are classified as uncontrollable and controllable.

A number of theoretical and empirical studies have addressed factors that affect rock fragmentation by blasting and developed site specific models on how these factors are related and influence fragmentation. However, there is no single model that determines how these parameters are interrelated for many open pits and therefore determining the theoretical percentage contribution of theses parameters to influencing rock fragmentation by blasting..

This paper seeks to develop an interrelations diagram for factors influencing rock fragmentation by blasting and to determine their theoretical contribution towards influencing rock fragmentation by blasting. The Interrelations diagram will also give an insight on how the factors that affect or influence rock fragmentation by blasting are general interrelated.

In order to meet this objective, a literature review on interrelations diagram will be provided. Secondly, the interrelations diagram of factors affecting rock fragmentation by blasting will be present. Then, the theoretical percentage contribution of each factor towards rock fragmentation by blasting will be presented. Then the results will be discussed and concluded.

2.0 LITERATURE REVIEW ON INTERRELATIONS DIAGRAMS

The Interrelations diagrams (ID), originally known as the relations diagram, is root cause analysis framework tool, which was developed by the Society of Quality Control Technique Development in association with the Union of Japanese Scientists and Engineers in 1976 (Dogget, 2005). It is part of a toolset known as the seven new quality control (7 new QC) tools and was designed to clarify the intertwined causal relationships of a complex problem in order to identify an appropriate solution. The interrelations diagrams have evolved into a problem-solving and decision-making method from management indicator relational analysis, a method for economic planning and engineering. Original relations diagrams analyzed cause-and-effect relationships using complex calculations for each factor (Mizuno, 1988).

Brassard (1996) states that the interrelationship diagram takes complex, multivariable problems and explores and displays all of the interrelated factors involved. It also graphically shows the logical relationships between factors. Furthermore, Interrelations Diagram is a tool used to identify logical relationships between different ideas or issues in a complex or confusing situation and borders on being a tool for cause-and-effect analysis (Andersen and Fagerhaug, 2006). Brassard and Ritter (1994) observed that the ID allows groups to identify, analyze, and classify the cause-and-effect relationships that exist among all critical issues so that key factors can be part of an effective solution. The ID assists in systematically surfacing basic assumptions and reasons for those assumptions (Dogget, 2005).

The ID uses arrows to show cause-and-effect relationships among a number of potential problem factors. Short sentence, phrases or symbols expressing the factor are enclosed in rectangles or ovals (Brassard, 1996; Brassard and Ritter 1994). Arrows drawn between the factors represent a relationship. As a rule, the arrow points from the cause to the effect or from the means to the objective. The arrow, however, may be reversed if it suits the purpose of the analysis (Muzino, 1988).

The format of the ID is generally unrestricted with several variants. Other variants include the centrally converging ID which places the major problem in the center with closely related factors arranged around it to indicate a close relationship. The directionally intense ID places the problem to one side of the diagram and arranges the factors according to their cause-and-effect relationships on the other side. The applications format ID can be unrestricted, centrally converging, or directionally intense, but adds additional structure based on factors such as organizational configuration, processes, or systems (Dogget, 2005).

There are two types IDs format, quantitative or qualitative. In the qualitative format, the factors are simply connected to each other and the root cause is identified based on intuitive understanding. Numeric identifiers are used to determine the strength of relations between factors and the root cause is identified based on the numeric value in the quantitative format as opposed to the qualitative format (Andersen and Fagerhaug, 2000). Mizuno (1998) recommends the following steps when creating a relations diagram:

Step 1: Collect information from a variety of sources.

Step 2: Use concise phrases or sentences as opposed to isolated words.

Step 3: Draw diagrams only after group consensus is reached.

Step 4: Rewrite diagrams several times to identify and separate critical items.

Step 5: Do not be distracted by intermediate factors that do not directly influence the root causes.

Andersen and Fagerhaug (2000) stated that the first step for using an ID is to determine and label the factors, then place them on an easel or whiteboard in a circular shape and assess the relationship of each factor on other factors using arrows. After all relationships have been assessed, count the number of arrows pointing into or out of each factor. A factor with more “out” arrows than “in” arrows is a cause, while a factor with more “in” arrows than “out” arrows is an effect. The causal factors form the starting point for analysis

3.0 METHODOLOGY FOR DEVELOPING INTERRELATIONS DIAGRAM AND IDENTIFYING MAIN FACTORS AFFECTING ROCK FRAGMENTATION BY BLASTING

The unrestricted quantitative ID format was used in this study. In this format, all interrelations between factors affecting rock fragmentation by blasting were given equal weightings and assigned a numerical value of 1. These factors were simply connected to each other based on their influencing factors as stated in the literature to determine the major contributor to rock fragmentation. The following steps were used to construct the interrelations diagram and identify main factors affecting rock fragmentation by blasting;

1. Identification of factors influencing fragmentation;

2. Grouping of uncontrollable factors whose influencing factors are difficult to pin point into three major categories
3. Identification of the cause-and-effect relationships between all factors causing fragmentation
4. Arranging all factors affecting fragmentation in orderly fashion;
5. Drawing arrows to indicate directions of influence among factors;
6. Calculating the theoretical percentage contribution for each factor towards influencing rock fragmentation

The flow chart of the methodology used to evaluate factors affecting fragmentation using interrelations method is shown in Figure 1

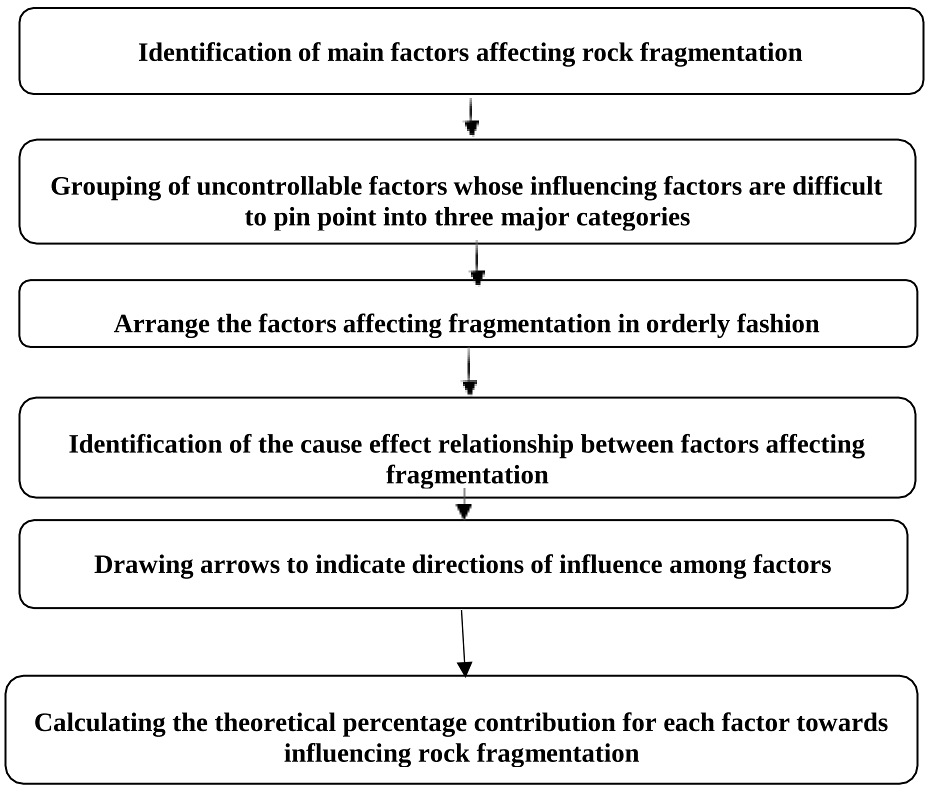

Figure 1: Flow chart of the methodology

3.1 Identification of factors influencing rock fragmentation

All possible factors that influence rock fragmentation by blasting needed to be identified. To achieve this, an extensive literature review on factors affecting or influencing rock fragmentation by blasting was conducted. The review of factors affecting rock fragmentation by blasting is presented in the following paragraphs of this section.

Factors that affect rock fragmentation by blasting are mainly classified as uncontrollable and controllable. Uncontrollable factors constitute rock mass characteristics while controllable factors constitute drill and blast parameters and explosive properties that can be optimised (Singh et al, 2016).

Uncontrollable factors or parameters that affect or influence rock fragmentation by blasting include intact rock properties and structural discontinuities. Intact rock properties include Compressive strength, Tensile strength, Density, Velocity of wave propagation, Porosity, Young's modulus and Poisson's ratio. Intact rock properties affect the extent of rock fragment in competent massive rock mass (Chiappetta, 1998). However, in highly fractured, laminated or soft rock types, intact rock properties do not truly indicate whether the rock mass is easy or difficult to blast because structural discontinuities overshadow the influence of physico-mechanical properties (Grurk and Pfleider, 1968, Chiappetta, 1998). The structural discontinuities of a rock mass include joints, bedding planes, foliation, faults, etc, which may be called joints in general. They are characterised by their orientation, number of sets, spacing, continuity and filling material. Structural discontinuities divide rock masses into a collection of separate blocks. The size and shape of the blocks are controlled primarily by the orientation and spacing of the discontinuities. These blocks exert a significant control over rock fragmentation by blasting blasting (la Pomte and Ganow, 1986, Goodman and Shi, 1985, Chakraborty et al, 1994 and Ouchterlony et al, 1990). Furthermore, Hagan (1995) observed that the rock fragmentation resulting from blasting was affected more by rock properties than by any other variables. Mohamed et al (2015) also observed that the presence of discontinuities can affect the blasting results to higher degree and plays a very important role in achieving the required fragmentation (results) with a given explosive charge.

The drill and blast parameters, which are controllable factors, that affect rock fragmentation by blasting include the burden, spacing, height of the bench, stemming length, blast hole length, delay sequence, firing pattern, diameter of hole, number of holes, explosive per hole, and powder factor (Adamson et al, 1999 and Wang et al, 1996). Singh et al (2015) indentified certain important controllable factors which decide the fragmentation level of particular blast. These factors include burden to blast hole diameter ratio, Spacing to burden ratio, Stemming Column length, Charge factors, stiffness ratio, explosive amount, distribution and its type, delay time, initiation sequence and initiation pattern. These factors can be controlled on the basis of the rock mass characteristics (Prasad et al, 2017).

The explosive properties that affect rock fragmentation by blasting include Velocity of Detonation (VOD), Detonation pressure and Explosive density (Dimitry and Evgeny, 2005). The velocity of detonation of an explosive is the speed at which the detonation travels through the explosive and, therefore, is the factor which defines the rhythm of energy released. The factors which influence VOD are charge density, diameter, explosive type, confinement, imitation (temperature and degree of priming) and aging of the explosive (Dimitry and Evgeny, 2005). The detonation pressure is generally considered as the pressure in the shock zone ahead of the reaction zone. According to Jimeno (1995) the detonation pressure of an explosive is a function of the density and of the square of the detonation velocity. The density of an explosive is its specific weight expressed as kilograms per liter (kg/l) or grams per cubic centimeter (g/cm3). It influences directly the detonation velocity and detonation pressure. The greater the density, the more breakage it provides (Hopler, 1998). The summary of factors affecting fragmentation by rock blasting is presented in Table 1.

Table 1: A summary of factors affecting fragmentation by blasting

FACTORS AFFECTING ROCK FRAGMENTATION BY BLASTING

Uncontrollable Parameters		Controllable Parameters	
Physico- Mechanical	**Structural Discontinuities**	**Explosive Properties**	**Drill And Blast Parameters**
• Uniaxial Compressive strength	• Joints	• VOD	• Burden
• Tensile Strength	• Bedding planes	• Detonation Pressure	• Spacing
• Density	• Foliations	• Explosive density • Charge density	• Stemming length
• P-Wave Velocity	• Faults	• Explosive Strength	
• Porosity	• In situ Block sizes		• Bench height
• Young's Modulus			• Explosive Amount /hole
• Poisson's ratio			• Explosive amount distribution
			• Powder Factor
			• Delay Timing
			• Initiation Sequence • Blast hole diameter • Sub drill length

3.2 Grouping of Uncontrollable factors into major categories

Uncontrollable factors that affect rock fragmentation by blasting are intrinsic. They depend on the complex formation of process of the rock mass and it is therefore difficult to pin point factors that influence them. For easy analysis, uncontrollable factors were group in major categories that are known to affect rock fragmentation by blasting. Physico mechanical properties were group as hardness factor and geological structures were group as joints (size and orientation) and in-situ block size.

3.3 Identification of the cause-and-effect relationships between factors causing fragmentation

Through literature review, the cause and effect relationships between factors influencing rock fragmentation by blasting were identified. This was done by starting with any of the factors affecting rock fragmentation and working through the relationships in sequence. For instance, consider Burden, the controllable factor that affects rock fragmentation by blasting. Burden is function of blast hole diameter (D) (Anderson, 1952; Pearse,1955; Frankel, 1952; Langfores and Kihlstrom, 1963; Konya and Walter,1990; Rustan, 1990), Rock density (Konya and Walter,1990; Ash, 1968), Explosive Strength (ES) (Dimitry and Evgeny, 2005; Konya and Walter,1990), Explosive Density (ED) (Dimitry and Evgeny, 2005; Konya and Walter,1990; Berta,1990), Hardness Factor (HF) (Pearse, 1955) and Powder Factor (PF) (Berta, 1990 and Blair, 2015), Charge density (CD) (Langfores and Kihlstrom, 1963), Colum charge length (CL) (Frankel, 1952), Detonating Pressure (DP) (Pearse, 1955). Therefore, causing or influencing factors for Burden are Blasthole diameter, Rock density, Explosive strength, explosive density, hardness factor, powder factor, charge density, Colum charge length and Detonating pressure. The same approach was taken for all the parameters affecting fragmentation by blasting. The summary of each factor and factors that affect or influence it's value are presented in Table 2.

Table 2: Summary of cause and effect relationship between factors causing fragmentation

FACTOR (Symbol)	**INFLUECING FACTORS**
Burden	• *Blast hole diameter* (Anderson, 1952; Pearse,1955; Frankel, 1952; Langfores and Kihlstrom, 1963; Konya and Walter,1990; Rustan, 1990) • *Rock density* (Konya and Walter,1990; Ash, 1968) • *Explosive strength* (Dimitry and Evgeny, 2005; Konya and Walter,1990), • *Explosive density* (Dimitry and Evgeny, 2005; Konya and Walter,1990; Berta,1990), • *Hardness factor* (Pearse, 1955) • *Powder factor* (Berta, 1990 and Blair, 2015) • *Charge density* (Langfores and Kihlstrom, 1963), • *Colum charge length* (Frankel, 1952) • *Detonation Pressure* (Pearse, 1955)

Table 2 Continues

Spacing (S)	• *Burden* (Konya and Walter,1990; Pughese, 1972; Gregory, 1984) • *Delay Timing* (Konya and Walter,1990; Dick et al, 1986) • *Joints (spacing)* (Bhandari and Bedal, 1990) • *Blast hole diameter* (Rajmeny et al, 2006)
Blast Hole Diameter (D)	• *In-situ Block size* (Dick et al, 1986 and Thomas, 1986) • *Bench* height (Dick et al, 1986 ; Thomas, 1986 and Parida, 2016) • *Explosive distribution* (Parida, 2016)
Bench Height (BH)	• *Fixed for a blasting Engineer*
Colum Charge Length (CL)	• *Sub-drill length* (Muhammad, 2009) • *Bench height* (Muhammad, 2009) • *Stemming length* (Muhammad, 2009
Stemming Length (SL)	• *Burden* (Ash, 1968) • *Hardness factor* (Hagan and Kennedy, 1977) • *Explosive Strength* (Boshoff, 2009) • *Explosive Density* (Boshoff, 2009) • *Velocity of Detonation* (Boshoff, 2009)
Sub Drill Length (SBL)	• *Burden* (Ash, 1968)
Initiation Sequence (IS)	• *Delay timing* (Parida, 2016) • *Burden* (Parida, 2016) • *Spacing* (Parida, 2016)
Delay Timimg (DT)	• *Burden* (Chiappetta, 1998 and Boshoff, 2009) • *Blast hole diameter* (Chiappetta, 1998 and Boshoff, 2009) • *Explosives Density* (Chiappetta, 1998 and Boshoff, 2009) • *VOD* (Chiappetta, 1998 and Boshoff, 2009) • *Hardness factor* (Chiappetta, 1998 and Boshoff, 2009)
Powder Factor (PF)	• *Hardness Factor* (Parida, 2016) • *Rock density* (Parida, 2016) • *Explosive Strength* (Parida, 2016) • *Drill hole diameter* (Parida, 2016) • *Charge density* (Parida, 2016) • *Explosive distribution* (Parida, 2016)

Explosive Amount And Distribution (EMD)	• *Explosive Amount per hole* (Muhammad, 2009) • *Burden* (Muhammad, 2009) • *Spacing* (Muhammad, 2009)
Explosive Amount Per Hole (EAH)	• *Length of Colum charge* (Muhammad, 2009) • *Blast hole diameter* (Muhammad, 2009) • *Charge density* (Muhammad, 2009*)*
Explosive Amount Per Hole (EAH)	• *Length of Colum charge* (Muhammad, 2009) • *Blast hole diameter* (Muhammad, 2009) • *Charge density* (Muhammad, 2009)
Velocity Of Detonation (VOD)	• *Charge density* (Dimitry and Evgeny, 2005) • *Explosive strength* (Dimitry and Evgeny, 2005) • *Blast hole diameter* (Dimitry and Evgeny, 2005)
Detonation Pressure (D/P)	• *Charge Density* (Persson et al, 1994) • *Velocity of Denotation* (VOD) (Persson et al, 1994)
Charge Density (CD)	• *Explosives Density* (Blair, 2015) • *Blast hole diameter* (Blair, 2015)
Explosive Strength (ES)	• *Explosives Density* (Blair, 2015)
Explosive Density (ED)	• *Fixed for a Blasting Engineer*
Joints (Spacing And Orientation) (J)	• *Fixed for a Blasting Engineer*
In Situ Block Size (IBS)	• *Joint (Spacing and Orientation) (*Gnirk and Pleider, 1968)
Rock Density (RD)	• *Fixed for a Blasting Engineer*
Hardness Factor (USC/YOUNG' MODULUS) (HF)	• *Fixed for a Blasting Engineer*

3.4 Arranging factors that influence fragmentation and drawing arrows to indicate directions of influence among them

Factors that affect rock fragmentation by blasting were arranged in an orderly fashion and arrows were drawn to indicate the direction of influence among them. Symbols for each factor used in Table 1 were used in the ID diagram instead of the name of the actual factor for convenience. For each relationship pair, an arrow was drawn from the factor that is the cause to the factor that is influenced. No arrows were drawn if there was no relationship between factors. The resulting interrelations diagram is presented in Figure 2.

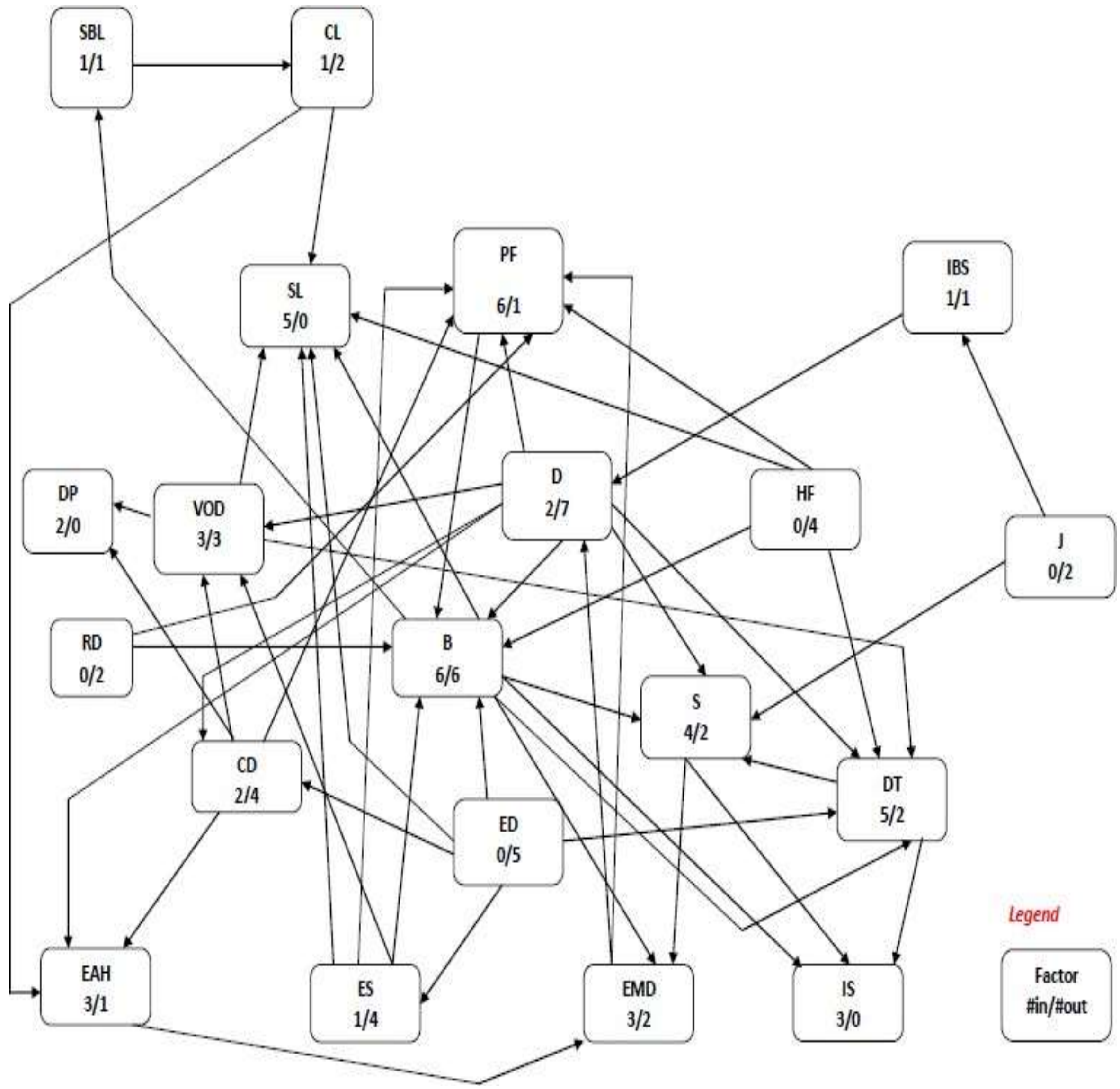

Figure 2: Interrelations diagram for factors affecting rock fragmentation by blasting

3.5 Calculating the theoretical percentage contribution for each factor towards influencing rock fragmentation

For each factor, the number of arrows entering (causing factors) and the number of arrows leaving (influencing factors) were clearly recorded. Then the total number of arrows, sum of number of arrows in and number of arrows out, for each factor was obtained. All arrows were given an equal weighting of 1. The percentage contribution of each factor to rock fragmentation by blasting was then calculated using equation 1;

$$\frac{Total\ number\ of\ arrows\ per\ factor}{Total\ number\ of\ arrows\ in\ the\ ID} \times 100 \qquad equation\ 1$$

The results of the percentage contributions are presented in Table 3

Table 3: Percentage Contribution of factors towards influencing rock fragmentation by blasting

FACTORS	IN	OUT	TOTAL	CONTRIBUTION (%)
Burden (B)	6	6	12	12
Blast Hole Diameter (D	2	7	9	9
Delay Timing (DT)	5	2	7	7
Powder Factor (PF)	6	1	7	7
Spacing (S)	4	2	6	6
Velocity Of Detonation (VOD)	3	3	6	6
Charge Density (CD)	2	4	6	6
Stemming Length (SL)	5	0	5	5
Explosive Strength (ES)	1	4	5	5
Explosive Amount And Distribution (EMD)	3	2	5	5
Explosive Density (ED)	0	5	5	5
Initiation Sequence (IS)	3	1	4	4
Explosive Amount Per Hole (EAH)	3	1	4	4
Hardness Factor (HF)	0	4	4	4
Colum Charge Length (CL)	1	2	3	3
Bench Height (BH)	0	3	3	3
Sub Drill Length (SBL)	1	1	2	2
Detonation Pressure (DP)	2	0	2	2
Joints (Spacing And Orientation) (J)	0	2	2	2
In Situ Block Size (IBS)	1	1	2	2
Rock Density (RD)	0	2	2	2

4.0 DISCUSSION

Using ID method, the theoretical percentage contributions of factors towards influencing rock fragmentation have been calculated. The top four influential controllable parameters towards rock fragmentation are Burden with 12%, Blasthole diameter with 9%, Powder factor with 7% and Delay timing with 7%. The most influential uncontrollable parameter towards rock fragmentation is Hardness Factor with 4%. The concept of this analysis is based on a one to one relationship between one factor and the other. It focuses on the direct effect of one parameter on the other. If indirect relations between parameters were to be considered, the ratios of Burden and Blasthole diameter, Spacing and Burden, Stemming length and Column charge length, Burden and Bench Height would come out as strong influencers of rock fragmentation by blasting. This would agree with the observations made by Singh et al (2016). It was further revealed that Controllable factors are more influential toward rock fragmentation by blasting than uncontrollable factors. This can be seen from the cumulative percentage contribution of 90% for controllable parameters compared to cumulative percentage contribution of 10% by uncontrollable factors.

5.0 CONCLUSION

The interrelations diagram method of the management and planning tools (MPT) was used to develop an interrelation diagram for factors affecting fragmentation by rock blasting. The percentage contribution of each of these factors was calculated to determine the influence of each factor towards rock fragmentation by blasting. The percentage contributions were based on the direct influence of one factor on the other.

The top four influential contributors towards rock fragmentation include burden, Blasthole diameter, and delay timing. Further, it can be concluded that controllable parameters are more influential towards rock fragmentations as compared to uncontrollable parameters. There optimising controllable parameters will lead to optimal rock fragmentation.

ID method provides insight on how the factors that affect rock fragmentation are generally interrelated and identifies the theoretical percentage contribution of factors towards influencing rock fragmentation by blasting. It further highlights the main parameters which should be focused on when optimising rock fragmentation.

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