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Blasting pattern optimization in open-pit mines by using the genetic algorithm

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ABSTRACT

The blasting operations in open-pit mines are one of the most sensitive and complex mining methods which are defined under special circumstances and specific purposes. The suitable and optimal pattern selection where could be capable to covering the various environmental factors and affected on economic, technical, engineering and safety is the main goal of the operation. The genetic algorithm (GA) is the recommended method to utilizing the optimized pattern for the blasting pattern selection under the many effective parameters which is the variety of noteworthy detected on selected pattern from different mines. In this work the GA used to propose optimal blasting operation pattern by consideration of good coverage with field and geo-parametric in open-pit mine. For this purpose, the optimal design simulation of blasting pattern for open pit mines with one and two work-faces (for two standard 100×100 and 70×40m sides) by the Python programming language was conducted. Based on the results, this algorithm is quite successful in simulating the blasting pattern which it providing field decorations, the collapse (damage) rate and maximized exploitation (excavation).

1. Introduction

Open-pit mining can be considered as the oldest topic in industry and civilization of different countries which is holded the basic industry and economic works (Bise, 2003). With an attitude to the open pit mining evolution in different countries – especially in advanced countries – it is clear that the methods that have been accompanied by increased work efficiency have always been accepted and developed (Azarafza and Asghari-Kaljahi, 2016). Today, with the mine-related technologies advancement, different methods and techniques have been introduced in the mines excavation, extraction and sustainability fields such as boring machines, drilling hammers, cutting chains, blasting, etc; which is that application of each method depending on the geological conditions, ore body and type, region tectonics, ore origin, ore geometry and geo-mechanical parameters of mine, physical and mechanical properties of materials, hydrological/hydro-geological conditions (Hudson and Harrison, 1997; Azarafza et al., 2017). The blasting is one of the most sensitive and efficient method in open-pit mining which associated with special attention. The selection of blasting pattern can be considered as the most important part of the entire fire-work mining which ought to be evaluated for whole mining process which is economically and technically performed were each parameter has special effect on it. So, these parameters are used to the comprehensive calculation of blasting framework and characteristics such as technical and economic status for the mine. On the other hand, in each blast cycle, displacement production and excavation should also be economically justified and highly efficient (Azarafza et al., 2015). Also, safety tips should be considered for rock throwing, fly-rock, back break, noise, personnel safety, unwanted damaging, vibration, sliding, etc (Azarafza et al., 2017). However, the optimal selection of the blasting pattern requires the series of continuous/interdependent parameters with particular value which are capable to covering the economical and technical supply to achieve maximum material out-comes.

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Nowadays, by the technological advancement and computer-based assessment entry, in the field of mining engineering, various approaches based on the mining requirements are implemented by computer programs and complex engineering problems are involved in it solved by various algorithms. The design of blasting operations as one of the most complex issues in mining can be optimized which it can be able to recommend the appropriated economical pattern with the low cost and high efficiency. In order to provide an optimal plan for blasting and exploding quarry in mines, different approaches have been proposed that are applied depending on the prevailing and geo-materials conditions. The application of the artificial intelligence approaches and optimizes algorithms such as genetic algorithms (GA).The results of the explosive emplacement pattern and excavation plan are shown magnificent and more improvement. In this study, the GA was used to propose an optimal and appropriate explosive emplacement pattern for the blasting operations on open-pit mine.

2. Genetic Algorithms programming

The genetic algorithm (GA) is based on consistent and optimal search between elements and conditions for the mechanisms and identification rules to evaluating of system-environment relation. In order to obtain these approximate solutions which are used optimization techniques- operations research that was first dealt with by John Holland in the 1975 (Holland, 1992; Mitchell, 1998). The GA generally utilized to create the high-quality solutions to optimization and search problems by depending on biological motivate operators such as a mutation, crossovers and selections (Mitchell, 1998). GA typical tasks are the best values that finding and a free parameters sets predefinition associated with either a model process or vector controlling named, system identification which is one of the GA research active areas. The GA is based on evolutionary techniques such as an inheritance and mutation were founded on natural selection principles are used to find the optimal formula for patterns prediction or adaptation. The work of Holland was implemented comprehensively by Goldberg and was named genetic algorithm. Goldberg (1989) completed his thesis on using the proposed Holland algorithm for controlling gas transmission lines. After this date, the GA has expanded widely in various sciences, and the development of approaches based on this algorithm is still ongoing.

In the approach GA investigation, approximated optimizations are used to solving the problem. In this regard, the first, by defining a primitive set called the «initial population» that features the «gene» for this community; these genes are contain values or intuition for a particular parameter/question variable where community is chromosomes composed. These chromosomes have the ability to move from parent to child and provide elitism and optimal selection, allowing for the ability to mutate, orient, and select appropriate for future generations. This function makes it possible to screen and optimize the best value for new generations (Simon, 2013). In general, the GA is parameter that is able as follows (Kramer, 2017):

- Random generation of chromosomal features to solve and define issues of the initial population,
- Estimate the best fitting value for each chromosome,
- Generate new generations using repeated implementations and generations to replace the new generation,
- Revision of the evolutionary process and chromosomal production final result in order to mutate and optimum selection,
- Final generation's evaluation and generation's assessment.

Random assignment and descriptions capability of parameters with different values, which allow for optimal selection in subsequent generations, had led to the use of probabilistic methods in many engineering works, especially geotechnical engineering. The issues raised in the field of engineering applications related to the genetic algorithm are as follows (Sheppard, 2016):

- Optimization by using the continuous or discrete variables,
- No need for additional information,
- Best fitting of data close approximation related to data with high uncertainty (data gaps in engineering is quite common),
- Implicit search of variables (samples) and system elements,
- Considering a large number of variables,
- Implementation in step-by-step approaches and parallel computer programs,
- Optimization of complex parameters and sets,
- Provide a list of optimal variables to achievement to final answer,
- Ability to encoding optimized variables,
- Ability to use random numbers and probabilistic to generate dependent-independent data or analysis functions.

According to the above, the GA optimization in engineering sciences can be summarized in Fig. 1.

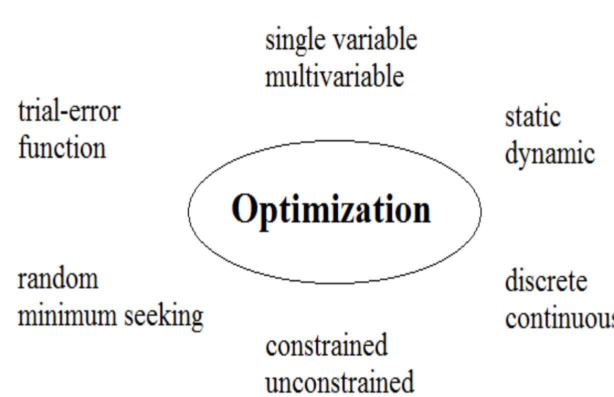

Figure. 1. Optimization classification by GA (Kramer, 2017)

The GA is using methods such as Elitist Selection (is a selection strategy where a limited number of individuals with the best fitness values are chosen to pass to the next generation, avoiding the crossover and mutation operators where are the most appropriate member of each population is chosen), the Roulette Wheel (a selection method which an element near the fitting curve is detected was selected), Scaling Selection (by increase in the average of population, the selection weighed and more detailed. The method is applicable when the set contains elements with large fitness values and only have the small differences between them), and Tournament Selection (a subset of population's characteristics are selected and members of that set compete together, eventually only one feature from each subgroup is selected for generation which allocates the best and most suitable attributes for the child's population).These attributes are using by two crossover and mutation operators and transport/transform to the next generation of the population where the work is close loop and start again (Goldberg, 2008). In Fig. 2, the flowchart of this process by GA is shown.

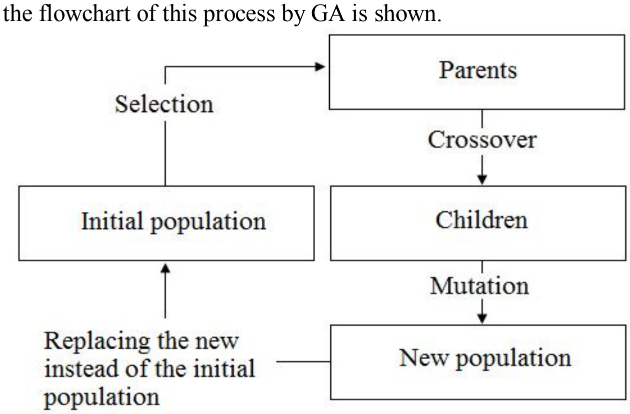

Figure. 2. GA processing flowchart (Goldberg, 2008)

The Crossover operator is a reconstructing and recombining operator that randomly exchanges parts of the chromosomes during the operation. These make the children have combination of their parent's characteristics and are not exactly like one parent. The purpose of this work is to create new children in the hope that the good qualities of the two beings in their child are gathered and produce a better creature. This operator performs the following recombination operation (Sheppard, 2016):

- Select a random point from the chromosomal string,
- Apply the shift of the gene after that point.

The chromosomal recombination operation is generally carried out by the following methods which is Fig. 3 is illustrates the shame of these operations types (Kramer, 2017):

- *Single-point Crossover*: Recombination operation is started from a point, and the displacement and reconstruction is performed thereafter,
- *Two-point Crossover*: Recombination operations are started from two points, and the displacement and reconstruction are performed thereafter,
- *Multi-point Crossover*: Recombination operations are started from multi-points, and the displacement and reconstruction are performed thereafter,
- *Uniform Crossover*: Recombination operations are considered for all parts of the chromosome and the displacement and reconstruction are carried out comprehensively.

In this study, tried to provide an appropriate model for explosive emplacement pattern for blasting operation on open-pit mines by using the GA optimization with the highest coverage of involved parameters (geologic, environment, economic, technical, etc.).

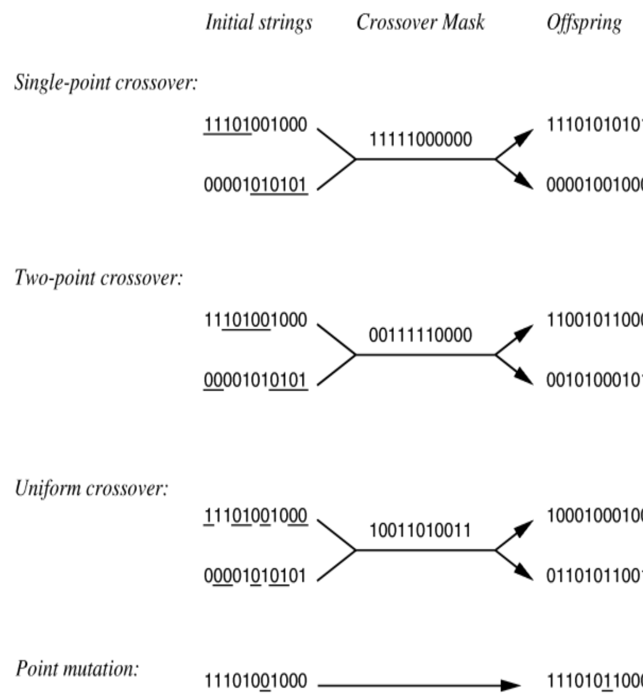

Figure. 3. Types of crossover operators (Kramer, 2017)

3. Blasting in open-pit mines

Blasting operation in open-pit mines is the means the use of explosives (materials that are excited by external forces with high speed and intensity) and placement by some instructions on ore body in order to continuous mining work and material exploitation. Special instructions based on the explosives, transportation, connections, environmental and geological conditions are prepared and used by the relevant organizations. These regulations cover a lot of aspects of the blasting operation, but it does not cover the explosive emplacement pattern. Generally, in mines (especially in Iran), this model obtained from simple manual calculations or excel software which that more relying on the engineer responsible experience of operation. There are many parameters involved in blasting pattern which can be divided into the following groups (Singh and Singh, 1995; Bye and Bell, 2001; Hustrulid, 2005; Sari et al., 2014; Demirel et al., 2018; Kozan and Liu, 2018):

- Environmental conditions (e.g. atmospheric conditions, access conditions, topographic conditions),
- Geological conditions (e.g. deposit type, ore deposit area, amount of mineral deposit, tectonic and faulting, nature of ore, petrography of ore deposit),
- Geo-mechanical conditions (e.g. mass geometry, mine dimensions, faces number, slopes, mass strength, discontinuity network, blast-ability),

- Explosives conditions (e.g. the explosives type, cost, amount, ability and efficiency, the materials performance),
- Technical conditions (e.g. equipment cost, equipment burnout, precision monitoring capabilities, instrumentation),
- Economic conditions (e.g. shipping costs, material costs, drilling costs, personnel costs, unexpected costs),
- Safety (HSE) conditions (e.g. fly-rock, earthquake, landslide, rock throwing, unwanted damaging, vibration, back break noise, installations damage, environmental pollution, dust).

Each of the parameters expressed has a very significant impact on mining fire-work operations. So, discard any of them will have consequences on operations or environment. In the other hand, the open-pit mines blasting pattern is evaluated by the mining and engineering experience of the responsible engineer. The Fig.4 the ordinary shame of blasting pattern is presented.

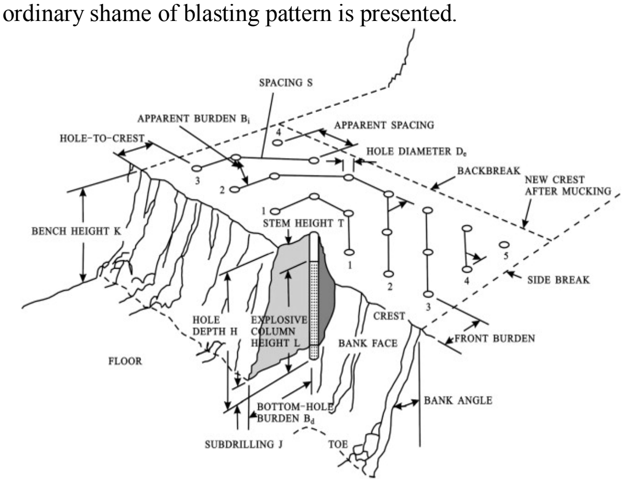

Figure. 4. A view of the blasting pattern in open-pit mine (Hustrulid, 2005)

4. GA based optimization methodology

According to the statement presented in this study, the optimal selection of blasting operations in the open-pit mines is run based on the suitable positions and explosives placement which by consideration of utilizing the least weight of these explosive materials with most effective exploitation (slopes slides) and excavation. In addition to, the national mining regulations are available to use as functional framework. But the explosive implementation pattern in blasting operation is empirically and based on the supervising of expert is conducted. The principles of blasting work are founded on one goal «low cost for materials and high influence excavation and exploitation» were mostly by empirical work does not materialize. The GA based assessment and optimization is the strong progress system to achieves the optimum multi-goals like this were used to the optimum determination and elitism between each parameters and their factors to obtained the successful optimization (Sheppard, 2016).

In this study, GA has been used to perform optimal selection and explosive implementation pattern designed in open-pit mines by consideration of good coverage with field and geo-parametric in open-pit mine. For this purpose, the optimal design simulation of blasting pattern for open pit mines with one and two work-faces (for two standard 100×100 and 70×40m sides) by the Python programming language was conducted. The input parameters for this assessment classified in 15 groups contain climatic conditions, accessibility conditions, topography, type of deposit (metallic or non-metallic), ore deposit area, mineral storage, type and nature of ore, mass geometry, mine area, number of working-faces, joint density, geo-mechanical features, tectonics and faults and ore quality. The output of simulation is presented as like Fig. 4. The key variables in simulation and optimization for suggestion pattern are mine area, depth of digging borehole, digging borehole locations, digging borehole effective radius, ore quality, Geo-mechanical features, ore deposit area, tectonics and faults, number of working-faces, joint density, dynamite borehole number, side break, spacing, apparent burden, collapse rate. The flowchart of the simulation process is shown in Fig. 5.

5. Optimization of blasting pattern by genetic algorithm

The results of the simulation and optimization base on GA algorithm for two standard 100×100 and 70×40m sides are presented in Figs. 6 to 15. According of these Figures can be stated that the zonal (areal) pattern is more than other placements are good answered.

On the other hand, location of the empty borehole between explosives can be increase the rate of exploitation and decrease the costs of the entire operations. Also the number of working-faces, joint density and ore deposit area is mainly effected the pattern of explosive implementation and blasting. The computer optimization relations of the excavation uncertainties are evaluated as follow:

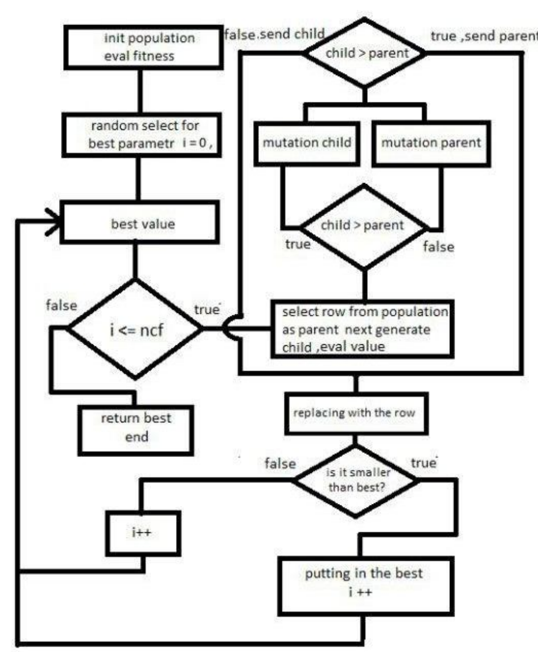

Figure. 5. Flowchart of simulation and optimization process

$$\text{Best fitness} = \sum_{i=1}^{\text{point}} (\text{Mscale}_e^2 \times \text{Gr}_h^2) - \text{Dyn}_n \times \text{Pow}_i \quad (1)$$

$$\text{Point}_{\text{gamma}} = \frac{x}{\text{Mscale}} \times \frac{y}{\text{Mscale}} \quad (2)$$

Where, Mscale: the mine dimension or area, Gr_h: earth hardness factor (geological), Dyn_n: the number of required dynamites, Pow_i: damage power of explosives.

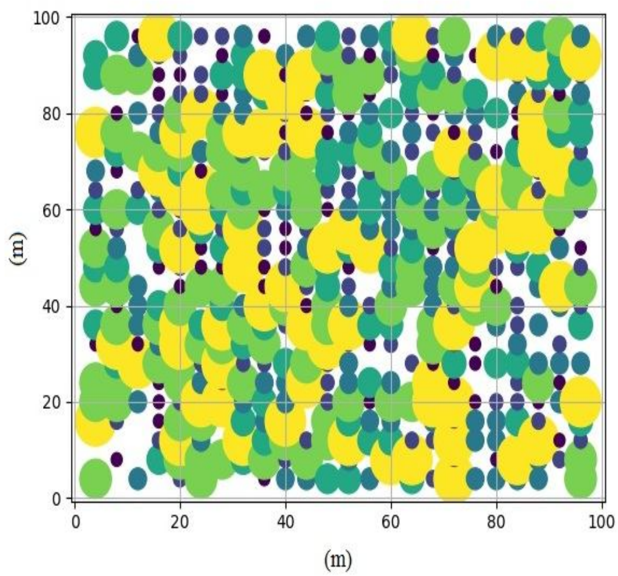

Figure. 6. Optimum pattern and impact radius for 100×100 m pit in one work-face

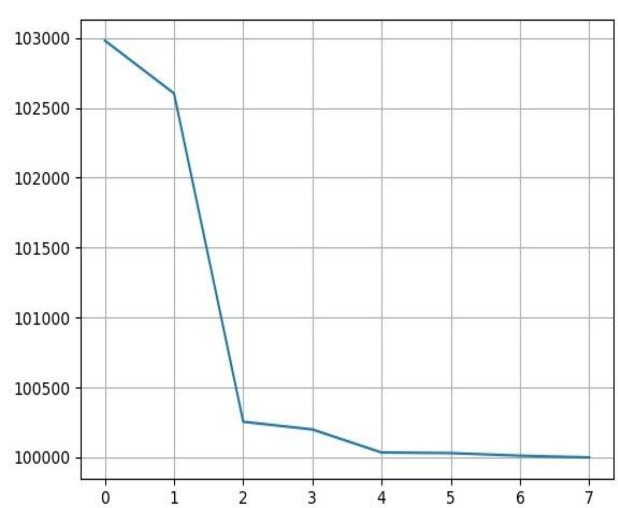

Figure. 7. Algorithm performance based on excavation uncertainties rate for 100×100 m pit in one work-face

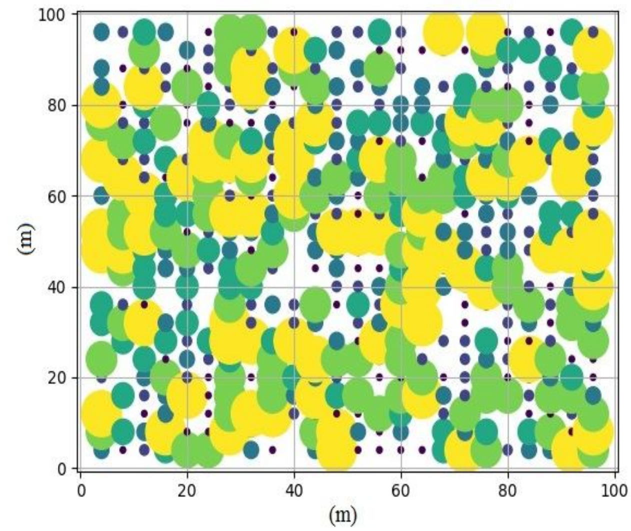

Figure. 8. Optimum pattern and impact radius for 100×100 m pit in two work-faces

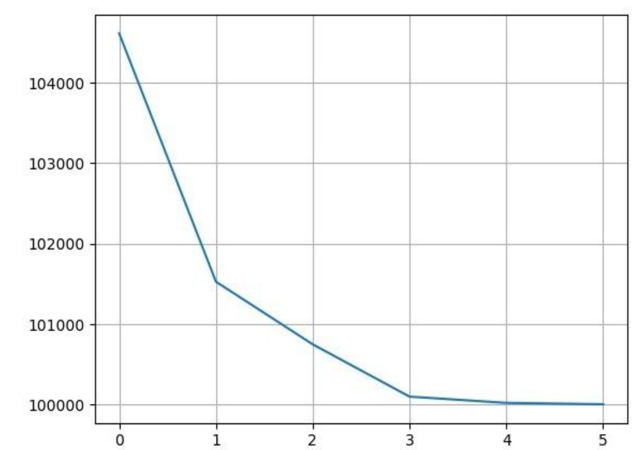

Figure. 9. Algorithm performance based on excavation uncertainties rate for 100×100 m pit in two work-faces

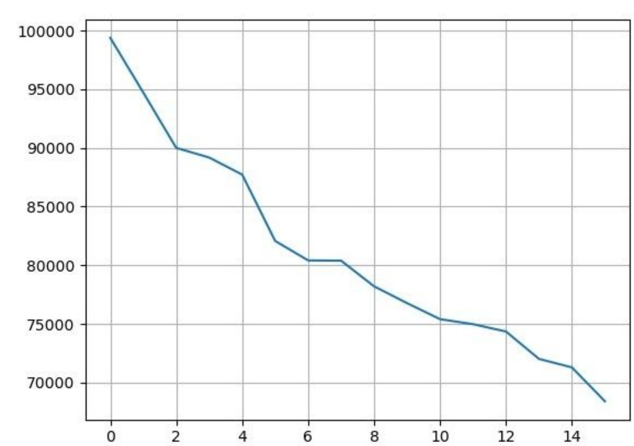

Figure. 10. Algorithm performance based geo-mechanical and deposit nature uncertainties rate for 100×100 m pit

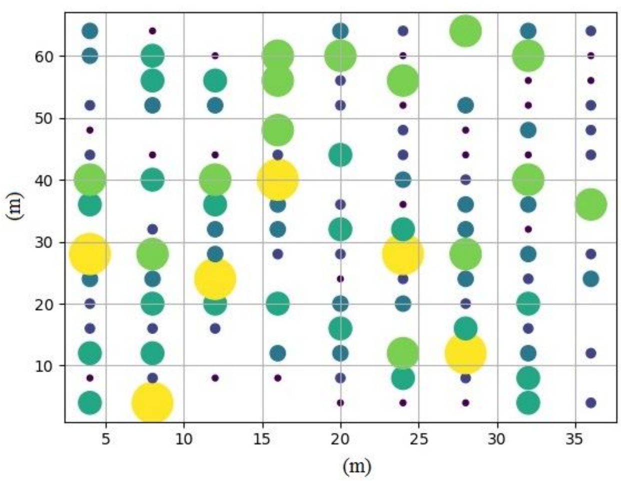

Figure. 11. Optimum pattern and impact radius for 70×40 m pit in one work-face

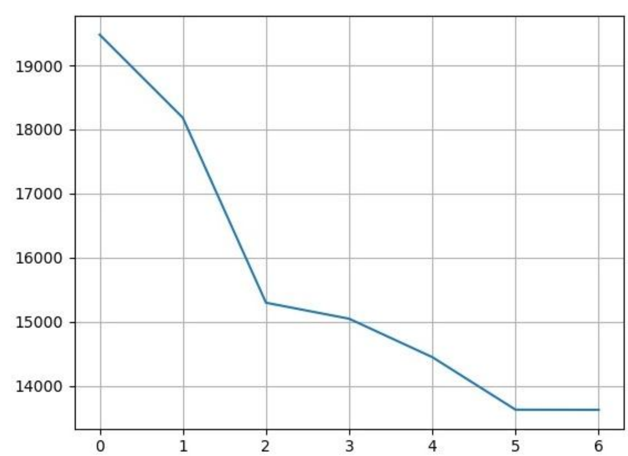

Figure. 12. Algorithm performance based on excavation uncertainties rate for 70×40 m pit in one work-face

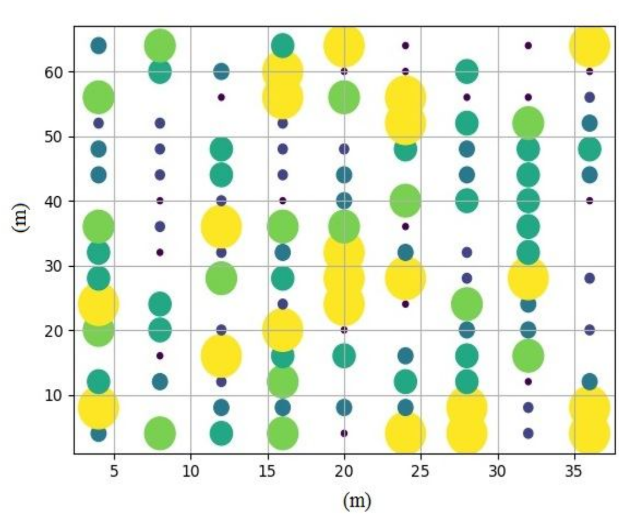

Figure. 13. Optimum pattern and impact radius for 70×40 m pit in two work-faces

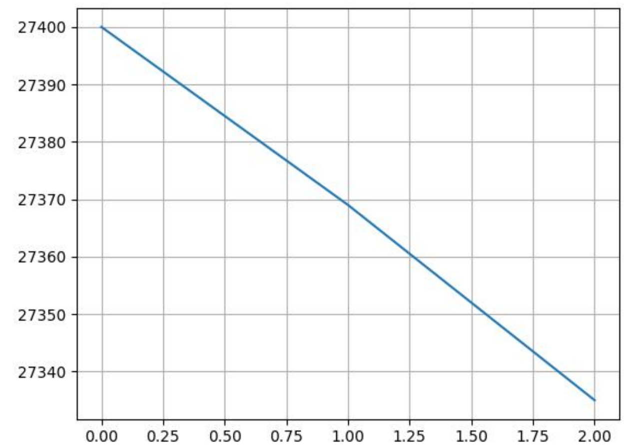

Figure. 14. Algorithm performance based on excavation uncertainties rate for 70×40 m pit in two work-faces

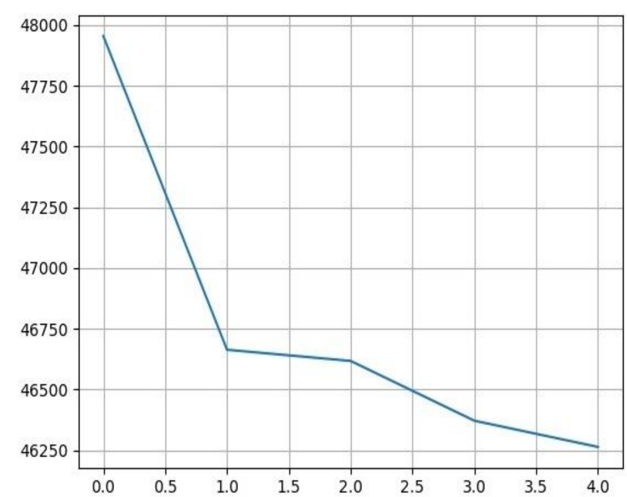

Figure. 15. Algorithm performance based geo-mechanical and deposit nature uncertainties rate for 70×40 m pit

6. Conclusion

Blasting operations is one of the most important approaches to open-pit mining, which is very sensitive than other methods were used in mine exploitation. The blasting operations methods are categorized as instructions are prepared but it does not cover the explosive emplacement pattern. Generally, in mines (especially in Iran), this model obtained from simple manual calculations or excel software which that more relying on the engineer responsible experience of operation. There are many parameters involved in blasting pattern which can be divided into the following groups like environmental, geological, geo-mechanical, explosives, technical, economic and safety (HSE) conditions. In this study, GA has been used to perform optimal selection and explosive implementation pattern design in open-pit mines by consideration of good coverage with field and geo-parametric in open-pit mine. For this purpose, the optimal design simulation of blasting pattern for open pit mines with one and two work-faces (for two standard 100×100 and 70×40m sides) by the Python programming language was conducted. The input parameters for this assessment classified in 15 groups contain climatic conditions, accessibility conditions, topography, type of deposit (metallic or non-metallic), ore deposit area, mineral storage, type and nature of ore, mass geometry, mine area, number of working-faces, joint density, geo-mechanical features, tectonics and faults and ore quality. The key variables in simulation and optimization for suggestion pattern are mine area, depth of digging borehole, digging borehole locations, digging borehole effective radius, ore quality, Geo-mechanical features, ore deposit area, tectonics and faults, number of working-faces, joint density, dynamite borehole number, side break, spacing, apparent burden, collapse rate. According of simulation can be stated that the zonal pattern is more than other placements are good answered. On the other hand, location of the empty borehole between explosives can be increase the rate of exploitation and decrease the costs of the entire operations. Also the number of working-faces, joint density and ore deposit area is mainly effected the pattern of explosive implementation and blasting.

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