Optimising the Loading System of Gol-e-Gohar Iron Ore Mine of Iran by Genetic Algorithm

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ABSTRACT

In mining industries, materials handling costs represent a significant component of the operational cost. A variety of methods have been applied in surface mine equipment selection in order to select the suitable loading system with the lowest loading operation cost. These are queuing theory, bunching theory, linear programming and genetic algorithm. Among them, genetic algorithm is a simple method and applied for preliminary selection of the loading system. In this study, gathering information from anomaly No 2 of Gol-e-Gohar iron mine of Iran, loading system (number and its capacity) has been optimised by genetic algorithm. The study results showed that two shovels 8.25 m^3 are required for the removal of 60 million tonnes of overburden. After removal overburden, these two shovels contribute to the extraction of 42 million tonnes of ore with a stripping ratio of 1:1.

INTRODUCTION

Equipment selection is one of the most important aspects of open pit design. Mining costs are mainly affected by the number and capacity of equipment. The purpose of equipment selection is to select the optimum size and number of equipment with minimal cost (Bascetin, 2004).

A review of relevant literature indicated that operational research optimisation techniques currently in use have serious limitations. These techniques lacked flexibility and were often invalidated by their inability to cope with a large number of variables, constraints and uncertainty, which are a natural part of the process of removing overburden and ore extraction (Jayawardane and Harris 1990). Research in other areas indicated that genetic algorithms, which are inspired by the theories of evolution and biogenesis, had potential application in the selection of optimal solutions. There is evidence that it had been used successfully to solve complex problems in engineering, and their nature in being non-linear, stochastic and highly dimensional facilitated their application to problems of infinite variety (Holland, 1992).

In this research, the genetic algorithm was used to determine the number and size of loading equipment. The main objective of the study was to assist the open pit mining company in the decision-making for selecting the right size and number of equipment and compare their decision with the proposed model outcome.

OVERVIEW OF GOL-E-GOHAR MINE

The Gol-e-Gohar open pit iron ore mine is located 300 km south-west of Kerman province in Iran (see Figure 1). This mine has six anomalies, spread over an area of 40 km^2. The iron ore in this region is estimated to be up to 1135 million tonnes (Mt) and currently anomaly No 1 with 185 Mt of mineable ore is mining. The length of anomaly No 2 is 1100 m with a width of 200 m. Total mineable reserves and removable waste of anomaly No 2 were estimated to be about 42 Mt and 103 Mt respectively. According to the mine conditions, the overall stripping ratio (including overburden and waste) is 2.4:1. This deposit has been extended from 1755 m to 1530 m above sea level. Based upon the feasibility study the suitable bench height is 15 m and the mine depth is 225 m. Overburden thickness varies between 41 m

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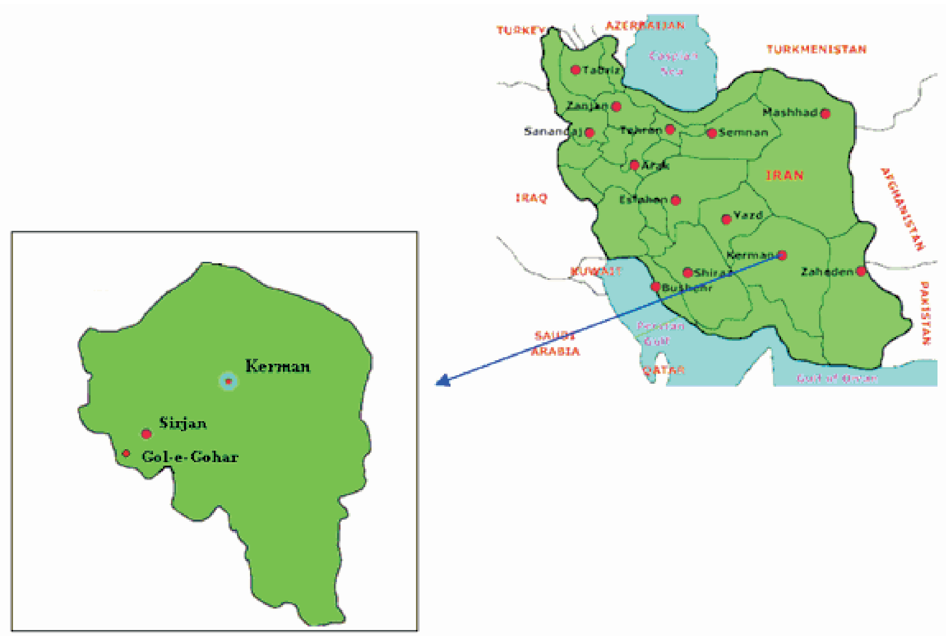


FIG 1 - Geographical location of Gol-e-Gohar iron mine.

and 91 m and 60 Mt materials must be removed. The annual rate of removing overburden is 10 Mt. Due to this annual rate, the total overburden can be removed in six years. According to the previous study (Eskandari, 2006), the proper production rate of ore is calculated to be 5 Mtpa, with removal waste of 5 Mt. The total working days per year is 285 with three shifts per day and six working hours per shift. The main loading system of anomaly No 1 is mechanical shovel, which was manufactured by P&H company, with 7.6 m^3 capacity. The haulage system is Terex truck with 120 tonne capacity.

GENETIC ALGORITHM

Genetic algorithm (GA) is an artificial intelligence technique inspired by the theory of evolution and biogenesis. Genetic algorithm is a search algorithm inspired by Darwin's theory of evolution (Holland, 1992). It is aimed at imitating the abilities of living organisms of being consummate problem-solvers through the apparently undirected mechanism of evolution and natural selection (Davis, 1991).

In GA, a population of individuals that are representing a possible solution to the problem is initially created in random procedure. In turn, random pairs of individual solutions are combined to produce offspring for the next generation. A mutation process is also used to randomly modify the genetic structure of some of the members of each new generation. The system is repeated to create a sequence of successive generations. Because the probability of an individual reproducing is proportional to the 'goodness' of the solution it represents, the quality of the solutions of successive generations should improve. The process is terminated either once an acceptable or optimum solution is found, or a predetermined solution time limit has elapsed (Lowndes Fogarty and Yang, 2005).

Genetic algorithms can converge quickly on near solutions in large spaces through their remarkable ability to focus their attention on the most promising parts of a solution space and their ability to combine strings containing partial solutions. Due to their ability to solve poorly understood, loosely defined problems or problems characterised by many constraints, uncertainty and an abundance of feasible solutions, genetic algorithms have made breakthroughs in the design of many complex systems in various fields (Loughlin and Ranjithan, 1995).

The following section introduces the case study of GA on a loading equipment selection for an open pit mine and the implementation of GA will be discussed in more detail.

APPLICATION PROCEDURE

Application of GA for a loading system involves the use of optimisation techniques to define the size and number of the equipment that would produce the minimum total cost of the operation. To process this sort of problem, it needs to be presented synthetically, which involves deriving a set of input parameters required to generate a set of desired outcomes. The sequences for presenting the problem are:

1. Determine the objective function, which is the numeric variable that needs to be optimised. In this case, minimising the total cost of owning and operating the loading equipment (shovels) to operate in the mine is the objective function. It is a function of the number and capacity of equipment to be utilised and their cost.
2. Determine the independent variables, which are the number of each model and the number of hours the equipment operates over its operating life.
3. Determine the dependent variables, which are the production of the equipment, the life of the equipment and the per cent factor it costs to operate the equipment over its operating life.
4. Define the constraints, which are the maximum or minimum limitations of the problem that must be satisfied. These constraints are:
   a. the total production required in the mine,
   b. the mine's life,
   c the minimum and maximum number of loading systems to be used, and
   d. the maximum and minimum number of operating hours of each model.

The optimisation problem is formulated as follows:

$$Min\,f = \sum_{i=1}^{n}\left(C'_{X_i} + C''_{x_i}\right) + \sum_{i=1}^{n}\left(k.x_i\right) + \sum_{i=1}^{n}\left(\lambda.l_f.x_i\right) \qquad (1)$$

Subject to:

$$\sum_{i=1}^{n} P.x_i \le P_t$$

$$\sum_{i=1}^{n}\left(L.x_i + l_f x_i\right) \le L_t$$

$$\sum_{i=1}^{n} X_i \le N$$

$$\sum_{i=1}^{n} l_f \le 0.5L$$

$$\sum_{i=1}^{n} x_i \ge 0$$

$$\sum_{i=1}^{n} l_f x_i \ge 0$$

$$x_i \ge 0$$

where:

C'_{x_i} cost of owning shovel

C''_{x_i} transportation cost of shovel from manufacture to site

k unit operation cost of equipment

x_i type of shovel

λ per cent factor it costs to operates over its operating life (if applicable for shovel)

l_f number of hours the shovel operate over its operating life (if applicable for shovel (variable))

P unit production of shovel

P_t total production required in mine (constant)

L life of equipment

L_t total life of mine (constant)

N maximum number of shovel that can be used in mine

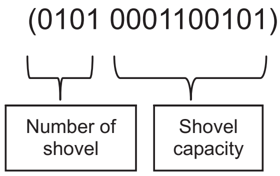
n number of equipment

With regards to the Iranian mining industry, λ and l_f are considered in this formula and a non-linear problem should be solved. To solve this sort of problem requires a method that is capable of solving optimisation problems with more than one type of independent variable, which is beyond the capability of traditional optimisation techniques, such as linear, integer and dynamic programming. Therefore, the use of intelligent search and optimisation techniques, such as genetic algorithms, is essential to solve the problem.

Parameters evaluation

The ability of genetic algorithms to focus their attention on the most promising parts of a solution space is a direct outcome of their ability to combine strings containing partial solutions (Holland, 1992). After the initial generation, the random search of better solutions for the rest of the generations is controlled through the evolution operators.

At first, the decision variable set (vector) of the optimisation problem is encoded into a string called a chromosome. A binary coding is most often used, but an integer coding or even a real numbered coding can also be utilised. If there are m decision variables in an optimisation problem and each decision variable is encoded as an n-digit binary number, then a chromosome is a string of $n \times m$ binary digits, as shown below. In this model, the number of shovels and shovel capacity were calculated and the range of shovel quantity is 'between' one to eight and the range of shovel capacity is between 5.01 m^3 and 9.99 m^3. This binary code was chosen for solving problem such as:



This binary code indicates five shovels with a capacity of:

$$5.5\ m^3 \left(5.1 + \frac{9.99-5.01}{2^{10}-1} \times (0001100101)_2\right)$$

In the proposed model 20 chromosomes were produced. After the initial generation, the random search of better solutions or the rest of the generations is controlled through the evolution operators. There are three main operators:

1. *Crossover:* this is the random recombination of the genes of two parents to form a child. In other words, for every two parents that are selected, two child strategies whose gene values are a random combination of the parents are generated. A randomly generated crossover 'template' defines which genes go to which child. The two most fit of the parents and children are chosen to survive to the next population (Loughlin and Ranjithan, 1995). In a genetic algorithm problem, crossover is a random binary combination of the genes of two separate chromosomes to provide a new 'child' chromosome. Figure 2 shows the rearrangement of the genes of two random chromosomes using two point crossover. In this model, two point crossover was implemented and codes two and ten were selected for the crossover stage. The crossover rate was assumed 0.4.

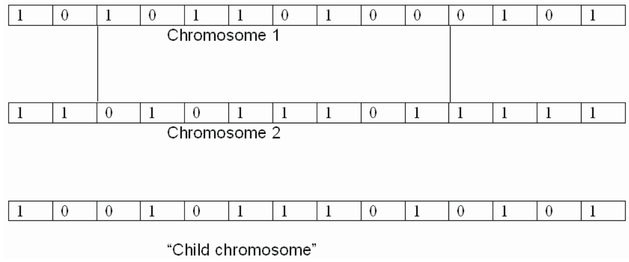


FIG 2 - Crossover between two chromosomes.

2. *Mutation:* this is used to add new genetic materials to the gene pool and is also part of the mechanism of retaining bad values by creating a whole new number in the chromosome. Mutation alone does not generally advance the search for a solution but it does provide insurance against the development of a uniform population incapable of further evolution. It is the action of random mutation that lets genetic algorithms avoid being captured by local minima. The mutation rate in this model was assumed 0.04.

3. *Adaptation:* this, like mutation, is a random change to the value or order of genes within the chromosomes. However, it is different from mutation as it retains only improved values. As such, adaptation is a wise mutation that helps to accelerate the search for the solution (NAOUM, 2000).

GOL-E-GOHAR IRON ORE MINE EQUIPMENT SELECTION

Anomaly No 2 of Gol-e-Gohar mine contains 145 Mt of material, which includes ore, waste and overburden of 42 Mt, 43 Mt and 60 Mt respectively. Annual production rate in this anomaly is 10 Mt and total overburden must be removed in six years. After overburden removal, 5 Mt of ore will be extracted with a stripping ratio of 1:1. The mine's life is 14 years and the maximum number of shovels that can be used in this anomaly is eight.

Figure 3 illustrates the relation between C'_{x_i} costs of owning shovel and shovel capacity. In this model, C''_{x_i} is a critical parameter and depends on several parameters, such as transportation type, shovel manufactory, company policy, etc.

The production of equipment is directly proportional to the equipment characteristics (ie bucket size, depth of cut and

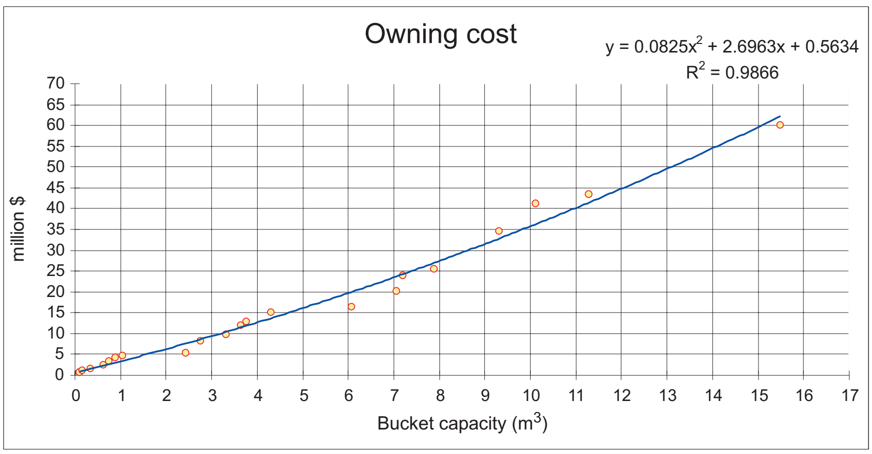


FIG 3 - Relation between owning cost and bucket capacity.

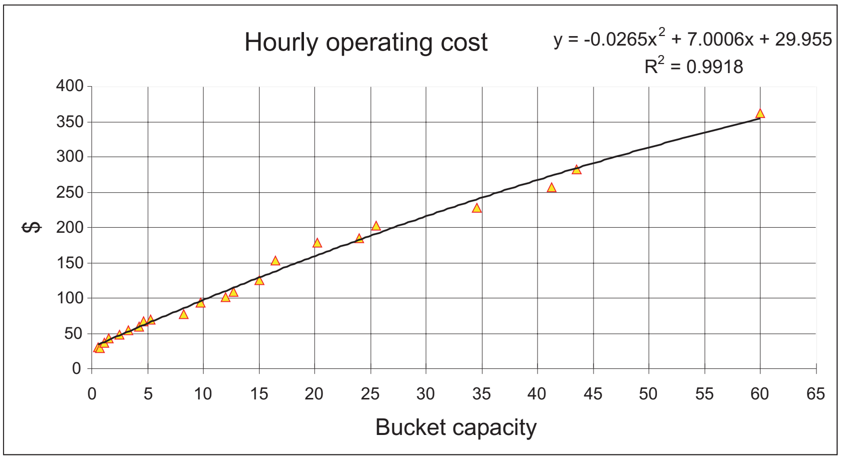


FIG 4 - Relation between operating cost and bucket capacity.

speed), the mine parameters (ie swell factor, optimum depth of cut and distance of dump location) and the operating times and the operating conditions (job and management conditions). All factors are considered constant over the period of the project life as they are predetermined at the early stages when planning a mine.

For operating cost estimation (k) all costs such as repair, maintenance, labour, interest, taxes, insurance and depreciation were calculated. Figure 4 illustrates the relation between shovel capacity and total unit operation cost. In Table 1 unit operation cost and owning cost is illustrated. The penalty considered in this model was:

- If production rate in the mine is less than the total production rate we define a new parameter, which shows with ξ and describe the difference between production and total production rate. Then a constant factor such as 'z' was defined, which equals $30/tonne for this mine. Finally, $\xi \times Z$ was calculated; therefore fitness function was equal to summation of production cost and $\xi \times Z$.

A flow chart for programming the optimal cost is illustrated in Figure 5. For solving fitness function, MATLAB R2006a

TABLE 1

Data of power shovel costs.

Shovel capacity (m^3)	Owning cost ($ M)	Hourly operating cost ($)
0.57	0.1001	30.32
0.75	0.1056	29.62
1.15	0.1606	36.37
1.5	0.341	42.7
2.5	0.6314	48.08
3.25	0.74	54.95
4.2	0.88	59.36
4.6	1.05	66.62
5.25	2.43	66.69
8.28	2.76	77.12
9.75	3.31	94.12
12	3.65	101.6
12.75	3.76	108.93
15	4.31	125.12
16.5	6.08	153.47
20.25	7.07	178.34
24	7.21	185.11
25.5	7.88	203
34.5	9.31	228.34
41.25	10.11	256.42
43.5	11.29	282.84
60	15.5	362.62

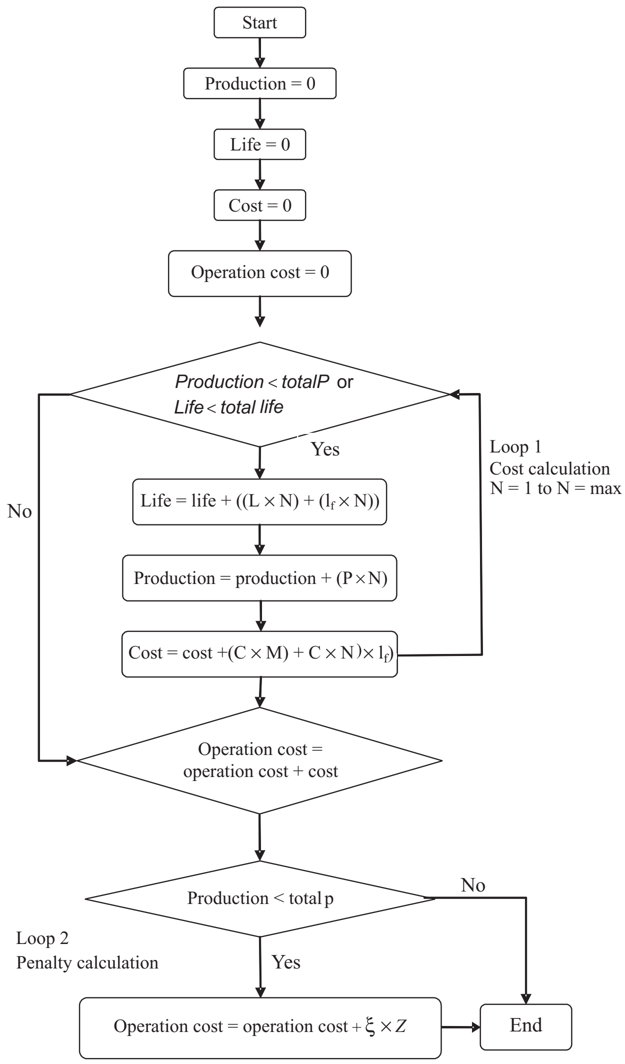


FIG 5 - Flow chart for programming the optimal cost.

software was used and after running the model, two shovels with 8.25 m^3 capacity were selected for anomaly No 2. These two shovels are suggested for removing overburden in the first six years, then one of them is used in ore zone and another is used in the waste zone. For mechanical efficiency and unpredicted condition, three shovels are recommended.

CONCLUSIONS

Equipment selection is one of the important aspects of mine planning and although the optimum equipment selection for a mine is a complex decision, it can be broken down into a series of relatively well-defined variables that are directly related to the general mine conditions. Genetic algorithm is a powerful algorithm to solve complex models and was used in this research. The results are relatively optimal and with increasing iteration in genetic algorithm, the difference between real optimum and genetic algorithm output is decreased. This model was used in Gol-e-Gohar mine and the result was verified.

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