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An Approach to Locate an In Pit Crusher in Open Pit Mines

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ABSTRACT

Haulage costs accounts for 45 to 60% of the total operating costs in large open pit mines. Cost efficiency and high reliability of semi mobile or combined "In Pit Crushing-Conveying (IPCC) and truck" systems compared to conventional truck-shovel systems alone, makes it more appealing to be utilized in modern mining activities. Semi mobile systems have the advantages of both systems, and its operating costs depend on the location of the in pit crushing unit. In this paper, the effective factors on determination of a suitable location of an IPCC are studied and it is investigated as a single hub location problem. The main concerns of the optimum location are minimizing haulage costs and choosing a location regarding the environmental concerns. The method is applied in Sarcheshmeh Copper Mine (SCM), and according to the results, locations C1 to C4 are candidate locations, and applying the hub model, location C2 on level 2450 is suggested to locate the IPCC.

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1. INTRODUCTION

Open pit mining is a large operation of excavation within which considerable amount of material should be extracted and removed out of the mining terrain. An open pit mine consists of pit or pits (where the ore and waste rock is extracted), mill, waste dumps, and stockpile. The materials inside the pit are excavated and loaded to the haulage system and according to materials type, they are hauled to the predefined locations. In open pit mines, hauling costs are about 60% of the total operating costs [1]. Meng et al. developed a data-driven modeling and simulation framework to support decisions on equipment selection [2]. Topal and Ramazan studied the uncertainty of maintenance costs on trucks scheduling [3]. Vayenas and Peng investigated maintenance schedule in order to improve the productivity of mining operation and decrease the extra capital to compensate unexpected equipment failures [4]. Rodrigo et al. showed that reliability, availability and maintainability of equipment reveal specific information on the production availability and maximizes the total production of the system [5]. Souza et al. dealt with the problem of optimizing the mineral extraction through minimizing the number of trucks as a dynamic truck allocation problem [6]. Lio and Kozan developed an interactive mine planning and scheduling framework to optimize mine planning and short-term haulage operations from pits to crushers [7].

In recent years, application of in-pit crushing and conveying systems is of interest in open pit mines design and planning. Apart from choosing a suitable type of crushing and conveying system for the mines, the location of the system should also be optimized to reduce the mine operating costs. A suitable location for an in-pit crusher should have the following conditions:

- In pit crushing unit should be in an optimum distance from each working face.
- It would be better if the location of the crusher be fixed at least for a period of one year. This will reduce the number of times that the crushing unit is

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moved. So, the overall cost of crusher reinstallation will be reduced.

Londono et al. studied different combinations of in-pit crushers and conveyor systems [8]. The most related works on selection of an optimal location for in-pit crushing system includes Robertson, Sturgul, and Konak et al. [9-11]. Optimization of a crusher location and haulage distances are first introduced by Robertson. Konak et al. discussed the effects of pit geometry and mine access requirements on optimum crusher location selection that are mainly based on the establishment of minimum haulage distance. They established a trial and error process and applied their method in an aggregate mine.

In the present paper the problem of allocating in pit crushers is described as a hub-location problem. Before proceeding to the problem of locating the in pit crusher, different types of haulage systems in surface mines are investigated.

2. HAULAGE SYSTEMS IN OPEN PIT MINES

The materials inside the pit are excavated and loaded to the haulage system and according to type of the materials (ore or waste) they are transferred to a predefined location (mill, stockpiles or waste dumps). The main haulage systems in open pit mines are (1) Trucks, (2) Conveyor, (3) Rail, and (4) Rope way. As shown in Figure 1, based on mine conditions, haulage distance and mining rate, each of these haulage systems could be applied in a mining operation.

The most important factor in selection of mine equipment is unit operation. The unit operation or operating system in open pit mines can be one of the following alternatives [12]:

a) Conventional operation: in which a shovel-truck system is used and the primary crushing unit is near the mineral processing plant.
b) Semi mobile operation: this allows for using a primary crushing unit inside the pit together with a shovel-truck system; and the materials are hauled by conveyor to the processing plant.
c) Full mobile operation: a combination of shovel and mobile crusher is implemented and the materials are hauled by conveyor to the material preparation plant. In this system, the shovel productivity and the availability of the whole system are maximized.

Studies show that introducing parallel conveyor lines with spreaders is capable of improving IPCC productivity up to 12.6% [8]. Each of the above unit operations has its own cost structure, but it should be reminded that haulage costs are major part of each operating mine. Haulage costs have always been a significant part of capital and operating costs of large open pit mines. In Figures 2 and 3, typical open pit mine capital and operating cost distributions for a large deep mine using a conventional shovel-truck are shown.

According to these figures, haulage costs are almost over45% of operating costs in the life of a mine and it is about 40-50% of capital costs [13]. In open pit metal and nonmetal mines, hauling cost constitutes roughly 60% of the operating costs [1]. The cost factors in a shovel-truck system are fuel, spare parts, tires, operator's costs [13], road construction and maintenance cost, and vehicle maintenance.

Li and Knights used the concept of real option in dump truck dispatching and short term planning [14]. According to their method, during high fuel price periods, it is better to transport waste material to the nearby dumps and vice versa. This strategy may not be applicable in long term planning because of complicated fuel price forecasting.

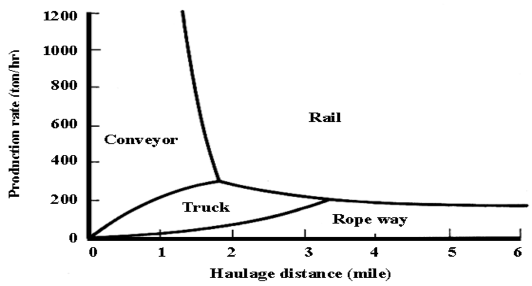

Figure 1. Haulage system in surface mines

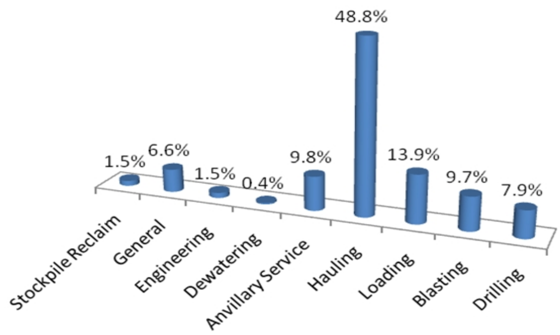

Figure 2. Capital costs in large open pit mines [13]

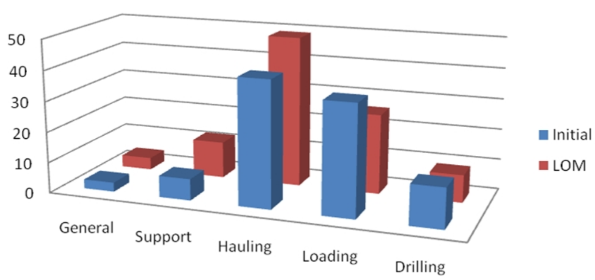

Figure 3. Typical operating cost in large open pits [13]

The fluctuations in fuel and equipment price, labor shortages and the increasing need of moving large volume of materials in mining operations, emphasis the need and importance of in pit crushing and conveying systems in large open pit mines as a long term option [15]. An in pit crushing and conveying system must satisfy two competing criteria in order to be the most appropriate selection for an operation in deep open pit mines: (1) physically be able to excavate and deliver material to some form of out-of-pit system at the required capacity, and (2) be acceptably cost-effective during both the capital and operating phases of the operation. On the other hand, trucks are well suited to short hauls (less than 3 miles according to Figure 1) and selective mining and dumping. As the mines deepen, the haulage distance increases, so the required time of haulage will increase. The number of loads by truck will decrease as a result the cycle time increases. To overcome this problem, sometimes the capacity of haulage system may be increased. Here one can name a few disadvantages of pure truck-shovel system:

a) Pit deepening will increase the haulage distance,
b) increase of haulage distance requires an increase in the number of trucks,
c) the initial capital cost of trucks is getting higher due to improvements on its break, tire, and capacity. Trucks with 360 tons of payload cost more than US$3 million.
d) as the number of trucks increases, traffic in the mine, will be an important problem that requires efficient management,
e) maintenance, repair and operation costs will become higher,
f) number of mine labor will increase, and requires more supervision,
g) more trucks is required in pure truck-shovel system compared to semi mobile systems,
h) a truck consumes 60% of its energy to move itself, and,
i) trucks move empty in 50% of the working time.

The other option is to use conveyor system incorporating with an in-pit crusher, truck, and shovel to continue a cost effective operation. This alternative has the advantages of both methods (i.e. pure truckshovel and full mobile systems). Open pit mines with longer haul distance requires more numbers of trucks. A deeper and larger pit normally requires more capital for additional trucks relative to extending a conveyor system [1]. The longer the life of the project, the more economical the conveyor system, especially in deep pits or pits that gradually increase in depth. Thus, taking into account the necessity of purchasing additional trucks to accommodate increasingly difficult haulage routes and to replace trucks as they wear out, conveyor systems will actually require lower capital costs over the life of a mine. Conveyor systems handling ore in numerous large crushing and port facilities have clearly demonstrated a useful conveyor life of more than 25 years. In contrast, off-highway trucks have life spans of six to eight years [1]. Studies show that semi mobile and full mobile systems can save costs up to 40% and this is considerable comparing the amount of material hauled in open pit mines. In case of availability, the availability of conveyors is 95% and for mobile crusher/conveyor system is more than 85% which is far better than truck operations [12].

Taking into account the future characteristics of open pit mines [16] naming low grade mining from depth in large quantities, increasing overburden ratio, and longer haulage distances, considering a semi mobile system seems to have the potential of reducing costs in future mining activities. In giant or large scale open pits, the majority of operating cost is tied to overburden removal and waste handling which forces mining companies to conduct a cost effective haulage system. There are 33 different factors that affect the type of haulage system in a mining operation (Table 1). These factors are site specific, and decision making methods are useful tools for selection of a suitable haulage system in any mining operation.

A combination of Delfi and weighting techniques is used to prioritize the factors in Table 1. Researches show that in general, mine life, equipment's useful life, haulage distance, and production rate are the governing factors that affect the haulage system in any mining activity. Considering these factors and applying decision making approaches [17-20] one could determine whether to equip the mine with semi mobile systems or with the conventional truck-shovel system. It is also possible to make decision among the types of available equipment as well. However, when one decides to apply a semi mobile operation in a mine, the main problem that arises is the decision on the locating of an in-pit crushing unit.

3. HUB-LOCATION PROBLEM

One of the new topics in location problems is the hub location problem [21, 22]. The first paper on hub location problem was published by Toh and Higgins and it was about the application of hub location problem in airlines and airports [23]. A comprehensive survey on hub location models and problems can be found in Alumur and Kara [24].It is supposed that there are N nodes, and if each node can be either an origin or a destination, then within a fully connected network, where each node is connected to all of the other nodes, there are N(N-1) origin-destination pairs of nodes. Notice that the pair i-j is different from the j-i pair. Figure 4 shows a network with six nodes [25]. It is assumed that in this network each vehicle could service five origin-destination pairs every day, and then with six vehicles, six nodes could be serviced every day.

TABLE 1. Important factors that affect the selection of haulage system in surface mines

Item Num.	Affecting factors on the selection of Semi mobile vs. Truck & Shovel system
1	Mine size and Production rate
2	Essence of continues production
3	Selective mining requirements
4	Mining face length (or length of working benches)
5	Depth of the deposit and pit
6	Topography of the pit surroundings
7	Pit geometry (periodic pits and final pit geometry)
8	Haul road grade and condition
9	Projected mine life
10	Useful life of equipments
11	Haulage distance
12	Dumping level
13	Dump configuration (Side-hill, Valley-fill, or Heaped)
14	IPC relocation and installation time
15	Capital costs
16	Operational cost
17	Net to Tare ratio
18	Reliability
19	Availability
20	Flexibility of the system
21	Material size
22	Material moisture
23	Density and swell factor
24	Ground condition
25	Safety
26	Climate and weather condition
27	Environmental factors (Noise)
28	Gas emission
29	Dust emission
30	Land disturbance
31	Labour costs
32	Management required
33	Support and availability of spare parts

If one of these nodes is set as a hub node and then connected to all of the other nodes (which are called spoke), then there will be 2(N-1) connections to service all the spokes via a hub node [26]. This network is presented in Figure 5 and in this figure, node A is supposed to be the hub node. In this case, if each vehicle could service five origin-destination pairs every day, then in this network, with six vehicles, 16 spokes could be serviced every day.

Thus, with a fixed haulage capacity, it is possible to service more spokes within a hub network than within a fully connected network [26]. In hub networks, instead of servicing each spoke directly, hub facilities concentrate flows in order to take advantage of economy of scale.

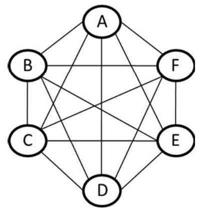

Figure 4. A fully connected network (6 nodes and 30 origin-destination pairs)

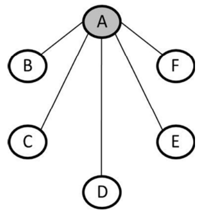

Figure 5.A hub and spoke network (6 nodes with 5 origin-destination pairs)

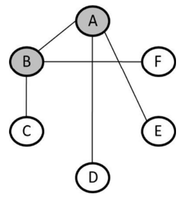

Figure 6. Example of a hub network with 2 hubs

Flows from a spoke are transported to the hub, and combined with flows that have different origins but the same destination. This fact will reduce the total haulage cost. In multi-hub networks, the hub nodes are completely connected to one another and each spoke is connected to at least one hub such as the network shown in Figure 6.

In multi-hub networks, the assumption is that the hubs are connected through low cost and high capacity pathways which cause a discount on the haulage costs between any given hub nodes [27]. The advantage of using hubs is to gain the economic profits by establishing more qualitative paths between the hubs. It should be noted that increasing haulage capacity decreases the haulage costs. On the other hand, due to traffic issues, increasing haulage capacity is not possible on every path. However, introducing the hub nodes can effectively solve this problem. It means that not only haulage capacity increases, but also there is a low traffic problem as compared to the situation where there is not a hub node.

4. MATHEMATICAL MODEL

In a hub network, the objective is to minimize the total cost of hauling between hubs, facilities and destination nodes. In single hub location problems, each destination or demand node must be allocated to be linked to one hub. Location of an in-pit crusher can be modeled as a single hub location problem. The linear form of a single hub problem is given in Equations (1)-(5).

$$Min\left\{\sum_i\sum_j C_{ij}y_{ij}\left(out_i+in_i\right)+\sum_j H_jR_j\right\} \quad (1)$$

$$Subject\ to:$$

$$\sum_j H_j = 1 \quad (2)$$

$$y_{ij} - H_j \le 0,\ \forall i, j \quad (3)$$

$$H_j = 0\ or\ 1,\ \forall j \quad (4)$$

$$y_{ij} = 0\ or\ 1,\ \forall i, j \quad (5)$$

In this model, out_i is the total out flow of node i, and in_i the total inflow of node i, and C_{ij} the unit cost of flow between nodes i and j. If H_j is equal to 1, it means that we have to locate a hub at node j, and R_j is the cost of removing and reinstalling the hub located at node j. y_{ij} shows that node i is connected to hub located at node j.

Equation (1) is the objective function and it minimizes the total costs. Equation (2) ensures that only one node is allocated as the hub node. Equation (3) ensures that node i cannot be connected to hub at node j unless we locate the hub at node j. Constraints in 4 and 5 are integrity constraints of the model. Alumur et al. studied hub location problem in presence of costs and demands uncertainty [28]. Tavakkoli et al. studied single hub problems to determine the location and the capacity of hub node [29].

5. IN PIT CRUSHER LOCATION

In this section a method to optimize the location of an in-pit crusher, is introduced. As open pit mines deepens, the haulage distance increases. Deep open pit mines or those open pits with longer haulage distances, require more numbers of trucks (or larger trucks) to produce a constant amount of material. It should be noted that, increasing the numbers of trucks or haulage capacity could decrease costs, but increasing the capacity may not be possible on every path. As the haulage capacity increases, the traffic of the path will become an important issue.

Introducing an in-pit crushing and conveying system as a hub node can effectively solve the problem. Introducing a hub node, not only increases haulage capacity, but also it lowers the traffic problems. On the other hand, in case of applying an in pit crushing and conveying system, large pits normally require less capital for extending the conveyor system relative to purchasing additional trucks in pure truck-shovel systems. Besides, installing a conveyor system in a long life mining project appears to be more economical. The location of an in pit crusher should be:

I. Within an optimum distance from each working face.

This will reduces the total distance between the crusher and the working faces, so, the system will require less number of trucks in the faces. Hence, the capital and operational cost of truck fleet reduces. The optimum distance from each working face should consider the total amount of material that must be mined from each working face according to the mine production plan. This item brings the IPC location to the center of gravity of working faces.

II. The location of the crusher must be fixed at least for a period of one year.

The optimum location of an IPC must be fixed for a period of time. Because working faces are dynamic and the pit shape changes through time, therefore, in determining a location for an IPC, the mine plan and working schedule should be taken into account. A suitable location would be the one which is not inside the mine working area at least for a period of one year. If this point is not considered, then the number of times that the crushing facilities is removed and reinstalled will increase. Harcus showed that in a typical IPCC operation, about 1% of the calendar time is allocated for conveyor relocations.

With respect to the fact that removing, civil works, and reinstalling of the crusher unit requires time and is costly, these operations could disturb the mine production scheduling. The frequency of relocating a semi-mobile system is an economic decision, but a period of 5 to 10 years between relocations is common. The concluding remark is that, the IPC system and location must be determined along with the mine production and development plan.

However, there are some other factors that affect the optimum location of IPC units. The mine planner should identify the possible locations for the IPC, taking into account all the factors that affect the location of IPC unit. Decision making approaches are common tools for determination of candidate IPC locations. Then, assuming these locations as the potential hub nodes, and applying the single hub location model described in section 4, the location of the in pit crusher is optimized.

Selecting a suitable location for an IPC unit is a hierarchical problem. Thus, considering the characteristics of each alternate site; and rating of these factors for each one, the proposed locations are ranked. The hierarchy structure of the problem is given in Figure 7. There are 17 factors that affect the IPC locating and they are categorized into two economic and technical factors

(Figure 7). Based on the strategy of decision makers, the importance of these two groups could be adjusted. However, in this paper it is assumed that these two groups of factors have the same weight of importance.

In Figure 7, the judgment scale is the one proposed in Analytical Hierarchical Process (AHP) method by Saaty [30- 32]. AHP is a powerful tool used for the hierarchical decomposition of complex problem and the synthesis of the criteria weights that result in the overall scores of alternatives. In this method, evaluation of criteria weights and the scoring of the alternatives against the criteria are determined by pairwise comparisons. The decision maker does not need to provide a numerical judgment; instead a relative verbal appreciation is sufficient. The result is a pairwise comparison matrix D such that:

$$D = \begin{array}{c} \\ x_1 \\ x_2 \\ \vdots \\ x_n \end{array} \begin{array}{c} \begin{array}{cccc} x_1 & x_2 & \cdots & x_n \end{array} \\ \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \end{array}$$

D is a reciprocal matrix [33], i.e.

$$a_{ij} = \frac{1}{a_{ji}}, \forall\, i,\, j = 1, \ldots, n$$

within which, a_{ij} is the relative importance (or the degree of preference) of ith element over the jth element (or attribute). This matrix is provided for any given two alternatives and criteria.

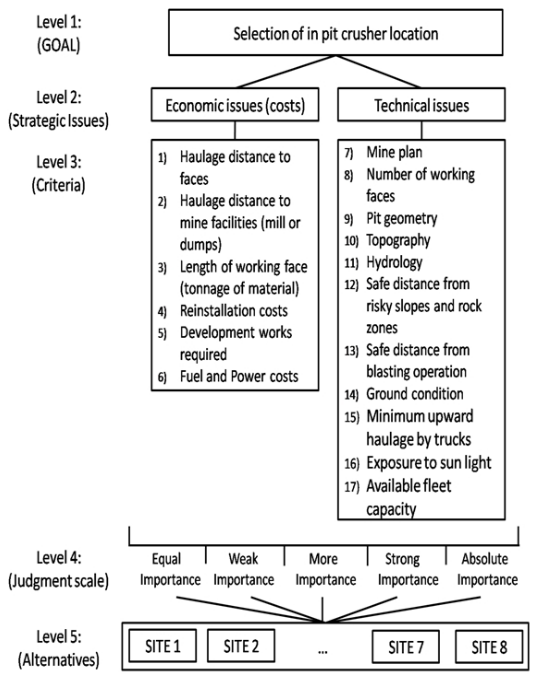

Figure 7. Hierarchical structure for IPC location problem

The strength of AHP is the ability to evaluate both quantitative and qualitative criteria on the same preference scale. In AHP method the scales, equally important, weak importance, more important, strong importance, and absolutely more important are quantified as 1, 3, 5, 7, and 9 respectively [34]. The scale of preference or importance between criteria is 1 to 9 where 1 stands for equal importance and 9 stands for absolutely importance of element i to j [32]. The weights of the criteria are calculated in these steps:

1) Sum up the elements in each column j:

$$\sum_{i=1}^{n} a_{ij}, \forall\ j = 1, \ldots, n \tag{6}$$

2) Divide each element by its column sum to normalize the comparison matrix:

$$a'_{ij} = \frac{a_{ji}}{\sum_{i=1}^{n} a_{ij}}, \forall\ j = 1, \ldots, n \tag{7}$$

3) Calculate the mean of each row:

$$p_i = \frac{\sum_{i=1}^{n} a'_{ij}}{n}, \forall\ i = 1, \ldots, n \tag{8}$$

The goal of AHP is to find the set of priorities for the alternatives, and in the step 3, p_i is the score or weight of importance of the ith element. Finally, the obtained relative weight vector ($P = [p_1, \ldots, p_n]$) is multiplied by the coefficient of the element at higher level, until the top of the hierarchy reached. In this paper the AHP method is applied to determine the priorities of the factors that affect the IPC location. This makes it possible to rank the alternatives and select the most appealing ones. The overall ranking and the weight of importance of each factors is given in Figure 8. According to this figure, the factors that affect the location of IPC unit are classified into 4 groups of factors. Mine plan, haulage distance to faces, and mine facilities (mill, stockpiles, or dumps) are the primal and most effective factors on IPC locating problem. These factors force the crusher to be located outside the mine working area and within an optimum distance to working faces and mine facilities to minimize the operating cost.

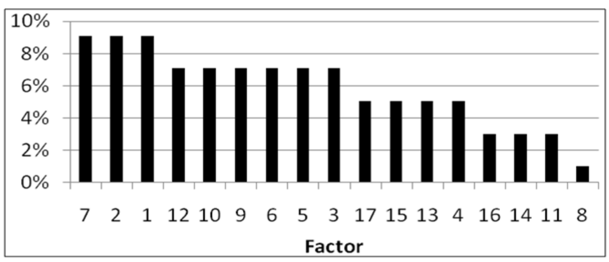

Figure 8. Ranking of the 17 factors affecting IPC location (number of the factors accords with the number in Figure 7)

Length of working face, pit geometry, topography, and safety distance from risky slope, development works required, and fuel and power costs are the secondary important factors on IPC locating problem. Lengths of the working faces indicate the tonnage of material in each face. This factor moves the crusher location near the large mining faces. Besides, the crusher location must be in a safe distance from mining activities, and it must be located away from risky regions as well. This will minimize the risk of equipment loss in case of any slope failure in the mine. Pit geometry at the beginning of the operation and its periodic states, as well as the topography of the mining area affect the amount of civil and development works, cost of crusher installation, and the path on which the roads and the conveyor are established. Fuel and power costs affect the operating cost of trucks and the conveyor. If fuel is more expensive than power, then it forces the crusher to be located near the working faces (and vice versa).

Available fleet capacity, safe distance from blasting operation, reinstallation costs, and minimum upward haulage by trucks is the tertiary important factors on IPC locating problem. IPC must be located such that not only no more truck fleet capacity is required, but also the efficiency of the fleet is kept as maximum as possible. Net to tare ratio of truck fleet is high and a truck consume 60% of its energy to move itself, thus, minimizing the upward haulage by trucks (if it is possible) will decrease the operating costs. The remaining factors are considered as less important factors on IPC locating problem compared to other factors. Exposure to sunlight, ground condition, and hydrology will change the site characteristics, and improve the working condition in the crushing site.

In the preliminary stage of locating problem, there may exist many alternatives. Decision making tools such as AHP are applied in this stage to eliminate the unsuitable locations. Then, the highest ranked alternatives are selected for the next stage of locating optimization. After identifying the candidate sites and constructing the representative network of the problem, the mathematical model can be solved as an integer-programming problem. The result of the model indicates that which candidate site has been selected as the location for the IPC. These steps are given in Figure 9. This procedure is applied in Sarcheshmeh copper mine to determine the optimum location of an in-pit crushing and conveying unit.

6. CASE STUDY

The procedure of determining the IPC&C location is depicted in Figure 9. In this section this method is applied to determine the optimum location of an IPC&C in Sarcheshmeh copper mine (SCM). Sarcheshmeh (Figure 10) is the largest copper complex in Iran located in 160 km southwest of city of Kerman.

According to the mine schedule, about 380 million tons of waste will be mined within the next 10 years. The mined waste material will be sent to two dumps located in the North-West and North-East of the pit. It means that Sarcheshmeh will produce about 40 million tons of waste rock per annum from the open pit. Based on the assessment and comparison of possible waste handling methods, it is certain that the in pit crushing and conveying is the more economic method in SCM than the trucking option. In this mine, Mineral Sizer is suggested as the crushing unit.

Considering the procedure in Figure 9, in the first step, taking into account the mine plan, eight alternatives (named from C1 to C8) are considered as candidate sites to locate the IPC unit. In the second step, applying the AHP method, the candidate locations of the in pit crushing and conveying unit is selected to be on sites C2, C4, C1, or C3. These sites are selected such that the preference weight of each individual is more than the average weight. Figure 11 shows the ranking of all the alternatives for IPC location, and the locations of the 4 selected sites are shown in Figure 12. By this step, based on the expert's opinion, the more appealing alternatives are selected for the next stage.

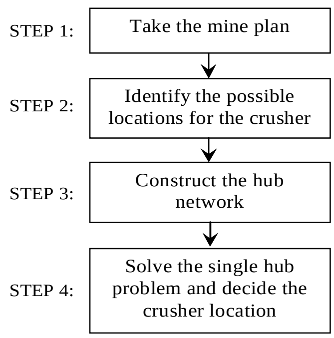

Figure 9. Steps required to find an optimum location for the in pit crusher

Figure 10. Location of Sarcheshmeh copper complex in Iran

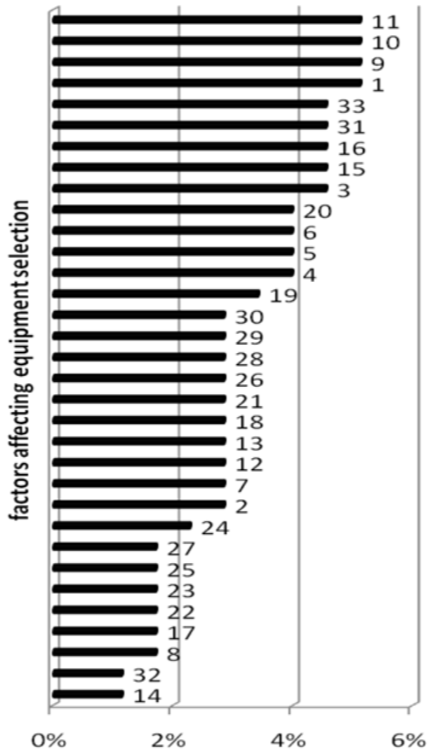

Figure 14. Factors affecting equipment selection (numbers on the bars indicate the number of the factor according to Table 1

The proposed method is applied to determine the optimum location of the in-pit crushing and conveying system in Sarcheshmeh copper mine. It is also assumed that there is only one IPC&C unit for which the optimum location must be determined. In cases of using multiple IPC&C units in a mine, hub location problem can be applied as well. The preliminary studies showed that the hub locating problem could be used to determine the location of the IPC&C systems in open pit mines. Based on the method, C2 is selected for locating the IPC unit and W2 is the selected destination for waste material handling.

8. REFERENCES

1. Frizzell, E.M. and Martin, T.W., "Inpit crushing and conveying", ***Mining engineering handbook. Hartman et al., Eds., Society for Mining, Metallurgy, and Exploration***, Vol., No., (1992), 1343-1351.Hartman, H.L. and Britton, S.G., "Sme mining engineering handbook, Society for Mining, Metallurgy, and Exploration, Vol. 2, (1992).
2. Meng, C., Nageshwaraniyer, S.S., Maghsoudi, A., Son, Y.-J. and Dessureault, S., "Data-driven modeling and simulation framework for material handling systems in coal mines", ***Computers & Industrial Engineering***, Vol. 64, No. 3, (2013), 766-779.
3. Topal, E. and Ramazan, S., "Mining truck scheduling with stochastic maintenance cost", ***Journal of Coal Science and Engineering (China)***, Vol. 18, No. 3, (2012), 313-319.
4. Peng, S. and Vayenas, N., "Reliability analysis of underground mining equipment using genetic algorithms: A case study of two mine hoists", ***Journal of Quality in Maintenance Engineering***, Vol. 20, No. 1, (2014), 3-3.
5. Mena, R., Zio, E., Kristjanpoller, F. and Arata, A., "Availability-based simulation and optimization modeling framework for open-pit mine truck allocation under dynamic constraints", ***International Journal of Mining Science and Technology***, Vol. 23, No. 1, (2013), 113-119.
6. Souza, M.J., Coelho, I.M., Ribas, S., Santos, H.G. and Merschmann, L.H.d.C., "A hybrid heuristic algorithm for the open-pit-mining operational planning problem", ***European Journal of Operational Research***, Vol. 207, No. 2, (2010), 1041-1051.
7. Liu, S.Q. and Kozan, E., "An interactive planning and scheduling framework for optimizing pits-to-crushers operations", ***Industrial Engineering & Management Systems***, Vol. 11, No. 1, (2012), 94-102.
8. Londoño, J., Knights, P. and Kizil, M., "Modelling of inpit crusher conveyor alternatives", ***Mining Technology***, Vol. 122, No. 4, (2013), 193-199.
9. ROBERTSON, J., "Inpit crusher cuts truck haul", ***Rock Products***, Vol. 87, No. 8, (1984), 40-42.
10. Sturgul, J.R., "How to determine the optimum location of inpit movable crushers", ***Geotechnical and Geological Engineering***, Vol. 5, No. 2, (1987), 143-148.
11. Konak, G., Onur, A. and Karakus, D., "Selection of the optimum inpit crusher location for an aggregate producer", ***Journal of the South African Institute of Mining and Metallurgy***, Vol. 107, No. 3, (2007), 161-166.
12. Tutton, D. and Streck, W., "The application of mobile in pit crushing and conveying in large, hard rock open pit mines", in Mining Magazine, Canada. (2009).
13. Li, S.-X. and Knights, P., "Integration of real options into short-term mine planning and production scheduling", ***Mining Science and Technology (China)***, Vol. 19, No. 5, (2009), 674-678.
14. Atchison, T. and Morrison, D., "In-pit crushing and conveying bench operations", in Iron ore conference, Perth. (2011).
15. Osanloo, M., "Future challenges in mining division, are we ready for these challenges? Do we have solid educational program?", ***Cuprum: Czasopismo Naukowo-techniczne Górnictwa Rud***, (2012), 61-70.
16. Ekipman, A.O.M.Ğ.O., Bir, S.İ., Sistemi, K.D. and Prosesi, A.H., "A decision support system for optimal equipment selection in open pit mining: Analytical hierarchy process", ***Istanbul University, Mining Engineering Department***, Vol. 16, No. 2, (2003), 1-11.
17. Bascetin, A., Oztas, O. and Kanli, A., "Eqs: A computer software using fuzzy logic for equipment selection in mining engineering", ***Journal-South African Institute of Mining and Metallurgy***, Vol. 106, No. 1, (2006), 63-70.
18. Aghajani Bazzazi, A., Osanloo, M. and Karimi, B., "Deriving preference order of open pit mines equipment through madm methods: Application of modified vikor method", ***Expert Systems with Applications***, Vol. 38, No. 3, (2011), 2550-2556.
19. Tavakkoli-Moghaddam, R., Heydar, M. and Mousavi, S., "An integrated ahp-vikor methodology for plant location selection", ***International Journal of Engineering-Transactions B: Applications***, Vol. 24, No. 2, (2011), 127.
20. Setak, M., Karimi, H. and Rastani, S., "Designing incomplete hub location-routing network in urban transportation problem", ***International Journal of Engineering-Transactions C: Aspects***, Vol. 26, No. 9, (2013), 997.
21. Ghodratnama, A., Tavakkoli-Moghaddam, R. and Baboli, A., "Comparing three proposed meta-heuristics to solve a new p-hub

location-allocation problem", ***International Journal of Engineering-Transactions C: Aspects***, Vol. 26, No. 9, (2013), 1043.

22. Toh, R.S. and Higgins, R.G., "The impact of hub and spoke network centralization and route monopoly on domestic airline profitability", ***Transportation Journal***, (1985), 16-27.
23. Alumur, S. and Kara, B.Y., "Network hub location problems: The state of the art", ***European Journal of Operational Research***, Vol. 190, No. 1, (2008), 1-21.
24. Daskin, M.S., "Network and discrete location: Models, algorithms, and applications, John Wiley & Sons, (2011).
25. Hekmatfar, M. and Pishvaee, M., Hub location problem, in Facility location. Springer, (2009) 243-270.
26. Naeem, M., "Using genetic algorithms for the single allocation hub location problem", (2010).
27. Alumur, S.A., Nickel, S. and Saldanha-da-Gama, F., "Hub location under uncertainty", ***Transportation Research Part B: Methodological***, Vol. 46, No. 4, (2012), 529-543.
28. Tavakkoli-Moghaddama, R., Gholipour-Kananib, Y. and Shahramifarc, M., "A multi-objective imperialist competitive algorithm for a capacitated single-allocation hub location problem", ***International Journal of Engineering-Transactions C: Aspects***, Vol. 26, No. 6, (2013), 605-612
29. Saaty, T.L., "Exploring the interface between hierarchies, multiple objectives and fuzzy sets", ***Fuzzy Sets and Systems***, Vol. 1, No. 1, (1978), 57-68.
30. Saaty, T.L., "Modeling unstructured decision problems—the theory of analytical hierarchies", ***Mathematics and Computers in Simulation***, Vol. 20, No. 3, (1978), 147-158.
31. Saaty, T.L., "Decision making with the analytic hierarchy process", ***International Journal of Services Sciences***, Vol. 1, No. 1, (2008), 83-98.
32. Ramík, J., "Consistency of pair-wise comparison matrix with fuzzy elements", in IFSA/EUSFLAT Conf. (2009), 98-101.
33. Ishizaka, A. and Labib, A., "Review of the main developments in the analytic hierarchy process", ***Expert Systems with Applications***, Vol. 38, No. 11, (2011), 14336-14345.

An Approach to Locate an In Pit Crusher in Open Pit Mines

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چکیده

هزینه حمل 45 تا 60 درصد هزینه‌های عملیاتی معادن رو باز بزرگ را تشکیل می‌دهد.هزینه عملیاتی کم و قابلیت اطمینان بالای سیستم‌های نیمه متحرک یا همان سیستم مرکب سنگ‌شکن درون پیت- حمل مواد با نوار و کامیون در قیاس با سیستم متداول شاول و کامیون، باعث گسترش استفاده از این سیستم در معادن شده است. هزینه‌های عملیاتی سیستم‌های نیمه متحرک تابعی از موقعیت سنگ شکن است. در این مقاله موقعیت مناسب برای استقرار سیستم سنگ‌شکن درون پیت با توجه به عوامل متعدد بررسی و به صورت یک مساله هاب مدل‌سازی شده است. در تعیین موقعیت بهینه سنگ‌شکن درون پیت، باید با توجه به شرایط محیطی، کل هزینه حمل به حداقل برسد. این روش برای تعیین محل استقرار سیستم سنگ‌شکن درون پیت در معدن مس سرچشمه مورد بررسی قرار گرفته است. طبق نتایج، چهار گزینهC1 تا C4 برای استقرار سیستم سنگ‌شکن شناسایی شدند که در نهایت موقعیتC2 واقع در تراز 2450 به عنوان گزینه بهینه اتخاب گردید.

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