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A New Developed Model to Determine Waste Dump Site Selection in Open Pit Mines: An Approach to Minimize Haul Road Construction Cost

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ABSTRACT

Today, during the life of an open pit mine, million tons of materials, including waste and ore, are displaced by truck fleets. In the case of a shallow ore deposit, which is located up to 300 meters to the ground surface, depending on preliminary equipment size and capacity, it will take three to five years to remove overburden and waste rocks to expose the ore body. In that period, the main waste dump site will be used as a disposal of waste dump. Apart from considering the characteristics of the waste dump location such as geological and geotechnical properties, the major factors influencing the hauling process are topography, hauling length and construction cost of the haul road. Truck transportation cost depending on the circumstances comprises 45 to 60% of the cost of mining of one tonne ore. Thus, well site selection of waste dump in coordination with the main haul road path confidently leads to a significant saving of economic resources. In this research, while identifying the effective factors in selecting the waste dump sites, a linear mathematical model is developed to find a suitable site for waste dump disposal considering minimizing haul road construction cost.

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1. INTRODUCTION

Waste dump site selection is of significant importance due to economic, technical, and environmental concerns. Environmental restrictions/law or regulations and also the location of the mine exit point will restrict the site path for road construction ending to waste dump. For example, if mine pit has two exit points for carrying materials, the dump location should be in a balanced position to both of them. If it has only one road exit point, then according to mine expansion direction, it is possible to consider other exit points. In this case, this can be viewed as a problem of the allocation of facilities [1]. The location site in this regard needs to be substructural resistant while respecting technical and economic issues such as proximity to the pit. The road properties factor, such as distance, is of particular importance between others, like geotechnical characteristics, final pit limit, and landform, due to their long-term and indirect impact on the productivity of mine fleet. Traveling cycle time of mine fleet is undeviatingly linked to traversing distance. According to the typical classification of mine haul road, main hauling distances are from pit extraction face toward (average the first five years), crusher, processing plant, and mine facilities [2]. Figure 1 displays a schematic path length of the truck's trip through its main directions inside and outside of the pit.

Customary, one of the main places for carrying materials after extraction from the pit, is the waste dump. Therefore, the shorter the length of the route, leads to a reduction in transportation time and relevant factors such as fuel consumption, maintenance cost, as well as the productivity of machinery increases. To have an idea about the main travel route overpass by trucks, they categorized in Table 1, according to the beginning and ending locations. Defined periods are merely corresponding to hauling distance; we ignored other periods regarding the truck cycle.

Looking for more efficiency in mining operations has many aspects. One aspect is the hauling of the rock/overburden fleet in the shortest period toward destinations. Moreover, transportation costs are

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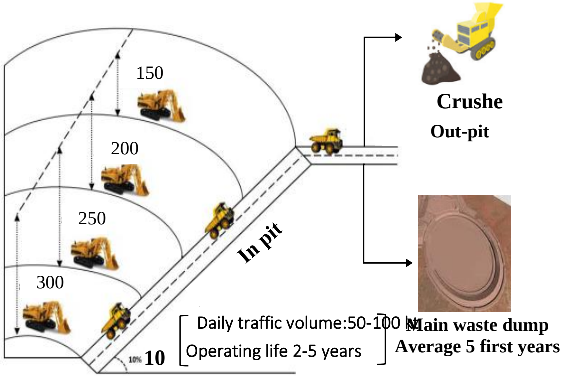

Figure 1. Schematic main places of material handling in open pit mines

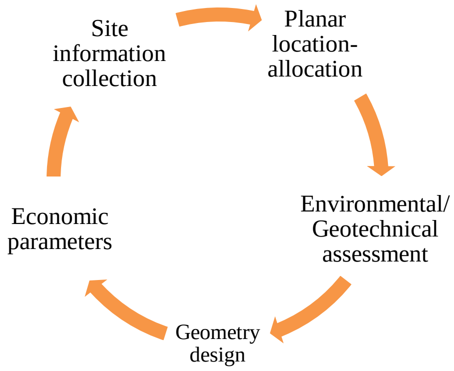

Figure 2. Main steps of mine waste dump design

TABLE 1. Main hauling travel route of mine fleet

Location	Definition	Corresponding time definition
Truck entrance location	Distance from truck entrance location to the extraction site	Time elapsed from the truck entrance point to extraction site
Truck enter elevation change	Distance from ramp to next level	Time elapsed to reach the next level
Truck loading location	Distance from the extraction point to the loading point	Time elapsed from extraction point to loading point
Exit point	Distance from the loading point to the pit exit point	Time from loading location to exit point location
Processing plant location	Distance from exit point to processing plant	Time from the exit point to reach the processing plant
Mine facility location	Distance to the mine facility	Time to reach to mine facility
Waste dump location	Distance from the extraction to waste dump	Time from extraction point to reach waste dump

TABLE 2. Main stages of mine waste dump design

Stage	Description
Site information	Vehicle type, Traffic volume, Haulage unit cost, Road life, Construction material available, Waste volume
Planar-location-allocation	Considering the location of the pit exit point, Minimum distance, Minimum cut and fill cost of connecting road, proximity to a waterbody, Limits of pit
Environmental/Geotechnical assessment	Layer works material strengths, Mechanical quality parameters, Environmental restrictions (tree/vegetation), Seepage, Flood safety
Geometry design	Waste dump Capacity, Repose Angle, Shape
Economic parameters	Capital cost, Operational cost

approximately 45 up to 60% of mining cost based on Equation (1). It is apparent that the less hauling cost, the less mining cost. One of the most visited places is the main waste dump; therefore, connecting the haul road should consider location and subsequent active factors. The main steps of waste dump site allocation should follow the diagram in Figure 2 and Table 2.

$$C_M = \frac{C_D+C_B+C_L+C_H}{Pr} \qquad (1)$$

where:

C_M: Cost of mining ($/ton)
C_D: Cost of drilling ($/h)
C_B: Cost of blasting($/h)
C_H: Cost of hauling ($/h)
Pr: Production rate(ton/h)
CL: Cost of loading ($/h)

Nowadays, the selection of a preferred waste disposal site is based on multiattribute decision making (MADM) methods. However, very little decentralized research has been done on the selection of waste dumps location using mathematical methods. Summarizing the above points, well location selection of waste dumps in alignment with the main road construction cost confidently contributes to significant economic resource savings during mine planning stage. Therefore, posing a mathematical method to determine the right place, regardless of qualitative methods, is at the highest priority in this stage.

2. BACKGROUND HISTORY

Optimization of target route from extraction point inside the pit to any facility location, waste dump, and processing plant should consider the following factors:

1. Location of other facilities relative to each other 2. Minimum earthwork moving 3. Environmental, geometry, stability control, constraints 4. Fixed cost such as a) building bridges b) tunnels (in case of need) and c) path/road repair and maintenance. Depending on types of mines, the cost of haul road construction varies from mine to mine. The majority costs associated with road building are including 1. Pre-road construction preparation (sub-grade, sub-base, base placement and preparation, berm placement and ditching), 2. Preparation of raw materials [3] which is the excavation of soil from the cut or borrow part and haul to fills or waste dump and compact to shape the ground. As a result of these operations, imposed costs arise. The first model of earthwork allocation was developed based on previous model by considering accommodation setup cost of the external source of material and landfill. In the proposed model, the costs were considered constant. Further research was carried out by Easa [4] for linear programming and quadratic programming. Son et al. [5] presented their achievements for the period of 1990 to 2005. Horizontal alignment [6-11] and environmental consideration [12-17] are other aspects of this subject. During the recent decade, some researchers have developed models in rock waste dump management, aiming to reduce the cost associated with waste rock haulage from the pit toward proposed destinations [18-20]. Based on previous studies, various quantitative and qualitative factors are involved in the selection of mine waste dump locations (see Table 3). Recommended underlined parameters need an adjustment to match modern mining activity and minimize total cost; thus, a new column added to carry out this task. Also, multi-objective papers in other fields based upon mathematical models or MADM studied this problem. MADM studies main goal is to select a qualified place among several pre-defined locations (see Table 4).

All the above studies disregard the earthwork costs are only base on qualitative parameters. In this regard, some researchers focused on scheduling waste dumping sites (see Table 5). As can be seen in Table 5, more than 88% of the studies have been formulated using the MIP method. This is due to the nature of the type of problem (removing or placing a block). Besides, some researchers combined mine planning somehow into waste dumping site selection [28-34]. Their concept of waste dump management is base on stockpiling such that to allocate low-grade material to appropriate stockpiles. In the

TABLE3. Effective factors in waste dump site selection

Main criterion	Sub criteria	To match modern mining and minimize cost
Topographic conditions	The shape of the ground, Capacity, Hauling distance	Combine with earthwork management and pit expansion direction
Hydrology and weather conditions	Precipitation amount, Wind speed and direction ،Acid Mine Drainage, Regional water regime, Quality of surface water, Downstream conditions	
Geology and geomechanical conditions	Subgrade condition, Porosity and seepage, Fault, Waste material strength, Earthquake /Blast vibration	Interrelation with layer works material strengths of the road path
Technical aspects	Mining method, Ultimate pit limit, haulage system, Volume of waste material	
Environmental aspects	Physical and chemical properties of waste materials, Reclamation	Sustainable development issues, Future land use
Economic parameters	Capital cost/Operational cost	Earthwork cost, Tunnel and bridge cost

TABLE 4. History of mine waste dump sites selection [21-27]

Author	Article	Year	MADM context	Method
Osanloo	Factors Affecting the Selection of Site for Arrangement of Pit Rock-Dumps [21]	2003	Pit rock dump site selection	SAW
Mensah	Integrating Global Positioning Systems and Geographic Information Systems in Mine Waste disposal:[22]	2007	Waste dump site selection	GIS
Hekmat	New approach for selection of waste dump sites in open pit mines [23]	2008	Waste dump site selection	SAW, TOPSIS, AHP
Yazadni-Chamzini	Waste dump site selection by using fuzzy vikor [24]	2012	Waste dump site selection	Vikor
Suleman	Selecting Suitable Sites for Mine Waste Dumps Using GIS Techniques [25]	2017	Waste dump site selection	GIS
Oggeri	Overburden management in open pits [26]	2019		Multi-disciplinary
Fazeli, Osanloo	Mine Facility Location Selection in Open-Pit Mines Based on a New Multistep-Procedure [27]	2014	Disposal site selection	Envirinmental impact assessment

current study, unlike existing methods that rely on expert opinion, which-firmly fixed on the specified location, a base MIP model is formulated to minimize hauling cost during the waste dumping period. It can be a tool for experts to have an evaluation of road construction costs before or after choosing any places for waste dumping.

3. METHODOLOGY

One of the main components of choosing a dump site location is the connecting road beginning from the pit and ending to the entrance of dump site. If the selection of

TABLE 5. Literature survey of mathematical model for scheduling of mine waste dumping site [18-20, 26-32]

Author	Article	Year	Research feature	Method
M. Kumral	Selection of waste dump sites using a tabu search [28]	2008	minimization of dump transportation costs	MIP tabu search
Yu Li	Waste rock dumping optimisation using (MIP) [29]	2013	Optimizing dumping plans	MIP
Yu Li	Optimisation of waste rock placement using (MIP) [18]	2014	Optimizing dumping plans	MIP
Zhao Fu	A New Tool for Optimisation of Mine Waste Management in Potential Acid Forming Conditions [30]	2015	planning of mine waste rock movement	MIP
Jorge Puell	Methodology for a dump design optimization in large-scale open pit mines [31]	2017	Optimizing dumping plans	MIP
Yu Li	Optimising the long-term mine waste management and truck schedule in a large-scale open pit mine [20]	2017	Optimizing dumping plans	MIP
Yuksel Asli	A landfill based approach to surface mine design [19]	2018	Combining mine scheduling with waste dump filling	MIP
M. Adrien	A stochastic optimization method with in-pit waste and tailings disposal for open pit life-of-mine production planning [32]	2018	Combining production scheduling with waste dump managing	Two-stage stochastic MIP
Claudio Oggeri	Overburden management in open pits [26]	2019	Waste dump site selection	Multi-disciplinary

location considering the waste dump is according to the qualitative factors (see Table 3), then the optimal location must contain the shortest distance, but always the shortest route is not the least cost path. It is due to many factors, such as building construction. The haulage route is from the mining point to landfill location through the pit exit point. This road must obey vertical alignment in such a way that road profile fit to the ground profile concerning grade constraints. The major problem is to detect an area outside the pit with appropriate size to encompass waste from mining blocks for the specific period, such that to minimize associated haulage distance, cost of building, and preparation cost. In this situation, it is an excellent strategy to use waste material in connecting road path construction as a source of filling material in case of possibility. Excavation of soil from the cut or borrow part and haul to fills or waste dump and compact to shape the ground imposes a cost which is called earthwork cost. The proposed model should consider the earthwork cost model while minimizing distance. The main steps of the methodology are as follows: a) Input: Highlighting the candidate route using existing techniques such as satellite images or photogrammetry (Figure 3a), b) Process: In the first step; 3D blocking the path with a safety margin and defining forbidden area (Figure 3b) (Natural protected areas, Location of buildings, Plant and crusher location and final pit limit), next step; applying model, c) Output: Find a suitable location for waste dump according to the capacity required and optimize haul road construction cost and length.

3. 1. Proposed Model

To complete the mathematical model of waste dump site selection, incorporating the earthwork cost model into the hauling cost model must be considered. The main steps of road design can be broken into three principal components: a) Horizontal alignment, which is a trajectory from a satellite's eye view, and using surveying that can introduce candidate routes as input for optimization, b) Vertical alignment, which is a profile of curve from beginning to the ending point of the road. It fits road profile to the ground profile by respecting to terrain grade constraint. c) Earthwork activity which moves blocks into/out of the terrain to determine a smooth surface.

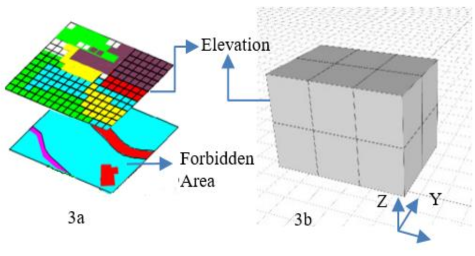

Figure 3. a) Digital elevation layout information of ground b) Blocks layout including information

Mathematical modeling framework begins by applying blocks into connection road from exit point of the pit to the entrance of waste dump. Depend on block position relative to terrain, they classify into the cut and fill blocks. The decision variable $T_{b,b'}$ is the tonnage to be cut from block b and move to block b'. For each b ϵ cut∪ $fill$ the amount of required change in the volume is computed: If this change is negative, then it would be considered as a cut and should be removed, and in case of positive, it is considered as fill. For each pair of b, b' ϵ cut∪ $fill$ (b $\neq$ b'), $D_{b,b'}$ parameter is defined as the distance between the middle point of two blocks. Other parts called waste dump and borrow pit (waste blocks inside the pit) to dump or supply material, are required to be introduced in this problem with the sign of Ш and Ъ to ensure that there is at least one pit and one waste dump location with substantial capacity. Partial transfer of material from the pit to a block of the road can be shown with the variable $T_{b,b'}$ where bϵЪ and $b'ϵB^+$.

Similarly, transfer a part of the material from the road part to the waste dump or fill section can also be shown with the variable $T_{b,b'}$, bϵB^- and $b'(B^+ \cup$ Ш$)$. Movement of materials other than these two places is prohibited. Usually, the cost of moving materials from the pit is higher than the cost of moving materials from the road section. Since payment depends on the amount hauled tonnage per distance, this cost factor is neglected in the model. The primary model is to minimize total distance and movement of all material from mining block to nominated 3D block domain considering for waste dump location and keeping away the proximity to water bodies (Equation (2)). It also must be noted to create a logical path which, means those included blocks must be adjacent.

$$Min\text{: } \sum_{t\in T}\sum_{b\in(B^-\cup Ъ)}\sum_{b'\in(B^+\cup Ш)}\{(D_{b,b'}\times T_{b,b'}^t)\times a_{b,b'}\}/(1+r)^t \quad (2)$$

where:

$D_{b,b'}$	Flat distance between the middle point of two blocks;
$T_{b,b'}^t$	Volume to be cut from block b and move to block b′ during period t
$a_{b,b'}$(binary variable)	1 if block b is adjacent to block b′ and have directed path, 0 otherwise
r	Discount rate
B^-	Set of cut blocks
Ъ	Set of pit blocks
B^+	Set of fill blocks
Ш	Set of waste dump blocks
T	Set of time period
b	Block model index

Allocation of material in the earthwork problem must be logical. If the unit of the material belongs to road section, then the place of transfer must be either fill sections or the place of the waste dump:

if $bϵB^-$ (cut section) then $b'ϵB^+$∪Ш

Similarly, if the unit of the material belongs to mine pit, then the place of transport can be either road fill sections or waste dump:

if bϵЪ then $b'ϵB^+$∪Ш

If the unit of the material belongs to the waste dump, then the target location is empty, or there is no transferring location:

if bϵШ then $b'ϵ\phi$

They eliminate the pair of indices b and that are not logical moves. For example, transfer from the road block to the pit is unacceptable. The above definition will be provided mathematically during the text.

a) Location Constraint

To use mine pit and waste dump option, they should have been previously created with sufficient slack. When a cube block extracted, it becomes a square frustum when dumping on the ground (Figure 4). For the convenience of computation, it considered a pyramid. Thus, let C_w denotes the capacity of blocks in the waste domain.

$$C_w = \frac{1}{3}\times h_w \times S_b \quad (3)$$

$$LW_e = \frac{2h_w}{tan\,(\alpha_s)} \quad (4)$$

$$S_b \geq 0 \; and \; integer \quad (5)$$

where:

C_w	Maximum capacity of waste dump section
h_w	Height of waste dump
S_b	Number of blocks existing in the length of the waste dump location

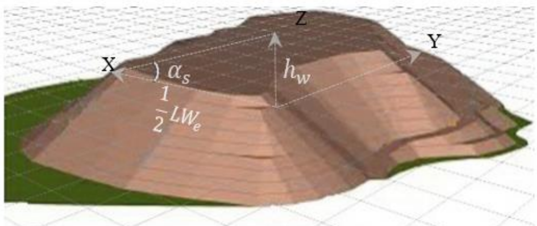

Figure 4. Terminology of location constraint in a mine dump

α_s	Angle of tailing dump
LW_e	Equivalent length of waste dump
Δx_b	Dimension of a block

Remark 1: Environmental regulations determine the height of the pyramid.
Remark 2: Only one landfill entry point is considered.
Remark 3: An aggregation of waste dump is considered if more than one exists.

$$C_w = \sum_{i\in Ш} C_i,\ C_b = \sum_{i\in Ƀ} C_i,\ T_{cut} = \sum_{i\in B^-} T_i,\ T_{fill} = \sum_{i\in B^+} T_i \quad (6)$$

$$T_{cut} \le C_w \quad (7)$$

$$T_{fill} \le C_b \quad (8)$$

where:

T_{cut}	Total amount of cut tonnage
T_{fill}	Total amount of fill tonnage
S_b	As described before
α_s	Angle of tailing dump
R	Equivalent length of waste dump
C_w, Ш, Ƀ	As described before
Δx_b	Dimension of a block in x-direction
C_b	Maximum capacity of waste blocks in pit

b) Capacity Constraint

The following equations enforce the maximum capacity for the pit, and the waste dump is not over-utilized.

$$\sum_{t\in T} \sum_{b'\epsilon B^+\cup Ш} T^t_{b,b'} \le C_b \qquad \forall b \in Ƀ | g_b \le g_o \quad (9)$$

$$\gamma^E_s \times \gamma^F_s \sum_{t\in T} \sum_{b\epsilon B^-\cup Ƀ | g_b \le g_o} T^t_{b,b'} \le C_w \qquad \forall b' \in Ш \quad (10)$$

where:

γ^E_s	Expansion factor of material in excavation
γ^F_s	Compaction factor of material in filling
g_b	Grade of mining block
g_o	Cut-off grade
$T^t_{b,b'}$, b, B^-, Ƀ, C_w, Ш, C_b	As described before

c) Material Balance

Material hauled from or into each part must be equal to a defined amount of cut or fill.

$$s^t_b = \sum_{t\in T} \sum_{b'\in B^+\cup Ш} T^t_{b,b'} \qquad \forall b \in B^- \cup Ƀ | g_b \le g_o \quad (11)$$

$$\gamma^E_s \times \gamma^F_s \times \sum_{t\in T} \sum_{b\in B^-\cup Ƀ | g_b \le g_o} T^t_{b,b'} = d^t_b \ \forall b' \in B^+ \cup Ш \quad (12)$$

where:

s^t_b	Amount of cut in each block (supply) in period t;
d^t_b	Amount of fill in each block (demand) in period t;
T, B^+, Ш, B^-	As described before
Ƀ, g_b, g_o, γ^E_s, γ^F_s	As described before

d) Block Constraints

If a waste block is extracted from mine pit or road section, then it must be hauled to a single adjacent fill block. Similarly, each fill block can receive material from one single cut block.

$$\sum_{b\in B^-\cup Ƀ | g_b \le g_o} (a_{b,b'}) = 1 \qquad \forall b' \in B^+ \quad (13)$$

$$\sum_{b'\in(B^+\cup Ш)} (a_{b,b'}) = 1 \qquad \forall b \in B^- \quad (14)$$

where:

$a_{b,b'}$	As described before
T, B^+, Ш, B^-, Ƀ, g_b, g_o	As described before

Movement of waste material into a mine pit or out of a waste dump site is not permitted.

$$a_{b,b'} = 0 \qquad \forall b \in Ƀ,\ b' \in Ƀ \quad (15)$$

$$a_{b,b'} = 0 \qquad \forall b \in Ш,\ b' \in Ш \quad (16)$$

e) Access Constraints

Overlying blocks must be extracted to access a block in the pit during the time period or earlier time. In the case of the filling block, underlying blocks must be filled during the time period or earlier time.

$$\sum_{w=1}^{t} x^w_b \le \sum_{w=1}^{t} x^w_{\hat{b}} \qquad \forall t, b \in Ƀ, \hat{b} \quad (17)$$

where:

w	Time period
$\hat{b}$	Overlying block index (1,…,9)

$b, Ƀ$	As described before
$x_b^{t(w)}$(binary variable)	1 if block b is extracted at time t, 0 otherwise

f) Vertical Cut-Fill Precedence

Vertical precedence assigning of cut blocks to fill blocks must be considered to make the resource allocation feasible. If the model assigns material according to Figure 5, then to cover the space of the block b_1 using block b material, we must wait until b'_1 is filled using material from b'. Otherwise, the assignment is violated. block b must land out and set aside, extract block b' and haul to b'_1 location Later, pick up material of b and move to b'_1.

Top-down cutting and the bottom-up filling equations are as follow:

$$a_{a,d} + a_{b,c} \leq 1 \qquad \forall(a,b,c,d) \in \psi \tag{18}$$

where:

$$\psi = \{(a,b,c,d) | (a,b) \in B^{-}_{p-q}, (c,d) \in B^{+}_{p-q}, [(z_a > z_b) \wedge (z_c < z_d)] \vee [(z_a < z_b) \wedge (z_c > z_d)]\} \qquad \forall(a,b,c,d) \in \psi \tag{19}$$

where:

$$B^{-}_{p-q} = \{(b,b') \in B^{-} \cup Ш\}, \quad B^{+}_{p-q} = \{(b,b') \in B^{+} \cup Ƀ\} \tag{20}$$

where:

$a_{a,d}$	As described before
z_a	Elevation of block a
z_b	Elevation of block b
ψ	Set of blocks with specific precedence
$T, B^{+}, Ш, B^{-}$	As described before
$Ƀ, g_b, g_o$	As described before

g) Proximity to Waterbody

A boundary is proposed in a set of ɸ to consider not passing through a forbidden area like a potential waterbody zone.

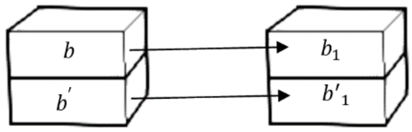

Figure 5. A possible model of allocating block to the locations

$$\sum_{b \in B^{-} \cup Ƀ} a_{b,b'} + \sum_{b' \in ɸ} a_{b,b'} = 0 \qquad \forall b' \in ɸ, \quad b \in B^{-} \cup Ƀ \tag{21}$$

where:

ɸ	Set of blocks in the forbidden area (like water body)
$a_{b,b'}, b, B^{-}, Ƀ$	As described before

Equation (22) ensures that if excavated block is belonging to cut sections and destination is belong to the forbidden area, no volume of material is hauled.

4. NUMERICAL ANALYSIS

A hypothetical block model representing terrain complexities and the same 3D blocks of dimension for pit and 3D blocks for cut and fill section were defined to demonstrate the efficiency of the model. This combination layout depicted in Figure 6. Details are summarized in Table 6. Other parameters like compaction and expansion factor, cut-off grade, and the rest were considered in the normal range within the block model. Also, different block sizes applied to the road path and waste dump location section. The blocks in the pit must be removed and haul to waste dump during their scheduled time, according to Table 7.

Referring to given equations, those blocks with the grade less than cut-off grade sent to dump or filling position. Besides, cut blocks located in the proposed connecting road must add up to this set, with the above

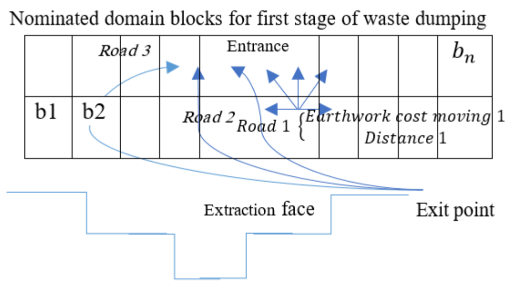

Figure 6. Conceptual layout of nominated domain blocks for waste dumping showing the different connecting path

TABLE 6. Parameter values for study

Parameter	Value
Number of periods (years)	5
Discount rate(prercent)	10
Maximum road grade (percent)	13
Minimum road grade (percent)	10

assumptions, the MIP model designed for lingo software. The model was solved using a PC with the specification of 3.2 GHz CPU with 16 GB of RAM.

5. RESULTS AND DISCUSSION

The solution results of decision variables shape the schedule of hauling blocks, including waste in the pit and those in the proposed connection road toward fill or waste location. By this method, it is guaranteed to use the waste material of pit blocks in construction road as a filling material. The objective function also promises minimum cost (hauled material per distance) during the life-of-mine. All block contains elevation data. The terrain profile in line with the proposed connecting road is shown in Figure 7.

The resulting accuracy intensely depends on block size. A Different block size (20, 20, 1) also was planned to examine the model. Different planning in block size leads to distinct cut and fill volumes and hence the other results. Table 8 compares the results of (5, 20, 1) and (20, 10, 1) block size. Figure 8 shows a profile section for cut and fill blocks.

Density for all blocks was considered hemogenous, but it can be defined in the model as a variable. Truck capacity has a remarkable effect on the result. More capacity leads to more hauling tonnage, but further maintenance and fuel costs must be into consideration to adjust for fleet selection. Here, we consider fleet capacity the same, which means tonnage per distance has no irregular rising and falling.

TABLE 7. Number of waste blocks in mining schedule

Time	Number of blocks
1	320
2	289
3	405
4	310
5	280
Total	1604

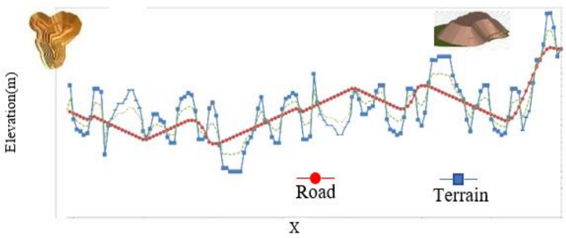

Figure 7. Profiles of the ground and proposed road surface

The result in column Distance×Tonnage shows a more compacted block size, improves the quality of the solution, but these scores do not have a linear relation to block size. It can be concluded that the smaller the dimensions of the blocks, the higher the accuracy of the path determination, which is due to the increase of grid resolution. The reduction of costs is also due to the increase in the resolution of the grid. In both terms of length and cost, grid size-reduction gives us a more accurate evaluation. Otherwise, the whole route and the location of the route will not change. However, natural physical features of an area and terrain have anonymous effects on the percentage of change. To deal with smaller block size, enough memory, and better configuration is also needed. To achieve a more accurate solution, the assignment of blocks must obey the realistic configuration. Removal of significant obstacles before the movement of a block to the destination is necessary. An obstacle is those blocks in a large area like a topographical feature or lake. Consider cut block 4 in Figure 9; to access it, fill block 3 needs to be removed first. Only in rare cases, this occurs in mines because of the proximity of the site of waste dump to the pit. However, this should not be overlooked. This issue can be handled before optimization by modifying such considerable barriers or considering it in the model. To extend the linear program constraints, we can incorporate time-steps into the removal stages.

The proposed model needs additional variables with temporal properties to represent the logical movement of

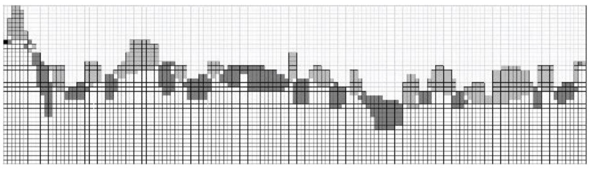

Figure 8. A profile section for cut and fill blocks ($\Delta x = 50, \Delta y = 20, \Delta z = 1$. Cuts are light grey, and fills are dark grey)

TABLE 8. Different block size analysis

Block Size	Number of Blocks (Pit+Road)	Distance (km)	Distance×Tonnage ($)
(50, 20, 1)	2554	15.870	128000
(20, 20, 1)	3720	12.940	72000

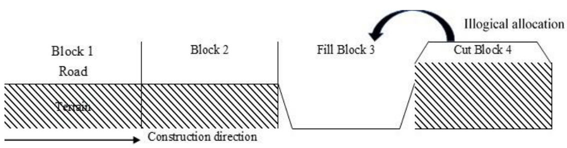

Figure 9. Unrealistic removal solution of obstacle

blocks via the access road. Such blocks without access road cannot be operated on in this situation before at least the obstacle is eliminated. The time-step idea can schedule the delay and precedence the removal of blocks.

6. CONCLUSION

The purpose of this paper is to find the optimal location of the main waste dump in such a way that balances the trade-off among hauling cost, connecting road construction cost and environmental impact. In this research, we investigate the factors that influence waste dump location and review the past activities of other researchers. It focuses on incorporating earthwork moving plans to locate a waste dump location. Unlike previous multi-objective models that were only concentrating on rock dump placement optimization and management, the current model finding a more realistic waste dump position. According to Table 4, most researches on waste dump site selection are based on the screening or ranking methods. First, the potential sites, alternative, and their attributes such as dump capacity and haulage distance are defined. Next, by using a conventional way, the qualitative attribute converts to quantitative. At the last step by ranking alternatives, the best one that fits on the applied method is chosen. The current model finds sufficient capacity using Equation 3 for waste dumping and determine minimum haulage distance road. It tries to use mine waste dump blocks as a filling material, and by scheduling an assignment of cut and fill parts, reduce the costs. Since transportation costs are approximately 45 to 60% of mining cost, it also addresses the reader that haul road construction cost is a good point of beginning for waste dump site selection, and other factors could follow it. To clear up the subject, we consider the given approach in most articles on the selection of the waste dump location in open pit mines. First, they are using MADM methods that obtain the overall preference value for each alternative, and then the best alternative is selected. The preparation expenditure that mostly includes the construction of access roads is per dollar. It only considers the length of the direct route per kilometer. The restrictions such as forbidden area or topographical conditions not considered. There is no view on the road construction operation section. Therefore, the applied scores are not accurate enough. As discussed, the cost of transportation plays an essential role in the mining economy, so choosing the location of the waste dump by mistake leads to loss of capital expenditures. It is necessary to use trucks to carry out material in real work. To have a real schedule, integration of earthwork planning and truck selection also seems to be very necessary. For future works, combining of time scheduling and capacity constraints of trucks is necessary. In part 4, by solving a numerical example, we also showed the effects of block size on the results but discussed to have a better sight; more different analysis is needed. It noted to overcome the restriction movement of blocks to remove untrue allocation; time-steps approaches need to incorporate into the model. A constraint is added to the model not to pass through blocks to consider environmental restrictions, but more investigation must consider to handle the real-world problem. If, for example, we only consider not passing through a woodland area, but near it, most likely, continuity of animal life is put on danger. That is why to consider this restriction carefully. To improve this topic for future, sustainable development and future land use issues in the mining area in addition to the processing plant location and their impacts on ex-pit road location enriches this research.

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Persian Abstract

چکیده

در طول عمر یک معدن روباز میلیون‌ها تن از مواد اعم از باطله و ماده معدنی توسط ناوگان کامیونی جابجا می‌شود. در مواردی که ماده معدنی در عمق تا سیصد متر از سطح زمین قرار گرفته است، بسته به اندازه و ظرفیت اولیه تجهیزات، بین سه تا پنج سال جهت روباره و باطله برداری نیاز است تا به ماده معدنی دسترسی پیدا شود. جدا از در نظر گرفتن ویژگی‌های محل دفع باطله مانند خصوصیات زمین‌شناسی و ژئوتکنیکی، مهمترین عوامل موثر در قسمت حمل شامل توپوگرافی، طول مسیر و هزینه ساخت مسیر می‌باشد. هزینه حمل با کامیون بسته به شرایط مختلف بین ٤٥ تا ٦٠ درصد از هزینه استخراج یک تن سنگ را به خود اختصاص می‌دهد. لذا مکانیابی مناسب مکان دامپ باطله که در هماهنگی با مسیر جاده معدن باشد در اقتصاد معدن تاثیر زیادی دارد. در این تحقیق ضمن شناسایی عوامل موثر در مکان احداث دامپ باطله، یک مدل ریاضی خطی با هدف پیدا کردن محل مناسب دفع باطله و کمینه‌سازی هزینه ساخت جاده توسعه داده شده است.