-RESEARCH PAPER-

International Journal of Mining and Geo-Engineering IJMGE

IJMGE 57-2 (2023) 123-130 DOI: 10.22059/IJMGE.2022.344423.594976

Designing of open-pit mines using new corrected form of the Korobov algorithm

Ebrahim Elahi Zeyni [a,*], Seyed-Mohammad Esmaeil Jalali [b], and Reza Kakaie [b]

[a] *Department of Mining Engineering, University of Sistan and Baluchestan, Zahedan, Iran.*

[b] *Department of Mining, Petroleum and Geophysics Engineering, Shahrood University of Technology, Shahrood, Iran.*

Article History:

Received: 13 June 2022.

Revised: 28 September 2022.

Accepted: 03 November 2022.

ABSTRACT

In the open-pit mining method, it is necessary to design the ultimate pit limit before mining to determine issues, such as the amount of minable reserve, the amount of waste removal, the location of surface facilities, and production scheduling. If the obtained profit from the extraction of the pit limit becomes maximum, it is called the optimum pit limit. Various algorithms have been presented based on heuristic and mathematical logic for determining the optimum pit limit. Several algorithms, such as the floating cone algorithm and its corrected forms, the Korobov algorithm and its corrected form, dynamic programming 2D, the Lerchs and Grossmann algorithm based on graph theory have been presented to find out the optimum pit limit. Each of these algorithms has particular advantages and disadvantages. The designers of the corrected form of the Korobov algorithm claim that this algorithm can yield the true optimum pit in all cases. Investigation shows that this algorithm is incapable of yielding the true optimum conditions in all models, and in some models the method produces an optimum with a negative value. In this paper, this algorithm has been evaluated, and a modification model is also presented to overcome its disadvantage. This new algorithm was named the Korobov algorithm III. In this paper, this new algorithm was considered in different models of two and three-dimensional space. A case study for designing of the optimum pit limit in three-dimensional space was done for a gold mine in the sewed country. The outcomes of Table 9 show that this new method designs a pit limit with a value of 69428.59 that has better results than previous Korobov algorithms.

Keywords: *Open pit mining, Ultimate pit limit, Korobov algorithm.*

1. Introduction

The open pit method is one of the most famous surface mining methods. The most essential issue in the design of open pit mines is the design of the ultimate limit of the mine, which represents the shape of the mine at the end of its life. With the determination of the ultimate limit of the mine, parameters such as the dimensional of longitudinal, lateral, and depth of the mine, access routes to the mineral material, the location of the tailing's depot, the site of the surface facilities, the ratio of tailing removal, the mine's lifespan, the amount of mineable reserve, the amount of tailings removal, and production scheduling can be estimated [1].

The design of the optimal limit of open pit mines is mainly based on block models. For this purpose, firstly, the grade block model is prepared, and then, with the determination of the revenues and costs of extracting blocks of ore and waste, the economic block model is designed. In this block model, blocks of ore have a positive value, waste blocks have a negative value, and air blocks that are above the topographic level have a value of zero. In most of the design methods, the economic block model is used to determine the ultimate optimal limit. The main goal of all of these is to find a group of ore blocks where their extraction profit based on economic science and technical limitations is maximized [2].

Various algorithms, such as the floating cone methods [3-8], dynamic programming [9-11], the Lerchs and Grossmann algorithm based on graph theory [12,13], the Korobov algorithm [14], the corrected form of the Korobov algorithm [15,16], the genetic algorithm [17,18], and the flashlight algorithm [19] have been used for designing the optimal limit. Each of these methods has particular advantages and disadvantages.

The floating cone algorithm is one of the easiest and fastest algorithms for the determination of the ultimate limit, but it is not able to design the true optimum limit. Two algorithms, dynamic programming (2D), and Lerchs and Grossmann (3D) always design the true optimum limit. However, the Lerchs and Grossmann algorithm depends on graph theory which has its own complexity.

The Korobov algorithm and its corrected model were presented for eliminating the disadvantages of the floating cone method and avoiding the complexity of the graph theory algorithm. Despite these corrections, these two methods are not able to obtain the true optimum limit in all models, because Investigations have shown that the corrected form of the Korobov algorithm occasionally produces a result with a negative value. Therefore, this method needs more corrections. This paper presents a new edition of the Korobov algorithm for covering the shortcomings of previous methods. This new method is named the Korobov algorithm III.

2. Technical limitations of extraction

Designing the ultimate pit limit is one of the main purposes of open-pit mines. The ultimate pit limit involves a set of extraction cones. Each extraction cone is approximately similar in shape to an inverse cone in

* Corresponding author: *Tel:* +98-5431132704, *E-mail address:* elahi@eng.usb.ac.ir (E. Elahi Zeyni).

three-dimensional space. Also, each extraction cone should be drawn based on the technical limitations of extraction. From a theoretical point of view, different models, such as 1-3, 1-5, 1-5-9, and conical models with fixed and variable slopes have been defined for the technical limitations of extraction. If the geometric center of gravity of each of the blocks of the economic block model is inside the technical limitations of extraction, then those blocks are considered to be a part of the extraction cone [20,21].

a. Model 1-3

This model is a technical limitation of extraction in two-dimensional space. Accordingly, for the extraction of any ore block, it is necessary to remove three blocks of a higher level (Figure 1).

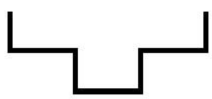


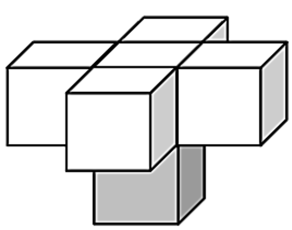
Figure 1. The technical limitation of extraction for the model 1-3 [20].

b. Model 1-5

This model is a technical limitation of extraction in three-dimensional space. Accordingly, for the extraction of any ore block, five blocks of the higher level should be removed. The interpretation of this model for an ore block at level 2 has been presented in Figure 2.

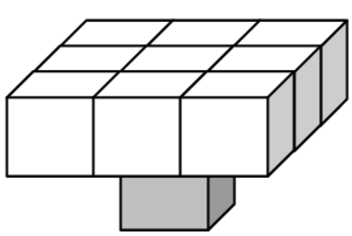
c. Model 1-9

This model is a technical limitation of extraction in three-dimensional space. Accordingly, for the extraction of any ore block, nine blocks of a higher level should be removed. The Interpretation of this model for an ore block at level 2 has been presented in Figure 3.



	1	
1	2	1
	1	

Figure 2. The technical limitation of extraction for the model 1-5 [20,21].



1	1	1
1	2	1
1	1	1

Figure 3. The technical limitation of extraction for the model 1-9 [20,21].

d. Model 1-5-9

This model is a technical limitation of extraction in three-dimensional space. Accordingly, for the extraction of any ore block, five blocks from a higher level should be removed, followed by removing nine blocks from its two upper levels. For example, to extract an ore block on the third level, 26 blocks must be removed from the two upper levels. The interpretation of this model for an ore block at level 3 has been presented in Figure 4.

e. Conical Model

This model is a technical limitation of extraction in two and three-dimensional space. In this model, according to Figure 5, an inverse cone with a fixed or variable slope is drawn based on slope stability at the geometric center of gravity of the ore block. Blocks inside this extraction cone are selected for the next stage of design.

	1	1	1	
1	1	2	1	1
1	2	3	2	1
1	1	2	1	1
	1	1	1	

Figure 4. The technical limitation of extraction for the model 1-5-9 [21].

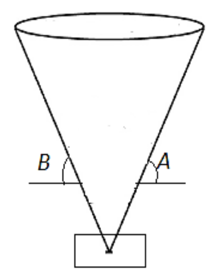


Figure 5. The technical limitation of extraction for the conical model.

3. An overview of Korobov algorithms

3.1. The Korobov algorithm

This method was presented by David et al. in 1974, similar to the floating cone method based on the economical block model [14]. The stages of this algorithm are as follows:

a. Based on the technical limitations of extraction; an extraction cone is formed for each positive block (ore).

b. The positive value of each extraction cone is allocated to negative blocks. In this step, each extraction cone of the positive block is allocated to its positive value The positive value of each extraction cone is allocated to negative blocks. negative blocks until no blocks with negative values exist or until the positive block value is zero.

c. Selection of the ultimate limit. If the positive block value of each extraction cone remains positive, at this stage, all the blocks inside the cone are considered to be a part of the ultimate limit, and the search for another positive block from the remaining blocks with the initial value continues. If the positive block value of each extraction cone remains zero, at this stage, this cone is not considered to be part of the ultimate limit, and the search for another positive block from the next block continues.

Although this algorithm is simple and easy to understand, but is not able to yield a true optimum pit limit. For example, for the economical block model shown in Figure 6, when the final dip of the pit is 1:1, the Korobov algorithm produces an optimum pit limit with the value of -2 (Table 1 and Figure 7).

3.2. The corrected form of the Korobov algorithm

The corrected form of the Korobov algorithm was introduced and presented by Dowd and Onur in 1992. The Korobov algorithm has an error caused by blocks that are common to both cones. It was corrected by the following logic: "If two or more cones have blocks in common, then blocks not in common must be paid for first; common blocks are only paid for after all blocks, not in common have been paid for" [15]. The stages of this algorithm are as follows:

a. Formation of ore groups. In this stage, groups of ore blocks are formed on each level based on positive blocks, and within each group, several compounds are created according to table 2 (Ci, ore block).

b. Identification of common blocks. In this step the compositions that have common blocks in their extraction cones are identified.

c. Allocation of positive to negative values. This allocation is done firstly for non-common blocks and then for common blocks, but each positive block become zero for both the non-common and common blocks within its extraction cone.

d. Selection of the ultimate limit, if the remaining value of each ore blocks remains positive, in this case, the ore block along with its extraction cone is selected as part of the ultimate limit, the search then begins for the next common compositions of the remaining blocks with the initial value of the economic block model. Also, if the residual value of any of any ore blocks is not positive, in this case is not selected for the ultimate limit. Therefore, the search for the next common composition starts from the next level of the economic block model. Also, compositions that do not have common blocks must be calculated according to the Korobov algorithm.

	1	2	3	4	5	6	7	8	9
1	-2	-2	-2	-2	-2	-2	-2	-2	-2
2	-4	-4	-4	-4	-4	-4	-4	-4	-4
3	-6	-6	+14	-6	+12	-6	+18	-6	-6

Figure 6. The first economic block model.

	1	2	3	4	5	6	7	8	9
1	-2	-2	-2	-2	-2	-2	-2	-2	-2
2	-4	-4	-4	-4	-4	-4	-4	-4	-4
3	-6	-6	+14	-6	+12	-6	+18	-6	-6

Figure 7. The Optimum pit limit by the Korobov algorithm.

Table 1. The stages of the Korobov algorithm.

Stage	Block No	Block value	Remains value	Minable?	Search method?
1	(3,3)	+14	0	No	Next
2	(3,5)	+12	0	No	Next
3	(3,7)	+18	+2	Yes	Initial
4	(3,3)	+14	0	No	Next
5	(3,5)	+12	+4	Yes	Initial
6	(3,5)	+12	+2	Yes	Initial

The validation performed on the corrected form of the Korobov algorithm shows that this algorithm cannot design the true optimal limit in all models and needs to be corrected again [16]. For example, in the economical block model shown in Figure 6, when the final dip of the pit is 1:1, according to the graph theory and dynamic programming 2D algorithm, the optimal limit does not exist in this economic block model, but the corrected form of the Korobov algorithm produces an optimum limit with a value of -2 would be obtained (Table 3 and Figure 8). The stages of this algorithm are as follows:

a. The only level that contains ore blocks is the third level with three blocks of ore. According to Table 2, this level consists of seven different compositions from columns 1 to 3. Four compositions of them are common blocks, and another three compositions are not in common blocks. The names of common compositions are C1&C2, C1&C3, C2&C3, and C1&C2&C3.

b. Allocation of positive to negative values: according to Table 3, firstly, the values are allocated for each of the three compositions that have two members in common, such as C1&C2, C1&C3, and C2&C3. The results show that none of the above three compositions can be extracted. Therefore, the only common combination that remains is the combination C1&C2&C3. The allocation of the positive to negative values is done according to steps 4 to 6 of Table 2 and this composition can be extracted. Finally, the ultimate pit limit and other limits are presented in Figures 8, and 9 with the value of 2.

Table 2. Groups of ore blocks [15].

1	2	3	4	...	n	Group
C_1	C_2	C_3	C_4	...	C_n	
	$C_2\&C_1$	$C_3\&C_2$	$C_4\&C_3$	...	$C_n\&C_{n-1}$	
		$C_3\&C_1$	$C_4\&C_2$	...	$C_n\&C_{n-2}$	
		$C_3\&C_2\&C_1$	$C_4\&C_1$	...	...	
			$C_4\&C_3\&C_2$	...	...	
			$C_4\&C_3\&C_1$	...	...	
			$C_4\&C_2\&C_1$	...	$C_n\&C_1$	
			$C_4\&C_3\&C_2\&C_1$	...	$C_n\&C_{n-1}\&C_{n-2}$	
					$C_n\&C_{n-1}\&C_{n-3}$	
					...	
					$C_n\&C_{n-}1\&C_1$	
					...	
					$C_n\&C_{n-1}\&...C_1$	

Table 3. Stages of the corrected form of the Korobov algorithm.

stage	level	Common blocks?	Number of blocks	composition	Block value	Remains value of uncommon blocks	Remains value of common blocks	Minable?	Search method?
1	3	Yes	(3,3)	$C_1\&C_2$	+14	+2	0	No	Next composition
			(3,5)		+12	0	0	No	
2	3	Yes	(3,3)	$C_1\&C_3$	+14	0	0	No	Next composition
			(3,7)		+18	0	0	No	
3	3	Yes	(3,5)	$C_2\&C_3$	+12	0	0	No	Next composition
			(3,7)		+18	+6	0	No	
4	3	Yes	(3,3)	$C_1\&C_2\&C_3$	+14	+2	0	No	Initial
			(3,5)		+12	+8	0	No	
			(3,7)		+18	+6	+2	Yes	
5	3	Yes	(3,3)	$C_1\&C_2$	+14	+2	0	No	Initial
			(3,5)		+12	+8	+2	Yes	
6	3	No	(3,3)	C_1	+14	+2		Yes	Initial

4. The Korobov algorithm III

Although the corrected form of the Korobov algorithm overcomes some disadvantages of the Korobov algorithm, in some models, this method cannot design a true optimum pit limit. Therefore, a new correction is needed. The style of allocating positive values to negative values for common blocks is an error in this algorithm. To solve this error, the weight of common blocks and cones needs to be calculated. A flowchart of the Korobov algorithm III is shown in Figure 10. The stages of this algorithm are as follows:

	1	2	3	4	5	6	7	8	9
1	-2	-2	-2	-2	-2	-2	-2	-2	-2
2	-4	-4	-4	-4	-4	-4	-4	-4	-4
3	-6	-6	+14	-6	+12	-6	+18	-6	-6

Figure 8. Optimum pit limit by the corrected form of the Korobov algorithm.

	1	2	3	4	5	6	7	8	9
1	0	0	-2	-2	-2	-2	-2	0	0
2	-	0	0	-4	0	-4	0	0	-
3	-	-6	+2	-6	+8	-6	+6	-	-

Allocative positive values to negative non-common blocks

	1	2	3	4	5	6	7	8	9
1	0	0	0	0	0	0	0	0	0
2	-	0	0	-4	0	0	0	0	-
3	-	-6	0	-6	0	-6	+2	-	-

Allocative positive value to negative common blocks

	1	2	3	4	5	6	7	8	9
1	-2	-2	-2	-2					
2	-4	-4	-4	-4	-4				-4
3	-6	-6	+14	-6	+12	-6		-6	-6

The first optimum pit limit

	1	2	3	4	5	6	7	8	9
1	0	0	-2	-2					
2	-4	0	0	-4	0				-4
3	-6	-6	+2	-6	+8	-6		-6	-6

Allocative positive values to negative non-common blocks

	1	2	3	4	5	6	7	8	9
1	0	0	0	0					
2	-4	0	0	0	0				-4
3	-6	-6	0	-6	+2	-6		-6	-6

Allocative positive value to negative common blocks.

	1	2	3	4	5	6	7	8	9
1	-2	-2							
2	-4	-4	-4						-4
3	-6	-6	+14	-6		-6		-6	-6

The second optimum pit limit

	1	2	3	4	5	6	7	8	9
1	0	0							
2	-4	0	0						-4
3	-6	-6	+2	-6		-6		-6	-6

Allocative positive value to negative blocks

	1	2	3	4	5	6	7	8	9
1	-2	-2	-2	-2	-2	-2	-2	-2	-2
2	-4	-4	-4	-4	-4	-4	-4	-4	-4
3	-6	-6	+14	-6	+12	-6	+18	-6	-6

Final optimum pit limit with value of -2

Figure 9. The fourth to sixth stages of the corrected form of the Korobov algorithm.

3.1. Finding ore blocks (positive blocks) from the first level of the economic block model to other levels, and also in each level, all ore blocks up to the first level are considered.

3.2. Formation of extraction cones for all ore blocks, using technical restrictions such as 1-3, 1-5, 1-5-9, and conical models.

3.3. Non-common blocks between extractive cones for each positive block must become zero.

3.4. Common blocks between extractive cones of each positive block must become zero. It is as follows:

3.4.1. Calculation of the importance degree for each of the negative common blocks. This is equivalent to the number of times that the block is repeated in different extraction cones.

3.4.2. Calculation of the importance degree for each of the extraction cones. This is equivalent to the sum of the importance degree of the common blocks in its extraction cone.

3.4.3. Sorting extraction cones based on their importance degree in ascending method.

3.4.4. Sorting common blocks for each extraction cone based on their importance degree in ascending method.

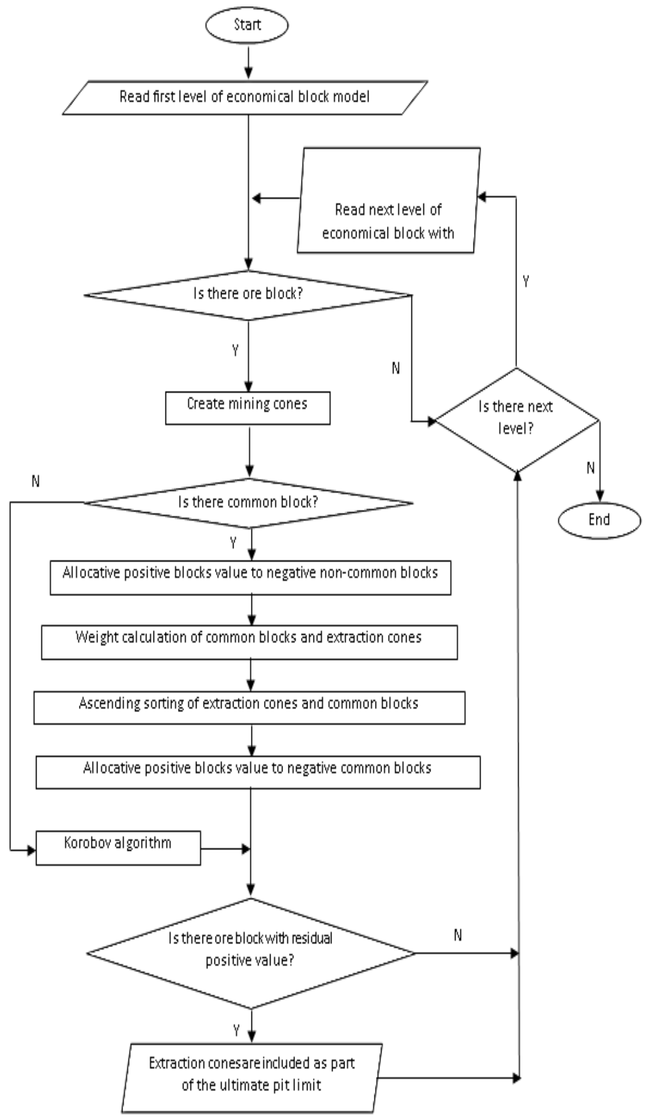


Figure 10. Flowchart of the Korobov algorithm III.

3.4.5. Allocating positive to negative values for the first ore block based on the sorted negative blocks, while the value of the ore block is zero or no negative block remains.

3.4.6. Allocating positive to negative values for other ore blocks based on the sorted values.

3.5. Checking the residual value for each of the ore blocks as follows:

3.5.1. If the value of each ore blocks remains positive, its extraction cone is selected as part of the ultimate pit limit. Then the search for another pit limit continues from the first level of the remaining blocks whit the initial value of the economical block model.

3.5.2. If all ore blocks become zero, its extraction cone is not selected as part of the ultimate pit limit. Then the search for another pit limit from the next level of the remaining blocks with the initial value of the economical block model continues.

The stages of the Korobov algorithm III are explained by a simple example according to the economical block model presented in Figure 6. According to the information below, this algorithm dose not design a pit limit because there is not a true optimum pit limit in this example (the final dip of the pit is 1:1).

The first level that contains ore blocks is the third level. The different stages of the algorithm for this level are as follows:

Stage 1: Calculation of the importance degree of common blocks, according to Figure 11.

Stage 2: Calculation of the importance degree of extraction cones along with ascending sorting, as presented in Table 4.

Stage 3: Ascending sorting of the common blocks based on their weights, as presented in Table 5.

Stage 4: Allocation of the ore blocks values to negative non-common blocks of its extraction cone, as presented in Figure 12.

Stage 5: Allocation of the positive block value (+2) to negative common blocks for extraction cone (3,3), as presented in Figure 13.

Stage 5: Allocation of the positive block value (+2) to negative common blocks for extraction cone (3,3), as presented in Figure 13.

Stage 6: Allocation of the positive block value (+6) to negative common blocks for **extraction** cone (3,7), as presented in Figure 14.

Stage 7: Allocation of the positive block value (+8) to negative **common blocks for extraction** cone (3,5) according to Figure 15.

	1	2	3	4	5	6	7	8	9
1	0	0	2	2	3	2	2	0	0
2	0	0	0	2	0	2	0	0	0
3	0	0	0	0	0	0	0	0	0

Figure 11. Importance degree of common blocks.

Table 4. the weight of extraction cones along with ascending sorting.

level	Number of blocks	Weight
3	(3,3)	9
	(3,7)	9
	(3,5)	15

Table 5. Ascending sorting of common blocks.

	Number of extraction cone		
	(3,3)	(3,7)	(3,5)
Number of common blocks	(1,3)	(1,6)	(1,3)
	(1,4)	(1,7)	(1,4)
	(2,4)	(2,6)	(1,6)
	(1,5)	(1,5)	(1,7)
	-	-	(2,4)
	-	-	(2,6)
	-	-	(1,5)

	1	2	3	4	5	6	7	8	9
1	0	0	-2	-2	-2	-2	-2	0	0
2	-4	0	0	-4	0	-4	0	0	-4
3	-6	-6	+2	-6	+8	-6	+6	-6	-6

Figure 12. Allocation of positive blocks value to negative non-common blocks.

	1	2	3	4	5	6	7	8	9
1	0	0	0	-2	-2	-2	-2	0	0
2	-4	0	0	-4	0	-4	0	0	-4
3	-6	-6	0	-6	+8	-6	+6	-6	-6

Figure 13. Allocative of positive block value to negative common blocks for extraction cone (3,3).

After the allocation of the value of the positive block to negative blocks for each extraction cone, it is observed that the residual ore blocks value in this model are not positive. Therefore, these extraction cones are not accepted as a part of the optimum pit limit. Therefore, there is not a true optimum pit limit in this example.

Example 2

In order to show the ability of the Korobov algorithm III, another simple example is shown in Figure 16. In this model, the final dip of the pit is 1:1. Both the Korobov algorithm and its modification produce a pit with a value of +3, as presented in Table 6, Table 7, and Figure 17. Also, the results of the Korobov algorithm III are reported in Table 8 and Figure 18. The results of this new method are perfect matching the dynamic programming 2D algorithm, and it creates a true optimum pit with a value of +6, as presented in Figure 19.

	1	2	3	4	5	6	7	8	9
1	0	0	0	-2	-2	0	0	0	0
2	-4	0	0	-4	0	-2	0	0	-4
3	-6	-6	0	-6	+8	-6	0	-6	-6

Figure 14. Allocation of the positive block value to negative common blocks for extraction cone (3,7).

	1	2	3	4	5	6	7	8	9
1	0	0	0	0	-2	0	0	0	0
2	-4	0	0	0	0	0	0	0	-4
3	-6	-6	0	-6	0	-6	0	-6	-6

Figure 15. Allocation of the positive block value to negative common blocks for extraction cone (3,5).

	1	2	3	4	5	6	7	8	9
1	-2	-2	-2	-2	-2	-2	-2	-2	-2
2	-4	+6	+8	-4	-4	-4	-4	-4	-4
3	-6	-6	-6	-6	-6	+12	+10	-6	-6
4	-8	-8	-8	+23	-8	-8	-8	-8	-8

Figure 16. The second economical block model.

Table 6. The stages of the Korobov algorithm.

Stage	Block	Block	Remains	Minable?	Search
1	(2,2)	+6	0	No	Next
2	(2,3)	+8	+6	Yes	Initial
3	(2,2)	+6	+4	Yes	Initial
4	(3,6)	+12	0	No	Next
5	(3,7)	+10	0	No	Next
6	(4,4)	+23	+1	Yes	Initial
7	(3,6)	+12	+6	Yes	Initial
6	(3,7)	+10	+4	Yes	Initial

Table 7. Stages of the corrected form of the Korobov algorithm.

stage	level	Common blocks?	Number of blocks	composition	Block value	Remains value of uncommon blocks	Remains value of common blocks	Minable?	Search method?
1	2	Yes	(2,2)	C_1&C_2	+6	+4	0	No	Initial
			(2,3)		+8	+6	+6	Yes	
2	2	No	(2,2)	C1	+6	+4		Yes	Initial
3	3	Yes	(3,6)	C_1&C_2	+12	+8	0	No	Next composition
			(3,7)		+10	+4	0	No	
4	4	No	(4,4)	C1	+23	+1		Yes	Initial
5	3	Yes	(3,6)	C_1&C_2	+12	+12	+6	Yes	
			(3,7)		+10	+4	+4	Yes	Initial

Table 8. Stages of the Korobov algorithm III.

stage	level	Common blocks?	Number of blocks	Weight of cones	composition	Block value	Remains value of uncommon blocks	Remains value of common blocks	Minable?	Search method?
1	2	Yes	(2,2)	4	C_1&C_2	+6	+4	0	No	Initial
			(2,3)	4		+8	+6	+6	Yes	
2	2	No	(2,2)	-	C1	+6	+4		Yes	Initial
3	3	Yes	(3,6)	12	C_1&C_2	+12	+8	0	No	Next composition
			(3,7)	12		+10	+4	0	No	
5	3	Yes	(3,7)	16	C_1&C_2&C_3	+10	+4	0	No	Next composition
			(4,4)	16		+23	+1	0	No	
			(3,6)	20		+12	+12	0	No	

	1	2	3	4	5	6	7	8	9
1	-2	-2	-2	-2	-2	-2	-2	-2	-2
2	-4	+6	+8	-4	-4	-4	-4	-4	-4
3	-6	-6	-6	-6	-6	+12	+10	-6	-6
4	-8	-8	-8	+23	-8	-8	-8	-8	-8

Figure 17. Optimum pit limit of the Korobove algorithm and its modification.

	1	2	3	4	5	6	7	8	9
1	0	2	2	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0

a: Weight of common blocks.

	1	2	3	4	5	6	7	8	9
1	0	-2	-2	0	-2	-2	-2	-2	-2
2	-4	+4	+6	-4	-4	-4	-4	-4	-4

b: Allocative to negative non-common blocks.

	1	2	3	4	5	6	7	8	9
1	0	0	0	0	-2	-2	-2	-2	-2
2	-4	0	+6	-4	-4	-4	-4	-4	-4

c: Allocative to negative common blocks.

	1	2	3	4	5	6	7	8	9
1	-2				-2	-2	-2	-2	-2
2	-4	+6		-4	-4	-4	-4	-4	-4

d: The first pit limit.

	1	2	3	4	5	6	7	8	9
1	0				-2	-2	-2	-2	-2
2	-4	+4		-4	-4	-4	-4	-4	-4

e: Allocative to negative blocks.

	1	2	3	4	5	6	7	8	9
1					-2	-2	-2	-2	-2
2	-4			-4	-4	-4	-4	-4	-4

f: The second pit limit.

	1	2	3	4	5	6	7	8	9
1	0	0	0	0	2	2	2	2	0
2	0	0	0	0	0	2	2	0	0
3	0	0	0	0	0	0	0	0	0

g: Weight of common blocks.

	1	2	3	4	5	6	7	8	9
1					-2	-2	-2	-2	0
2	-4			-4	0	-4	-4	0	-4
3	-6	-6	-6	-6	-6	+8	+4	-6	-6

h: Allocative to negative non-common blocks.

	1	2	3	4	5	6	7	8	9
1					0	0	0	0	0
2	-4			-4	0	0	-4	0	-4
3	-6	-6	-6	-6	-6	0	0	-6	-6

i: Allocative to negative common blocks.

	1	2	3	4	5	6	7	8	9
1	0	0	0	2	3	3	3	2	0
2	0	0	0	0	2	3	2	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0

j: Weight of common blocks

	1	2	3	4	5	6	7	8	9
1					-2	-2	-2	-2	0
2	-4			0	-4	-4	-4	0	-4
3	-6	-6	0	0	0	+12	+4	-6	-6
4	-8	-8	-8	1	-8	-8	-8	-8	-8

k: Allocative to negative non-common blocks.

	1	2	3	4	5	6	7	8	9
1					0	0	0	0	0
2	-4			0	0	-3	0	0	-4
3	-6	-6	0	0	0	0	0	-6	-6
4	-8	-8	-8	0	-8	-8	-8	-8	-8

l: Allocative to negative common blocks

Figure 18. Stages of the Korobov algorithm III.

	1	2	3	4	5	6	7	8	9
1	-2	-2	-2	-2	-2	-2	-2	-2	-2
2	-4	+6	+8	-4	-4	-4	-4	-4	-4
3	-6	-6	-6	-6	-6	+12	+10	-6	-6
4	-8	-8	-8	+23	-8	-8	-8	-8	-8

Figure 19. Dynamic programming algorithm 2D.

5. Case study

In this section for a more accurate investigation of the Korobov algorithms, a case study in three-dimensional space is used. In this case study, the results obtained from the Korobov algorithms on a three-dimensional block model have been performed based on the technical limitation of a conical model with fixed slopes. The case study is the geological block model of the BjÖrkdal gold mine, which is approximately 35 km northeast of Skellefteå in Sweden [14]. Firstly, the economic block model of this mine has been prepared using Pitwin32 software. This software identifies ore and waste blocks based on the grade block model and cut-off grade. Then, an economical block model is created based on different characteristics, such as block height in the vertical direction, block length in the north-south direction, block width in the east-west direction, ore density, waste density, ore price, extraction cost, processing cost, smelting cost, refining cost, waste removal cost, and overall efficiency.

In this case study, the dimensions of each block in the east-west directions are equal to 15 meters, north-south direction equals 10 meters, and in the vertical direction equal to 5 meters, and the slope of the extraction conical is equal to 58 degrees. Also, the dimensions of this economical block model are equal to 101 × 82 × 36, with 101 blocks in the east-west direction, 82 blocks in the north-south direction, and 36 blocks in the vertical direction. To determine the ultimate pit limit of this mine, a computer program was written in the C ++ language for the

Korobov algorithms. Accordingly, after running the computer program, the results of the ultimate pit limits of the case study are presented in Table 9. According to Table 9, the ultimate pit limit of the Korobov algorithm III has a higher value than the Korobov algorithm and its corrected model. In other words, the Korobov algorithm III produces an ultimate pit limit with a higher value.

Table 9. Overall results of the Korobov algorithms.

Description	Korobov algorithm	Korobov algorithm II	Korobov algorithm III
Number of blocks in the ultimate pit limit	66030	65822	64820
Number of ore blocks in the ultimate pit limit	5573	5564	5429
Number of waste blocks in the ultimate pit limit	60457	60258	59391
Value of ore blocks in the ultimate pit limit	91072.57	90888.92	90241.42
Value of waste blocks in the ultimate pit limit	-21834.00	-21561.39	-20816.83
The total value of the ultimate pit limit (10000 SEK)	69238.57	69327.53	69428.59

6. Conclusion

Various methods have been reported to design the ultimate pit limit of open mines. One of them is the Korobov algorithm and its modified model. The execution of extraction technical limitations with different methods, such as methods 1-3, 1-5, 1-5-9, conical model in fixed and variable slopes without any limitation is used in the Korobov algorithms.

Although the corrected form of the Korobov algorithm overcomes the disadvantages of the Korobov algorithm, but examples were presented in this paper, where the corrected form has produced a pit limit with a negative value. Accordingly, the Korobov algorithm III was presented in this paper to eliminate its disadvantages.

The disadvantage of the Korobov's previous algorithms is related to allocation positive to negative blocks value. In the Korobov algorithm III, for rectifying disadvantages, the issues of the importance degree of extraction cones and commons blocks have been discussed. Therefore, in the Korobov algorithm III, firstly, the common blocks are identified, and then, based on the priority of their importance, the allocation of positive to negative block values is done.

According to Table 9, the results of the case study of the gold mine show that the economic block model includes 298,152 blocks, and the Korobov algorithm III was able to design a more profitable range than the previous two methods. In this case study, the value of the ultimate pit limit for the Korobov algorithm is equal to 69238.57, the corrected form of the Korobov algorithm is equal to 69327.53, and the Korobov algorithm III is equivalent to 69428.59. Therefore, it can be expressed that the new method has been able to eliminate some of the disadvantages of the previous methods of the Korobov algorithm.

REFERENCES

[1] Khalokakaie, R., Dowd, P.A., Fowell, R.J. (2000). Lerchs-Grossmann algorithm with variable slope angles. Trans. Instn Min. Metal, (Sect. A: Min. industry), 109, A77-A85.

[2] Khalokakaie, R., Dowd, P.A., Fowell, R.J. (2000). A windows program for optimal open pit design with variable slope angles. International Jounal of Surface Mining, Reclamation and Environment. 14, 261-275.

[3] Carlson, T.R., Erickson, J.D., O'Brain D.T., Pana, M.T. (1966). Computer techniques in mine planning. Mining Engineering, 18 (5), 53-56.

[4] Wright, E.A. (1999). MOVING CONE II - A Simple Algorithm for Optimum Pit Limits Design. Proceedings of the 28th Symposium on the application of computers and operations research in the mineral industries (APCOM), (Colorado USA), 367-374.

[5] Khalokakaie, R. (2006). Optimum open pit design with modified moving cone II methods. Journal of engineering in Tehran University, 4 (3), 297-307, (in Persian).

[6] Elahi, E, Kakaie, R, yusefi, A. (2012). A new algorithm for optimum open pit design: Floating cone method III, Journal of Mining and Environment, 2(2), 118-125. doi: 10.22044/jme.2012.63.

[7] Ares, G, Castañón Fernández, C, Álvarez, I.D, Arias, D, Díaz, A.B. (2022). Open Pit Optimization Using the Floating Cone Method: A New Algorithm. Minerals. 12, 495. https://doi.org/10.3390/min12040495.

[8] Turan, G, Onur, A.H. (2022). Optimization of open-pit mine design and production planning with an improved floating cone algorithm. Optim Eng. https://doi.org/10.1007/s11081-022-09725-4.

[9] Koenigsberg, E. (1982). The optimum contours of an open pit mine: an application of dynamic programming. Proceedings of the 17th Symposium on the application of computers and operations research in the mineral industries (APCOM), (New York: AIME), 247-287.

[10] Wilke, F.L., Wright, E.A. (1984). Determining the optimal ultimate pit design for hard rock open pit mines using dynamic programming. Erzmetal, 37, 139-144.

[11] Yamatomi, J., Mogi, G., Akaike, A., Yamaguchi, U. (1995). Selective extraction dynamic cone algorithm for three-dimensional open pit designs. Proceedings of the 25th Symposium on the application of computers and operations research in the mineral industries (APCOM), Brisbane, 267-274.

[12] Lerchs, H., Grossmann, I.F. (1965). Optimum design of open pit Mine. CIM Bulletin, 58, 47 – 54.

[13] Khalokakaie, R. (1999). Computer-Aided Optimal Open Pit Design with Variable Slope Angles. Ph.D Thesis for the degree of Doctor of Philosophy, Department of Mining and Mineral Engineering the University of Leads.

[14] David, M., Dowd, P.A., Korobov, S. (1974). Forecasting departure from planning in open pit design and grade control. Proceedings of the 12th Symposium on the application of computers and operations research in the mineral industries (APCOM), (Golden, Colo: Colorado School of Mines), 2, F131-F142.

[15] Dowd, P.A, Onur, A.H. (1993). Open pit optimization - part 1: optimal open pit design. Trans. Instn Min. Metall. (Sect. A: Min. industry), 102, A95-A104.

[16] Elahi Zeyni, E., Khalokakaie, R. (2012). Validation of the corrected form of the Korobov algorithm with the Lerchs and Grossmann method based on graph theory. Iranian Journal of mining engineering, 6 (13), 93-97, (in Persian).

[17] Denby, B. Schofield, D. (1994). Open-pit design and scheduling by use of genetic algorithms. Trans. Instn Min. Metall. (Sect. A: Min. industry), 103, A21-A26.

[18] Azadi, N, Mirzaei-Nasirabad, H, Mousavi, A. (2022). Evaluating the efficiency of the Genetic algorithm in designing the ultimate pit limit of open-pit mines. International Journal of Mining and Geo-Engineering. doi:10.22059/ijmge.2022.340973.594963.

[19] Jodeiri, B, Dehghani, H, Sadeghi, M. (2021). Ultimate Pit Limit Determination Using Flashlight Algorithm. International

Journal of Mining and Geo-Engineering. 55(1): 43-48. doi:10.22059/ijmge.2020.296120.594840.

[20] Hustrulid, W., Kuchta, M. (1995). Open pit mine planning & design volume 1 –Fundamental. BALKEMA, ROTTERDAM.

[21] Elahi, E. (2013). The Principles of Designing Open Pit Mines. Publication of Jihad Amikabir University, (In Persian).