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Investigation and analysis of mining methods from the perspective of the ultimate limit determination requirement

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ABSTRACT

Determining the ultimate limit (UL) of a mine is one of the first steps in mine design, which plays a key role in determining the net present value and profitability of the project. For the open-pit mining method, the importance of determining the ultimate pit limit (UPL) when designing a mine is obvious. However, in the case of reserves that, due to their geological or geotechnical conditions, mining is done by a method other than an open pit, the necessity of UL determination is not clear to engineers. Therefore, in this study, both surface and underground mining methods are considered. The open-pit method was investigated to determine the need for UL design for each method by determining the factors affecting the variability of the mining method. The results showed that among the surface methods, dredge mining, borehole mining, and in-situ leaching can determine the UL, while in quarry mining, open cast (strip) mining, auger mining, and the hydraulic method, it is not applicable to determine the UL. Among the underground mining methods, the results showed that it is possible to determine the UL in the stope and pillar, sublevel stoping, cut and fill, stull stoping, and square.set stoping, sublevel caving, and block caving due to the presence of grade variability (mineral quality). While for room and pillar mining, shrinkage stoping, and long-wall mining methods, it seems that determining the UL is not applicable due to the immutability of the method.

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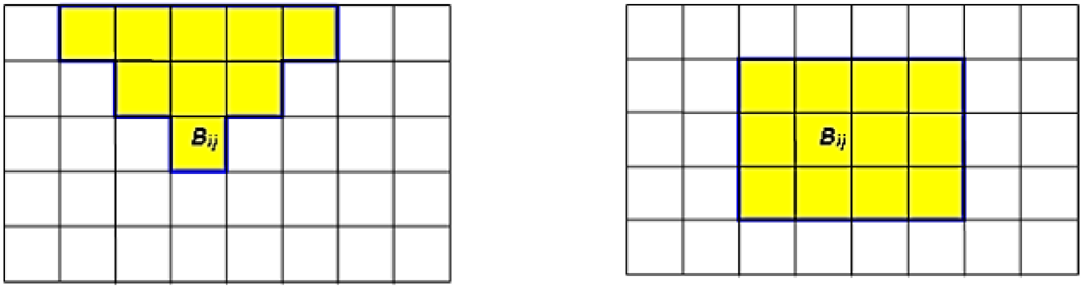
1. Introduction

The most critical aspect of the preliminary mine design is determining the ultimate limit (UL), as it defines the extent, depth, and layout of the main components of the mine within the mining area and estimates the quantities of ore and waste. Following feasibility studies, a base mine design is developed to present the overall architecture of the mine and provide essential information to identify the dimensions and geometric characteristics of the mine, as well as to estimate the volumes of mining activities.

The UL refers to the space that will be formed after mining operations are complete, shaped by the technical conditions of the chosen extraction method. If this UL is established in such a way that a certain factor, as prioritized by the mine designer/engineer, is maximized or minimized after mining, the UL is referred to as the optimal limit. Although UL optimization might have a variety of goals, such as maximizing ore or minimizing waste, it is currently conducted with an economic focus aimed at achieving the highest possible profit. This approach is known as the economic optimization of the UL.

The concept of the UL differs between surface and underground mining methods. It is classified based on the factors of the deposit's geometric characteristics, mining technique, deposit shape and size, mineral type, block extraction method, geomechanical conditions, equipment dimensions, etc. Among surface mining methods, open-pit mining is the most commonly applied. In open-pit mining, the UPL is a block modeled area that maximizes current profit by extracting both ore and waste blocks within it, taking technical constraints into account. In underground mining, the UL is defined by the specific underground mining method used and represents an economically feasible area in which ore blocks can be extracted while adhering to technical and geometric limitations, such as minimum stope dimensions. Selectivity of the method, grade variability (mineral quality), mineral type (metallic or non-metallic), deposit consistency, and dip are primary criteria for defining the ultimate limit in underground mining. The main distinction between the UL in surface and underground mining methods is in the shape of the UL. The UL's shape typically resembles an inverted cone in surface mining methods, whereas, in underground mining methods, it is rectangular (Fig.. 1). Since the introduction of the first UL optimization algorithms in 1965 until 2021, numerous algorithms have been developed for optimizing the UL of mines. Tables 1 and 2 show the specific algorithms for surface and underground mining methods. As indicated, optimization algorithms for surface mining methods are exclusively designed for open. Pit mining with no algorithms available for other surface methods. Similarly, underground algorithms apply to a limited number of underground mining methods, often involving considerable simplifications.

Additionally, the optimization logic in algorithms can be categorized into two types: rigorous and heuristic. Algorithms that are rigorous within the limits of the assumptions applied are consistently capable of finding the optimal solution. In contrast, heuristic algorithms can only find a limit near the optimal solution.



(a) (b)

Fig.. 1. Comparison of geometric constraints in surface and underground mining methods
a) extraction of block Bij in the surface mining method, and b) extraction of block Bij in the underground mining method [1].

Table 1. Optimization algorithms for UL in underground mining methods.

Algorithm	Developer(s)	The used logic	The mining method (according to the developers' opinion and claim)	Year of publication
Dynamic Programming [2]	Riddle	Rigorous	Block caving method	1977
Downstream Geostatistical [3]	Deraisme & Fraisse	Rigorous	Cut and fill method, Sublevel stoping method	1984
Branch and Bound [4, 5]	Ovanic & Young	Rigorous	All methods	1995.1999
Floating Stope [6]	Alford	Heuristic	All methods	1995
Octree Division [7]	Cheimanoff et al.	Heuristic	All methods	1989
MVN [8, 1]	Ataeepour	Heuristic	All methods	2000.2005
OLIPS [9]	Jalali et al.	Heuristic	All methods	2004
Probabilistic method [10]	Dimitrakopoulos & Grieco	Heuristic	All methods	2009
Topal and Sens [11]	Topal & Sens	Heuristic	All methods	2010
Network Flow [12]	Bai	Heuristic	Sublevel stoping method	2013
Sandanayake [13]	Sandanayake	Heuristic	All methods	2014
Greedy [14, 15]	Nikbin et al.	Heuristic	All methods	2017.2021

Table 2. Optimization algorithms for UL in surface mining methods.

Algorithm	Developer(s)	The used logic	The mining method	Year of publication
Dynamic Programming [16]	Lerchs & Grossmann	Rigorous	Open pit	1965
Graph Theory [16]	Lerchs & Grossmann	Rigorous	Open pit	1965
Moving Cone [17]	David et al.	Heuristic	Open pit	1965
Maximum Flow [18]	Johnson	Rigorous	Open pit	1968
Korobov [19]	Korobov	Heuristic	Open pit	1974
Lerchs and Grossmann [20]	Johnson & Sharp	Heuristic	Open pit	1971
Graph Theory [21]	Zhao & Kim	Rigorous	Open pit	1992
Moving Cone II [22]	Wright	Heuristic	Open pit	1999
Network Optimization [23]	Khodayari	Rigorous	Open pit	2013

According to Tables 1 and 2, prior research has not examined the feasibility of determining the UL for various mining methods based on geological characteristics. To address this, the current study examines all major mining methods, both surface and underground, to assess the necessity of defining the UL for each mining technique. The primary research question is why the concept of UL determination has been successfully developed and implemented specifically for open. Pit mining, while similar efforts in other methods, particularly in underground mining, has seen limited success. In the first section, surface mining methods are briefly introduced, and the necessity of UL determination for each method is evaluated. The same approach is then applied to underground mining methods, followed by a discussion and conclusion in the final section.

2. Examination of the necessity for determining the UL in mining techniques

In determining the UL of a mine, economic objectives are often prioritized. To achieve this, it is essential to assess the economic value of each block. However, the ability to create an economic block model is not feasible in all mining methods (both surface and underground) due to factors such as selectivity in the essence of the mining method and grade variability within the mineral itself. This means that in cases where the deposit being extracted consists of coal, quarry stone, or any type of non-metallic mineral for which grade determination and cutoff grade assessment within the mining limit are not possible, the determination of the UL according to what is typically practiced in metal mines becomes meaningless. Additionally, if the chosen mining method lacks flexibility regarding the extraction or retention of the ore, the determination of the UL will not be applicable. Consequently, the parameters of the selectivity of the mining method and grade variability were chosen as the focal parameters of this study (Fig.. 2).

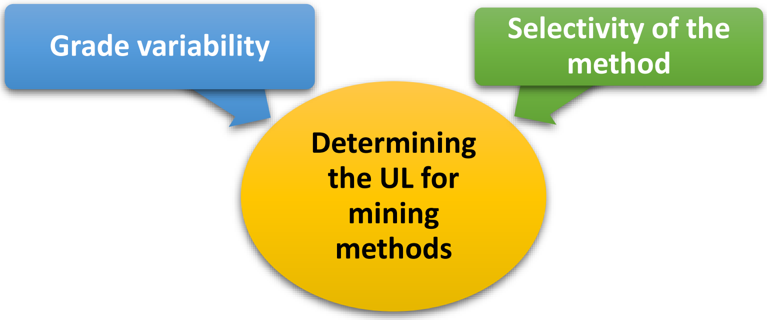


Fig. 2. Influential parameters in determining the UL for mining methods.

2.1. Surface mining methods

2.1.1. Quarry mining method (decorative and facade stones)

In this method, a relatively large, prism-shaped blocks with smooth surfaces are extracted from the deposit [24]. The inherent difference between quarrying and non-quarrying methods lies in their chemical and physical properties. For decorative and facade stones, physical characteristics and stone quality, such as color, appearance, density, homogeneity, strength, and the absence of fractures, cracks, discontinuities, etc., are critical. In contrast, for other deposits like metallic ones, the parameters such as grade or cutoff grade (for determining the optimal UL) are critical. Thus, it can be said that in these deposits, the chemical properties and compositions of the minerals are the focal points, and to extract the metal as efficiently as possible, the ore must be crushed, followed by melting and pyrometallurgical processes that break the chemical bonds through heat, allowing the desired metal to be separated. However, in the quarrying method, the chemical properties are not significant; instead, the focus is on their physical characteristics. Therefore, as much as possible, these types of stones should not be crushed or broken and must be extracted in intact, cubic pieces.

In metallic deposits, it is possible to define an economic block model based on the grade parameter and subsequently determine the optimal UL of the mine using an optimization algorithm. However, in the quarry mining method, since the economic value is not defined based on the grade parameter and the quality of the stone is of greater importance, it is not feasible to establish and define an optimal UL similar to that used in the open.pit mining method. Instead, the desired properties related to stone quality can be evaluated for samples taken from boreholes using a scoring system, assigning a weight to each property. The final value of these properties can then be determined according to their weights. Following this, by performing block modeling and assigning scores to each block, and by defining a parameter known as cutoff quality (similar to cutoff grade in open-pit mining), the optimal UL can be determined using a scoring system tailored for this type of deposit.

Although in decorative and facade stone deposits, the deposit can be divided into several large blocks or sections, allowing for the determination of the UL for each section using a scoring system, the genesis of these deposits and the minimal and gradual nature of variations in these sections (as opposed to the grade variations in metallic deposits) make it impractical to define the UL in the same way as in open.pit mining method. Additionally, the economic viability and profitability of extracting the deposit to a certain depth or extent can be determined by using the stripping ratio.

2.1.2. Open cast (strip) mining method

The open-cast (strip) mining method is primarily used for extracting coal deposits [24]. Since the grade parameter is not defined in relation to coal mining, it is not possible in this method to define a grade (geological) block model, and consequently, an economic block model used for determining the UL. In the surface mining method, the mine is located in a mountainous and elevated area, and since the coal seams are horizontal and relatively thin, and the coal remains uniform throughout the layer with nearly constant characteristics, the entire layer can be extracted without difficulty; thus, there is no need to determine the UL. The contour mining method is applied when the horizontal coal seam is situated in a mountainous and elevated area, and the thickness of the waste above the coal is such that not all of the coal can be extracted. In this method, extraction and advancement continue from the outcrop to a predetermined depth defined by the stripping ratio. Therefore, by utilizing the stripping ratio, it can be determined how much can be extracted. The UL in this method defines the economic limit of the project and is determined using the stripping ratio.

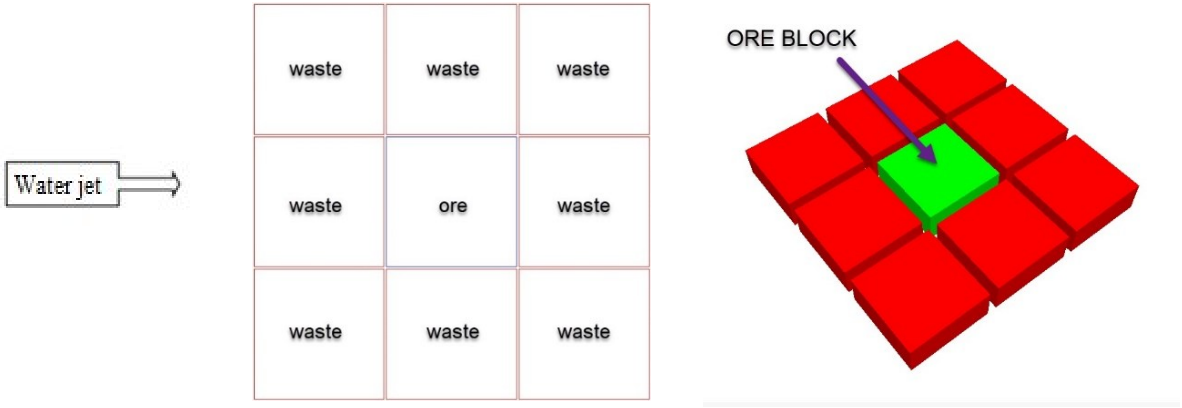
2.1.3. Auger mining method

This method is employed for the recovery of coal in outcrops of deposits or high walls resulting from the contouring method, by drilling or creating spaces within the coal seam located beneath the overburden [25, 26]. Since the grade parameter is not defined in relation to coal mining, it is not possible in this method to define a grade block model or an economic block model used for determining the UL. Additionally, since the coal seams are horizontal and relatively thin and the coal remains uniform throughout the layer with nearly constant characteristics, the entire layer can be extracted without difficulty; thus, there is no need to determine the UL. The practice of leaving pillars in this method is primarily for safety considerations and to prevent the collapse of the stope; thus, it cannot be attributed to the low grade or the designation of the pillar as waste material.

2.1.4. Hydraulic mining method

This method has been applied non-mechanically to shallow deposits since 1850. The technology used in this method varies according to the type of mineral being extracted (such as gold or clay) [25].

The hydraulic method is applied in ore deposits that are uniform and exhibit minimal grade variation. To facilitate extraction and access to the ore, it is initially assumed that the deposit is horizontal, allowing for a one-dimensional analysis of the deposit. In this scenario, since the block model is one-dimensional, the UL can be determined using algorithms such as branch and bound. However, if the number of water jets increases, the block model becomes two-dimensional, and the problem becomes more complex. In a two-dimensional block model, water jets advance along each row to the end. Consequently, waste blocks must also be removed because the water jets operate directly in only one direction for the extraction process (as shown in Fig.. 3). As a result, depending on the alignment of the water jet along the X or Y axis, it is not feasible to leave a block designated as waste unextracted. This means that failure to extract one block imposes constraints on the remaining blocks. Therefore, to access the ore, given the low extraction cost and the continuity of the method due to the fixed position of the water jet at the extraction site, it is not possible to leave waste or low-grade blocks unextracted; they must be mined. Thus, in the hydraulic method, because selectivity is not feasible, the UL cannot be defined.



a) Two-dimensional block model b) Three.dimensional block model

Fig. 3. Two-dimensional and three.dimensional block models and water jet positioning.

2.1.5. Dredge method

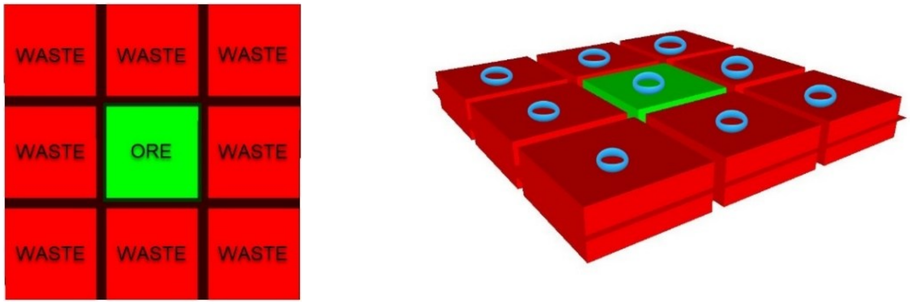
The placer method is used to extract alluvial materials with high economic value. These materials include pure gold, platinum, silver, heavy minerals such as tin, titanium, rare elements, iron, diamonds, and similar resources. The decision to employ the dredge method depends on the rock characteristics, water availability, and deposit conditions [25].

In the dredging method, because extraction occurs continuously and progresses in a single direction and orientation, and if the ore is homogeneous and uniform, it is not possible to selectively extract the ore, nor can the UL be defined. However, if operational constraints can be identified, it may be possible to define the UL through an algorithmic approach, allowing for the extraction of ore while leaving waste materials in place.

2.1.6. Borehole mining method

As conventional ore production becomes increasingly challenging and costly, solution mining methods are gaining appeal as primary or secondary mining techniques. In the borehole mining method, water is injected into the mineral formation through wells, causing the dissolution, melting, or conversion of the valuable mineral into a slurry, which is then brought to the surface through discharge wells [24].

This method is employed in large deposits, where the deposit can be divided into blocks to facilitate the drilling of boreholes within them. Therefore, it can be said that the dimensions of the blocks are determined in two surface dimensions depending on the spacing of the boreholes, while the third dimension, along the depth (Z direction), may vary significantly. In other words, flexibility is limited in the depth direction, whereas in the other two surface dimensions, boreholes can be drilled within the ore, leaving low-value sections as waste or pillars (Fig 4). As a result, this method allows for the potential application of UL optimization.



a) Two-dimensional block model b) Three.dimensional block model and borehole positions

Fig. 4. Two-dimensional and three.dimensional block models.

2.1.7. Solvent mining method: leaching

The leaching mining method refers to the extraction of metals and minerals from an in-situ deposit or from previously extracted materials. This method is particularly applicable to low-grade deposits and is divided into two main categories [24]:

1. In-situ leaching (e.g., uranium)
2. heap leaching (e.g., copper, gold, silver)

In the heap leaching method, since variability parameters are not of significant importance, the extraction or non-extraction of a particular block does not impose restrictions on the extraction of other blocks. The variations within the accumulated material are generally minimal, and the materials are of equivalent value.

In-situ leaching is applied to large deposits, making it essential to perform block modeling of the deposit. When determining the borehole grid dimensions, the spacing between boreholes along the X and Y axes can be designed, whereas the spacing along the Z axis depends on the ore's extent. Additionally, tectonic issues, solvent recovery conditions, permeability, and other crucial factors must be carefully examined to optimize recovery using this method. For example, portions of the ore may be within a fractured or faulted zone, which could hinder the recovery of the leaching material. During the design phase, these areas can be left unextracted despite containing ore material. This method thus allows for selectivity, underscoring that it is possible to apply UL optimization effectively.

2.2. Underground mining methods

2.2.1. Room and pillar mining method

This method is used for horizontal (or nearly horizontal), flat, and relatively thin bedded deposits. Mining spaces are created as rectangular rooms spaced at regular intervals, with rectangular or square cross-section pillars left in place to provide natural support [24].

In the room and pillar method, given the extraction method and the uniform nature of the ore, with the entire deposit consisting of coal, the critical factors are the dimensions of the pillars and the mining spaces, which are defined based on the geo-mechanical properties of the space. The placement of these pillars does not influence the determination of the UL of the mine. UL determination becomes important only when block extraction depends on location, grade, and economic value. Therefore, when the extraction location within the ore does not vary, defining the UL becomes unnecessary.

2.2.2. Stope and pillar method

This is a non-support method where horizontal stopes are excavated in the deposit, either in a regular or irregular pattern, resulting in the formation of pillars for ground support [24]. In determining the optimal UL for the stope, selectivity and leaving blocks unmined are considered. Since this method is typically applied to metallic minerals and since metallic deposits are not uniform, a cut-off grade is defined. Unlike the room and pillar method, where the location of pillars is fixed and arranged in a regular pattern for roof safety, the stope and pillar method does not have precisely defined pillar locations. Instead, pillars can be placed in areas containing waste material (leaving waste blocks in situ). Given the flexibility in pillar placement, which allows for a higher degree of selectivity, it is possible to define the UL in this method. Therefore, in the design phase, prior to the start of extraction operations, block modeling must be conducted. This allows for the determination of the cut-off grade and the subsequent classification of ore based on this parameter, enabling clear identification of extractable and waste blocks.

2.2.3. Shrinkage stoping method

This method refers to vertical mining techniques employed when the deposit is oriented vertically or nearly vertically, at an angle greater than the repose angle of the broken ore [24].

In the shrinkage stoping method, the defined block serves both as a working platform for upper cuts and as a means of maintaining and supporting the stope. In this method, if blocks with negative economic value or blocks with grades lower than the cut-off grade are left in situ, operational issues may arise for the discharge of materials. Consequently, this method has a low to moderate selectivity. In this technique, if a block is left unmined, assuming it is waste, access problems can occur for other sections of the stope, making it difficult to traverse from one side of the stope to the other. Also, since the discharging of the ore occurs from the bottom of the stope through discharge chutes, the ore materials remain on the waste blocks that have been left in situ, reducing the recovery rate of the method. Given that this method is typically applied to deposits with relatively high grades, the impact of reduced recovery cannot be ignored. Therefore, based on these considerations, the feasibility of defining the UL for this method is very weak.

2.2.4. Sublevel stoping method

The sublevel stoping method is a vertical overhead mining method that involves drilling long holes and blasting in sublevels to break and crush the ore. The ore flows naturally throughout the stope under the influence of gravity and is discharged from the haulage level [24].

In the sublevel stoping method, the size of each cut in the Z direction corresponds to the height of a sublevel during each blast. Therefore, this method does not allow for leaving and abandoning sections as pillars; all the ore is broken through drilling and blasting and is discharged from the stope via discharge points. As a result, there is no possibility of leaving sections as pillars, making the determination of the UL in this method unlikely.

2.2.5. Cut and fill method

The cut and fill method is an artificial support mining method applicable in steep deposits with significant vertical height [24, 25]. This method is the most flexible for non-layered deposits regarding application and execution conditions, yielding better results as the steepness of the deposit increases. In this method, block modeling is performed for each panel, and the extracted ore materials are replaced with backfill materials for support. Additionally, it is possible to leave waste blocks unmined, which gives the method selectivity. The ore in this method exhibits grade variability, and the flexibility of the method allows miners to selectively extract blocks based on their grades. Therefore, identifying which blocks to extract and which to leave in situ is of particular importance. Consequently, given the adaptable nature of this method, it can be concluded that there is potential for defining the UL.

2.2.6. Stull Stoping method

The stull stoping method is rarely used today and is suitable for specific deposit conditions, such as thin deposits, those with variable dips, or layered deposits with relatively weak surrounding rocks [24].

Since this method is small-scale in terms of production, detailed and meticulous preparation is neither recommended nor necessary. Similar to the cut and fill method, ore with grades lower than the cut-off grade is left unmined in the stope and can be considered as pillars for support. As a result, like the cut and fill method, this technique offers high flexibility and selectivity. Additionally, the low Selective (Smallest) Mining Unit (SMU) in this method enhances the potential for selectivity. Therefore, it can be concluded that there is an opportunity to develop an algorithm for determining the UL. In this method, due to the very thin thickness of the ore, the model can be considered in two dimensions, allowing for optimization using existing algorithms in a two-dimensional framework.

2.2.7. Square.set stoping method

The square set stopping method is one of the techniques that involves support for the mined space, but it has become obsolete worldwide for economic reasons. In this method, the extraction and timbering costs are very high, and for this reason, the grade of the ore must be significantly high to justify the elevated costs of the method [27].

In this method, after the extraction of each section of ore, and depending on the geo-mechanical properties of the surrounding rocks, wooden supports are used for reinforcement and support. When necessary, backfill materials may also be used for filling purposes. Thus, it can be concluded that some form of block modeling is performed within the deposit, where the size of the blocks corresponds to the dimensions of the supports. This method is also employed in metallic deposits, allowing for the definition of a cut-off grade, which enables the differentiation between waste and ore blocks. In mining stopes utilizing the square set stoping method, it is possible to provide auxiliary or additional support by leaving pillars of low-grade ore or waste material unmined.

Additionally, this technique is small-scale in terms of production (with a small SMU) and has a high selectivity potential. Therefore, in this method, defining the UL can be effective in determining which blocks should be extracted and which should remain in situ.

2.2.8. Block caving method

The block caving technique is considered the most attractive alternative to the open-pit mining method. In this method, the gravitational flow characteristics of the ore and waste materials play a crucial role in determining ore recovery and material blending. These characteristics must be taken into account during the design stages of the block caving process to establish the optimal spacing between discharge points [28].

In the block caving method, due to the weakness of the ore and surrounding rocks and the high costs associated with creating levels, it is not possible to selectively establish levels within the ore. Therefore, considering the high caving potential of the ore and surrounding rocks, it can be concluded that there is no variability or selection capability in the Z direction. However, in the X and Y directions, lower-grade blocks of ore can be left as pillars while extracting higher-grade ore blocks, based on the grade of the ore. Thus, the extracted blocks can vary in the X and Y directions, but there is no selection capability in the Z direction. This method is applicable in metallic deposits, where the determination of the UL is also feasible.

2.2.9. Sublevel caving method

This method is used for large deposits, where the entire ore is drilled and blasted, with only the waste material located above the stope being caved under the influence of gravity. The mining method and creation of sublevels occur from the top down, and the shape of the stope is that of a rhomboidal prism [29, 30].

This method is also primarily utilized in metallic deposits characterized by significant grade variability, and the determination of the UL is feasible. In UL optimization for this method, the direction of extraction relative to the location of the access points and the transportation of materials becomes important.

A notable point regarding the determination of the optimal UL for the extraction stope is the technique of drilling and blasting in the blocks between levels. In determining the optimal UL for the extraction stope in the sublevel caving method, selectivity and the ability to leave blocks unmined are feasible. Given the retreat mining approach, it is possible to leave waste blocks in situ while extracting the ore.

2.2.10. Long-wall mining method

This method is primarily used for coal deposits and rarely for metallic deposits (such as copper, iron, and gold). The shape of the orebody occurs in either layered or massive forms; if it is layered, uniformity is expected, and no variability or irregularity is observed. Additionally, there is no selectivity in this method [25]. In contrast to the block caving and sublevel caving methods, significant grade variability is not present in long-wall mining due to its primary application in coal seams (selectivity is low in this method), and there are no changes observed over a long distance in one direction. Therefore, grade does not play a determining role in establishing the UL in this method. In long-wall mining, the coal seam is divided into various panels; the length of the panel corresponds to the distance the stope moves, the width of the panel equals the length of the stope, the cuts represent the width of the stope, and the height of the stope is the thickness of the seam. Here, one can assume that each cut represents a block with no significant differences between the cuts. Thus, the concept of block modeling is not applicable in coal deposits, and there is no necessity to define the UL.

3. Discussion

In this study, both surface and underground mining methods were examined, and the importance of determining the UL according to the mining method, operational constraints, machinery, and other factors was discussed. Based on the current research, it can be concluded that methods characterized by grade variability can be investigated to determine the optimal UL. The results of this investigation are presented in Tables 3 and 4.

In the current study, the optimization capability of the UL is presented solely as a binary condition (yes/no). Future research should focus on assessing the likelihood of this capability.

Table 3. Optimization capability of UL in surface mining methods**.**

Influential factors **Mining method**	**Selectivity [24]**	**Grade variability (Mineral quality) [24]**	**Optimization capability of UL**
Quarry mining	High	No	No
Open cast (strip) mining	.	No	No
Auger mining	.	No	No
Hydraulic method	.	No	No
Dredge mining	Low	Yes	Yes
Borehole mining	Low	Yes	Yes
In.situ leaching	Low	Yes	Yes

Table 4. Optimization capability of UL in underground mining methods.

Influential factors Mining method	Selectivity [24]	Grade variability (Mineral quality) [24]	Optimization capability of UL
Room and pillar	Low	No	No
Stope and pillar	High	Yes	Yes
Shrinkage stoping	Low	Yes	No
Sublevel stoping	Low	Yes	Yes
Cut and fill	High	Yes	Yes
Stull stoping	High	Yes	Yes
Square.set stoping	High	Yes	Yes
Long.wall mining	Low	No	No
Sublevel caving	High	Yes	Yes
Block caving	Low	Yes	Yes

4. Conclusion

Determining the UL is one of the initial stages of mine design, playing a key role in establishing the net present value and profitability of a project. Accordingly, given the necessity of emphasizing the determination of the UL in various mining methods, both surface and underground, Hartman's classification was used as the basis for this research, and all primary methods were examined. Additionally, based on a review of previous research, it can be stated that numerous algorithms have been developed from 1965 to 2021 for UL optimization. These algorithms are categorized by surface and underground mining methods in Tables 1 and 2. Ultimately, it can be concluded that the selectivity and flexibility of the open-pit mining method are greater compared to the other techniques mentioned. This has led to the development of many algorithms aimed at determining the UL for this method. Therefore, the findings indicate that, given the selectivity and the grade variability parameters of each method, among the surface mining methods, dredge, borehole mining, and in-situ leaching can determine the UL, while in quarry mining, open cast (strip) mining, auger mining, and the hydraulic method, it is not necessary to determine the UL. Among the underground mining methods, the results showed that it is possible to determine the UL in the stope and pillar, sublevel stoping, cut and fill, stull stoping, and square.set stoping, sublevel caving, and block caving due to the presence of grade variability (mineral quality). For room and pillar mining, shrinkage stopping, and long-wall mining methods, determining the UL is not required due to the consistency of grade in these methods. Given that no comprehensive assessment of the necessity for UL optimization across all mining techniques has been conducted to date, the results of this study provide a pathway for future research aimed at developing algorithms for UL optimization in mining methods other than open.pit mining techniques.

Ethical Considerations

The authors avoided data fabrication, falsification, and plagiarism, and any form of misconduct.

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Conflict of Interest

The authors declare no conflict of interest.

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