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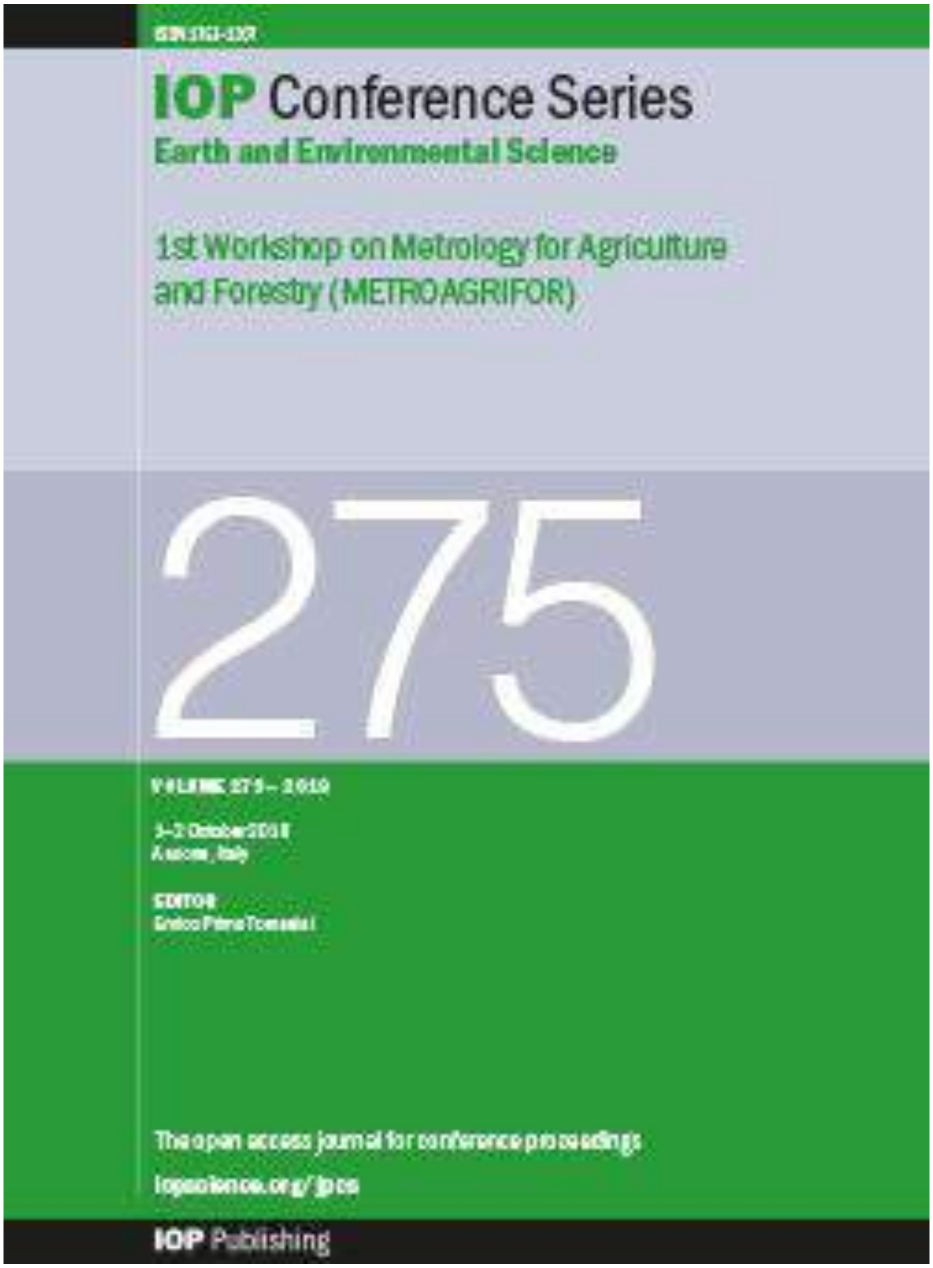

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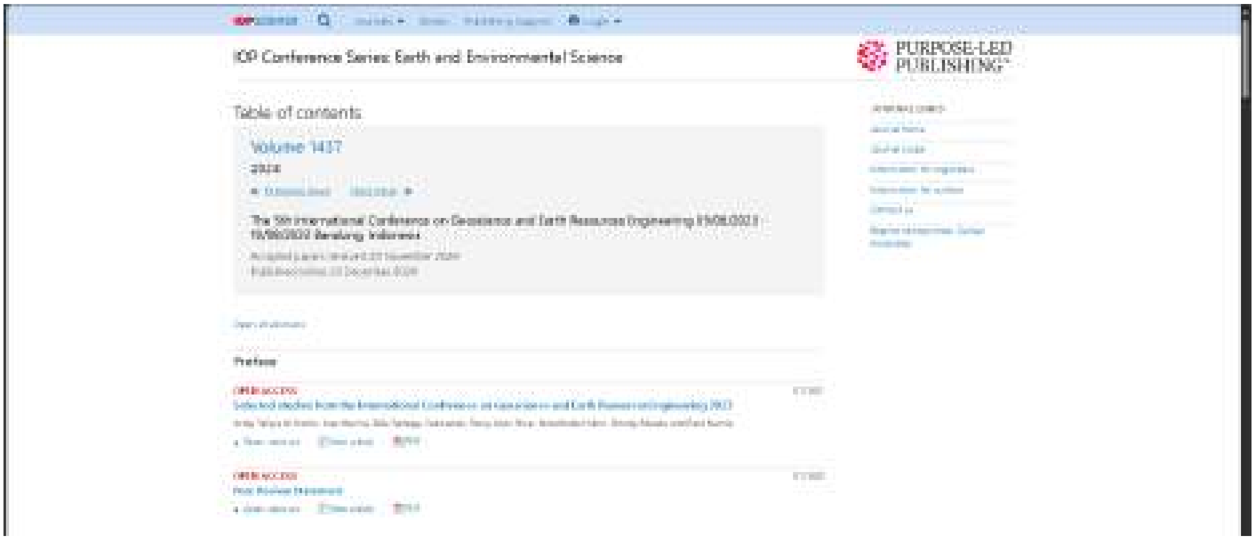

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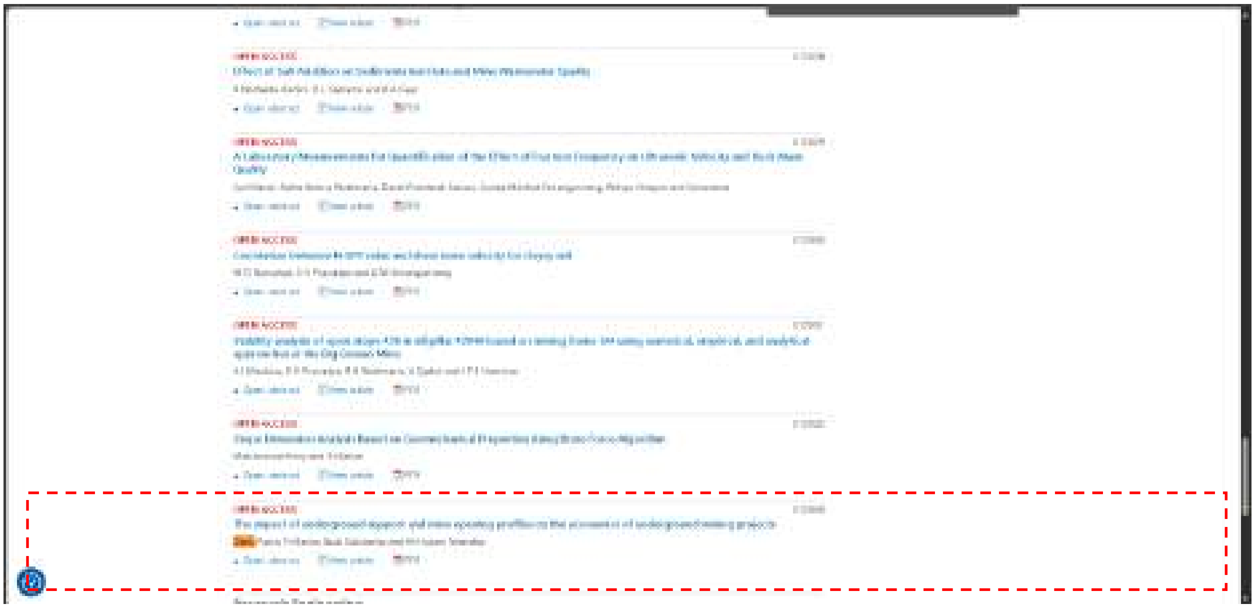

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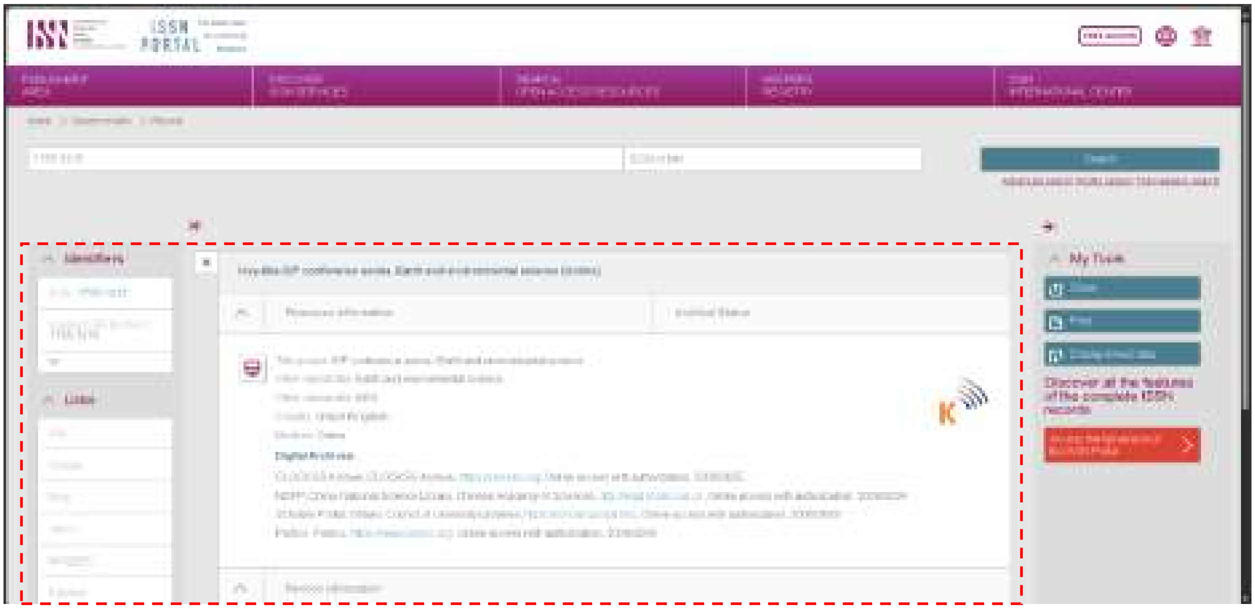

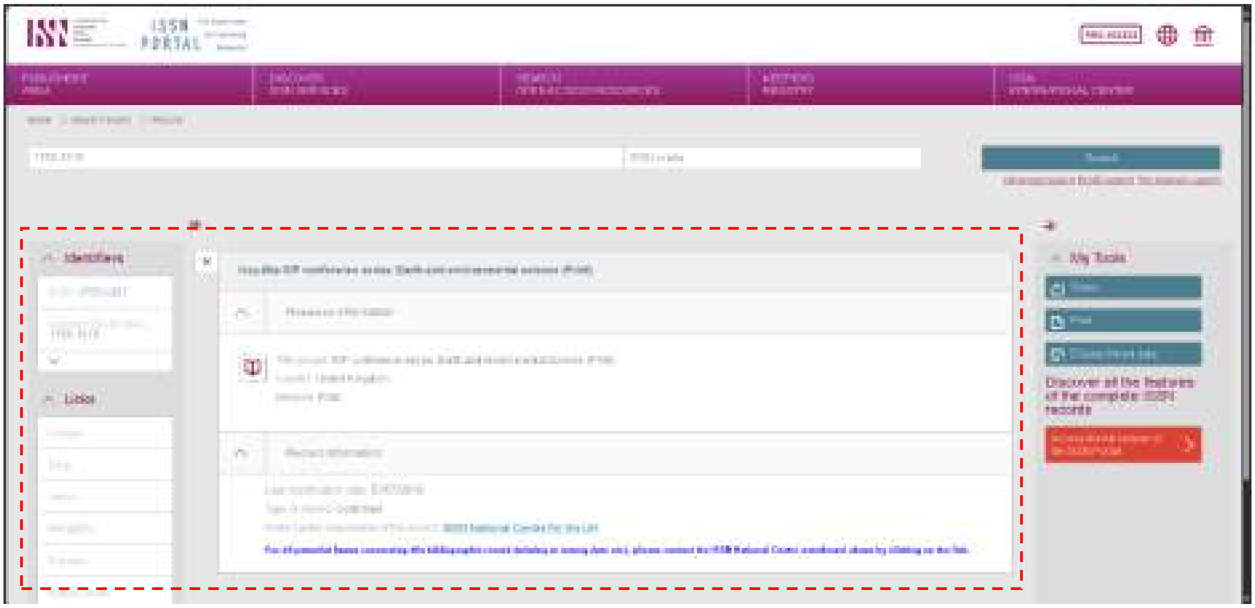

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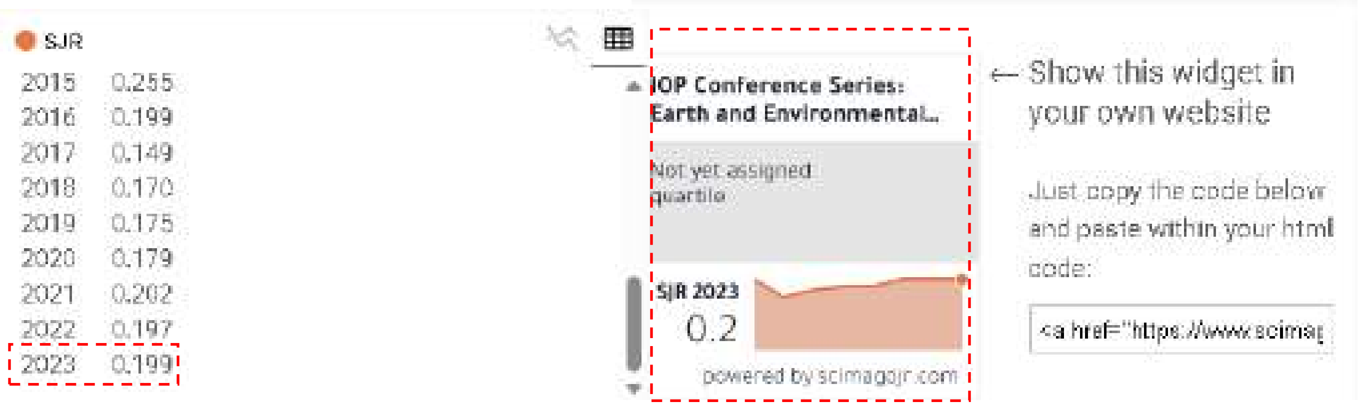

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The impact of underground support and mine opening profiles on the economics of underground mining projects

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The impact of underground support and mine opening profiles on the economics of underground mining projects

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Abstract. Underground mines, particularly in the cut and fill method, require careful consideration of stope or slice dimensions and support. Determining the appropriate and efficient dimensions and mine support is crucial to ensuring mine safety. An increase in stope size affects the amount and quality of mine support needed, thus increasing the overall mining cost, which can impact the feasibility of the project. On the other hand, it can lower overall mining costs, as the amount of extracted ore increases. Optimization by implementing mining scenarios is performed to assess the impact of support costs on the economy of a mining block. This study attempts to examine the feasibility of three mining scenarios with various excavation profiles. Excavation profiles of stope cut and fill with variations of 2 mW x 2.5 mH, 3 mW x 3 mH, and 5 mW x 5 mH, further referred to as scenarios 1, 2, and 3, respectively, are established as the base scenarios for optimization. The mine support requirements were determined based on the material load per square meter of tunnel progress and the available mine support specifications. Based on the types of supported requirements in the model, the analysis groups the required support into two categories: one for scenarios 1 and 2, and another for scenario 3. The categorization was made because the possibility of using one set of mine supports for the whole scenario wasn't possible. Scenario 3 necessitates stronger and more robust mine support, including the requirement for 18 pcs/m of dome plate type 47 (un-galvanized) and split set type 47 (un-galvanized), respectively, as well as 2 pcs of H-beam per meter of other primary support. The calculation of mine support costs was then performed and combined with other mining cost components to form the required cost parameter in the optimization process. The optimum stope shape for each scenario is then created through the optimization process using a widely known stope optimization module, Stope Shape Optimization (SSO), that is available in the Micromine educational package. The stope optimization results show the stope layout in the zone with high grade, where the total estimated reserves for each scenario are 20,482 metric tons, 30,057 metric tons, and 43,508 metric tons, with an average gold grade of 2.74 g/t, 2.73 g/t, and 2.71 g/t, respectively. Economic value calculations have also been performed on the amount of mined reserves in the optimization process, with the highest mining cost shown in scenario 1 at $1.40 million, resulting in a mining cost per ton of 59.93 $/ton. The highest revenue is obtained in scenario 3 with an economic value of $112.58 million, which is consistent with the profit of $109.17 million, indicating that scenario 3 is economically feasible.

Keywords: stope optimization, cut-and-fill, undergro

1. Introduction

The cut-and-fill method is commonly used in weak rock mass classes, and therefore intensive support is significantly needed. Support is one of the functions of rock mass classes [1], [2], [3], [4]. In addition to rock mass classes, other factors that influence instability include structure [5] and the presence of induced stresses [6], [7]. Both of these parameters are influenced by the mining opening (stope), where larger mining openings have a greater influence on induced stresses and instability [8], [9].The same conditions also apply to structural orientation. Structure orientation and stope orientation can adversely affect the stability of mining openings [10], [11]. In the cut-and-fill method, these factors are addressed through the use of support [12]. The heavy use of support certainly has an impact on mining's operational costs. Furthermore, these conditions can alter the feasibility of a mining project. This study aims to examine the influence of support on the feasibility of mining scenarios. A case study of underground gold mining using the cut and fill method is used as the basis for analysis in this research.

2. Ore Model

The underground gold mining case study using the cut and fill method is used to examine the influence of stability on project feasibility. The data for the optimization provided are in the form of an ore block model, which in this case refers to material with gold or silver grades above 0 g/t. The host rock, or surrounding rock with gold or silver grades of 0 g/t, is classified as waste and is represented as "air blocks." Figure 1 shows the extent of the ore model used in this study, which ranges from 9,550 to 9,880 easting, 11,322 to 11,393 northing, and 450 to 570 RL. The gold and silver grades range from 1.26 to 12.08 g/t and 14.71 to 212.20 g/t, respectively. In addition to the grades, Table 1 presents detailed attributes and additional attributes in the block model, such as rock density and resource classification, which are considered in the optimization process.

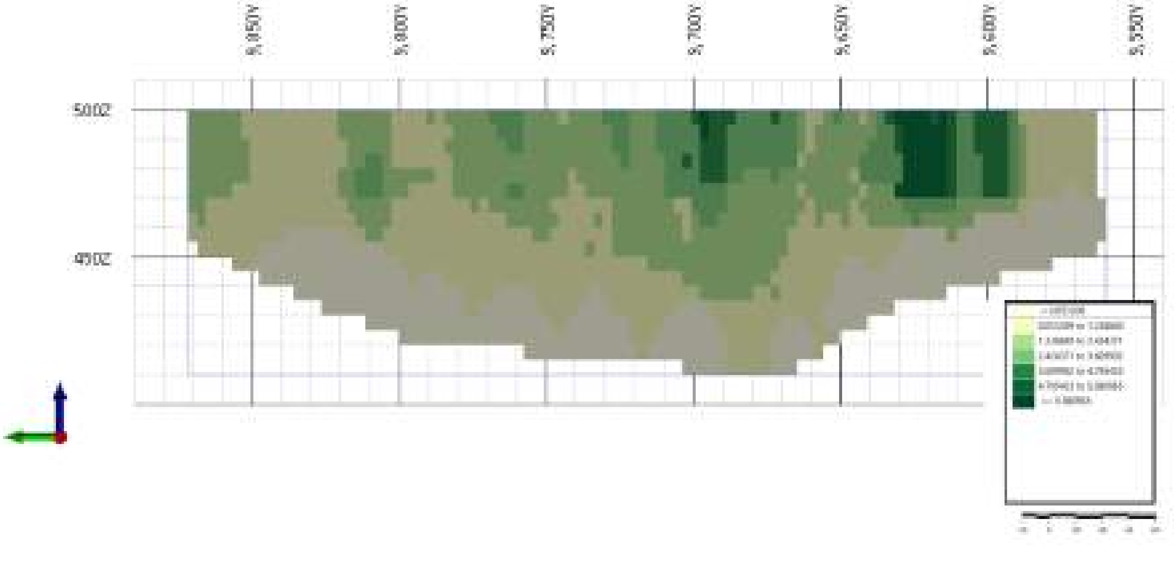


Figure 1. Ore block model

Table 1. Details of the ore block model

	Max	Min	Average
Northing (m)	9,880	9,550	-
Easting (m)	11,393	11,322	-
Elevation (m)	450	570	-
Resource	3	1	-
Au (g/t)	12.08	1.26	4.34
Density (ton/m^3)	2.5	2.5	2.5
Ag (g/t)	212.20	14.71	75.50

3. Stope and Support Design

The weak rocks that are present generally result in a high demand for support requirements as the stope or mine opening gets larger. This is due to many factors, such as stress conditions, rock structures, stope dimensions, and stope orientation. This study focuses on the stope dimensions as a variable, and explores how different mining profiles and dimensions lead to varying support requirements, which in turn create different economic parameters. Further, different economic profiles in each scenario were presented, and analyses were performed to determine the best scenario in terms of economics. The next section of this article explains the use of the profile scenarios employed in this research.

3.1. Stope Mining Profile

The mining profiles were determined based on several consideration such as the ore width, mining unit width, and various other mining profiles in different blocks within the same mine. Based on these considerations, three opening profile scenarios were formed as shown in Table 2.

Table 2. Optimization scenarios

Description	Scenario (meter x meter)		
	1	2	3
Production Stope/Slice	2 x 2.5	3 x 3	5 x 5
Extraction Mehtod	Traditional	Traditional	Mechanical

Scenarios 1 and 2 represent profiles used in mining with traditional methods, where excavation and loading are done manually without the use of mechanical equipment. On the other hand, scenario 3 depicts mining operations carried out using mechanical equipment.

Based on operational considerations, mining with a profile larger than 5 m wide by 5 m high has not been implemented in the entire mining block due to the high risk of instability caused by weak rock mass. Furthermore, the weak rock mass necessitates intensive support requirements. Further details regarding the support requirements for each scenario will be explained in Section 3.2.

3.2. Support Requirements

The support requirements were calculated based on the roof load at each of the stope profiles, while the surrounding rocks assumed homogeneity with no additional geological structure present. The calculation of support requirements is carried out for the three proposed mining scenarios based on the pre-deterimined support types and compatibility with the excavation profile, with a square profile being used.

Based on the mine support analysis, the types of support are divided into two main categories, with scenarios 1 and 2 classified in the same category, separated from scenario 3. This difference in support is mainly caused by the larger roof load as the excavation gets larger. The support needed between Senario 1 and 2 is quite the same, so the stope profile between scenario 1 and scenario 2 is not much different, quite the opposite from scenario 3.

Table 3 provides a detailed overview of the types and quantities of support used in each of the scenarios. It can be observed that different types of mesh barricades are used in the two categories of openings, with larger excavation profiles utilizing metal expanded mesh, which has a stronger strength profile compared to wire mesh. A quantity of 1.5 meters is used to cover a larger surface area of the excavation. In addition to the mesh barricade, scenario 3 also utilizes a more intensive anchoring method, using Split Set 47 (ungalvanized), Dome Plate 47 (ungalvanized), and Plate Strap. In the supporting structure, a much sturdier structure is clearly visible with the addition of H-beam, which is different from scenarios 1 and 2 that only utilize timber as the supporting structure. With this type of support, the cost intensity of the support is clearly different in the two support scenarios. Furthermore, this additional cost impacts the increase in mining costs.

Table 3. Support requirements per meter

Description	Scenario		
	1	2	3
Mesh Barricade			
Wiremesh (galvanized) (pcs/m)	0.5	0.5	-
Metal Expanded (ungalvanized) (pcs/m)	-	-	1.5
Anchor, Plate Anchor			
Split set 39 (galvanized) (pcs/m)	8	8	-
Dome plate 39 (galvanized) (pcs/m)	8	8	-
Split set 47 (ungalvanized) (pcs/m)	-	-	18
Dome plate 47 (ungalvanized) (pcs/m)	-	-	18
Plate Strap [5 meter] (pcs/m)	0.4	0.4	0.5
Timber			
Timber 2 m x 20 cm x 20 cm (pcs/m)	21	21	17
Nail 5inches (kg/m)	3	3	3
Bullhorn 32 mm (pcs/m)	4	4	-
H-Beam 4 m x 20 cm x 20 cm (pcs/m)	-	-	2
Angle structural (m/m)	-	-	9
Bolt Nut 5/8 in (pcs/m)	-	-	14

4. Price and Cost Components

In addition to the geological parameters represented by the block model, optimization can only be performed by incorporating additional economic components, such as costs and prices, that reflect the profiles of each optimization scenario. The impact of mine support variations on mining costs was investigated, allowing a better understanding of the relationship between stope size, mine support, and mine economics.

4.1. Price

The gold and silver prices used in this case study are based on current market values. The price of gold used is 54.82 US$/g, while the price of silver used is 0.70 US$/g. The dollar per gram unit was used as the revenue was calculated based on metal recovered based on the recovery parameter that has been set in the optimization.

Unlike the variation in mine supports that ultimately impacts the financing variations, each scenario has the same commodity price because the commodity values are independent of the mining method involved. In this case study, no intermediate products were used, so the commodity prices used represent pure material prices.

4.2. Mine support costs

The use of different types and quantities of mine supports in each scenario will result in varying support costs. However, the mine supports used have two distinct categories, as explained earlier. Therefore, the support costs will also exhibit the same tendencies as these characterizations.

The approach used to integrate support costs into mining operating costs is by calculating the cost of mine supports in tonnage units. This was done by multiplying the support cost unit by the quantity and type of mine supports needed for one meter of stope advancement. The $/ton unit was later achieved by dividing the mine support cost for one meter of advancement by the ton of material moved. Table 4 shows the support cost units for each of mine support types within each of the scenarios. The costs in this table reflect the characterizations of the support systems as described earlier.

Table 4. Cost components for each supporting requirement

Description	Scenario		
	1	2	3
Mesh Barricade			
Wiremesh (galvanized) (US$/pc)	198.3	198.3	-
Metal Expanded (ungalvanized) (US$/pc)	-	-	113.4
Anchor, Plate Anchor			
Split set 39 (galvanized) (US$/pc)	7.3	7.3	-
Dome plate 39 (galvanized) (US$/pc)	2.2	2.2	-
Split set 47 (ungalvanized) (US$/pc)	-	-	11.8
Dome plate 47 (ungalvanized) (US$/pc)	-	-	2.0
Plate Strap [5 meter] (US$/pc)	44.0	44.0	45.6
Timber/Structural Support			
Timber 2 m x 20 cm x 20 cm (US$/pc)	17.2	17.2	16.9
Nail 5 inch (US$/kg)	1.2	1.2	1.2
Bullhorn 32 mm (US$/pc)	29.0	29.0	-
H-Beam 4 m x 20 cm x 20 cm (US$/pc)	-	-	278.1
Angle Structural (US$/pc)	-	-	46.8
Bolt Nut 5/8 in (US$/pc)	-	-	0.4

4.3. Operating, Processing, and Selling Cost

In this study, operating cost is the cumulative total of expenses incurred to move one ton of materials. Certainly, operating costs are not solely based on support costs; other cost components in underground mining need to be considered, such as blasting costs, ventilation costs, dewatering costs, environmental-related costs, and other costs.

Other operating costs that are not included in support costs were provided. Generally, mining costs per ton will be inversely proportional to the level of production achieved. In this context, the use of larger opening profiles and the availability of mechanization in larger openings allow for greater production. As seen in Table 5, operating costs tend to decrease with increasing mining opening profiles. However, there are cost components, such as environmental and general administration costs, that do not significantly impact the level of production. This is because the same processes are followed regardless of the production scale used.

Mine support costs also tend to decrease as the excavation profile size increases, for similar reasons. However, this trend is reversed in scenario 3 for the costs associated with the use of structural support, as the beams used are one of the expensive components in this support scenario. This trend serves as one of the foundations for the optimization of stope design in the final stage of the study.

Table 5. Mine operating cost components

Description	Unit	Scenario		
		1	2	3
Supporting				
Mesh Barricade	US$/ton	8.81	4.59	2.26
Anchor, Plate Anchor	US$/ton	8.29	4.31	3.59
Timber/Beam	US$/ton	24.42	12.71	26.31
Blasting				
Drill Accessory	US$/ton	2.47	1.29	0.99
Blast Accessory	US$/ton	12.38	10.69	0.84
Ventilating				
Hose and Air Ducts	US$/ton	1.46	0.76	0.22
Dewatering				
HDPE	US$/ton	2.47	1.29	0.37
Environmental				
Backfilling	US$/ton	1.14	1.12	1.13
Other				
General & Administration	US$/ton	3.53	3.53	3.53

The processing cost was assumed to be the same for each scenario at $10.01 per ton. The uniformity of this cost is due to processing costs being independent of the mining scenarios implemented. In addition to processing costs, another cost with a consistent profile across scenarios is the selling cost. The magnitude of the selling cost is based on the smelting expenses incurred by the company to process semi-finished materials into finished products, specifically gold bars in this case. The cost amount remains the same in each scenario, with a value of $2.68 per ton.

5. Optimum Stope

The stope optimization was performed using the stope optimizer module provided by Micromine [13]. This optimization process involves input data consisting of the ore geological model, technical parameters, and economic parameters of the optimization scenarios. The distinct characteristics among scenarios necessitate separate optimization processes for each scenario. This includes differences in the stope profile of the stopes, adjusted level positions for each stope height, and cost profiles encompassing operating costs, processing costs, and selling costs.

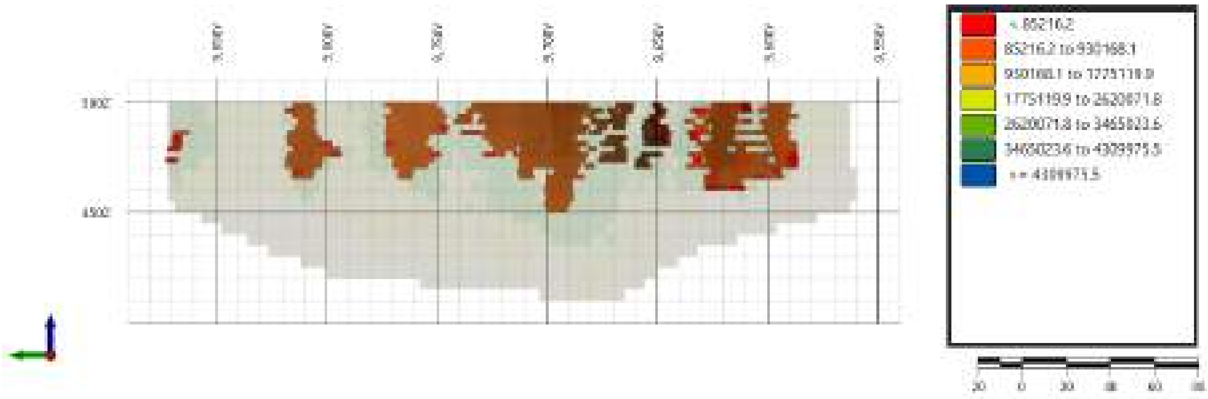
5.1. Stope Optimization Algorithm

The stope optimizer algorithm in Micromine software utilizes two types of algorithms, namely exact and heuristic, which are automatically selected based on the optimization profile chosen by the user. The heuristic algorithm is applied when optimization is restricted to prevent excessively long running times, while the exact algorithm is applied when optimization conditions are unrestricted. Some of the constraints include the achievement percentage of objectives, the number of iterations, and/or the duration of iterations.

In this study, the optimization process employs the exact algorithm, where the optimizer is unrestricted by any numerical constraints that limit optimization time.. The optimization process will terminate once the best value is achieved according to the user-defined input parameters for a given scenario. Resource constraints were implemented along with optimization, limiting only the measured and indicated blocks to be processed as ore material. Another technical constraint implemented was the stope width constraint and the stope length constraint. The preceding section's scenario served as the basis for setting up the width constraint, while practical recommendations guided the establishment of the 20-meter stope length constraint. Since the cut-and-fill method mines the material in slice-type stopes rather than individual box-shaped stopes, this represents the minimum viable stope length.

5.2. Stope Layout and Optimization Result

The optimization conducted for the three scenarios resulted in the distribution of optimal stopes within the ore block model. Figure 2 illustrates the distribution of stopes for each scenario. Generally, the stope layout follows the distribution of the gold and silver grades, as evidenced by the prevalence of stopes in blocks with high grades. Darker green blocks in the block model indicate the higher gold grades, while the stopes color represents their economic value, with blue indicating better economic value compared to red.



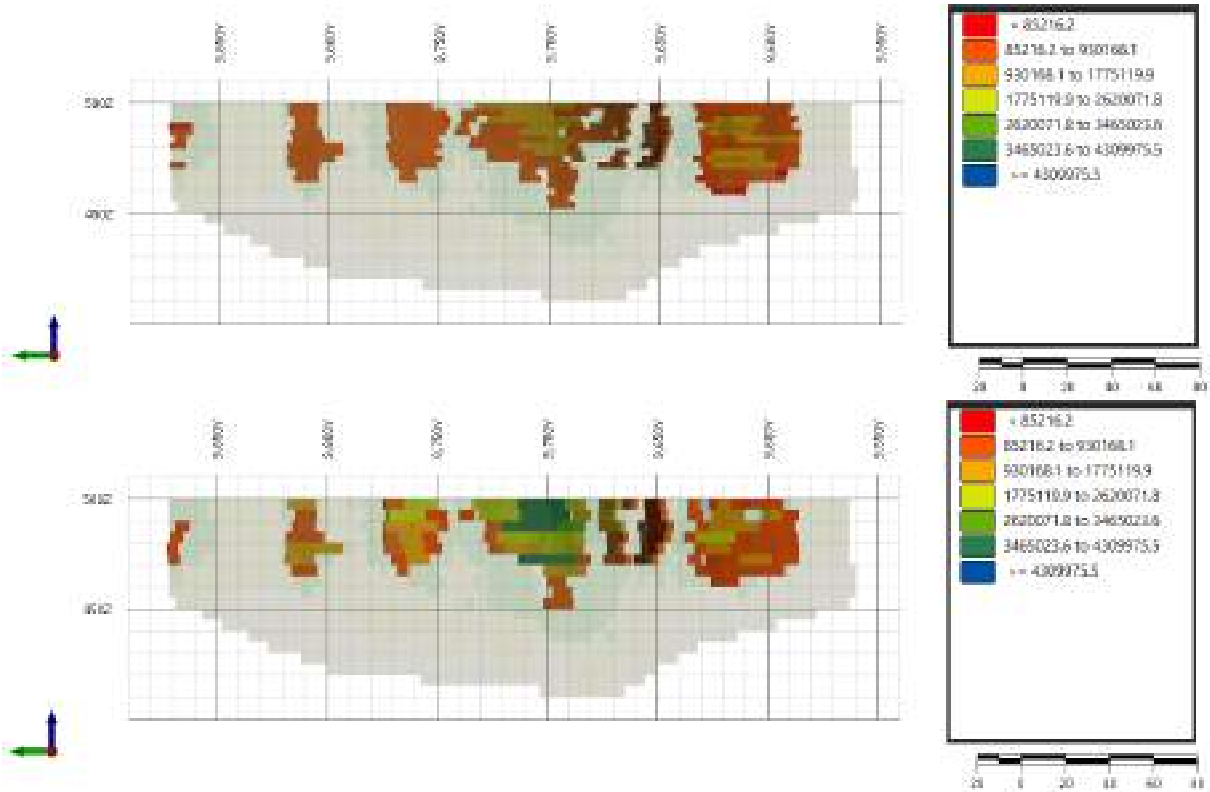


Figure 2. Stope layout for multiple scenarios: scenario 1 (upper); scenario 2 (middle); scenario 3 (lower)

Figure 3 depicts the total tonnage of extracted ore with the average gold and silver grades for various scenarios. It can be observed that scenario 3 has the highest amount of extracted ore, which is directly proportional to the larger opening profile. However, the average grades of the extracted ore remain consistent across the different scenarios. In addition to the quantity of extracted material, scenario 3 also exhibits the highest economic value, as shown in Figure 4. Furthermore, when considering the unit cost, scenario 3 demonstrates the lowest unit cost in terms of both operating cost and total cost. This suggests that the variation in support costs does not significantly impact the overall economic feasibility.

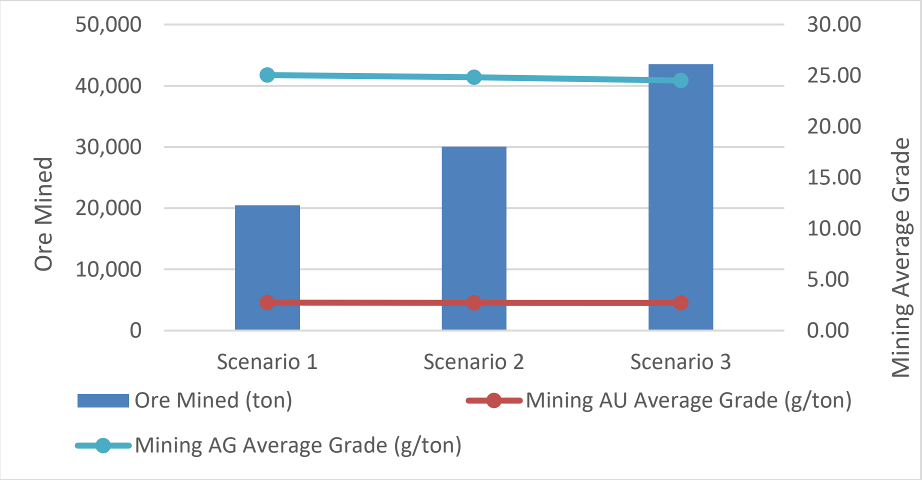


Figure 3. Project ore mined and mining average grades vs mining scenarios

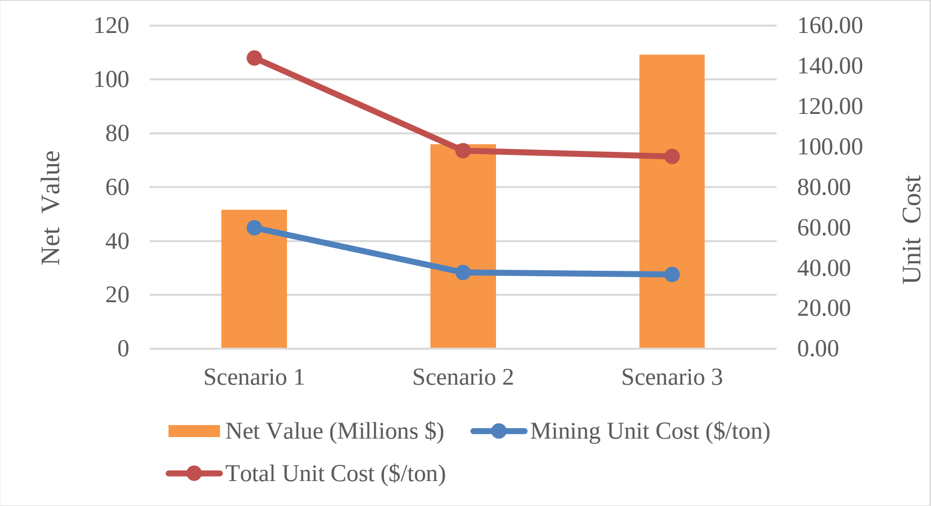


Figure 4. Project net value and unit cost vs mining scenarios

6. Conclusions

Optimization is a process aimed at achieving the best mining scenario based on certain parameters, constraints, and indicators. The commonly used indicators include minimizing mining costs or maximizing the current net present value (NPV). An optimization module is developed within mining software to facilitate this process, allowing for the testing of a larger number of mining scenarios in a short period of time with the hope of finding the most favorable mining scenario. One aspect of mining scenarios is the stope profile, which is closely related to the intensity of support required. This is particularly emphasized in cut-and-fill mining methods, as these methods are typically applied in conditions where the rock mass is less stable, necessitating significant support requirements. However, the current input parameters for the optimization module, which mainly focus on dimension, do not directly consider geomechanical parameters, especially the support requirements, as part of the input. A study has been conducted to examine the interactions between these parameters and their application in underground mining optimization.

Furthermore, the analysis results indicate that larger stope profile have a significant impact on the requirements for both the type and quantity of support, indirectly increasing the support cost by up to $32.2 per ton. However, this increase in support costs is not significant compared to the total production output, as evidenced by the operational cost of $39.24 per ton. The optimization results show that scenario 3 has the best economic value, as indicated by a net value of $109.2 million, despite the need for substantial support to accommodate instability.

Finally, this study indicates production related parameters may have larger impacts on project value than geomechanical direct costs, such as the costs of mine supports. Further research into productivity aspects of geomechanical engineering is critical to better understanding its impact on project value.

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The impact of underground support and mine opening profiles on the economics of underground mining projects

by Danu Putra FTKE

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The impact of underground support and mine opening profiles on the economics of underground mining projects

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Abstract. Underground mines, particularly in the cut and fill method, require careful consideration of stope or slice dimensions and support. Determining the appropriate and efficient dimensions and mine support is crucial to ensuring mine safety. An increase in stope size affects the amount and quality of mine support needed, thus increasing the overall mining cost, which can impact the feasibility of the project. On the other hand, it can lower overall mining costs, as the amount of extracted ore increases. Optimization by implementing mining scenarios is performed to assess the impact of support costs on the economy of a mining block. This study attempts to examine the feasibility of three mining scenarios with various excavation profiles. Excavation profiles of stope cut and fill with variations of 2 mW x 2.5 mH, 3 mW x 3 mH, and 5 mW x 5 mH, further referred to as scenarios 1, 2, and 3, respectively, are established as the base scenarios for optimization. The mine support requirements were determined based on the material load per square meter of tunnel progress and the available mine support specifications. Based on the types of supported requirements in the model, the analysis groups the required support into two categories: one for scenarios 1 and 2, and another for scenario 3. The categorization was made because the possibility of using one set of mine supports for the whole scenario wasn't possible. Scenario 3 necessitates stronger and more robust mine support, including the requirement for 18 pcs/m of dome plate type 47 (un-galvanized) and split set type 47 (un-galvanized), respectively, as well as 2 pcs of H-beam per meter of other primary support. The calculation of mine support costs was then performed and combined with other mining cost components to form the required cost parameter in the optimization process. The optimum stope shape for each scenario is then created through the optimization process using a widely known stope optimization module, Stope Shape Optimization (SSO), that is available in the Micromine educational package. The stope optimization results show the stope layout in the zone with high grade, where the total estimated reserves for each scenario are 20,482 metric tons, 30,057 metric tons, and 43,508 metric tons, with an average gold grade of 2.74 g/t, 2.73 g/t, and 2.71 g/t, respectively. Economic value calculations have also been performed on the amount of mineral reserves in the optimization process, with the highest mining cost shown in scenario 1 at $1.40 million, resulting in a mining cost per ton of 59.93 $/ton. The highest revenue is obtained in scenario 3 with an economic value of $112.58 million, which is consistent with the profit of $109.17 million, indicating that scenario 3 is economically feasible.

Keywords: stope optimization, cut-and-fill, undergro

1. Introduction

The cut-and-fill method is commonly used in weak rock mass classes, and therefore intensive support is significantly needed. Support is one of the functions of rock mass classes [1], [2], [3], [4]. In addition to rock mass classes, other factors that influence instability include structure [5] and the presence of induced stresses [6], [7]. Both of these parameters are influenced by the mining opening (stope), where larger mining openings have a greater influence on induced stresses and instability [8], [9].The same conditions also apply to structural orientation. Structure orientation and stope orientation can adversely affect the stability of mining openings [10], [11]. In the cut-and-fill method, these factors are addressed through the use of support [12]. The heavy use of support certainly has an impact on mining's operational costs. Furthermore, these conditions can alter the feasibility of a mining project. This study aims to examine the influence of support on the feasibility of mining scenarios. A case study of underground gold mining using the cut and fill method is used as the basis for analysis in this research.

2. Ore Model

The underground gold mining case study using the cut and fill method is used to examine the influence of stability on project feasibility. The data for the optimization provided are in the form of an ore block model, which in this case refers to material with gold or silver grades above 0 g/t. The host rock, or surrounding rock with gold or silver grades of 0 g/t, is classified as waste and is represented as "air blocks." Figure 1 shows the extent of the ore model used in this study, which ranges from 9,550 to 9,880 easting, 11,322 to 11,393 northing, and 450 to 570 RL. The gold and silver grades range from 1.26 to 12.08 g/t and 14.71 to 212.20 g/t, respectively. In addition to the grades, Table 1 presents detailed attributes and additional attributes in the block model, such as rock density and resource classification, which are considered in the optimization process.

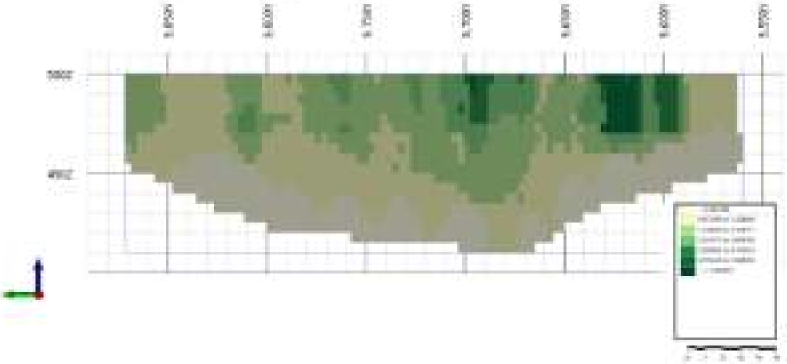


Figure 1. Ore block model

Table 1. Details of the ore block model

	Max	Min	Average
Northing (m)	9,880	9,550	-
Easting (m)	11,393	11,322	-
Elevation (m)	450	570	-
Resource	3	1	-
Au (g/t)	12.08	1.26	4.34
Density (ton/m³)	2.5	2.5	2.5
Ag (g/t)	212.20	14.71	75.50

3. Stope and Support Design

The weak rocks that are present generally result in a high demand for support requirements as the stope or mine opening gets larger. This is due to many factors, such as stress conditions, rock structures, stope dimensions, and stope orientation. This study focuses on the stope dimensions as a variable, and explores how different mining profiles and dimensions lead to varying support requirements, which in turn create different economic parameters. Further, different economic profiles in each scenario were presented, and analyses were performed to determine the best scenario in terms of economics. The next section of this article explains the use of the profile scenarios employed in this research.

3.1. Stope Mining Profile

The mining profiles were determined based on several consideration such as the ore width, mining unit width, and various other mining profiles in different blocks within the same mine. Based on these considerations, three opening profile scenarios were formed as shown in Table 2.

Table 2. Optimization scenarios

Description	Scenario (meter x meter)		
	1	2	3
Production Stope/Slice	2 x 2.5	3 x 3	5 x 5
Extraction Method	Traditional	Traditional	Mechanical

Scenarios 1 and 2 represent profiles used in mining with traditional methods, where excavation and loading are done manually without the use of mechanical equipment. On the other hand, scenario 3 depicts mining operations carried out using mechanical equipment.

Based on operational considerations, mining with a profile larger than 5 m wide by 5 m high has not been implemented in the entire mining block due to the high risk of instability caused by weak rock mass. Furthermore, the weak rock mass necessitates intensive support requirements. Further details regarding the support requirements for each scenario will be explained in Section 3.2.

3.2. Support Requirements

The support requirements were calculated based on the roof load at each of the stope profiles, while the surrounding rocks assumed homogeneity with no additional geological structure present. The calculation of support requirements is carried out for the three proposed mining scenarios based on the pre-determined support types and compatibility with the excavation profile, with a square profile being used.

Based on the mine support analysis, the types of support are divided into two main categories, with scenarios 1 and 2 classified in the same category, separated from scenario 3. This difference in support is mainly caused by the larger roof load as the excavation gets larger. The support needed between Senario 1 and 2 is quite the same, so the stope profile between scenario 1 and scenario 2 is not much different, quite the opposite from scenario 3.

Table 3 provides a detailed overview of the types and quantities of support used in each of the scenarios. It can be observed that different types of mesh barricades are used in the two categories of openings, with larger excavation profiles utilizing metal expanded mesh, which has a stronger strength profile compared to wire mesh. A quantity of 1.5 meters is used to cover a larger surface area of the excavation. In addition to the mesh barricade, scenario 3 also utilizes a more intensive anchoring method, using Split Set 47 (ungalvanized), Dome Plate 47 (ungalvanized), and Plate Strap. In the supporting structure, a much sturdier structure is clearly visible with the addition of H-beam, which is different from scenarios 1 and 2 that only utilize timber as the supporting structure. With this type of support, the cost intensity of the support is clearly different in the two support scenarios. Furthermore, this additional cost impacts the increase in mining costs.

Table 3. Support requirements per meter

Description	Scenario		
	1	2	3
Mesh Barricade			
Wiremesh (galvanized) (pcs/m)	0.5	0.5	-
Metal Expanded (ungalvanized) (pcs/m)	-	-	1.5
Anchor, Plate Anchor			
Split set 39 (galvanized) (pcs/m)	8	8	-
Dome plate 39 (galvanized) (pcs/m)	8	8	-
Split set 47 (ungalvanized) (pcs/m)	-	-	18
Dome plate 47 (ungalvanized) (pcs/m)	-	-	18
Plate Strap [5 meter] (pcs/m)	0.4	0.4	0.5
Timber			
Timber 2 m x 20 cm x 20 cm (pcs/m)	21	21	17
Nail 5inches (kg/m)	3	3	3
Bullhorn 2 mm (pcs/m)	4	4	-
H-Beam 4 m x 20 cm x 20 cm (pcs/m)	-	-	2
Angle structural (m/m)	-	-	9
Bolt Nut 5/8 in (pcs/m)	-	-	14

4. Price and Cost Components

In addition to the geological parameters represented by the block model, optimization can only be performed by incorporating additional economic components, such as costs and prices, that reflect the profiles of each optimization scenario. The impact of mine support variations on mining costs was investigated, allowing a better understanding of the relationship between stope size, mine support, and mine economics.

4.1. Price

The gold and silver prices used in this case study are based on current market values. The price of gold used is 54.82 US$/g, while the price of silver used is 0.70 US$/g. The dollar per gram unit was used as the revenue was calculated based on metal recovered based on the recovery parameter that has been set in the optimization.

Unlike the variation in mine supports that ultimately impacts the financing variations, each scenario has the same commodity price because the commodity values are independent of the mining method involved. In this case study, no intermediate products were used, so the commodity prices used represent pure material prices.

4.2. Mine support costs

The use of different types and quantities of mine supports in each scenario will result in varying support costs. However, the mine supports used have two distinct categories, as explained earlier. Therefore, the support costs will also exhibit the same tendencies as these characterizations.

The approach used to integrate support costs into mining operating costs is by calculating the cost of mine supports in tonnage units. This was done by multiplying the support cost unit by the quantity and type of mine supports needed for one meter of stope advancement. The $/ton unit was later achieved by dividing the mine support cost for one meter of advancement by the ton of material moved. Table 4 shows the support cost units for each of mine support types within each of the scenarios. The costs in this table reflect the characterizations of the support systems as described earlier.

Table 4. Cost components for each supporting requirement

Description	Scenario		
	1	2	3
Mesh Barricade			
Wiremesh (galvanized) (US$/pc)	198.3	198.3	-
Metal Expanded (ungalvanized) (US$/pc)	-	-	113.4
Anchor, Plate Anchor			
Split set 39 (galvanized) (US$/pc)	7.3	7.3	-
Dome plate 39 (galvanized) (US$/pc)	2.2	2.2	-
Split set 47 (ungalvanized) (US$/pc)	-	-	11.8
Dome plate 47 (ungalvanized) (US$/pc)	-	-	2.0
Plate Strap [5 meter] (US$/pc)	44.0	44.0	45.6
Timber Structural Support			
Timber 2 m x 20 cm x 20 cm (US$/pc)	17.2	17.2	16.9
Nail 5 inch (US$/kg)	1.2	1.2	1.2
Bullhorn 2 mm (US$/pc)	29.0	29.0	-
H-Beam 4 m x 20 cm x 20 cm (US$/pc)	-	-	278.1
Angle Structural (US$/pc)	-	-	46.8
Bolt Nut 5/8 in (US$/pc)	-	-	0.4

4.3. Operating, Processing, and Selling Cost

In this study, operating cost is the cumulative total of expenses incurred to move one ton of materials. Certainly, operating costs are not solely based on support costs; other cost components in underground mining need to be considered, such as blasting costs, ventilation costs, dewatering costs, environmental-related costs, and other costs.

Other operating costs that are not included in support costs were provided. Generally, mining costs per ton will be inversely proportional to the level of production achieved. In this context, the use of larger opening profiles and the availability of mechanization in larger openings allow for greater production. As seen in Table 5, operating costs tend to decrease with increasing mining opening profiles. However, there are cost components, such as environmental and general administration costs, that do not significantly impact the level of production. This is because the same processes are followed regardless of the production scale used.

Mine support costs also tend to decrease as the excavation profile size increases, for similar reasons. However, this trend is reversed in scenario 3 for the costs associated with the use of structural support, as the beams used are one of the expensive components in this support scenario. This trend serves as one of the foundations for the optimization of stope design in the final stage of the study.

Table 5. Mine operating cost components

Description	Unit	Scenario		
		1	2	3
Supporting				
Mesh Barricade	US$/ton	8.81	4.59	2.26
Anchor, Plate Anchor	US$/ton	8.29	4.31	3.59
Timber/Beam	US$/ton	24.42	12.71	26.31
Blasting				
Drill Accessory	US$/ton	2.47	1.29	0.99
Blast Accessory	US$/ton	12.38	10.69	0.84
Ventilating				
Hose and Air Ducts	US$/ton	1.46	0.76	0.22
Dewatering				
HDPE	US$/ton	2.47	1.29	0.37
Environmental				
Backfilling	US$/ton	1.14	1.12	1.13
Other				
General & Administration	US$/ton	3.53	3.53	3.53

The processing cost was assumed to be the same for each scenario at $10.01 per ton. The uniformity of this cost is due to processing costs being independent of the mining scenarios implemented. In addition to processing costs, another cost with a consistent profile across scenarios is the selling cost. The magnitude of the selling cost is based on the smelting expenses incurred by the company to process semi-finished materials into finished products, specifically gold bars in this case. The cost amount remains the same in each scenario, with a value of $2.68 per ton.

5. Optimum Stope

The stope optimization was performed using the stope optimizer module provided by Micromine [13]. This optimization process involves input data consisting of the ore geological model, technical parameters, and economic parameters of the optimization scenarios. The distinct characteristics among scenarios necessitate separate optimization processes for each scenario. This includes differences in the stope profile of the stopes, adjusted level positions for each stope height, and cost profiles encompassing operating costs, processing costs, and selling costs.

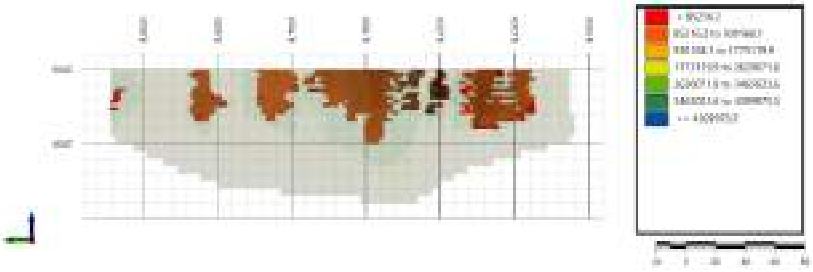
5.1. Stope Optimization Algorithm

The stope optimizer algorithm in Micromine software utilizes two types of algorithms, namely exact and heuristic, which are automatically selected based on the optimization profile chosen by the user. The heuristic algorithm is applied when optimization is restricted to prevent excessively long running times, while the exact algorithm is applied when optimization conditions are unrestricted. Some of the constraints include the achievement percentage of objectives, the number of iterations, and/or the duration of iterations.

In this study, the optimization process employs the exact algorithm, where the optimizer is unrestricted by any numerical constraints that limit optimization time.. The optimization process will terminate once the best value is achieved according to the user-defined input parameters for a given scenario. Resource constraints were implemented along with optimization, limiting only the measured and indicated blocks to be processed as ore material. Another technical constraint implemented was the stope width constraint and the stope length constraint. The preceding section's scenario served as the basis for setting up the width constraint, while practical recommendations guided the establishment of the 20-meter stope length constraint. Since the cut-and-fill method mines the material in slice-type stopes rather than individual box-shaped stopes, this represents the minimum viable stope length.

5.2. Stope Layout and Optimization Result

The optimization conducted for the three scenarios resulted in the distribution of optimal stopes within the ore block model. Figure 2 illustrates the distribution of stopes for each scenario. Generally, the stope layout follows the distribution of the gold and silver grades, as evidenced by the prevalence of stopes in blocks with high grades. Darker green blocks in the block model indicate the higher gold grades, while the stopes color represents their economic value, with blue indicating better economic value compared to red.



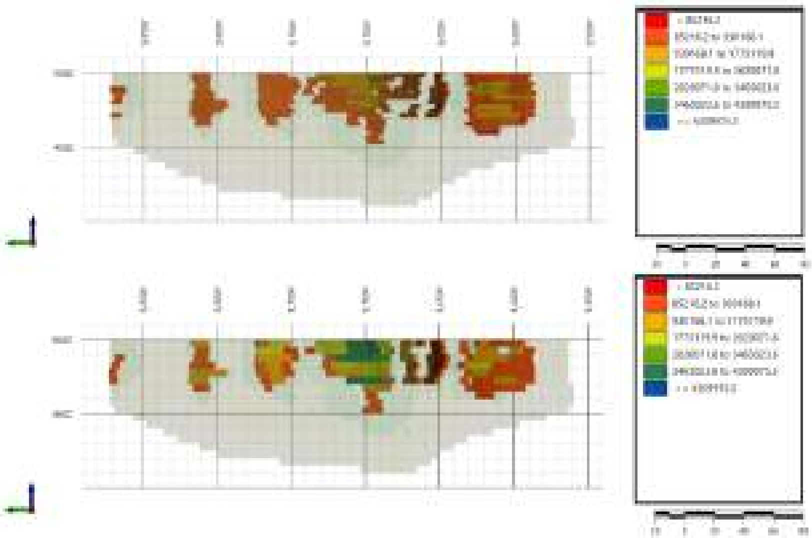


Figure 2. Stope layout for multiple scenarios: scenario 1 (upper); scenario 2 (middle); scenario 3 (lower)

Figure 3 depicts the total tonnage of extracted ore with the average gold and silver grades for various scenarios. It can be observed that scenario 3 has the highest amount of extracted ore, which is directly proportional to the larger opening profile. However, the average grades of the extracted ore remain consistent across the different scenarios. In addition to the quantity of extracted material, scenario 3 also exhibits the highest economic value, as shown in Figure 4. Furthermore, when considering the unit cost, scenario 3 demonstrates the lowest unit cost in terms of both operating cost and total cost. This suggests that the variation in support costs does not significantly impact the overall economic feasibility.

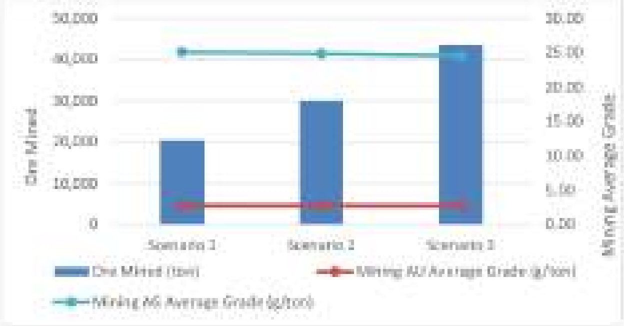


Figure 3. Project ore mined and mining average grades vs mining scenarios

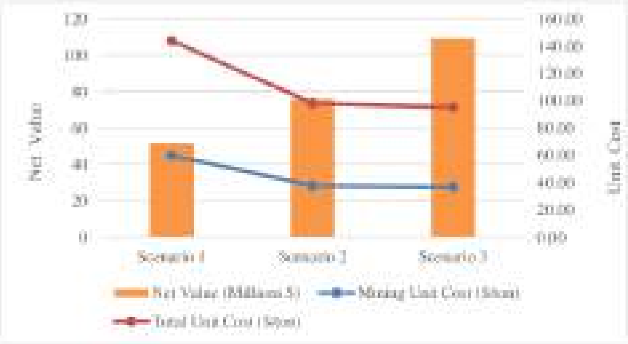


Figure 4. Project net value and unit cost vs mining scenarios

6. Conclusions

Optimization is a process aimed at achieving the best mining scenario based on certain parameters, constraints, and indicators. The commonly used indicators include minimizing mining costs or maximizing the current net present value (NPV). An optimization module is developed within mining software to facilitate this process, allowing for the testing of a larger number of mining scenarios in a short period of time with the hope of finding the most favorable mining scenario. One aspect of mining scenarios is the stope profile, which is closely related to the intensity of support required. This is particularly emphasized in cut-and-fill mining methods, as these methods are typically applied in conditions where the rock mass is less stable, necessitating significant support requirements. However, the current input parameters for the optimization module, which mainly focus on dimension, do not directly consider geomechanical parameters, especially the support requirements, as part of the input. A study has been conducted to examine the interactions between these parameters and their application in underground mining optimization.

Furthermore, the analysis results indicate that larger stope profile have a significant impact on the requirements for both the type and quantity of support, indirectly increasing the support cost by up to $32.2 per ton. However, this increase in support costs is not significant compared to the total production output, as evidenced by the operational cost of $39.24 per ton. The optimization results show that scenario 3 has the best economic value, as indicated by a net value of $109.2 million, despite the need for substantial support to accommodate instability.

Finally, this study indicates production related parameters may have larger impacts on project value than geomechanical direct costs, such as the costs of mine supports. Further research into productivity aspects of geomechanical engineering is critical to better understanding its impact on project value.

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The impact of underground support and mine opening profiles on the economics of underground mining projects

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