A Quick Guide to Developing a Mine Plan[1]

Mehmet Altinpinar (19ma57@queensu.ca)
Julian M. Ortiz (julian.ortiz@queensu.ca)

Abstract

Mining value chain is a series of interdisciplinary processes including prospecting, exploration, development, exploitation, mineral processing and reclamation. Mine planning plays an important role in the mining value chain for both open pit and underground mines starting from the end of the exploration stage and it continues toward the development and exploitation stages. In this paper, a quick guide for a life of mine planning process of open pit mining is provided and a case study is presented using a resource block model that is developed by implementing a synthetic drillhole campaign on a synthetic mineral deposit.

1. Introduction

In general terms, mine planning for an open pit operation starts with a block model and it involves determination of i) Whether a given block in the model should be mined or not; ii) If it is to be mined, when it should be mined; and iii) Once it is mined then how it should be processed (Dagdelen, 2001). Such block model used to be simply a geological model created by including the grades of the minerals to be exploited and processed. The current practices, on the other hand, involve more advanced models that incorporate expert knowledge from different areas like geology, mining, mineral processing, extractive metallurgy, mathematical modeling and computing to improve the use of resources such as ore, water, energy, equipment and labor (Ortiz, 2019).

After a resource block model is developed through exploration studies, three progressive stages of study are performed within the scope of planning (Hustrulid et al., 2013), namely:

1. Conceptual study (Scoping): This is the stage where a project idea is extensively transformed into an investment proposition by using historical data as a reference when making estimations regarding the capital and operation costs and highlighting the major aspects of a possible mining project.
2. Pre-feasibility study: This is an intermediate level study between a relatively inexpensive conceptual study and a relatively expensive feasibility study. It has a higher level of confidence compared to scoping, yet, still not suitable for an investment decision. Objective of the project, ore tonnage and grade, production schedule, capital cost, operating cost and revenue estimates, taxes and financing and cash flow tables are the important sections of a report to be generated at the end of a pre-feasibility study.

[1] Cite as: Altinpinar M, Ortiz JM (2021) A Quick Guide to Developing a Mine Plan, Predictive Geometallurgy and Geostatistics Lab, Queen's University, Annual Report 2021, paper 2021-06, 61-78.

3. Feasibility study: This is the stage in which a definitive technical, environmental and commercial base for an investment decision is provided. In addition to the important sections to be included in a pre-feasibility report, a feasibility report is prepared by including general information regarding the project area, such as topography, climate, population, services, etc., as well as the information about geology, mining, metallurgy, and environmental effects.

Besides resource estimation studies, these three stages of study should be carried out within the framework of a codified set of rules and guidelines such as NI 43-101 (National Instrument for the Standards of Disclosure for Mineral Projects within Canada), JORC (Joint Ore Reserves Committee) Code, SAMREC (South African Code for the Reporting of Mineral Resources and Mineral Reserves), etc., when reporting and disclosing information related to mineral properties. These guidelines do not only constitute instruments for reporting and disclosing purposes but also provide the mining companies with a vision to perform their technical studies in the most efficient and proper way. Some definitions and interpretations used in the following sections of this paper are taken from NI 43-101 (2016) and CIM (2014).

2. Methodology

In this study, a generalized methodology for mine planning is given for an open pit mine for a single commodity (e.g. copper). Different methodologies can be adopted based on project, type and number of commodities, mining method (i.e. open pit or underground), etc. Figure 1 shows the methodology followed in this study.

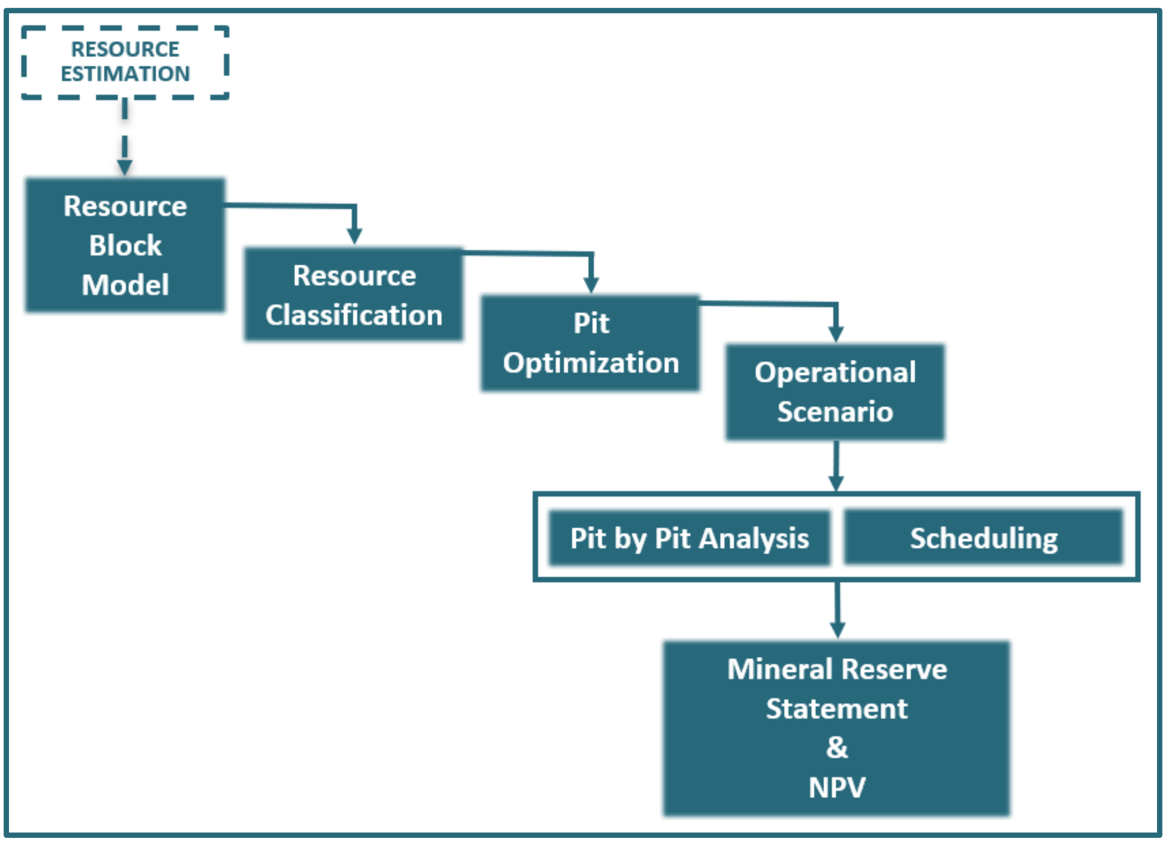

Figure 1 Methodology

2.1. Resource Block Model

A resource block model is obtained by performing resource estimation studies, and it should be validated before continuing with mine planning studies. After it is created and validated accordingly, the block model is now ready for the planning stage and it should, at least, include the parameters shown in Table 1 for the purpose of mine planning studies.

Table 1 Block Model Parameters for Mine Planning Studies

No	Variable	Remarks
1	xCentre	x coordinate of the centre of the block
2	yCentre	y coordinate of the centre of the block
3	zCentre	z coordinate of the centre of the block
4	xDimension	Dimension of the block in the x direction
5	yDimension	Dimension of the block in the y direction
6	zDimension	Dimension of the block in the z direction
7	Volume	Volume of the block
8	Domain	Domain of the block
9	Density	Block density for reporting tonnage.
10	RockCode	To determine if the block is ore, waste or airblock
11	NP	Number of estimation passes to categorize the block for resource classification
12	Grade	Grade of the element to be reported

The block model is typically comprised of several domains, which are basically identified according to the geological setting of the mineral deposit and based on the similarities and differences between the geological features, such as lithology, alteration and mineralization. Different types of rock materials present in a mineral deposit have different types of production (exploitation and excavation) and processing or treatment behaviours. Therefore, the domains in the resource model are categorized, in general, as:

1. Mineralized (ore) domains: The materials coming from these domains are sent to the mineral processing plant to extract the elements of interest.
2. Transition domains: The materials from these domains are either processed in processing plant or they are treated as waste materials. Further metallurgical tests are required to figure out how to treat these domains.
3. Waste domains: The materials coming from these domains are dumped in the waste dump areas within the project site.

2.2. Mineral Resource Classification

The resource block model is categorized based on the geological confidence as well as on the confidence level of the estimation process. There are three categories defined in NI 43-101 (2016) and CIM (2014), namely:

1. **Measured Mineral Resource:** A Measured Mineral Resource is that part of a Mineral Resource for which quantity, grade or quality, densities, shape, and physical characteristics are estimated with confidence sufficient to allow the application of Modifying Factors to support detailed mine planning and final evaluation of the economic viability of the deposit.

Geological evidence is derived from detailed and reliable exploration, sampling and testing and is sufficient to confirm geological and grade or quality continuity between points of observation.

A Measured Mineral Resource has a higher level of confidence than that applying to either an Indicated Mineral Resource or an Inferred Mineral Resource. It may be converted to a Proven Mineral Reserve or to a Probable Mineral Reserve.

Mineralization or other natural material of economic interest may be classified as a Measured Mineral Resource by the Qualified Person when the nature, quality, quantity and distribution of data are such that the tonnage and grade or quality of the mineralization can be estimated to within close limits and that variation from the estimate would not significantly affect potential economic viability of the deposit. This category requires a high level of confidence in, and understanding of, the geology and controls of the mineral deposit.

2. **Indicated Mineral Resource:** An Indicated Mineral Resource is that part of a Mineral Resource for which quantity, grade or quality, densities, shape and physical characteristics are estimated with sufficient confidence to allow the application of Modifying Factors in sufficient detail to support mine planning and evaluation of the economic viability of the deposit.

   Geological evidence is derived from adequately detailed and reliable exploration, sampling and testing and is sufficient to assume geological and grade or quality continuity between points of observation.

   An Indicated Mineral Resource has a lower level of confidence than that applying to a Measured Mineral Resource and may only be converted to a Probable Mineral Reserve.

   Mineralization may be classified as an Indicated Mineral Resource by the Qualified Person when the nature, quality, quantity and distribution of data are such as to allow confident interpretation of the geological framework and to reasonably assume the continuity of mineralization. The Qualified Person must recognize the importance of the Indicated Mineral Resource category to the advancement of the feasibility of the project. An Indicated Mineral Resource estimate is of sufficient quality to support a Pre-Feasibility Study which can serve as the basis for major development decisions.

3. **Inferred Mineral Resource:** An Inferred Mineral Resource is that part of a Mineral Resource for which quantity and grade or quality are estimated on the basis of limited geological evidence and sampling. Geological evidence is sufficient to imply but not verify geological and grade or quality continuity.

   An Inferred Mineral Resource has a lower level of confidence than that applying to an Indicated Mineral Resource and must not be converted to a Mineral Reserve. It is reasonably expected that the majority of Inferred Mineral Resources could be upgraded to Indicated Mineral Resources with continued exploration.

   An Inferred Mineral Resource is based on limited information and sampling gathered through appropriate sampling techniques from locations such as outcrops, trenches, pits, workings and drill holes. Inferred Mineral Resources must not be included in the economic analysis, production schedules, or estimated mine life in publicly disclosed pre-feasibility or feasibility studies, or in the life of mine plans and cash flow models of developed mines.

There are several parameters set during the estimation process and these parameters determine the level of confidence of each estimation pass. Such parameters include search ellipsoid radii, which are basically determined by performing variography analysis on element grade, the angles (i.e. bearing, plunge and dip) determining the positioning of ore body within mineral deposit, number of minimum and maximum samples to be used during each estimation pass, etc. Each estimation pass has a lower level of confidence than the previous pass. The estimation process is typically completed in 3 or 4 passes. Categorizing the estimation results based on the number of estimation pass is one of the ways for resource classification found in technical reports. However, there are better ways to categorize mineral resources according to the geological and geostatistical confidence, for example, the number of samples used to estimate a block grade, the distance between those samples and the estimated block, etc.

2.3. Pit Optimization

After resource classification, the resource block model is transferred to an optimization module or software to perform the pit optimization process. In this study, Geovia WhittleTM (Whittle) was used as the optimization software and the parameters defined in this study are the ones used in Whittle. The optimization is an implementation of the Lersch-Grossmann algorithm.

There are some adjustments made before transferring the resource model to Whittle in order to obtain proper results from the pit optimization process. These adjustments are explained below:

1. **Setting the grades of the blocks in the inferred mineral resource category to zero (0)** in order to ensure that they are excluded during the pit optimization and from mineral reserve statement. Only the measured and indicated mineral resource categories are taken into consideration when developing a production plan.

   This step includes all of the inferred blocks in the waste, transition and ore domains:
   a. Replacing the grades of all blocks in waste domains and transition domains (if they will be treated as waste material based on the results of metallurgical tests) with zero.
   b. Replacing the grades of all non-measured and non-indicated category blocks in ore domains with zero.

2. **Replacing all RockCode values with “6666” for the blocks with a grade value of zero (0)** in order to mark them as waste blocks in Whittle.
3. **Replacing all RockCode values with “5555” for the air blocks*** in the block model in order to mark them as air blocks in Whittle.

* air blocks are the ones above topography

Having completed these adjustments, the block model is now ready to be imported to Whittle for pit optimization. First, the optimization process is carried out by setting the parameters shown in Table 5 in order to generate nested pit shells for several revenue factors ranging from a low value (for example 0.1) to a high value (for example 2.0) with a reasonable step, such as 0.02. Here 0.1 and 2.0 are the coefficients to multiply the long term reference price of the commodity in question. So, it is expected to obtain a pit shell even with the lowest revenue factor, 0.1, and such pit shell would be the starter pit, i.e. where the excavator will be located in the field to start production. The pit shell to be obtained using the revenue factor 1.0 is the one that would be attained with the long term reference price of the commodity. All other pit shells to be created using different revenue factors are generated to account for possible fluctuations in the commodity price in the future and understand the best sequence of extraction, so that the risks and/or benefits associated with the project could be addressed and interpreted.

2.4. Operational Scenario

After completing the optimization process as explained in Section 2.3, a new operational scenario is added in Whittle by using the parameters shown in Table 7 and the pit by pit analysis and scheduling steps are performed.

2.4.1. Pit by Pit Analysis

A pit by pit graph is obtained as a result of the pit by pit analysis in Whittle. It is a bar chart where each bar represents a pit shell corresponding to a revenue factor. Starter pit, pushbacks and ultimate pit shell can be determined by looking at this graph. Ideally, each "jump" observed in this graph is a candidate of a pushback and should be used in different combinations with other pushback candidates when trying to obtain the optimum scheduling scenario using the "best approach" option in Whittle. In some cases, however, it may not be possible to schedule by using the best approach option due to the exposure of significant amount of ore and waste material at a certain point during the mine life. In such cases, the said significant amount of material should be evenly split into a number of pushbacks, which have approximately equal production lives that are reasonable according to the mining and processing capacity of the project.

Ultimate pit limit is another factor when conducting pit optimization process. According to Mwangi et al. (2020) the main idea behind ultimate pit limit (UPL) optimization is the maximization of the total difference between the total cost of mining the valuable minerals and the overlying waste and the value that is obtained from the valuable mineral that will be mined with respect to satisfying all the pit slope stability and operational constraints. Therefore, the ultimate pit limit should be determined by comparing the risk associated with extending the life of mine and thereby increasing the amount of material (both valuable minerals and the overlying waste) to be removed (excavated) with the value to be obtained from the operation. It should be emphasized that the determination of the ultimate pit limit does not account for the time value of money, that is, the undiscounted value of the pit is considered in the optimization. Therefore, the added value of an expansion in the future will not reflect its true present value, considering the discount rate.

2.4.2. Scheduling

After being determined as explained in Section 2.4.1, starter pit, pushbacks and UPL are used as parameters to run the scheduling module of Whittle. The resultant graph and the corresponding spreadsheet show the amount of ore and waste materials to be excavated in each period during the life of mine. Also, open pit cash flow, discounted open pit cash flow and discounted cumulative open pit cash flow are reported in the scheduling output spreadsheet.

2.5. Mineral Reserve Statement and NPV

The starter pit and the pushbacks as well as the ultimate pit shell are transferred back to the mining software (Maptek Vulcan was used in this study) for visualization and reserve calculation studies. The measured and indicated blocks inside the UPL are now labelled as proven and probable reserves, respectively. This is the simplified case of converting resources to reserves. In practice, however, all modifying factors including, but not limited to, mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governmental factors, which are set forth in the CIM Definition Standards for Mineral Resources & Mineral Reserves, should be taken into consideration (Altinpinar, 2021; CIM, 2014).

The net present value of a project can be obtained from the scheduling output spreadsheet generated at the end of scheduling module of Whittle. One could also calculate a project's NPV manually (in MS Excel for example) by using the same parameters shown in Table 7.

3. Case Study

3.1. Resource Block Model

The resource block model used in this study was obtained by performing a synthetic drillhole campaign on a synthetic mineral deposit, which was developed with a high resolution for a porphyry copper deposit (Altinpinar, 2021). The block model parameters are summarized in Table 2 and the domain classification is given in Table 3.

Table 2 Resource Block Model Parameters

No	Parameter	Value
1	# of blocks in the X (easting) direction	200
2	# of blocks in the Y (northing) direction	200
3	# of blocks in the Z (elevation) direction	100
4	Total # of blocks	4,000,000
5	Block dimensions in the X (easting) direction	10
6	Block dimensions in the Y (northing)direction	10
7	Block dimensions in the Z (elevation) direction	10
8	# of domains defined	16
9	# of ore domains	9
10	# of transition domains	2
11	# of waste domains	5
12	Density (fixed density value was used)	2.7 t/m3

Table 3 Domains in the Resource Block Model

Domain	Description	Category
111	Leached (LIX) - All Low Grade	Waste
222	Partially Leached (PLIX) - All Low Grade	Waste
333	Oxide (OX) - All Low Grade	Waste
444	Mixed (MIX) in Quartz (Qz)	Transition
499	Mixed (MIX) – Other	Transition
520	Primary in Sediments	Ore
530	Primary in Porphyries	Ore
532	Primary in Low Grade Porphyry	Ore
540	Primary in Dacite and Andesite	Ore
560	Primary in Hornfel, Skarn, Anhydrite	Ore
566	Primary in Hornfel	Ore
577	Primary in Skarn	Ore
580	Primary in Breccias	Ore
588	Primary Not Altered	Waste
599	Primary in Anhydrite	Ore
888	Host Rock	Waste

3.2. Mineral Resource Classification

The resource block model was categorized based on the estimation passes. In other words, the blocks estimated during the 1st pass were labelled as "Measured" mineral resource, the blocks estimated during the 2nd pass were labelled as "Indicated" mineral resource and the blocks estimated during the 3rd and 4th passes were labelled as "Inferred" mineral resource. The resource categories are summarized in Table 4.

Table 4 Resource classification

Parameter	Unit	Measured	Indicated	Inferred from the Mineralized Domains		Inferred from the Waste & Transition Domains	Inferred Overall
		NP_1	NP_2	NP_3	NP_4		
# blocks	count	306,487	148,450	123,298	264,537	2,683,821	3,071,656
Total Volume	m^3	306,487,000	148,450,000	123,298,000	264,537,000	2,683,821,000	3,071,656,000
Total Tonnage	t	827,514,900	400,815,000	332,904,600	714,249,900	7,246,316,700	8,293,471,200
Average Cu Grade	%	0.495	0.491	0.479		0.073	0.124
Total Cu	t	4,096,199	1,968,002	5,015,870		5,289,811	10,283,904

3.3. Pit Optimization

After resource classification was completed and the adjustments listed in Section 2.3 were made, the block model was imported to Whittle and pit optimization was performed by using the parameters shown in Table 5. Before the pit optimization process, the block model was reblocked in Whittle from 4 million blocks to 500 thousand block for ease of processing.

For the purpose of this case study, several combinations were tried for the range of revenue factor values and the corresponding pit by pit analyses were checked accordingly. Finally, the range from 0.1 to 0.52 with a step size of 0.005 was adopted as it generated the best alternative for the nested pit shells and also it was the best range option addressing the significant amount of ore and waste material exposed in year 4.2. The results of pit optimization process are shown in Table 6.

Table 5 Parameters for the pit optimization

Parameter	Unit	Value	Remarks
Slope	deg	45	Overall pit slope
Mining cost	$/t	2.75	Based on the industrial references
Mining recovery fraction	%	90	10% of the ore material will not be recovered during the production
Dilution	%	10	10% of the waste material will be sent to the processing plant
Processing cost	$/t	8	Based on the industrial references
Process recovery	%	85	Copper froth flotation recovery
Selling price	$/t	9750	LME – simply the current price was used
Selling cost	$/t	100	Including selling cost, insurance, freight
Revenue factors	-	0.1 to 0.52	Using 85 fixed factors with a step size of 0.005

Table 6 Generated pit shells

Pit	Minimum Revenue Factor	Maximum Revenue Factor	Rock Tones	Ore Tones	Strip Ratio	Max Bench	Min Bench	Cu Units	Cu Grade
1	0.34	0.345	10800	5346	1.02	44	43	2673	0.4999
2	0.35	0.355	27000	10692	1.53	44	43	5811	0.5435
3	0.36	0.37	129600	45441	1.85	45	42	25368	0.5583
4	0.375	0.375	276936300	91662517	2.02	48	25	49985506	0.5453
5	0.38	0.38	277068600	91943182	2.01	48	25	50071160	0.5446
6	0.385	0.385	291816000	99056035	1.95	48	24	53248638	0.5376
7	0.39	0.39	292607100	99459658	1.94	48	24	53421829	0.5371
8	0.395	0.395	310702500	107232742	1.9	48	24	56958453	0.5312
9	0.4	0.4	1280952900	463439398	1.76	48	10	229248172	0.4947
10	0.405	0.405	1294520400	468408506	1.76	48	10	231615624	0.4945
11	0.41	0.41	1321128900	478830533	1.76	48	10	236372364	0.4936
12	0.415	0.415	1345221000	488071094	1.76	48	10	240573258	0.4929
13	0.42	0.42	1468627200	520919591	1.82	49	9	258444841	0.4961
14	0.425	0.425	1496461500	530507642	1.82	49	9	262926543	0.4956
15	0.43	0.43	1534204800	542463971	1.83	49	8	268707117	0.4953
16	0.435	0.435	1547426700	548168153	1.82	49	8	271051757	0.4945
17	0.44	0.44	1564852500	555823625	1.82	49	8	274140416	0.4932
18	0.445	0.445	1578066300	561498404	1.81	49	8	276422454	0.4923
19	0.45	0.45	1630413900	580492743	1.81	49	8	284581087	0.4902
20	0.455	0.455	1645091100	586234347	1.81	49	8	286934404	0.4895
21	0.46	0.46	1654865100	590799831	1.8	49	8	288640431	0.4886
22	0.465	0.465	1665365400	595472235	1.8	49	8	290405259	0.4877
23	0.47	0.47	1701502200	607027614	1.8	49	8	295468453	0.4867
24	0.475	0.475	1718069400	612892176	1.8	49	8	297881050	0.486
25	0.48	0.48	1725075900	615575868	1.8	49	8	298935655	0.4856
26	0.485	0.485	1739553300	621207879	1.8	49	8	301104903	0.4847
27	0.49	0.49	1774890900	630993732	1.81	49	7	305540167	0.4842
28	0.495	0.495	1819268100	643201323	1.83	49	7	311039542	0.4836
29	0.5	0.5	1832814000	647753442	1.83	49	7	312859124	0.483
30	0.505	0.505	1883150100	663836883	1.84	49	7	319400841	0.4811
31	0.51	0.51	1902482100	670372368	1.84	49	7	321965508	0.4803
32	0.515	0.515	1917691200	675357514	1.84	49	7	323931481	0.4796
33	0.52	0.52	1931585400	679949728	1.84	49	7	325714262	0.479

3.4. Operational Scenario

After completing the pit optimization step, a new operational scenario was added using the parameters shown in Table 7 and pit by pit analysis and scheduling steps were run.

Table 7 Parameters for operational scenario

Initial capital cost	M$		500	Initial investment for the project
Terminal value	M$		50	Assets to be sold at the end of the project
Discount rate per period	%		10	The rate used in Discounted Cash Flow Analysis
Mining limit	Mt	Year 1	30	Annual open pit production capacity was assumed to be low during the first three years of the operation with an increasing rate and eventually reaching the full capacity at the fourth year.
		Year 2	60	
		Year 3	90	
		Year 4-18	120	
Processing limit	Mt		80	Annual processing plant capacity (based on the stripping ratio)
Mining cost adjustment factor	-	None		Adjustment factor was not applied
Processing cost adjustment factor	-	None		Adjustment factor was not applied

3.4.1. Pit by Pit Analysis

The results of the pit by pit analysis are shown in Table 8 and in Figure 2 as a graph.

Table 8 Results of the pit by pit analysis

Final pit	Open pit cashflow best disc ($)	Open pit cashflow specified disc ($)	Open pit cashflow worst disc ($)	Ore Input best (tonne)	Waste best (tonne)	Mine life years best	Mine life years specified	Mine life years worst	IRR best %	IRR specified %	IRR worst %
1	-449,854,976	-449,854,976	-449,854,976	5,346	5,454	0.0	0.0	0.0	0.0	0.0	0.0
2	-449,687,427	-449,687,427	-449,687,427	10,692	16,308	0.0	0.0	0.0	0.0	0.0	0.0
3	-448,660,277	-448,660,277	-448,660,277	45,441	84,159	0.0	0.0	0.0	0.0	0.0	0.0
4	1,321,835,117	1,321,723,265	1,321,723,265	93,343,833	183,592,467	3.9	3.9	3.9	48.9	48.8	48.8
5	1,322,944,917	1,322,958,987	1,322,958,987	93,440,061	183,628,539	3.9	3.9	3.9	48.9	48.9	48.9
6	1,419,722,843	1,415,707,788	1,415,707,788	100,574,298	191,241,702	4.0	4.0	4.0	50.8	50.0	50.0
7	1,424,545,976	1,420,245,209	1,420,245,209	100,846,944	191,760,156	4.0	4.0	4.0	50.8	50.0	50.0
8	1,544,174,588	1,532,655,196	1,532,655,196	108,721,601	201,980,899	4.2	4.2	4.2	52.4	50.1	50.1
9	4,372,395,169	3,466,108,146	3,466,108,146	495,357,685	785,595,215	12.9	13.0	13.0	53.6	28.8	28.8
10	4,399,537,802	3,462,636,363	3,462,636,363	499,303,033	795,217,367	12.9	13.1	13.1	53.6	28.6	28.6
11	4,459,663,124	3,472,658,482	3,472,658,482	508,693,282	812,435,618	13.1	13.3	13.3	53.6	28.2	28.2
12	4,513,496,779	3,481,083,449	3,481,083,449	517,033,042	828,187,958	13.2	13.5	13.5	53.7	27.9	27.9
13	4,726,216,184	3,407,245,975	3,407,245,975	549,306,843	919,320,357	14.3	14.4	14.4	53.7	26.1	26.1
14	4,773,594,194	3,387,226,300	3,387,226,300	557,986,074	938,475,426	14.5	14.7	14.7	53.8	25.7	25.7
15	4,832,006,744	3,364,501,391	3,364,501,391	569,298,210	964,906,590	14.8	15.0	15.0	53.8	25.3	25.3
16	4,853,321,420	3,362,941,916	3,362,941,916	574,109,610	973,317,090	14.9	15.1	15.1	53.8	25.2	25.2
17	4,883,526,547	3,360,953,090	3,360,953,090	581,021,988	983,830,512	15.1	15.2	15.2	53.8	25.0	25.0
18	4,905,460,918	3,360,465,255	3,360,465,255	585,710,430	992,355,870	15.2	15.3	15.3	53.8	24.9	24.9
19	4,985,845,794	3,328,612,470	3,328,612,470	604,325,202	1,026,088,698	15.6	15.8	15.8	53.8	24.3	24.3
20	5,005,432,691	3,318,632,797	3,318,632,797	608,954,838	1,036,136,262	15.7	15.9	15.9	53.8	24.2	24.2
21	5,018,816,787	3,306,180,874	3,306,180,874	612,475,179	1,042,389,921	15.8	16.0	16.0	53.8	24.1	24.1

Table 8 (continued)

22	5,032,512,917	3,297,718,479	3,297,718,479	616,201,341	1,049,164,059	15.9	16.1	16.1	53.8	24.0	24.0
23	5,076,523,492	3,265,071,050	3,265,071,050	626,917,398	1,074,584,802	16.2	16.4	16.4	53.8	23.6	23.6
24	5,096,475,507	3,249,369,884	3,249,369,884	632,049,558	1,086,019,842	16.4	16.5	16.5	53.8	23.4	23.4
25	5,104,039,026	3,239,385,058	3,239,385,058	633,901,947	1,091,173,953	16.4	16.5	16.5	53.8	23.3	23.3
26	5,121,227,528	3,225,145,789	3,225,145,789	638,972,628	1,100,580,672	16.5	16.7	16.7	53.9	23.2	23.2
27	5,154,872,808	3,182,157,563	3,182,157,563	648,023,406	1,126,867,494	16.8	16.9	16.9	53.9	22.8	22.8
28	5,196,279,800	3,122,062,345	3,122,062,345	659,707,089	1,159,561,011	17.2	17.3	17.3	53.9	22.3	22.3
29	5,209,276,496	3,104,521,979	3,104,521,979	663,708,570	1,169,105,430	17.3	17.4	17.4	53.9	22.2	22.2
30	5,255,794,518	3,045,152,821	3,045,152,821	679,628,958	1,203,521,142	17.7	17.8	17.8	53.9	21.8	21.8
31	5,272,292,903	3,015,841,770	3,015,841,770	685,651,227	1,216,830,873	17.9	18.0	18.0	53.9	21.6	21.6
32	5,284,296,033	2,996,149,103	2,996,149,103	690,042,966	1,227,648,234	18.0	18.1	18.1	53.9	21.4	21.4
33	5,296,073,784	2,977,502,943	2,977,502,943	694,119,291	1,237,466,109	18.1	18.2	18.2	53.9	21.3	21.3

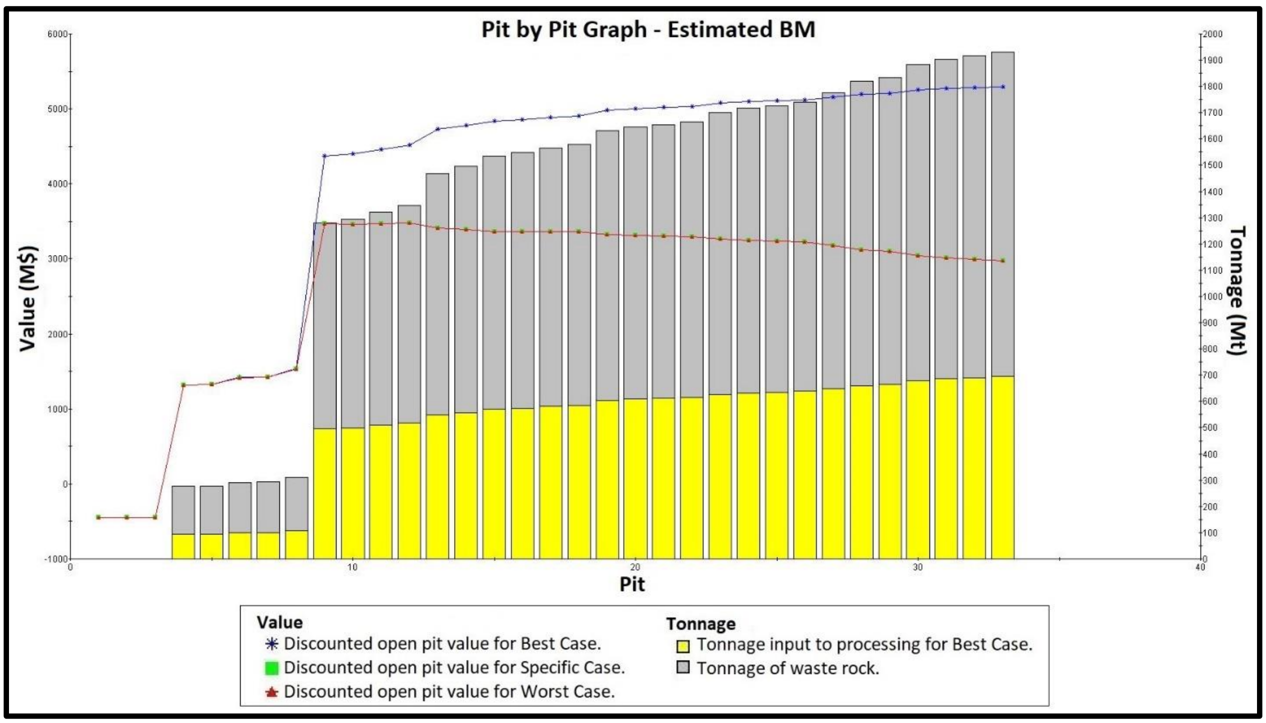

Figure 2 Pit by pit graph

As seen in Figure 2, a big jump in reserve at the 9th pit shell, which corresponds approximately to the fourth year of the operation, is obtained even with a slight increase in revenue factor and a significant amount of material (ore and waste) is exposed. This means that the scheduling after that period is not sensitive to the direction of mining and basically, similar materials are being accessed for a long period of time. Therefore, the life of mine was manually divided into periods that are close to each other as shown in Table 9 and the 33rd pit shell was selected as the ultimate pit limit.

Table 9 Pushbacks

Pushback	Period (Year)	Pit Shell
1	The first 4 years	Pit 8
2	The next 5 years	Halfway through Pit 9
3	The next 4 years	Until the end of Pit 9
4	Until the end of LOM (18 years)	Pit 33 (UPL)

3.4.2. Scheduling

The scheduling step was run using Whittle's Milawa NPV option, which aims at maximizing the net present value of the project. The scheduling graph and the scheduling outputs are given in Figure 3 and Table 10, respectively.

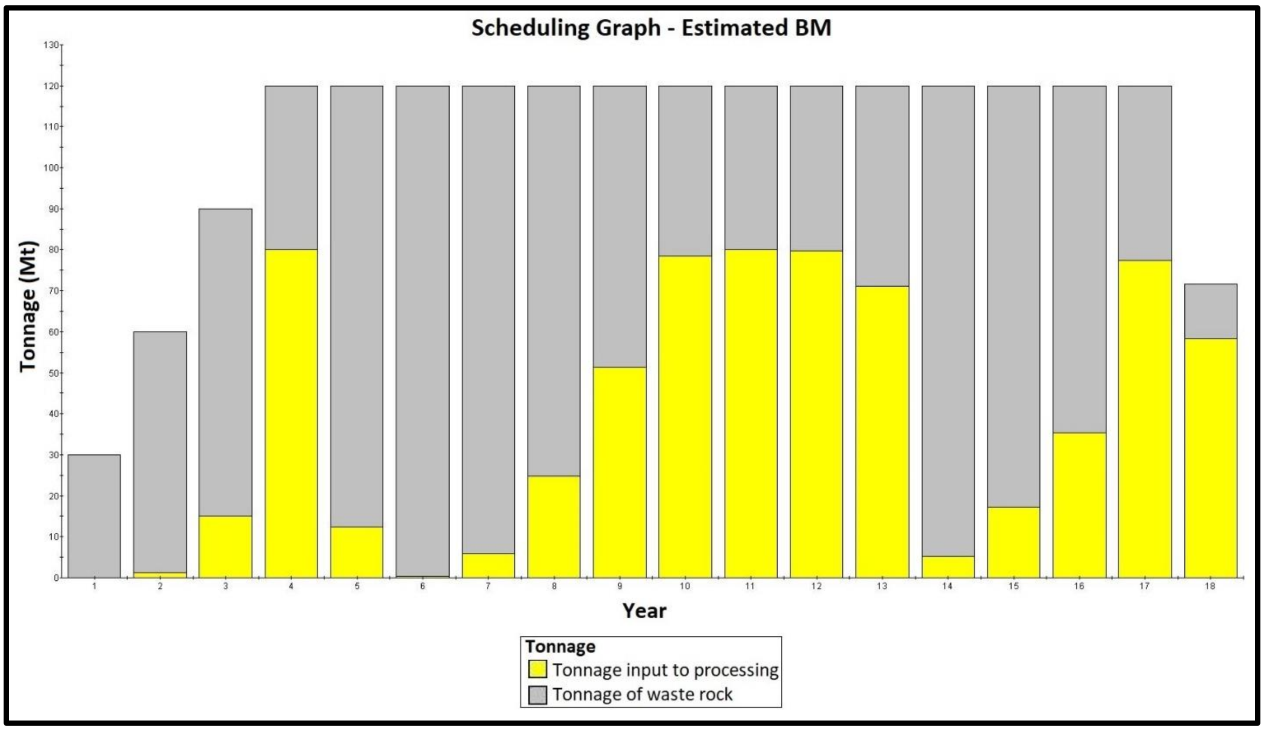

Figure 3 Scheduling graph

The pushbacks as well as the UPL were then transferred back to Maptek Vulcan to visualize the progress of the open pit operation as shown in Figure 4.

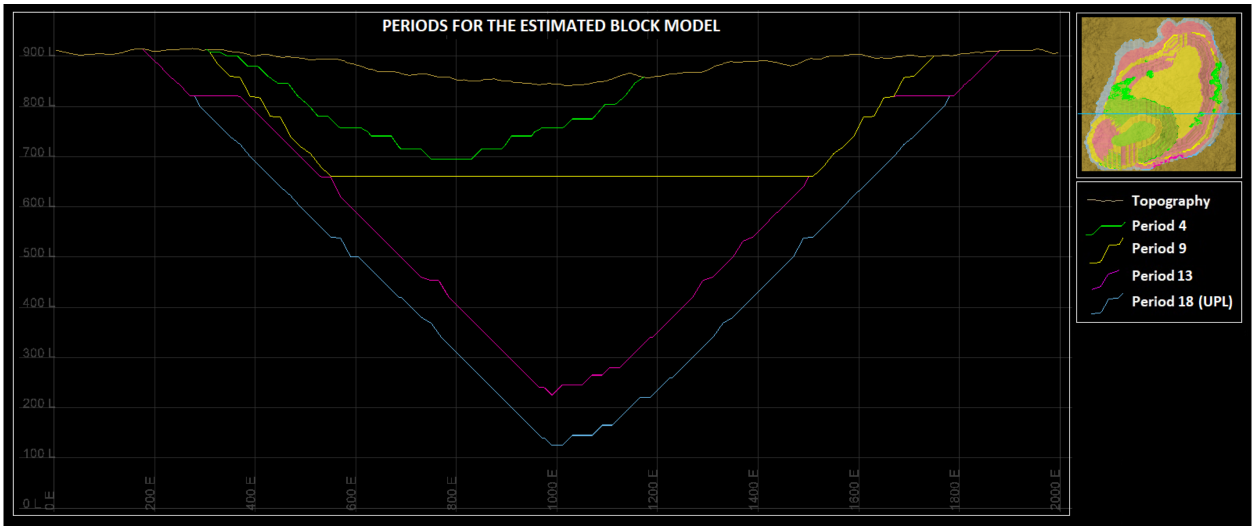

Figure 4 Progress of the open pit operation

Table 10 Scheduling outputs and net present value of the project

Period (year)	Tonne Input (kt)	Waste Tonne (kt)	Strip Ratio	Grade Input Cu (%)	Open Pit Cashflow (M$)	Open Pit Cashflow Discounted (M$)	Open Pit Cumulative Cashflow Discounted (M$)
1	8	29,992	999.99	0.5496	-82	-75	-75
2	1,209	58,791	48.64	0.4697	-128	-106	-181
3	15,085	74,915	4.97	0.4039	132	99	-82
4	80,000	40,000	0.5	0.5284	2,497	1,706	1,624
5	12,420	107,580	8.66	0.6732	256	159	1,783
6	345	119,655	347	0.4476	-320	-181	1,603
7	5,895	114,105	19.36	0.3713	-198	-101	1,501
8	24,847	95,153	3.83	0.3831	252	118	1,619
9	51,338	68,662	1.34	0.4085	980	415	2,034
10	78,515	41,485	0.53	0.4252	1,780	686	2,721
11	79,996	40,004	0.5	0.4221	1,799	631	3,351
12	79,768	40,232	0.5	0.5578	2,682	854	4,206
13	71,090	48,910	0.69	0.506	2,052	594	4,800
14	5,239	114,761	21.91	0.3258	-232	-61	4,739
15	17,305	102,695	5.93	0.3873	81	19	4,758
16	35,360	84,640	2.39	0.5208	898	195	4,954
17	77,410	42,590	0.55	0.4324	1,797	355	5,309
18	58,291	13,295	0.23	0.512	1,835	339	5,648
			Total		16,081	5,648	5,648

3.5. Mineral Reserve Statement and NPV

As shown in Table 10, the discounted net present value of the project was calculated by Whittle as US$ 5,648M. In Whittle, different options (e.g. Milawa Balanced, which aims at establishing a balance between the open pit production rate and the capacity of the mineral processing plant) can be selected based on the mine planning strategy of the project and different NPV values can be obtained.

After completing the pit optimization and scheduling process in Whittle, the UPL was imported to Maptek Vulcan to carry out mineral reserve calculations. The measured and indicated blocks inside the UPL were labelled as proven and probable reserves, respectively. The results are given in Table 11 for the case without a threshold and in Table 12 for the case where a threshold of Cu grade greater than and equal to 0.15% was applied. Figure 5 shows the proven and probable blocks within the UPL for the case with a threshold of Cu ≥ 0.15%.

Table 11 Mineral reserve statement (without a threshold)

Domain	PROVEN RESERVE				PROBABLE RESERVE				TOTAL PROVEN & PROBABLE			
	# of Blocks	Ore (kt)	Mean Grade Cu %	Metal Content (kt)	# of Blocks	Ore (kt)	Mean Grade Cu %	Metal Content (kt)	# of Blocks	Ore (kt)	Mean Grade Cu %	Metal Content (kt)
520	172,347	465,337	0.488	2,270.84	32,645	88,142	0.514	453.05	204,992	553,478	0.492	2,723.89
530	5,700	15,390	0.454	69.87	1,023	2,762	0.415	11.46	6,723	18,152	0.448	81.33
532	1,918	5,179	0.759	39.31	1,901	5,133	0.709	36.39	3,819	10,311	0.734	75.70
540	8,172	22,064	0.408	90.02	3,478	9,391	0.461	43.29	11,650	31,455	0.424	133.31
560	728	1,966	0.648	12.74	561	1,515	0.647	9.80	1,289	3,480	0.648	22.54
566	16,128	43,546	0.888	386.68	6,384	17,237	0.749	129.10	22,512	60,782	0.849	515.79
577	1,315	3,551	0.318	11.29	28	76	0.317	0.24	1,343	3,626	0.318	11.53
580	723	1,952	0.365	7.13	176	475	0.366	1.74	899	2,427	0.365	8.86
599	4,614	12,458	0.345	42.98	93	251	0.307	0.77	4,707	12,709	0.344	43.75
Total	211,645	571,442	0.513	2,930.86	46,289	124,980	0.549	685.85	257,934	696,422	0.519	3,616.71

Table 12 Mineral reserve statement with a threshold (Cu grade ≥ 0.15%)

Domain	PROVEN RESERVE				PROBABLE RESERVE				TOTAL PROVEN & PROBABLE			
	# of Blocks	Ore (kt)	Mean Grade Cu %	Metal Content (kt)	# of Blocks	Ore (kt)	Mean Grade Cu %	Metal Content (kt)	# of Blocks	Ore (kt)	Mean Grade Cu %	Metal Content (kt)
520	170,785	461,120	0.491	2,264.10	32,492	87,728	0.516	452.68	203,277	548,848	0.495	2,716.78
530	5,700	15,390	0.454	69.87	1,023	2,762	0.415	11.46	6,723	18,152	0.448	81.33
532	1,918	5,179	0.759	39.31	1,899	5,127	0.710	36.40	3,817	10,306	0.735	75.71
540	8,172	22,064	0.408	90.02	3,478	9,391	0.461	43.29	11,650	31,455	0.424	133.31
560	728	1,966	0.648	12.74	561	1,515	0.647	9.80	1,289	3,480	0.648	22.54
566	16,127	43,543	0.888	386.66	6,384	17,237	0.749	129.10	22,511	60,780	0.849	515.76
577	1,315	3,551	0.318	11.29	28	76	0.317	0.24	1,343	3,626	0.318	11.53
580	723	1,952	0.365	7.13	176	475	0.366	1.74	899	2,427	0.365	8.86
599	4,613	12,455	0.345	42.97	93	251	0.307	0.77	4,706	12,706	0.344	43.74
Total	210,081	567,219	0.516	2,924.08	46,134	124,562	0.550	685.49	256,215	691,781	0.522	3,609.57

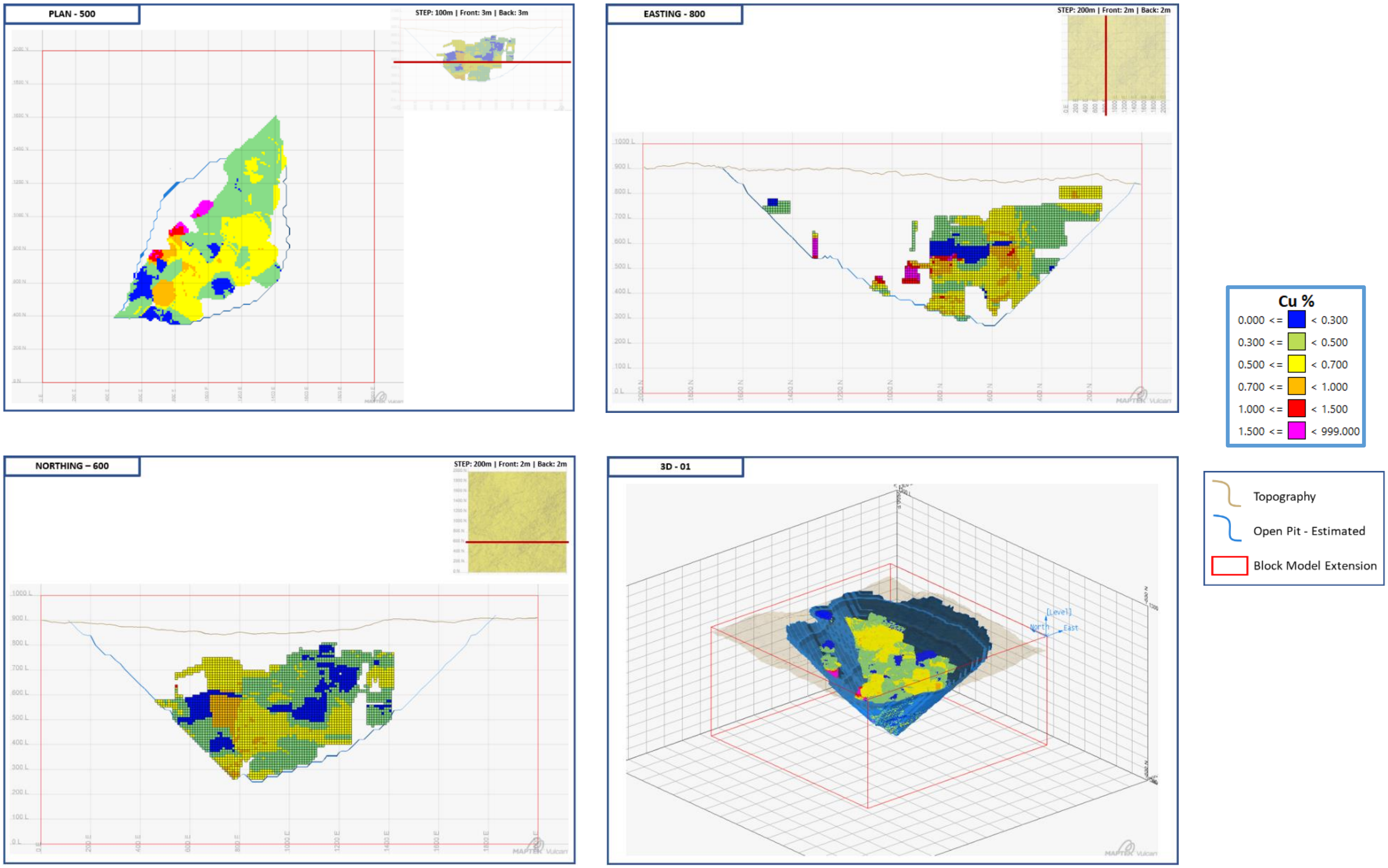

Figure 5 Proven and probable blocks within the open pit (Cu grade ≥ 0.15%)

4. Conclusions

Mine planning is one of the most important operational steps in achieving strategic objectives of a mining project. The entire mine planning process should be intently conducted with a very high level of detail and accuracy as there are already many uncertainties about the mining value chain. In this paper, the process of mine planning was outlined with a quick guide, which includes the steps for pit optimization, scheduling and mineral reserve statement. With the help of a case study, the methodology was applied on a block model, which was obtained through resource estimation studies performed by using a synthetic mineral deposit, and it was explained how the involved parameters can be used during the performance of mine planning.

The stages presented include the selection of the ultimate pit limit, which results from the application of the Lersch-Grossmann algorithm and uses undiscounted value. The selection of the ultimate pit limit should consider the risk of extending the life of the mine additional years, versus the value added by the additional ore. The time value of money reduces the present value of future resources, therefore, typically the ultimate pit limit is not the one that maximizes the undiscounted value. Once the UPL is selected, the pushbacks need to be determined, which provide the direction in which the pit evolves over time. These pushbacks should be large enough to contain several years of production and should be large so the pit can be expanded from one phase to the next with enough space to create working benches safely. Finally, the yearly schedule must account for a sustained ore feed to the processing plant, while maintaining a relatively steady stripping ratio, to facilitate the operation. Different optimization approaches are available for this purpose.

5. References

Altinpinar M (2021). Synthetic High Resolution Block Model For Benchmarking Mining Technologies. M.A.Sc. Thesis, Queens's University, Kingston.

CIM (2014). Definition Standards for Mineral Resources & Mineral Reserves.

Collins SE, Holbek P, Strickland D (2018). NI 43-101 Technical Report for the Copper Mountain Mine.

Dagdelen K (2001). Open Pit Optimization - Strategies for Improving Economics of Mining Projects Through Mine Planning, 17th International Mining Congress and Exhibition of Turkey – IMCET 2001, ISBN 975-395-417-4.

Hustrulid W, Kuchta M, Martin R (2013). Open Pit Mine Planning and Design, 3rd Edition.

Moore CM, Miranda HM, Hampton AP, Ritchie DG (2019). Lundin Mining Corporation. Technical Report on the Chapada Mine, Goiás State, Brazil.

Mwangi AD, Jianhua Z, Gang H, Kasomo RM, Innocent MM (2020). Ultimate Pit Limit Optimization Methods in Open Pit Mines: A Review. J Min Sci 56, 588–602. https://doi.org/10.1134/S1062739120046885

National Instrument 43-101 (2016). Standards of Disclosure for Mineral Projects.

Ortiz JM (2019). Geometallurgical modeling framework, Predictive Geometallurgy and Geostatistics Lab, Queen's University, Annual Report 2019, paper 2019-01, 6-16.

SRK Consulting (2020). NI 43-101 Technical Report, Feasibility Study for the Josemaria Copper-Gold Project, San Juan Province, Argentina.