Open Pit Mine Scheduling – A Case Study at Bogoso Gold Limited

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Key words:

SUMMARY

The main objective of this paper is to describe the process of mine scheduling as is being practiced At Bogoso Gold Limited in its mine planning activities.

The Bogoso area has a long and chequered mining history of both open pit and underground workings.

Open pit mining operations recommenced in 1990 to the present. Bogoso Gold Limited has moved from the exclusive use of mathematical models (excel spreadsheet) in its scheduling programs to a more sophisticated graphic-based method of scheduling – Minesched.

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1. WHAT IS SCHEDULING?

Scheduling may be defined as the allocation of available resources to activities over time in a manner to meet corporate objectives. According to RG Schroeder (2000) it is the final and most constrained decision in the hierarchy of mine planning decisions.

There is however no universal scheduling method for all situations. One scheduling method may not necessarily satisfy the requirements of another mine due to several reasons both tangible and intangible. Thus, the choice of a scheduling method/software should be dictated by the nature of the operation and its sophistication.

Bogoso Gold Limited have moved from the use of mathematical models (excel spreadsheet) to a more sophisticated graphical and spreadsheet methods of scheduling as their operations have become more complex and the use of only spreadsheets may be risky as one cannot determine which portion within the flitch is being mined.

The above criteria have guided Bogoso Gold Limited to adopt Minesched as its current scheduling tool.

Its benefits are follows:
- It operates in familiar environments as
  - Microsoft excel
  - Microsoft project interface
  - 3D viewing, validation and animation
- Process is user controlled
- Priority and sequencing rules are easy to set
- Shortfalls or risks are brought to the fore for resolution.

Though it has no financial modeling tool, it can be customized to achieve the relevant financial results/report.

There is no doubt that a mine scheduling exercise that is painstakingly done will bring to the fore the strengths, weaknesses and risks involved in executing that plan. Consequently it will offer a window for remedial measures prior to its adoption as a working plan.

Scheduling is required in both short-term and long-term production planning though they differ in sophistication. While the former is necessary for the function of an operating mine, the latter is usually done for feasibility or budget studies.

A practical question that confronts the planning engineer in scheduling is
"*how would I schedule this pit if I were the mine superintendent responsible for making it work"?*

Couzens (1979) has proposed the following five planning/scheduling "commandments" to guide the planning engineer in answering this question:

1.1 What is to be done?

This requires a clear definition of the objectives of a particular scheduling exercise. For instance a planning engineer may produce a one-year budget schedule with emphasis on the production of a particular type of ore for processing for that financial year. It must be cautioned that we are dealing with estimates of grade, projections of geology and guesses about economics as such there must be openness to change by all parties involved either actively or passively in the scheduling process.

1.2 When?

The time frame for executing the plan/schedule must be clearly specified. Since volumes must be moved in time to realize production goals, the productive use of time will determine efficiency and cost-effectiveness of the schedule.

1.3 By Whom?

Responsibilities as to who does what must be clearly defined devoid of any ambiguities. This calls for effective communication among all the key players. If the plan or schedule is not clear to those who must make decisions and to those who must execute the plans, then the plans/schedules stand a good chance of being misunderstood or ignored.

1.4 What Resources are Required?

Plans remain a mere paper work unless resources are allocated for their execution. This requires the allocation of equipment type and quantity and the quantum of manpower required for the equipment.

1.5 Cash Flow and Management Decisions

Every plan must have the blessing of management prior to its implementation. However, for such a decision to be made, knowledge of the cash-flow position is required.

2. MINESCHED FEATURES

Minesched is a mining scheduler for both surface and underground mining operations. It has been developed in 1999 by the Surpac Minex Group (SMG). Its versatility is due to the fact that it uses existing and proven technology where appropriate – Microsoft Excel is an integral

tool in minesched while it also has live, two-way communication with Microsoft Project, giving users the option to present and further refine their schedules.

One powerful feature of minesched is its ability to automatically create the graphical output that shows where mining has taken place for each scheduling time period, in the form of a three-dimensional solid. The polygons carry their associated tonnage and grade data as attributes allowing for easy map generation of the schedules. The mining sequence can be shown animated on-screen.

Reports in minesched are generated with production tonnage and grade data output for each time period. These reports can be presented in Microsoft Excel and their formats are flexible and user-defined. Templates are generally created so that report quality tables and graphs directly linked to the Minesched raw results can be studied and printed immediately upon completion of the Minesched scheduling run.

Minesched has no in-built financial modeling tool but can be customized to give cash-flow reports.

Minesched consists of a series of worksheets in Microsoft Excel. These worksheets constitute the '' engine room '' of the program and its output is depended on the quality of completing these worksheets. These worksheets include:

- Time Parameter Worksheet
- Block Model Parameter Worksheet
- Mining Location Worksheet
- Production Parameter Worksheet
- Report Definition Worksheet

2.1 Time Parameters

The time parameters sheet is where you define your scheduling start date, scheduling period length details, date and time formats, and holiday details. The time parameters sheet is used by both the production and development schedulers.

#	Time Parameters		Save Menu	Calendar
	Date and Time Formats	**Input**	**Report Output**	**Graphical Output**
	Date	dd/mm/yyyy	dd Month yyyy	dd-Mon-yyyy
	Time		HH:MM:SS	HH:MM
	Weekday		full name (Sunday)	short name (Sun)
	Order		Day Date Time	Date
	Scheduling Start Date	date 01/01/2001		
	Weekly Holidays	Sunday		
	Duration			
	Monthly Holidays	15		
	Duration	2		
	Annual Holidays	date 24/12/2001 12:00		
	Duration	7.5		
	One-Time Holidays			
	Duration			
		Number of Periods	**Time Units**	**Number of time units in one period**
	Scheduling Periods	3	days	
	Scheduling Periods	4	weeks	
	Scheduling Periods	23	months	
	...	3	years	

Choose day, date and time order from list

Figure 1.0: Time Parameter Sheet

2.2 Scheduling Periods

The user has complete flexibility in defining scheduling period lengths. The period length is specified by choosing the time units and the number of time units in a single scheduling period. You also choose the number of periods of this length that you wish to schedule for.Units go down to seconds, giving the user total flexibility.

Different scheduling period lengths can be scheduled on simply by choosing additional scheduling period lengths in successive rows. All of the periods specified in the first row will be scheduled and then all of the periods in the next row, and so on. For example, you may report weekly results for a few weeks, followed by monthly results, then quarterly results (see illustration in figure 1.0).

Example: to report quarterly (3 month) results for 2 years, the number of periods are 8, the time units are months and the number of time units in one period is 3. (8 months 3)

2.3 Block Model Parameters

The block model parameters sheet is where you enter information about the resource models you are scheduling from. Resource models are usually block models, however they can also be string models.(see illustration in figure 1.1)

Block Model Parameters | Save Menu | File Browser | Show Help

	Model 1	Model 2	Model 3
Model User Defined Name	LT		
Model File Name	..\Model\plant_north.mdl		
Material Attribute Name	ms_material		
Y Minimum	9775		
X Minimum	12200		
Z Minimum	4690		
Y Maximum	11950		
X Maximum	13200		
Z Maximum	5206		
Y Mining Block Size	12.5		
X Mining Block Size	6.25		
Specific Gravity Attribute Name or Value	sg		
Volume Adjustment Factor Attribute Name (optional)			
Production Factor #1 Attribute Code (optional)			
Production Factor #2 Attribute Code (optional)			

Material Definition				Attribute Definition								Model 2	Model 3
Description	Value	Calculate Grades?	MS Project?	Attribute Codes	Weight By	Report	Decimal Places	Graphics Output?	Project Output?	Project Field	Attribute Names	Attribute Names	Attribute Names
wst	0	Yes	No	W_OX_TON	Mass	Aggregate		yes	No		wc_ox_perc		
ox	1	Yes	No	W_TRANS_TON	Mass	Aggregate		yes	No		wc_trans_perc		
trans	2	Yes	No	W_SULF_TON	Mass	Aggregate		yes	No		wc_sulf_perc		
sulf	3	Yes	No	O_OX_TON	Mass	Aggregate		yes	No		oc_ox_perc		
				O_OX_AU	Mass	Aggregate		yes	No		oc_ox_cont		
				O_TRANS_TON	Mass	Aggregate		yes	No		oc_trans_perc		
				O_TRANS_AU	Mass	Aggregate		yes	No		oc_trans_cont		
				O_SULF_TON	Mass	Aggregate		yes	No		oc_sulf_perc		
				O_SULF_AU	Mass	Aggregate		yes	No		oc_sulf_cont		
				O_SPOIL_TON	Mass	Aggregate		yes	No		oc_spoil_perc		
				O_SPOIL_AU	Mass	Aggregate		yes	No		oc_spoil_cont		

Figure1.1: Block model Sheet

2.4 Mining Locations

The mining locations sheet is for defining *where* mining takes place.
Essentially a mining location is simply a group of blocks to mine. If this group of blocks comes from a block model, you can think of your location as simply a block model

constraint. We assign this group of blocks a name, which is the mining location name. In the locations sheet we also specify how we are going to mine this group of blocks. This may be by horizontal slices (benches) or by vertical cookie-cuts (polygons). We also specify our direction of mining. So think of the mining locations sheet as defining where and how you are going to mine, but nothing to do with when or at what rate you are going to mine.

LOCATION SHEET

Mining Locations — Save Menu — File Browser — Show Help

Location Name	Location Number	Prepare Model?	Mining Method	Block Model	Mining Direction	First Mid-Bench	Last Mid-Bench	Bench Height	String File Location	String File ID	String Range	String Name D field	Use Block Partial Percenta	Partial or Partial Polygon Constraint	Precisio	Not?	Operato	Constraint 1 Constraint Type	Location	ID
OZ_north	1	yes	benches	LT	south	5076	4920	3									INSIDE	CONSTRAINT	..\Model\lt_ore.con	
WZ_north	2	yes	benches	LT	south	5076	4920	3									INSIDE	CONSTRAINT	..\Model\lt_wz.con	
HW_north	3	yes	benches	LT	south	5076	4920	3									INSIDE	CONSTRAINT	..\Model\lt_hw.con	
OZ_south	4	yes	benches	LT	south	5076	4920	3									INSIDE	CONSTRAINT	..\Model\lt_ore.con	
WZ_south	5	yes	benches	LT	south	5076	4920	3									INSIDE	CONSTRAINT	..\Model\lt_wz.con	
HW_south	6	yes	benches	LT	south	5076	4920	3									INSIDE	CONSTRAINT	..\Model\lt_hw.con	
OZ_main	7	yes	benches	LT	south	5076	4920	3									INSIDE	CONSTRAINT	..\Model\lt_ore.con	
WZ_main	8	yes	benches	LT	south	5076	4920	3									INSIDE	CONSTRAINT	..\Model\lt_wz.con	
HW_main	9	yes	benches	LT	south	5076	4920	3									INSIDE	CONSTRAINT	..\Model\lt_hw.con	

Figure1.3: Mining Location Sheet

2.5 The Use of Constraints in Surpac

One of the very powerful features of Surpac Block Modelling is the ability to apply constraints. Constraints are the logical combinations of spatial operators and objects and may be used to control the selection of blocks from which information may be retrieved and/or into which interpolations may be made.

Constraints may be as simple or as complex as you like, and are most commonly used when:

- Filling the Block Model with values
- Producing Reports
- Viewing models in Graphics.
- Loading a constrained portion of a model

The choice of spatial operators you have are:

- ABOVE
- INSIDE
- >
- <
- =

The operator you will use will depend on the nature of your objects. In order to reduce the number of spatial operators , the word `NOT' is used to imply the opposite of an operation. For example, OUTSIDE would be represented by the expression NOT INSIDE.

The choice of objects you have are:

- Surpac Vision Digital Terrain Model (DTM)
- Surpac Vision Solid Model (3DM)

- Surpac Vision String
- Y , X and Z Planes
- Oblique Plane (specified by an equation)
- Block value

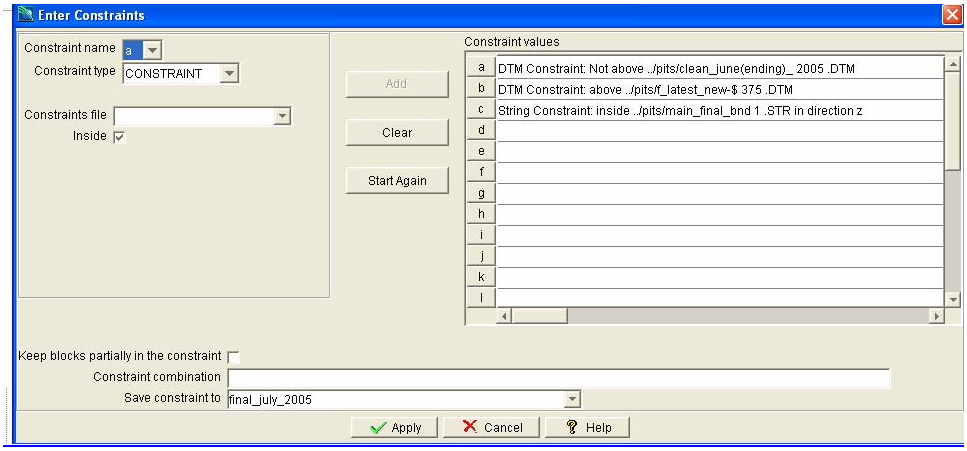


Figure1.4: Typical Constraint Table

3. PRODUCTION PARAMETERS

3.1 Introduction

The production parameters sheet is the main "working" sheet in MineSched. This is where you will spend most of your time refining your schedules.
The typical layout of the production parameters sheet is as shown in figure 1.5.

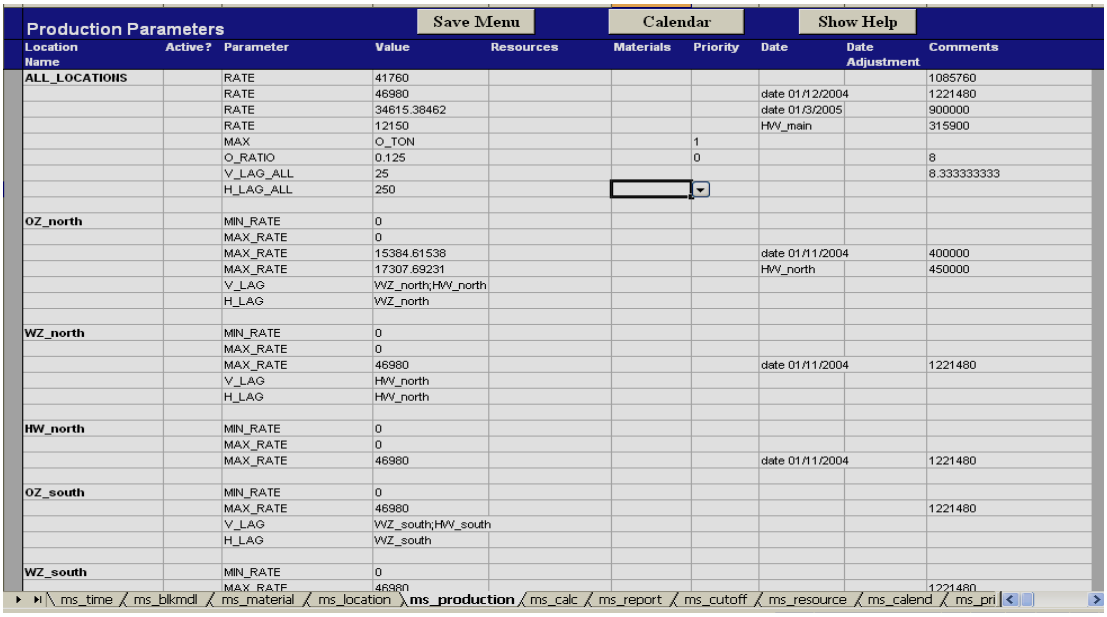


Figure 1.5: Production Parameter WorkSheet

Some Salient Production Definitions

MAX_RATE is defined as a daily rate. If you only know your production rate as a monthly or annual rate, this is where the benefit of having mathematical formulas within the user interface is evident. Enter the monthly rate in the comments column to the right. Then in the value column reference the cell containing the annual or monthly rate with an appropriate formula that converts this to a daily rate. For example this might be = K26 * 12 / 365 to convert a monthly rate to a daily rate.

V_LAG_ALL refers to vertical lag in all directions. Vertical lags determine when a block in the bench below becomes available for mining. It is called a "vertical" lag because block availability is controlled by the blocks on the bench vertically above.

H_LAG_ALL- Horizontal lags are similar to vertical lags in that they control when a block becomes available for mining. Vertical lags control when blocks in the bench vertically below the block being mined become available. Horizontal lags control when blocks on the same bench as the block being mined become available. They are called "horizontal" lags because they are between blocks on the same horizontal plane.

DESTINATION:It is used to specify the destination for the material that is mined

MAX_ACTIVE_BENCH : Mining can only occur from this many benches in the location at one time. Mining will not start on a new bench until one of the active benches has been completed (or the value for this setting changes). When mining starts in a location, if you have more benches with blocks available than your maximum number of active benches mining will start on the uppermost benches.

RATIO: The RATIO parameter is used in target scheduling to specify a material ratio target with ALL_LOCATIONS or with a DML that contains multiple materials.

DML- A stockpile is an example of a DML. Dynamic mining locations are called "dynamic" because they can have material added to them as well as removed.

SML-Static mining locations are fixed and can only have material removed from them. In the example above 'PIT' is a static mining location and the stockpile is a dynamic mining locations.

The production sheet is used to define when mining takes place from a location and at what rate. The production sheet is also where you define your targets. Production parameters can be specific to mining locations. Production parameters can also change at any time. The production parameter can change at an exact date and time or when a bench or polygon or static mining location finishes.

MineSched is run in two steps.
Step 1 prepares block models for scheduling.
Step 2 schedules.

The production parameters sheet is not used to “Prepare Model”, it is only used in “Schedule”. Therefore production parameters may be changed and “Schedule” can be immediately run again. “Prepare Model” does not have to be re-run. MineSched has been designed in this way so that the effects of different production scenarios can be quickly and efficiently studied and re-run.

3.2 Report Definition

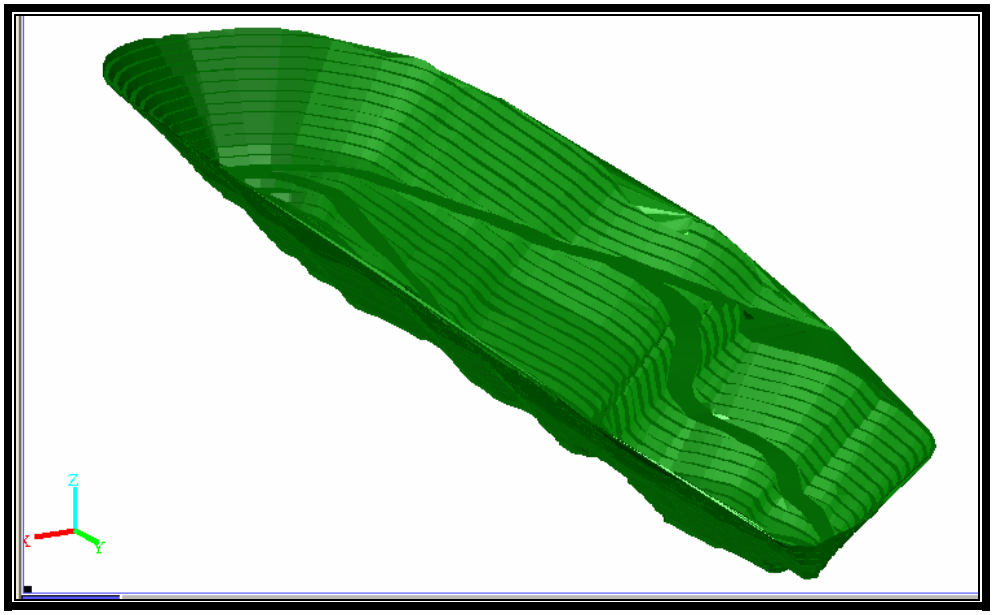
This sheet is where you define your custom reports. Reporting has always been a strength of MineSched because of its flexibility. Volume, mass, attribute and user calculation results can be reported for any combination of materials and any combination of locations. New in Version 4, ancillary activity quantities can also be reported. (see illustration in figure 1.6) This sheet gives you the flexibility to define exactly what is to be reported. You have complete control over the data that appears in the report and the order that it is reported. Period dates can be aligned along either rows or columns. Blank rows or columns can be inserted anywhere in the report. Row and column headings are completely under user control. Scale factors exist to factor the results.
Any number of reports can be generated in a single scheduling run. You can predefine a number of reports and then choose which reports to create when scheduling.
The output report format is a CSV file. This allows it to be brought into any number of downstream programs. The most common of course is Microsoft Excel. Although CSV files are simple text files and store no formatting information, this is not an issue because MineSched provides a function to open a number of CSV files at one time with corresponding XLS files. An XLS file that links to the CSV can be quickly and easily created in Excel. You then have all of Excels very powerful formatting, charting and presentation tools at your disposal to present the scheduling report data however you wish. Once a XLS template has been created, you never look at the raw CSV report again.

Report Definition	Save Menu	File Browser	Show Help					
Report Number	1							
Name of Output CSV File	pt_sched_results_by_row							
Period or Polygon Report	period							
Periods by Row or Column	row							
Title on Row	1							
Date on Row	2							
Start on Row	4							
Number of Title Lines	4							
Separators after Titles	1							
Separators after Dates	0							
Total?	yes							
Separators before Total	0							
Global Location Filter | Individual or Combined	*	COMBINED						
Specific Location Filter								
Code to Report	W_OX_TON	W_TRANS_TON	W_SULF_TON	O_OX_TON	O_TRANS_TON	O_SULF_TON	O_SPOIL_TON	O_CAL_T
Mining Materials or Activity Resources								
Removed/Balance/Added								
Title	All areas	All areas	All areas	All areas	All areas	All areas	All areas	All areas
Title	Oxide Wst	Transitional Wst	Sulfide Wst	Oxide Ore	Transitional Ore	Sulfide Ore	Spoil	Calcine
Title	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
Title	(t)	(t)	(t)	(t)	(t)	(t)	(t)	(t)
Factor								
Order								
Number of Separators			1					
Report Number	2							
Name of Output CSV File	_sched_locations_by_row							
Period or Polygon Report	period							
Periods by Row or Column	row							
Title on Row	1							
Date on Row	2							
Start on Row	4							
Number of Title Lines	4							
Separators after Titles	1							
Separators after Dates	0							
Total?	yes							

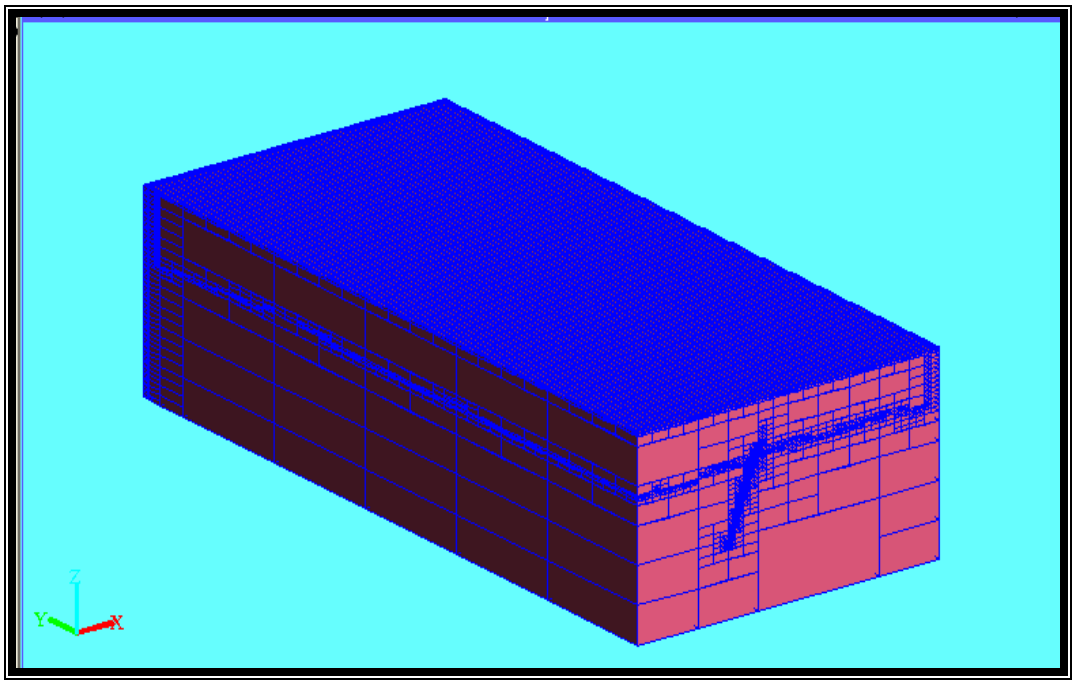
Figure 1.6: Report Definition Sheet

A CASE STUDY OF THE PLANT NORTH PIT OF BOGOSO GOLD LIMITED

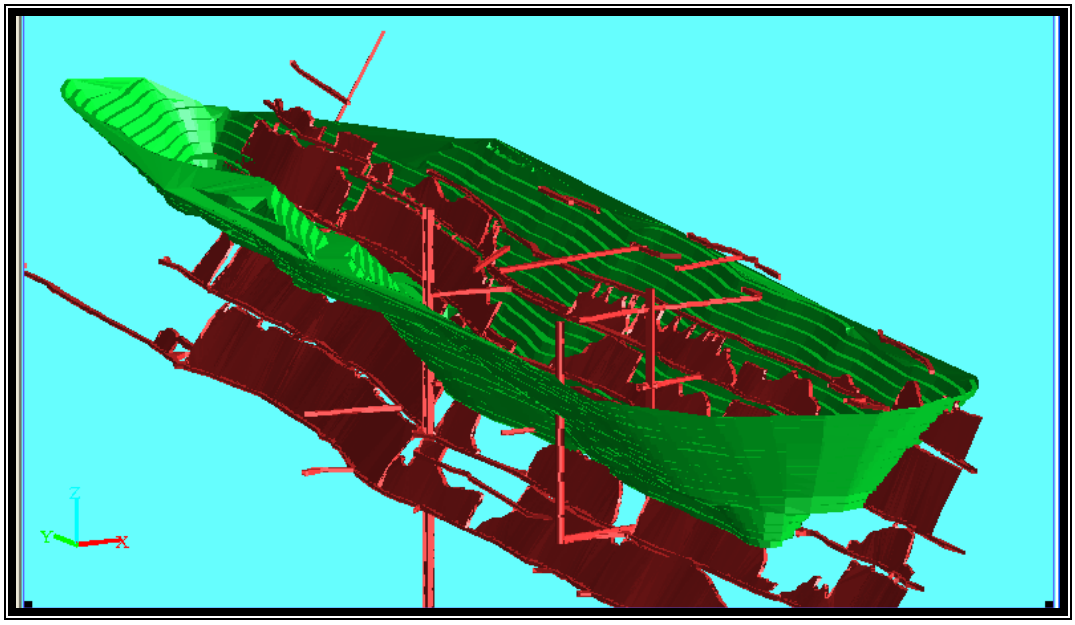
Pictorial View Of The Plant North Pit Of Bogoso Gold Ltd



Plant North Design Pit



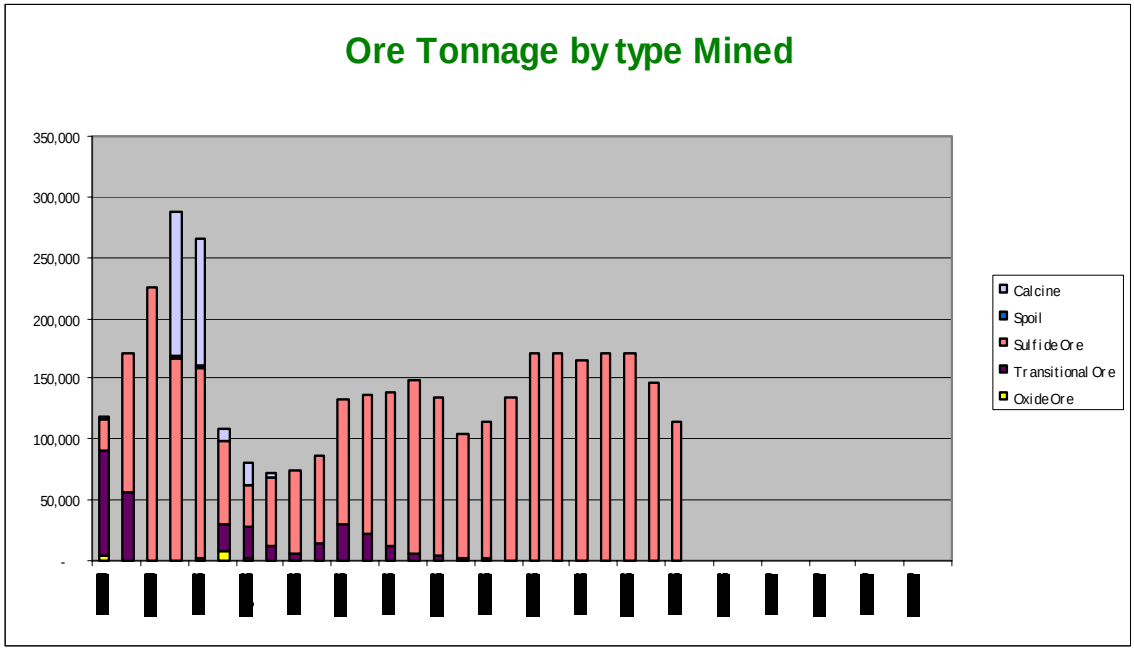
Block Model Of The Plant North Pit

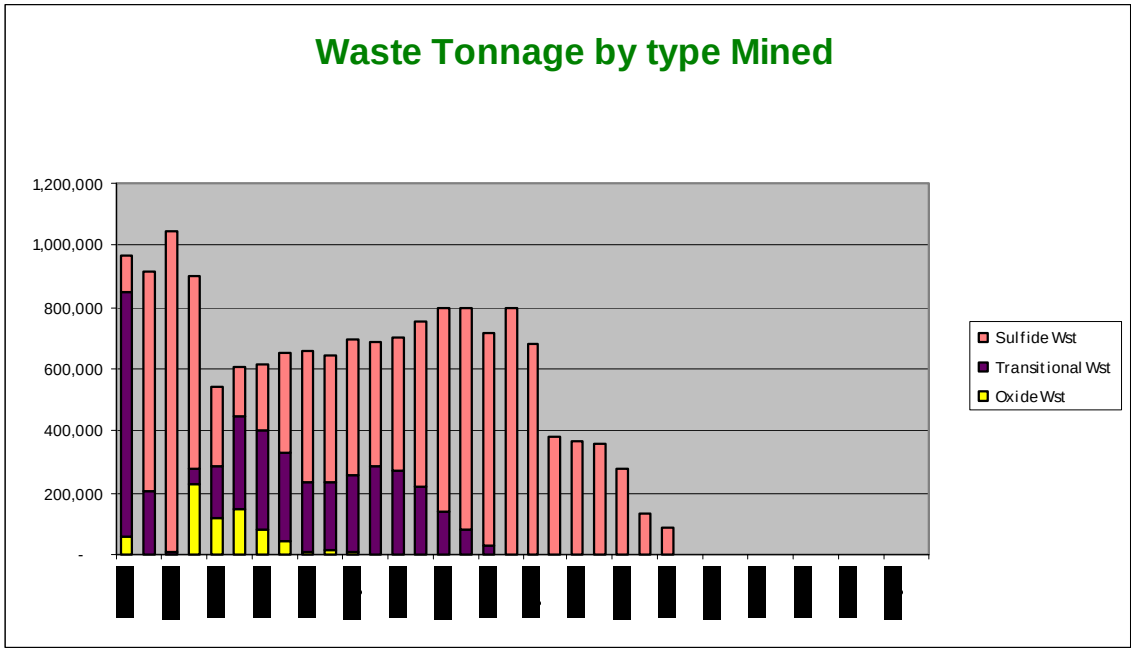


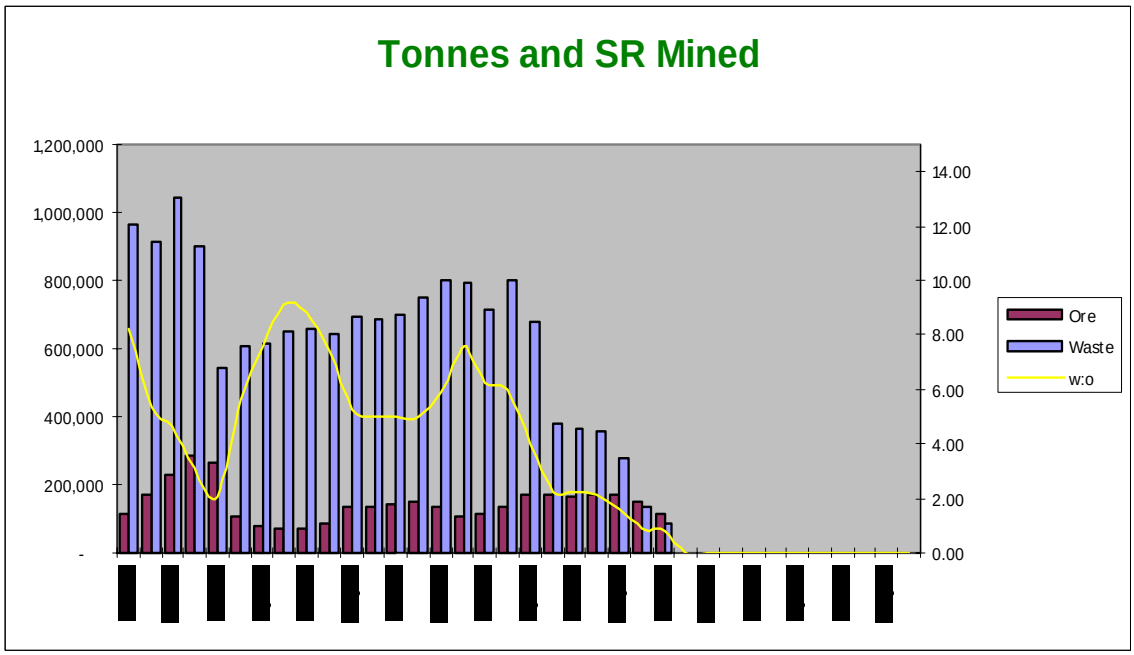
Underground Workings Within The Open Pit

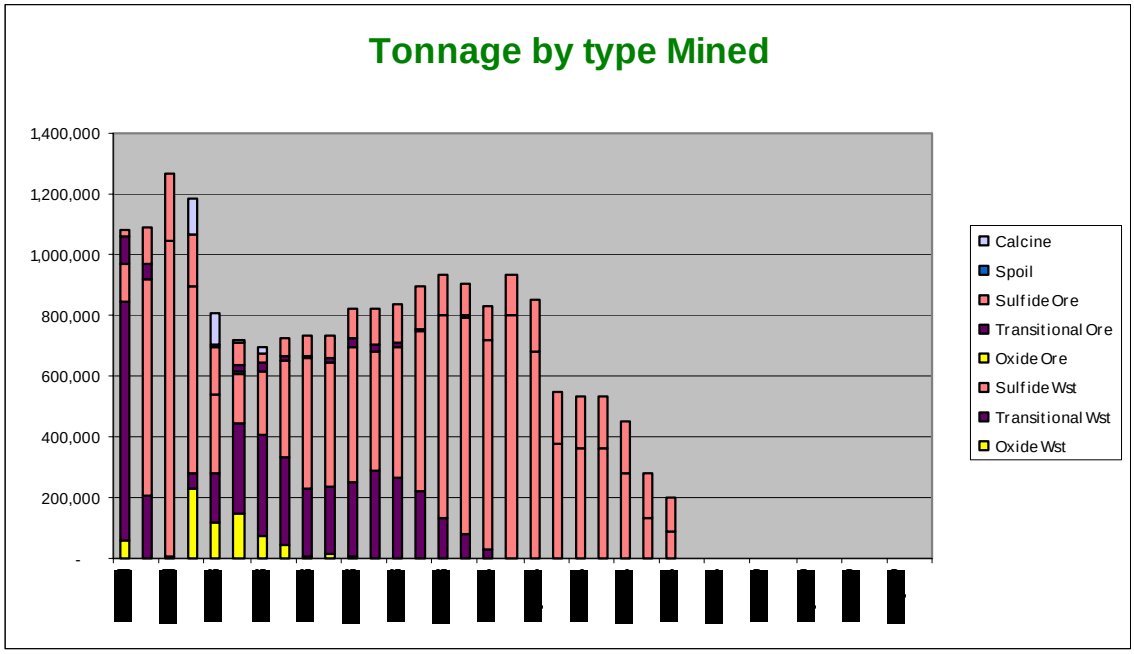
Quantitative Data Output Report

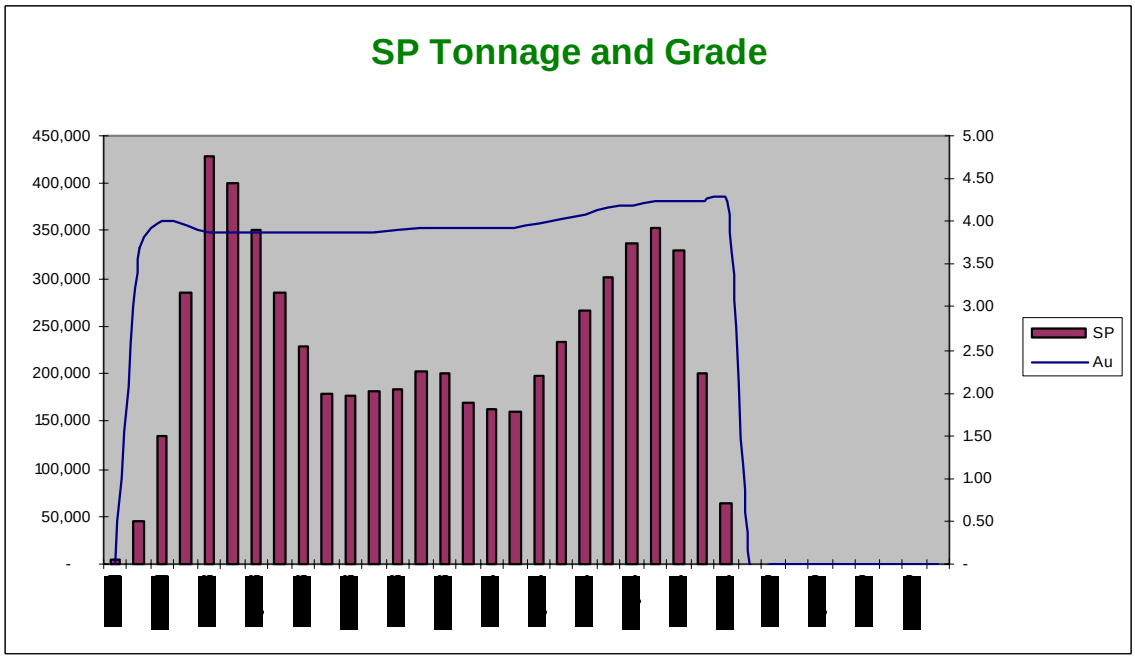
	Period Start	All areas Total Tonnes (t)	All areas Waste Tonnes (t)	All areas Ore Tonnes (t)	All areas Ore grade (g/t)	All areas SR w:o	All areas Oxide Wst Tonnes (t)	All areas Transitiona Tonnes (t)	All areas Sulfide Wst Tonnes (t)	All areas Oxide Ore Tonnes (t)	All areas Transitiona Tonnes (t)	All areas Sulfide Ore Tonnes (t)	All areas Spoil Tonnes (t)	All areas Calcine Tonnes (t)	All areas Oxide Or Au (g/t)	All areas Transition Au (g/t)
1	Oct-04	1,084,942	923,465	161,477	3.94	5.72	56,317	755,696	111,452	4,453	128,040	27,856	-	1,128	2.05	3.
2	Nov-04	1,086,342	950,207	136,135	3.89	6.98	1,681	237,675	710,850	-	15,026	121,009	-	100		4.
3	Dec-04	1,269,149	1,032,577	236,572	4.28	4.36	-	4,641	1,027,936	-	-	236,572	-	-		
4	Jan-05	1,222,295	930,303	291,991	3.98	3.19	193,070	34,010	703,224	131	-	184,243	2,803	104,814	1.80	
5	Feb-05	851,583	567,423	284,159	3.73	2.00	140,231	175,365	251,828	2,247	-	163,838	2,708	115,366	1.88	
6	Mar-05	579,024	545,140	33,884	3.41	16.09	148,826	298,494	97,820	2,946	6,359	15,580	64	8,935	1.88	2.
7	Apr-05	574,243	548,304	25,939	1.97	21.14	86,511	317,555	144,239	1,137	4,118	-	-	20,683	2.03	1.
8	May-05	589,808	586,631	3,177	1.92	184.66	34,129	275,384	277,118	800	2,109	-	-	268	1.79	1.
9	Jun-05	598,936	595,365	3,571	2.16	166.72	7,570	225,880	361,914	-	1,540	2,031	-	-		2.
10	Jul-05	621,479	606,094	15,385	2.65	39.40	12,023	248,806	345,264	-	10,523	4,862	-	-		2.
11	Aug-05	669,387	645,406	23,982	3.11	26.91	891	306,516	337,999	-	9,404	14,578	-	-		2.
12	Sep-05	662,063	642,167	19,897	3.09	32.28	891	275,264	366,012	-	5,395	14,502	-	-		2.
13	Oct-05	677,943	655,418	22,526	3.14	29.10	-	254,102	401,316	-	2,410	20,116	-	-		2.
14	Nov-05	774,909	752,740	22,169	3.19	33.95	-	132,960	619,780	-	886	21,283	-	-		1.
15	Dec-05	907,746	880,067	27,679	3.25	31.80	-	85,204	794,863	-	1,390	26,289	-	-		1.
16	Jan-06	906,183	864,895	41,288	3.02	20.95	-	20,794	844,101	-	862	40,426	-	-		1.
17	Feb-06	836,505	791,395	45,111	2.87	17.54	-	-	791,395	-	-	45,111	-	-		
18	Mar-06	940,923	805,161	135,762	3.33	5.93	13,227	62,507	729,427	5,678	37,355	90,090	-	2,638	3.80	3.
19	Apr-06	439,268	328,054	111,214	3.78	2.95	1,428	65,763	260,863	353	32,721	78,139	-	-	3.78	3.
20	May-06	290,898	191,119	99,779	4.59	1.92	-	28,679	162,440	-	12,056	87,724	-	-		3.
21	Jun-06	280,156	165,741	114,415	4.80	1.45	-	4,633	161,108	-	11,867	102,547	-	-		4.
22	Jul-06	280,169	146,528	133,641	4.56	1.10	-	676	145,852	-	6,027	127,614	-	-		3.
23	Aug-06	290,941	147,728	143,213	4.50	1.03	-	4,894	142,834	-	4,903	138,310	-	-		3.
24	Sep-06	280,151	140,919	139,232	4.58	1.01	-	15,623	125,296	-	3,971	135,262	-	-		2.
25	Oct-06	280,161	140,189	139,972	4.54	1.00	-	9,759	130,430	-	3,131	136,840	-	-		2.
26	Nov-06	280,167	143,543	136,623	4.51	1.05	-	7,031	136,512	-	1,734	134,889	-	-		3.
27	Dec-06	280,175	140,703	139,472	4.51	1.01	-	2,414	138,289	-	164	139,308	-	-		4.
28	Jan-07	290,955	146,575	144,380	4.52	1.02	-	-	146,575	-	-	144,380	-	-		
29	Feb-07	258,626	128,226	130,400	4.56	0.98	-	-	128,226	-	-	130,400	-	-		
30	Mar-07	290,955	143,671	147,284	4.78	0.98	-	-	143,671	-	-	147,284	-	-		
31	Apr-07	269,403	134,880	134,522	4.92	1.00	-	-	134,880	-	-	134,522	-	-		
32	May-07	290,955	143,296	147,659	4.81	0.97	-	-	143,296	-	-	147,659	-	-		
33	Jun-07	280,179	132,574	147,605	4.93	0.90	-	-	132,574	-	-	147,605	-	-		
34	Jul-07	182,362	78,828	103,534	4.48	0.76	-	-	78,828	-	-	103,534	-	-		
35	Aug-07	-	-	-			-	-	-	-	-	-	-	-		
36	Sep-07	-	-	-			-	-	-	-	-	-	-	-		
	Totals	19,418,980	15,775,330	3,643,650	4.23	4.33	696,794	3,850,325	11,228,211	17,747	301,994	3,064,402	5,576	253,932	2.58	3.4

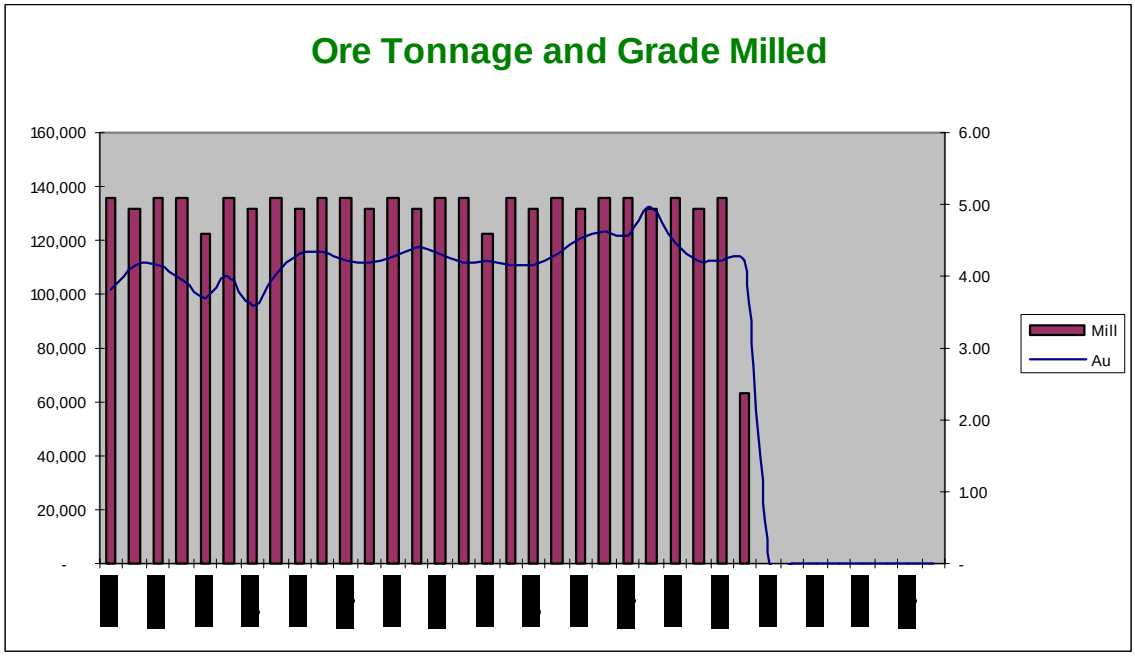



Waste Tonnage by type Mined
1,200,000
1,000,000
800,000
600,000
400,000
200,000
-
Sulfide Wst
Transitional Wst
Oxide Wst

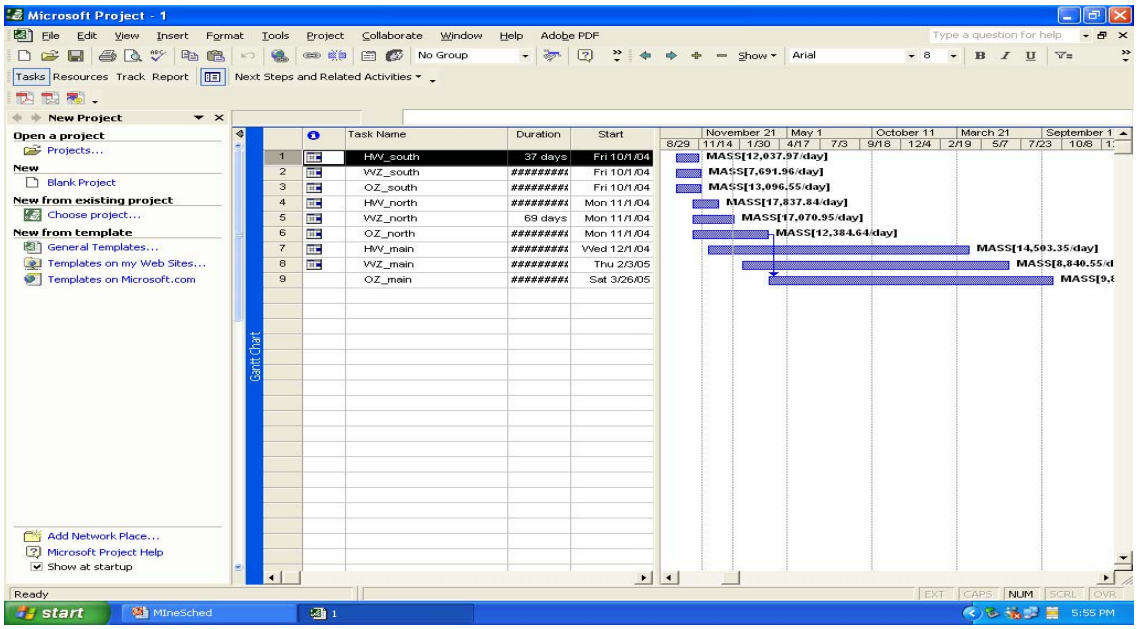

Tonnes and SR Mined
1,200,000
1,000,000
800,000
600,000
400,000
200,000
-
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Ore
Waste
w:o

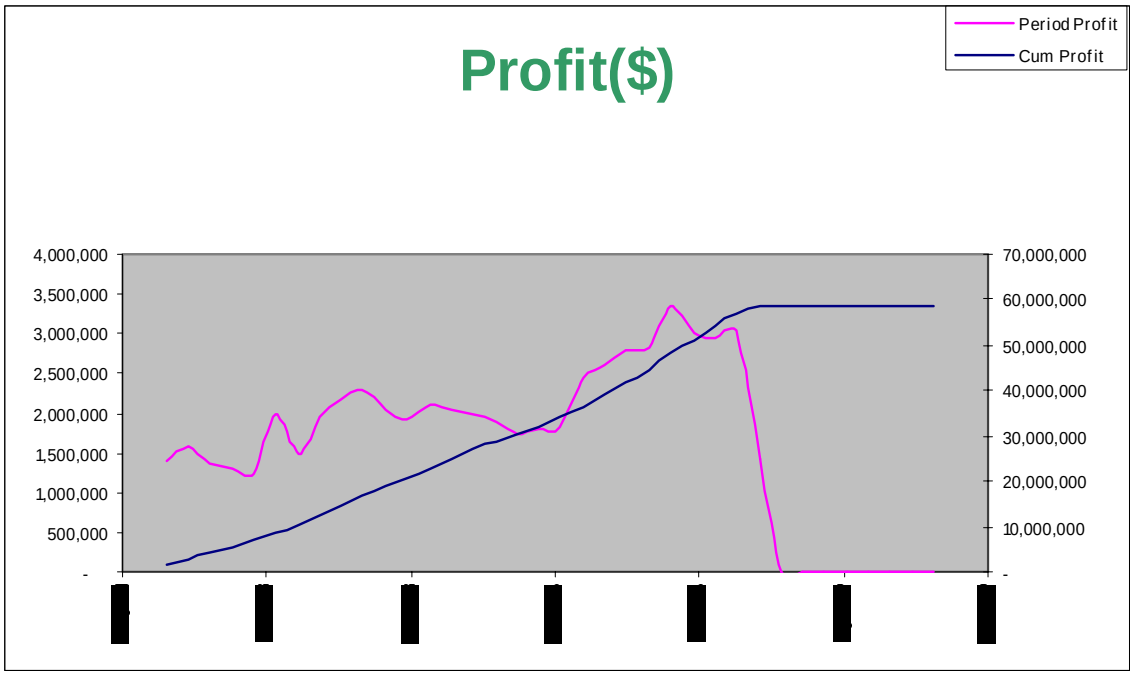

Tonnage by type Mined
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
-
Calcine
Spoil
Sulfide Ore
Transitional Ore
Oxide Ore
Sulfide Wst
Transitional Wst
Oxide Wst


SP Tonnage and Grade
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
-
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
-
SP
Au



MS Project Output Report





4. CONCLUSION

There is no doubt that the 20th century has witnessed a real revolution in computer technology and the mining industry has had its fair share. This has led to a sophistication in mine planning tools resulting in greater confidence level in planning results.

With mining operations becoming ever more complex and costly, the use of sophisticated methods/tools to accurately predict the strengths, weaknesses and risks of a particular operation cannot be over-emphasised.

No single scheduling method would be suitable for all situations due to the fact that all operations vary in size, location, material type and labour. One package may be suitably used at one site but may turn a disaster at another site.

The following criteria are therefore prescribed for the selection of a scheduling package for a mine site:

- Management's expectation of the results the package can provide for decision making.
- Management's knowledge in a particular package.
- The level of knowledge of the planning engineers in that package.
- Management's appreciation of the difficulties planning engineers encounter in producing a result for decision-making.
- The user-friendliness of the package.
- The cost of the package
- Training of staff and level of technical support.

A scheduling process that is painstakingly done would certainly pay dividends at the end. It is therefore advised that both time and money are invested for the above to be achieved.

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