Just-in-time development model for a sub-level caving underground mine in Zimbabwe

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Synopsis

Traditionally, mineral reserves management at most underground mines in Zimbabwe focus on maintaining large mineral reserves so that the time between development and production is as long as possible. Historical data at Shabanie mine, a Zimbabwean sub-level caving underground mining operation, confirms this practice. However, the high cost of underground development means that the luxury of large buffer mineral reserves cannot be justified. Furthermore significant increases in the costs of production, exacerbated by the current unfavourable economic climate, make the wisdom of extending development workings well ahead of use questionable. Poor ground conditions at Shabanie mine, mean that some development ends have to be re-mined two or three times due to partial or complete closure between the time they are mined and the time they are utilized. In order to reduce the inordinately high support costs associated with closure of development ends a new 'just-in-time' (JIT) approach that provides development ends as and when they are needed, has been adopted. Accordingly a model to determine an appropriate 'just-in-time' rate of development has been created. The JIT development model indicated that the mine could reduce development rates from 330 m/month in 2001, to 160 m/month in 2002 and achieve savings of about 50% on annual support costs, but still assure customers of a long-term product supply. The mine accepted the model in November 2001 and began implementing it in 2002. Results of the implementation will be reviewed in 2003.

Introduction

In terms of Zimbabwean mining definitions, reserves are classified into proved, probable and possible categories. Primary reserves (a category within proved reserves) constitute the buffer reserves referred to in this paper and are part of, but less than the proved mineral reserves. Primary reserves do not require any further development work to be brought into production and provide a buffer between development and production. The time lag (or buffer time) between development and production is a function of the buffer reserves and their rate of extraction. It is the period for which a mine can continue to produce at a given rate of extraction if all development work was stopped immediately. This means mining will be from blocks designated as buffer mineral reserves. Buffer time is therefore less than Life of Reserve (LOR) since the LOR is calculated on proved mineral reserves. Just-in-time (JIT) development therefore, is the amount of development required to maintain buffer mineral reserves at an optimal level relative to the rate of extraction of the mining operation.

Optimal buffer mineral reserves in the mining industry are equivalent to an Economic Order Quantity (EOQ) in the manufacturing industry. EOQ in the manufacturing industry is the optimal stock level that minimizes holding costs and ordering costs, but still assure projected levels of production[1]. In mining operations optimal buffer mineral reserves are the buffer mineral reserve levels that minimize funds 'locked up' in development while still providing customers with assurance of long-term product supply. The salient difference between the industrial and mining settings is that the EOQ is maintained through a certain process of placing and receiving orders in industry, whereas the mining optimal buffer mineral reserve is replenished through the uncertain process of exploration. The uncertainty associated with mineral exploration and the potential disruption of mining activities through unforeseen geological complexities such as faults and dykes, means that mines have an incentive to maintain large buffer mineral reserves as insurance against running out of reserves and ensuring long-term production. In the light of this, the Zimbabwean practice of keeping large buffer mineral reserves on operating mines can be understood. Other reasons for mines holding large buffer mineral reserves include the fact that:

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- It is less difficult to justify capital projects since long-term production can be assured through large buffer mineral reserves
- Large buffer mineral reserves offer operational flexibility including the ability to respond to sudden and unforeseen changes in the mineral price
- Development that is well ahead of production stopes creates open areas that naturally cool the mine and hence lower ventilation costs in the long-run.

However, there is no economic justification for investing in development ends simply for the sake of maintaining large buffer mineral reserves. Significant increases in the cost of production also make the wisdom of reef development well in advance of stoping areas questionable. These economic challenges could be addressed by adopting a JIT approach that provides development ends as and when they are needed.

Shabanie mine is a sub-level caving underground mining operation in Zimbabwe. Historical mine data (withheld for proprietary reasons) for the period 1990-2000 indicate that buffer mineral reserves have traditionally been maintained at about 4 years with the LOR in excess of 13 years. However the general decline in development rates ahead of mining over the last 10 years as shown in Figure 1 indicates that maintaining such large buffer mineral reserves is no longer considered necessary. These data are indicative of four distinct periods during which the attitudes of management to the need for development changed. They are:

- A steep decline between 1990 and 1991.
- An almost constant development rate between 1991 and 1996.
- Another steep decline between 1996 and 1998.
- A relatively constant development rate in the post-1998 period.

These periods are interpreted as a reflection of changes in the attitudes and vision of management personnel over the period 1990-2000. Over the decade in question the mine has cut development from around 24,000 m/year (i.e. 2,000 m/month) to about 3,900 m/year (i.e. 330 m/month) in 2001. Consequently the LOR has declined from 18 years in 1990 to just over 13 years in 2001 and the buffer time has similarly been reduced from 6 years in 1991 to about 4 years in 2001. If all development were to be stopped in 2001 the mine would have sufficient capacity to continue producing at the 2001 extraction rates for 4 years without requiring any additional development (except of course for any re-mining needed to keep ends open).

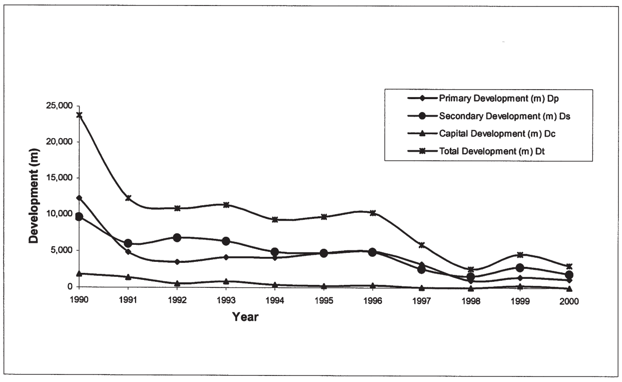

Figure 1—Development trends at Shabanie mine (1990–2000)

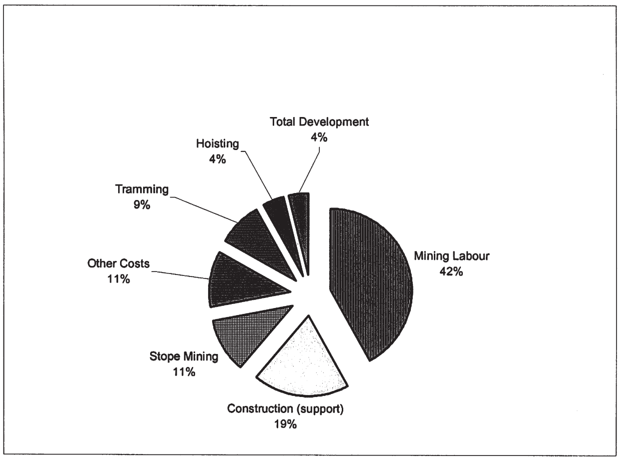

Figure 2—Distribution of mining costs by activity

The distribution of mining costs at Shabanie mine, as illustrated in Figure 2, shows that apart from labour, the largest costs of all mining activities are attributable to construction (support). Ground conditions at Shabanie are fair to poor since they lie in the Laubscher's geomechanics class range 2B to 4A[2]. High induced stress conditions have compounded the problem of poor ground conditions and it is therefore not surprising that some of the development ends have had to be re-mined two to three times due to partial or complete closure. Costs for support are unreasonably high and the need to review the mine's development support regime has become a priority. Stand-up time for most development ends is in the order of 6–12 months before significant closure or ground damage is experienced. From Figure 2 it can be inferred that the cost of supporting development ends is about four times that of simply mining the ends, again emphasizing the need to review the support regime on development ends. One option to reduce support costs is to review the support system to check whether the nature of the support is commensurate with the duty life of the excavation. An examination of the mine support system indicated that some of the ends were over-supported for their duty lives. Another option to reduce support costs would be to mine the development ends 'just-in-time' when they are needed but using high-speed techniques since the mining period will be much shorter. This approach would mean that support re-work is minimized.

Analysis of the second option culminated in a JIT development model for the mine, a need that was recognized much earlier and has grown over the years. The JIT model for development was implied in the proposal by Laubscher[3] that the period between development and production could be reduced if substantial mine planning information was available and development rates could be increased. Although it was not clear as to what constituted substantial mine planning information, we considered the statistical data over a 10-year period (1990–2000) to be a sufficient base for investigating how the period between development and production could be reduced at Shabanie mine. This was based on the premise that because the mine has operated since the 1930s a large amount of sapiential knowledge about the nature of the ore deposit has accumulated over the years. Current decisions on development and exploration on the mine are more informed compared to similar decisions made in the 1930s when knowledge of the deposit was minimal. Therefore, the current relationship between development and corresponding mineral reserves is a fair reflection of the success of exploration development work.

Model assumptions

The following constitute the assumptions made in the development of the JIT model.

- Experience has indicated that most development openings begin to show significant movement or ground damage 6–12 months after excavation. JIT buffer mineral reserves could therefore be reduced to the equivalent of six months production in order to minimize the costs of support.
- Buffer time is correlated with total development (i.e. capital, primary and secondary), proved mineral reserves and annual depletion rates of the mineral reserves.
- The major factor considered in classifying mineral reserves at Shabanie mine is the density of exploration drilling. The three mineral reserve categories used on the mine in order of increasing confidence (due to increased density of drilling) are possible, probable and proved mineral reserves. For example, to qualify into the proved category, the drilling density is a 30 m drillhole interval. The proved mineral reserves are further subdivided into several schedules depending on per cent development and accessibility of the particular reserve block. However, detailed as it is, the mine's mineral reserve classification system has no direct provision for buffer mineral reserves as is the practice on Zimbabwean gold reef mines, where proved mineral reserves are further classified as 'primary mineral reserves' if they do not need any further development to come into production. Therefore the equivalence of buffer mineral reserves for the mine was taken as the production tonnes (which include dilution tonnes) of column 25 in Schedule C of the mine's Annual Ore Reserves Reports, adjusted for current draw status and block development completion. The criteria for mineral reserves to qualify for entry into column 25 are that access haulages and ore passes are in place to facilitate ore movement from the designated block. The buffer mineral reserve tonnage was then calculated as a product of per cent development and production tonnes for all fully developed blocks or those from which ore was already being drawn. An example of these calculations is presented in Table I. The total buffer mineral reserves referred to in the Table are just the sum of the buffer mineral reserves for each block in the example, not for the whole mine.
- LOR is obtained by dividing the proved mineral reserves by the annual production call. Buffer time is obtained by dividing buffer mineral reserves by the actual current extraction rate. Buffer time should therefore be less than the LOR, the latter being based on proved mineral reserves while buffer time is based on a part of the proved mineral reserves.

Relationships between model parameters

Trends were plotted to determine if any of the anticipated correlations and relationships exist[4] between the factors relating buffer time, development rates, buffer mineral reserves and proved mineral reserves. In order to reduce the possibility that autocorrelation between data sets could produce a result where no relationship between data sets exists[5], trends were considered only for the following pairs of data that were expected to exhibit meaningful correlations:

Table I

Example of calculation of buffer reserves

YEAR			BLOCKS		
2000	**50A/570**	**53/690**	**58/790**	**59/690**	**60/690**
%block dev	100%	95%	25%	85%	75%
Block Production Tonnage (including dilution)	11,600	1,364,400	4,298,500	242,300	522,400
Buffer Mineral Reserves	11,600	1,296,180	1,074,625	205,955	391,800
Total Buffer Mineral Reserves	2,980,160				
1999	**50A/570**	**53/690**	**58/790**	**59/690**	**60/690**
%block dev	100%	95%	10%	80%	55%
Block Production Tonnage (including dilution)	48,600	1,534,900	3,406,370	242,330	523,490
Buffer Mineral Reserves	48,600	1,458,155	340,637	193,864	287,920
Total Buffer Mineral Reserves	2,329,176				
1998	**50A/570**	**53/690**	**58/790**	**59/690**	**60/690**
%block dev	99%	90%	5%	70%	25%
Block Production Tonnage (including dilution)	37,200	1,534,000	3,480,092	355,550	689,963
Buffer Mineral Reserves	36,828	1,380,600	174,005	248,885	172,491
Total Buffer Mineral Reserves	2,012,809				

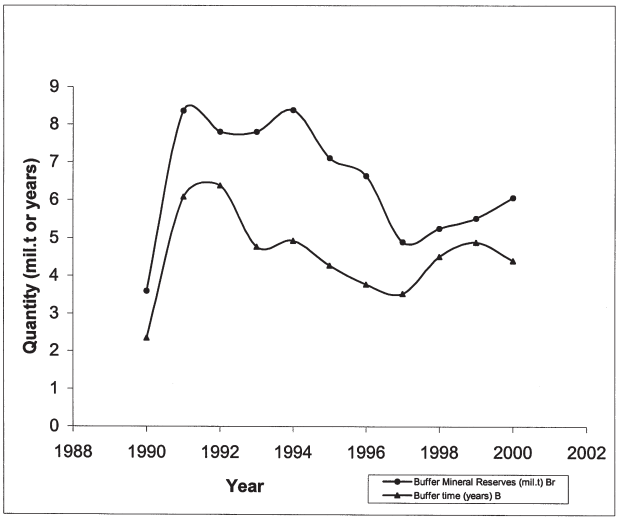

Figure 3—Buffer time vs. buffer mineral reserves

- ➤ Buffer time and buffer mineral reserves
- ➤ Total development and buffer mineral reserves
- ➤ Total development and proved mineral reserves
- ➤ Buffer mineral reserves and proved mineral reserves.

The identified relationships were quantified using correlation and regression analysis as presented later in this paper.

Buffer time and buffer mineral reserves

The Shabanie mine statistics confirm that there is a correlation between buffer time and buffer mineral reserves as illustrated in Figure 3.

Total development and buffer mineral reserves

The period 1990–1991 presents an anomaly in the expected trend (Figure 4), because although annual rates of development were declining, much of it was in secondary development an assumption that is confirmed by Figure 1. The trend in this period can also be interpreted to reflect the opening up of a new mining area and the exhaustion of ore in a major production section. The following blocks (i.e. 50A/570, 50B/570, 53/690, 58/2 and 58/3) were being brought into production, while long-standing production areas (i.e. 50B2/480, 51A1, 51C, 50B1/480, 52C, 53REM, 51A2, 51B3, 51B4, 52A/CP, 54/570 and 54/690) were reaching the end of their physical life due to depletion. Despite these plausible explanations, the decision to reduce the total development did not seem to markedly affect buffer mineral reserves suggesting that the pre-1991 period was characterized by over-development. Therefore disregarding the 1990 figures, there is a relationship between total development and buffer mineral reserves.

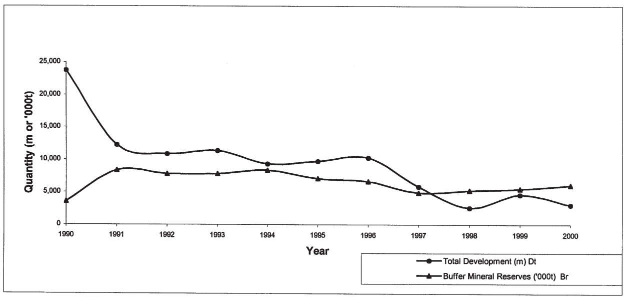

Figure 4—Development vs. buffer mineral reserves

Total development and proved mineral reserves

The relatively strong relationship between total development and proved mineral reserves shown in Figure 5 illustrates that more proved mineral reserves are likely to be found as more development is undertaken. Again in the 1990–1991 period a significant drop in development resulted in a slight fall in proved mineral reserve indicating over-development in the previous time periods.

Buffer mineral reserves and proved reserves

Disregarding the 1990 figures, it can be inferred from Figure 6 that a significant change in proved mineral reserves is accompanied by a slight change in buffer mineral reserves hence showing a weak relationship.

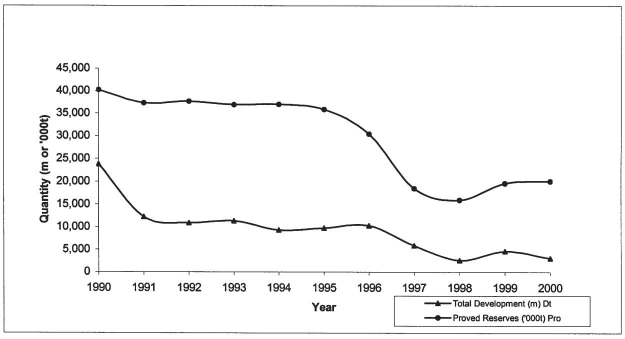

Figure 5—Proved reserves vs. development

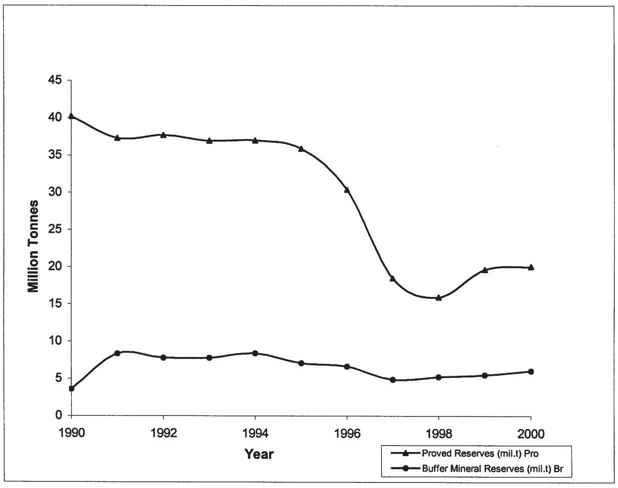

Figure 6—Buffer mineral reserves vs. proved reserves

Table II

Correlation analysis of model input parameters

	Dp	Ds	Dc	Dt	Pro	Br	LOR	B
Dp	1							
Ds	0.874	1						
Dc	0.826	0.876	1					
Dt	0.971	0.962	0.899	1				
Pro	0.688	0.895	0.710	0.804	1			
Br	-0.275	0.094	-0.034	-0.109	0.478	1		
LOR	0.541	0.755	0.737	0.672	0.739	0.212	1	
B	-0.528	-0.105	-0.115	-0.333	0.144	0.785	0.208	1

Correlation and regression analysis

It is apparent from Figures 3 to 6 that statistics for the period 1990–1991 are contradictory to expected trends and reasons have been given for these anomalies. Consequently the data for 1990 was excluded when a correlation and regression analysis of the data for the period 1990–2000 was performed. The results of the correlation analysis (Table II) show that all categories of development (capital, primary, secondary) have correlation coefficients above 0.74 and are strongly correlated with total development. This implies that total development could be taken to represent the three sub-classes constituting total development. Total development is strongly correlated to proved mineral reserves. Proved mineral reserves show a fair correlation with buffer mineral reserves. Buffer mineral reserves are strongly correlated to buffer time. The shaded boxes indicate areas of relatively high correlation.

A regression analysis was subsequently carried out to determine the nature of the meaningful correlation. The following relationships were then established:

$\mathbf{B} = 7 \times 10^{-7} \times \mathbf{Br}$ $\quad \mathbf{Pro} = 4.35 \times \mathbf{Br}$ $\quad \mathbf{Dt} = 0.3 \times 10^{-3} \times \mathbf{Pro}$

Where: **B** = Buffer time in years
Br = Buffer mineral reserves in tonnes
Pro = Proved mineral reserves in tonnes and
Dt = Total annual development in metres.

These three equations form the framework of the model for determining the JIT development rate for the mine. Based on rock mechanics constraints discussed earlier, the mine requires a JIT development period of no less than 6 months (i.e. 0.5 years), compared to the current development period of about 4 years. This would require a buffer mineral reserve base of about 715,000 t, which in turn would require a proved reserve base of about 3.1 million tonnes with a corresponding annual development rate of about 930 m/year (i.e. about 80 m/month). In essence, this implies lowering the development rate from the 2001 call of 330 m/month call to a call of 80 m/month. However, from a practical viewpoint not all development is always in the right place at the right time, particularly so if the buffer time is very long. Furthermore some openings have longer stand-up times than 6 months as mentioned earlier, with some remaining intact for close to 1 year. The foregoing data and reasons indicate that a 1-year JIT development period appears quite appropriate for the mine. This study therefore recommends a JIT development rate of about 160 m/month down from the current 330 m/month call. By almost halving the amount of development, the mine can expect to reduce annual support costs by a corresponding 50%. The new development rate equates to about 1.5 million tonnes of buffer mineral reserves and a corresponding 6.5 million tonnes of proved mineral reserves. At current annual extraction call of 1.35 million tonnes, the LOR is equivalent to about 5 years. This also means that customers are still assured of long-term product supply because the total mineral reserves indicate a projected LOR in excess of 13 years.

Conclusions

The JIT model for development proposed in this study suggests that Shabanie reduce the current development rate from 330 m/month to 160 m/month in order to save an anticipated 50% on annual costs of support. The model was accepted in November 2001 and implementation began in 2002. Although this model has potential to significantly reduce support costs, a parallel programme for re-assessing the mine's total support regime would further reduce support costs considering that some areas were observed to be over-supported for their duty lives.

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SPOTLIGHT ON
SAIMM Gravity Concentration Seminar

The SAIMM gravity concentration seminar, in collaboration with the Mine Metallurgical Managers Association (MMMA), took place on Wednesday, 29 January 2003 at Mount Amanzi, near Hartebeestpoort Dam, Gauteng. The objective of the seminar was to highlight the current state of gravity concentration in the South African mining industry and new developments in gravity concentration technology. To this end presentations were solicited from operators and vendors. Unfortunately only one operator presentation was obtained but 9 presentations were given by vendors. The operators approached were either too busy or their work was confidential. Although this situation is understandable, nevertheless the SAIMM should encourage more support from the operators for events like this in order to make them more effective from a user/supplier interface point of view.

The seminar was opened with a presentation from Anglo American Technical Division on applications of gravity concentration in South Africa. This set the scene for the seminar, highlighting the types of gravity concentration in use and where they are currently applied. The only operator presentation was given by Phamine Mining Holdings on their tin dump retreatment operations in the Limpopo province. They have secured the rights to re-treat all the tailings dams left behind from tin mining operations that were closed down more than 10 years ago. The flowsheet was described with emphasis on spiral and shaking table performance. Initially only James tables were used with unsatisfactory performance. When a Gemini table was installed to clean the James table product the quality of the tin concentrate was improved to 78% tin and less than 1% iron from 18% tin and 36% iron. This sparked a lively debate on the applications of the Gemini table with operators in the audience giving examples of similar experience and even opposite experience in one case.

The vendors represented were Multotec, Roche Mining, Knelson concentrators, Falcon concentrators, Gekko systems, Mintek and Outokumpu.

Multotec gave two presentations, the first covering the modelling of spiral performance and the second covering the current state of their spiral technology and new developments. Roche Mining, formerly Mineral Deposits, gave a presentation on the current state of their gravity concentration technology and new developments. This included spirals, the Kelsey centrifugal jig and the Gemini table. Knelson concentrators gave two presentations. The first covered the retrofitting of Knelson concentrators in gold milling circuits for the recovery of gravity recoverable gold (GRG), examples being detailed at ETC Sheba, President Steyn and Target-Lorain. The second covered the applications of the CVD Knelson concentrator, a continuous operation machine.

Falcon concentrators gave a presentation on the applications of their range of batch and continuous centrifugal concentrators. Gekko systems gave a presentation on the applications of their In Line Pressure Jig (IPJ) in gold and diamonds recovery. It is used to recover GRG in gold milling circuits and it is used to improve DMS efficiency in diamond treatment plants by producing a more concentrated DMS feed (Williamson diamond mine in Tanzania). Mintek gave a presentation on a batch jigging procedure that could replace heavy liquid sink/float analysis as a tool for optimizing jig performance, particularly for high SG setpoints. Outokumpu gave a presentation on the use of hindered settling to improve gravity concentration with spirals. Using their Floatex density separator they have demonstrated that in a mineral sands application the spirals circuit can be simplified leading to improved product grade control and lower capital costs.

The seminar attendance was 77. There was a good distribution of delegates between operators, vendors and consultants. Feedback from delegates was very positive and there was support for future similar events. It is recommended that this event be repeated every two years. Feedback on the venue was also positive and it can be recommended for future events. ◆

Marek Dworzanowski
Seminar Convenor