

Chapter 6
***Application of Explosives
Technology to the Mining
Industry - Case Studies***

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Defining the Effect of Varying Fragmentation on Overall Mine Efficiency

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Abstract

Significant research has been carried out over the years into what effect blast designs and techniques have on the final product in the mining process. There are numerous parameters that can be altered to deliver downstream benefits – the key is to determine which changes are appropriate for the rock body in question.

A project is currently underway at Thabazimbi Iron Ore Mine (Northern Province, South Africa) to improve the operational efficiency through attention to the blasting operation. Previous research suggests changing fragmentation will have an effect on mining efficiency, but no definitive model has been developed directly linking the two. Using data collected during the project, the author developed a sensitivity analysis tool, which defines the effect of changing fragmentation on overall mine efficiency. This prediction model was based partly on theory and partly on empirical information gathered from mine databases and personnel. Over the course of this project, this model was validated through the practical implementation of the theory behind its development. This involved decreasing powder factors by expanding the drilling pattern, thus changing the resulting fragmentation of the muckpile. Subsequently, downstream effects on mining efficiency were monitored and these results were recorded in the model.

The validated model suggests that there is room for improvement by reducing powder factors and generating larger mean fragmentation sizes, while reducing the overall cost per ton from R5.04/ton down to R4.91/ton. Assuming an annual waste mining tonnage of 30Mtons, this equates to a saving of R3 900 000/year. Two further opportunities for improvement were identified, firstly the implementation of a doped emulsion replacing ANFO across the mine, and secondly the introduction of electronic detonators. The second option would require further test work to develop confidence in the assumptions made in the model, concerning the effect of timing accuracy on fragmentation.

INTRODUCTION

African Explosives Limited (AEL) has been working together with Thabazimbi Mine in improving the operational efficiencies and recoveries through attention to the blasting operation. This involved a process of benchmarking the current mining operation, proposing an improvement plan, and implementing and monitoring the changes.

Integral to this process was the evaluation of fragmentation distribution and the effect which varying fragmentation size has on the operational efficiency of the mine. This paper outlines the background to this project and discusses the theory behind the need to define the correlation between fragmentation and operational efficiency. The concepts for creating a tool capable of this are detailed and each component of the resultant model is explained. This initial model is then validated by testing the theory through a series of test blasts. The results of these tests are then used to recalibrate the model and deductions are drawn from the model upon which recommendations are based.

Ore is mined with a stripping ratio of approximately 10:1 and as such the vast majority of the drilling, blasting, loading and hauling operation is carried out in waste material, which is predominantly comprised of Dolomite, Diabase, and Banded Ironstone. As a result, the primary focus of this project was on the waste mining operation. Neither milling nor beneficiation was considered here.

BACKGROUND

Thabazimbi Iron Ore Mine forms part of the Kumba Resources group. The mine is situated approximately 200km northwest of Johannesburg in the Northern Province

of South Africa. Thabazimbi provides iron ore (2 389 000 tonnes in 2003) for Iscor Limited's steelworks in Vanderbijlpark and Newcastle. There are four pits in operation on the mine, namely Donkerpoort West, Buffelshoek West, Kwaggashoek and Donkerpoort Neck.

AEL supplies the mine with ANFO (Ammonium Nitrate Fuel Oil) and blasting accessories. For the blast holes in which water is present, Bulk Mining Explosives' (BME) HEF100 (pure emulsion) is used. This is because while ANFO is not water resistant, pure emulsions and doped emulsions display excellent water resistant characteristics. Wet holes are predominantly encountered at Donkerpoort West as the pit level is approaching the level of the water table. The other three pits use ANFO most of the time.

The focus of this project was primarily on Donkerpoort West, where most of the test work was carried out. The main reason for this was a restriction on resources, making it difficult to carry out testing and monitoring work on all the pits simultaneously.

BENCHMARKING

A benchmarking exercise was conducted in order to define and quantify the current mining operation. This stage of the project involved the capture of information relevant to all the mining operations. This information included current and historical production figures such as tonnages, machine hours and operating costs (including owning costs). Benchmark information for drilling, loading, hauling and secondary equipment was captured and post blast results (floor conditions and back break) were recorded. Digital photographs of the muckpile were recorded for each of the blasts taken during the benchmarking phase of the project. These photographs were then analysed using Split

Desktop fragmentation analysis software.

The results were captured from the monitoring of a number of blasts as well as the analysis of historical data recorded over a period of six months.

Fragmentation

It is normally desirable to have uniform fragmentation (values of 1 or greater), thereby avoiding both excessive fines and oversize fragments in the broken ground.

A representative sample of images was taken of each muckpile. Figure 1 is the percentage passing graph of the waste block blasted (1000/4).

A number of images were taken across this muckpile. The calculated uniformity index *n*, for the sample analysed is 0.9 and the mean size, with 50% of the sample passing is 79.86mm.

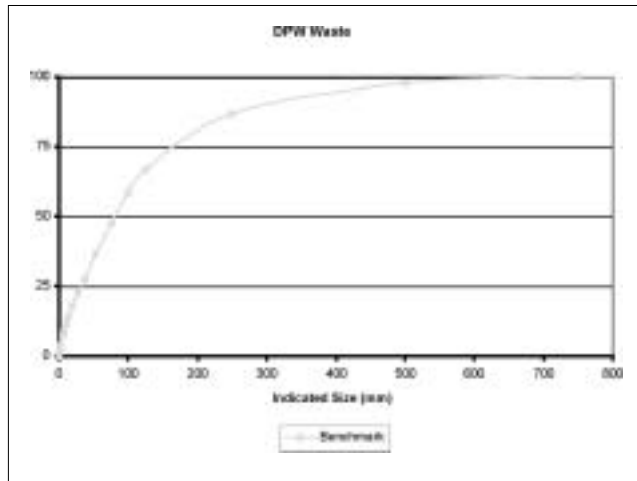


Figure 1: Percentage Passing vs. Indicated Size

The Uniformity index (*n*) in the Rosin-Rammler equation (Equation 1) gives a measure of this, with values greater than 1 indicating a more uniform sizing, whilst lower values result in higher proportions of fines and oversize.

$$\% \text{Passing} = 100 - \left(100 \times e^{-0.693 \times \left(\frac{\text{Meshsize}}{X_{50}} \right)^n} \right) \quad \text{-----Equation 1}$$

This information captured during the benchmarking phase of the project was then scrutinised to determine areas where efficiencies could be improved and in order to fully understand what economic effect changes to the blasting operation would have on the mining operation as a whole. During this process it was discovered that in order to gain this understanding, a tool, capable of predicting the economic effect of changing fragmentation through altering the blast design, was required.

THE INITIAL MODEL

The idea was to create a model that would have the capability of predicting the effect of introducing changes to the blasting operation. This required a process of conceiving the idea for the model, presenting certain assumptions and validating the model through practical application.

Discussion

The principle of the model is the effect that changing fragmentation size (through altered blast design) has on operating costs per ton throughout all the relevant mining

operations. From the benchmark, operating costs were calculated for the respective fragmentation distribution ranges for the various pits at that time. These fragmentation distributions were calculated using photographic analysis. Mean Fragmentation size is predicted using the Kuz-Ram equation (Cunningham, 1983).

Description of the model

Essentially, the concept for creating the model was to analyse all the information that was captured in the benchmark and identify the most appropriate method of relating fragmentation distribution to each of the mining operations.

Fragmentation analysis during the benchmark revealed the typical distribution trends for the various pits. This information was entered into the SABREX blast design package to calibrate the system and the predicted rock characteristics were generated. As a result of the ore and waste in most areas on the mine being relatively weathered and friable, the functional rock factor (*A*) was taken to be 1.92.

These rock properties were used with the Kuz-Ram equation to calculate the mean fragmentation size for various designs, based on certain input design parameters. The model then determines the fragmentation curve for each design using the Rosin-Rammler equation (Equation 1).

The Kuz-Ram equation is detailed below.

$$X_{50} = A \times \frac{Q^{1/6}}{K^{0.8}} \times \left(\frac{115}{REE} \right)^{0.633} \quad \text{-----Equation 2}$$

where

- X_{50} = Mean size (cm) – 50% passing
- A* = Rock Factor
- K* = Technical Powder Factor (excluding sub drill) (kg/m³)
- Q* = Mass of explosive in blast hole (excluding sub drill) (kg)
- REE* = Relative Effective Energy of explosive

The mean fragmentation size (Equation 2) was seen as the most appropriate measure to be used in the model. In order to generate different mean fragmentation sizes a change in the powder factor was required. For the model, it was decided to change the powder factor by altering the burden and spacing distances in the design. In association with this change, the sub-drill was also changed, in order to maintain the original burden to sub-drill ratio and control the final grade level.

The model is operated through Microsoft Excel and consists of a number of sheets with the input sheet being the main design sheet. A portion of this sheet is shown in figure 2.

The calculated drilling and blasting (including explosives and initiators) costs are visible on this sheet. In order to calculate the drilling cost, the system requires a drilling cost per metre. This value is calculated on a separate drilling cost sheet where all the data relevant to drilling is entered. This sheet contains information such as machine hours, metres drilled, and the operating costs associated with certain drill rigs in the specific area under consideration. The operating costs are separated into mining costs and engineering costs.

Mining costs consist of drill bits, drilling equipment and drilling accessories such as pipes and deck bushes. Engineering costs include services, repairs, maintenance,

Burden	4.45
Spacing	5.15
Burden ratio (hole diameters)	17.73
A	1.16
Sub-drill : burden	0.34
Hole Depth	11.53
Hole Angle	0.00
Hole Diameter	251.00
Bench Height	10.00
Bench Ht to Hole Diameter ratio	40
Stemming to Hole Diameter ratio	20
Tons per hole	733
Stemming Length	5.00
Sub-drill(u)	1.53
Charge above grade	5.00
Explosive Type	ANFO
Density	0.8
Kg Explosive per hole	258.39
Mc	39.59
Kact	1.13
Ktech	0.86
Rock Density	3.20
Surface IS Type and Length	HTD 10m
Quantity of HTD's	6
Total no of holes	150
Price/unit	17.27
HTD cost/hole	0.69
In-hole IS Type and Length	Handimaster 21m
Price/unit	48.74
Units/hole	1
Booster Type	400g Booster
Drilling cost per metre	63
Drill cost/hole	722.72
Drilling cost/ton	0.99
Blasting cost/ton	0.72
Cost/hole	1257.27
Cost/ton	1.71
Cost/m3	5.49
KUZ-RAM	
A	1.92
K	1.13
Q	258.39
REE	100
Mean Size (X)	4.82

Figure 2: Design Sheet

and miscellaneous costs as well as owning costs such as depreciation. Figure 3 shows the relationship that the model calculates for drilling cost and mean fragmentation.

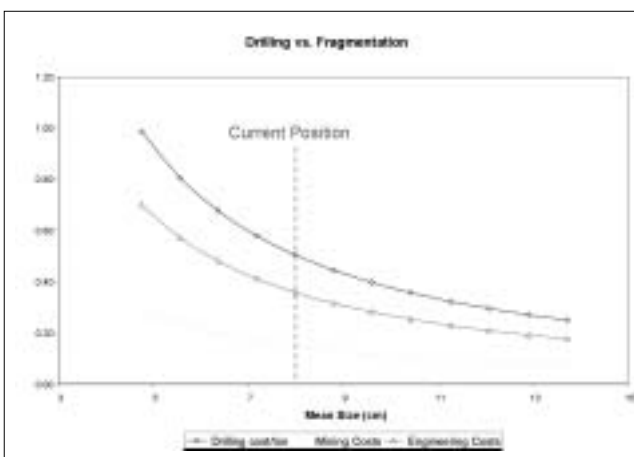


Figure 3: Drilling cost vs. mean fragmentation

The blasting cost is calculated on the principle of quantity per hole and this is linked to another sheet (Explosives and Initiation System units costs) where the actual cost, which the mine pays per unit (including handling costs) is sourced depending on the explosive or initiation type selected from the scroll down menu (figure 2). The system then calculates the relevant costs per ton for blasting. Figure 4 is a graphical representation of the relationship between blasting cost per ton and mean fragmentation size.

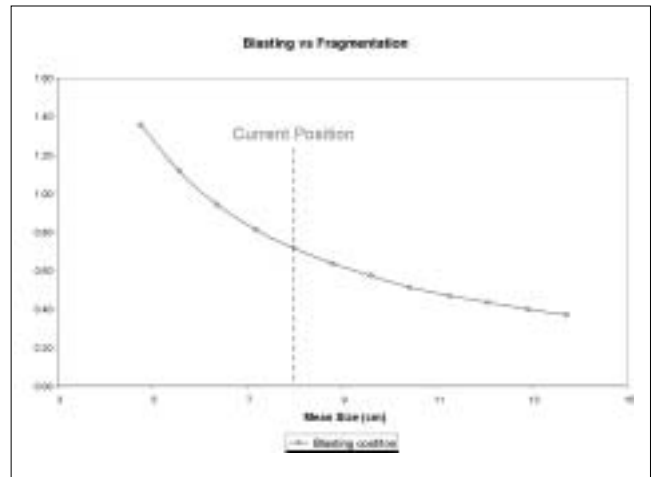


Figure 4: Blasting cost vs. mean fragmentation

The relationship between loading, hauling and secondary equipment costs and fragmentation distribution is not as clearly definable as with blasting and drilling. Before a relationship could be defined, it was necessary to make a number of assumptions.

The instantaneous loading rate is measured on the loading shovel and captured in the mine planning records. This rate is used as a measure of machine efficiency. In the short term, this rate will affect the net loading cost per ton as this cost is calculated from the equation:

$$\text{Tons / hr} = \frac{\text{Cost per hour}}{\text{Cost per ton}}$$

The first necessary assumption for loading is the relationship between mean fragmentation and loading cost. In order to determine this relationship, case studies, such as the one conducted by Bellairs (1998), were investigated. Various graphical representations were discussed, but no numeric relationship was found and therefore, initially, a rather broad-based assumption was necessary. During discussions with Thabazimbi mine management personnel¹, a number of different scenarios were represented with graphs for loading versus fragmentation size. Initially it was felt that a parabolic shaped curve was necessary, signifying an optimal lowest point with higher costs for both excessively fine material (the engineering component of loading costs increases due to excessive dust in the machinery – air filters, oil filters etc.) and excessively coarse material. In order to validate any assumed graph shape, it would be necessary to reproduce such extreme fragmentation sizes in reality. Owing to practical limitations, it was decided to make the focal point for this project a smaller window around the current benchmarked scenario. Further thought was then given to the required shape of the curve not only for loading, but also for secondary equipment and hauling as well. Considering a small window of the overall curve was examined (shown in figure 5), a straight-

line relationship was deemed to be a satisfactory representation.

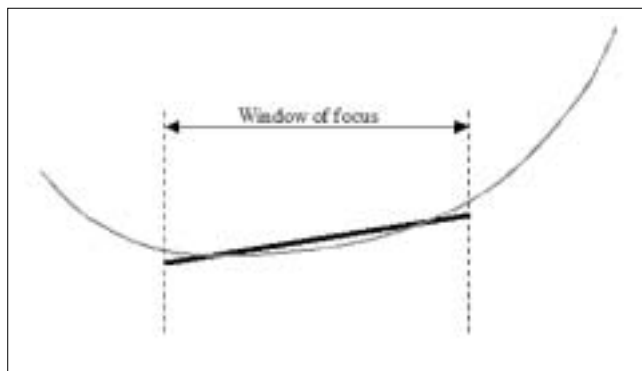


Figure 5: Area of Concern

Firstly, the minimum suitable limit was identified as R0.70/ton and it was decided that for every 1cm change in fragmentation (mean size) the cost per ton would change by R0.065/ton. This relationship was arrived at simply by plotting a straight line at a slope which was thought to be indicative of the effect changing fragmentation may have on loading rates and consequently loading costs. The resultant graphical relationship is shown in Figure 6.

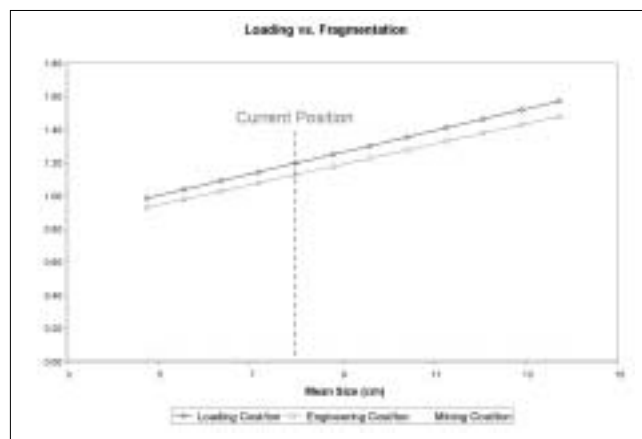


Figure 6: Loading cost vs. mean fragmentation

The impact of changing fragmentation on hauling and secondary equipment is likely to be negligible for minor changes in mean fragmentation size. There should however be some change and for the primary phase of the development of the model, a R0.03/ton change in cost per ton was assumed for every 1cm change in mean fragmentation. For hauling, the minimum suitable limit selected was R1.57/ton and for the secondary equipment, R0.53/ton was considered to be appropriate. Figures 7 and 8 show the generated graphical relationship between hauling and secondary equipment, respectively, and mean fragmentation. The same straight-line principle was applied to the generation of the hauling and secondary equipment graphs. It should again be stressed that these are broad-based assumptions arrived at through thorough discussion with mine management and investigation of data collected during the benchmarking exercise.

For secondary breaking, the mine employs a contractor who uses a "pecker" (mechanical breaker) machine. The operating cost is calculated and using the fragmentation distribution curves, the tonnage of oversize material (percentage above chosen dimension) generated is predicted. The calculated cost of this oversize is divided by

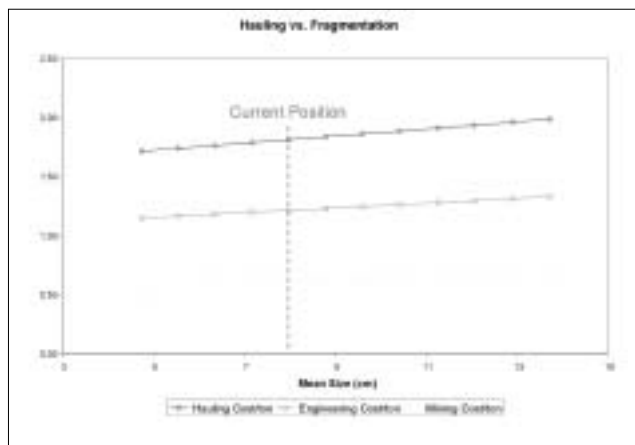


Figure 7: Hauling cost vs. mean fragmentation

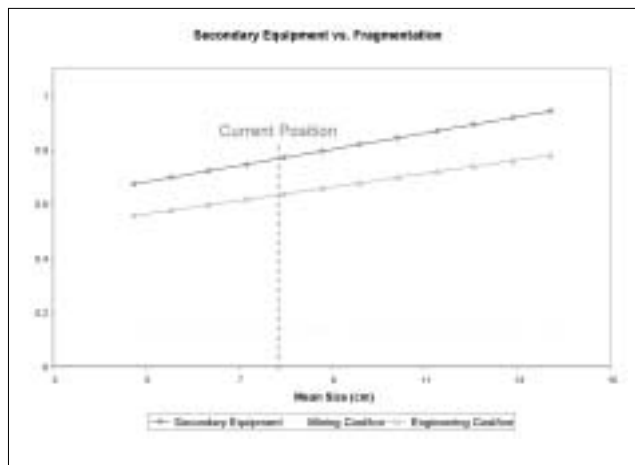


Figure 8: Secondary Equipment cost vs. mean size

the tonnage broken per hole to determine the cost per ton for a respective mean fragmentation size. Figure 9 shows the relationship between this cost and varying mean fragmentation sizes. It is noticeable that for this operation the cost for secondary breaking is negligible in comparison with the operating costs for the other operations.

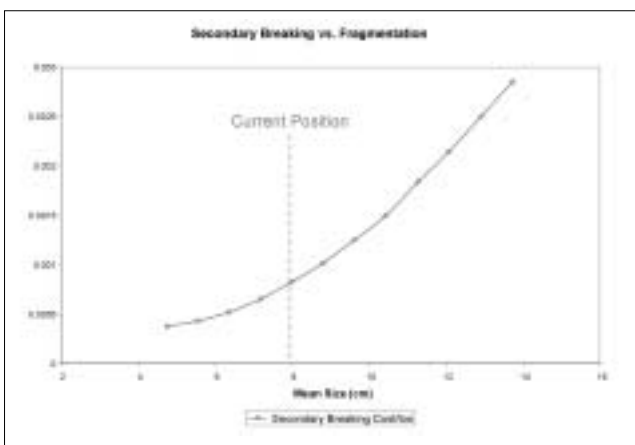


Figure 9: Secondary breaking cost vs. mean fragmentation

The resultant curve, which defines the entire waste mining operation, is simply the sum of all the graphically represented relationships already discussed. The true shape of the graph may or may not differ markedly from the version shown in Figure 10.

1 Discussions with A. Gricius, T. Otto and A. van den Brink at Thabazimbi Mine in 2004.

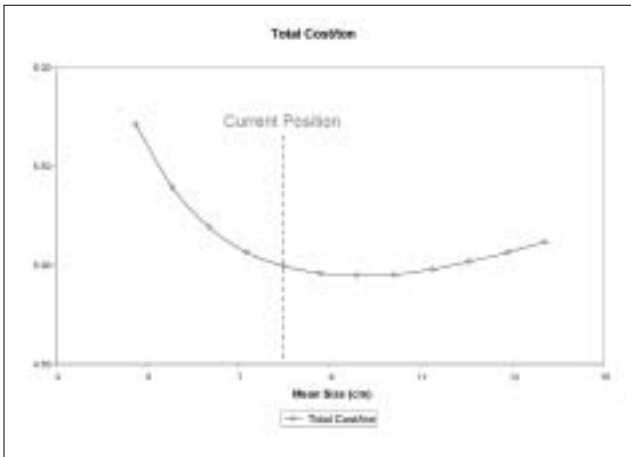


Figure 10: The Model

It is important to note that at this stage the model is dependent on the various assumptions previously discussed and therefore before it can become a working model, validity must be established.

The effects of highwall and floor conditions on mining costs as monitored in the benchmark, can only be determined in the longer term. The implementation of a change to the blast design in a pit, or across the mine would have to be followed by months of monitoring to determine the financial impact on both mining and engineering components that may be affected by the change.

The first step in achieving a near optimal mining operation is understanding the current operation in terms of the effect of changing variables on efficiencies.

The further development of the prediction model will ultimately allow for accurately forecasting the degree of economic change produced by implementing changes to blast designs or techniques.

PROVING THE MODEL

In order to authenticate and establish the validity of the model, it was necessary to generate varying mean fragmentation sizes and monitor the actual economic effect of this changing fragmentation on all of the mining operations. To generate this change in mean fragmentation, a change in the powder factor was required. Expanding the drilling pattern incrementally generated this change, and for each change, all the parameters relevant to the model were again evaluated.

The drilling patterns, sub-drill, and relevant blast block numbers are detailed in table 1. For consistency, the remaining blast parameters and the general area, size and shape of the blast blocks were, as far as was practical, kept consistent with the benchmark. The inter-row and intra-row delays for the timing designs were maintained. However, the point of initiation did vary, depending on the number of free faces. The drilling pattern employed in the benchmark was 6.4m x 7.4m.

Drilling Pattern (m)	Sub-drill (m)	Block No.
7 x 8.1	2.3	1000/16; 1000/18; 1000/20
7.3 x 8.5	2.4	990/06; 990/11
7.6 x 8.8	2.5	990/09
7.9 x 9.2	2.6	990/35

Results

The overall impression of the blast results for the pattern expansion test blocks at Donkerpoort West were good, with no obvious deterioration in fragmentation. This was supported by feedback from the load and haul team, garnered in feedback meetings held approximately 2 weeks subsequent to every blast, once the majority of the blasted block had been loaded out.

Geology

A decision was made to conduct all test blasting in areas with similar geological conditions and in line with the geology encountered during the benchmark blasts. As such, the formation for all the blocks blasted consisted of between 95% and 100% Banded Ironstone Formation (BIF), which is currently predominantly a waste material at Thabazimbi with an average density of 3.2g/cm³. The balance of material was made up of diabase, shale, and waste dump material, usually softer material than BIF and with a density of approximately 2.2 g/cm³.

Fragmentation

Figure 11 shows the measured fragmentation curves on a percentage passing vs. indicated size graph for each of the test blasts (detailed results in Appendix 3). It can be seen that with an increase in drilling pattern, although not obvious to the human eye, the resultant fragmentation distribution was in fact coarser than the benchmark curve, with the exception of blast block 990/11, which was in a different area of the pit to the remaining blocks. Here the fine fragmentation could be attributed to the geology encountered in this particular area.

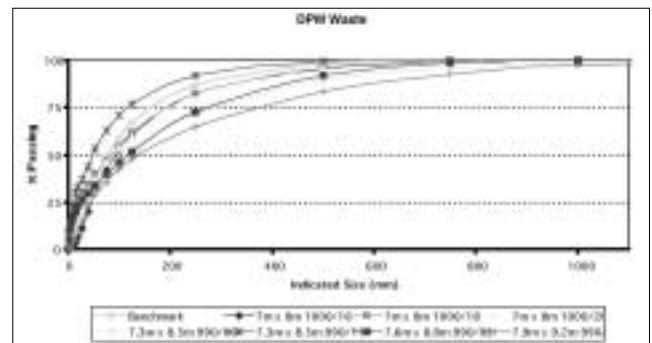


Figure 11: Summary of Fragmentation Distribution Curves

Table 2 is a summary of the uniformity index and mean size of the muckpiles generated for each blast. Again it can be seen that the mean size is markedly lower for 990/11 (highlighted in blue) than any of the other blasts. Consequently the results from this block were excluded as geologically controlled.

Loading Performance

The loading rates are the average instantaneous loading rates for the loading of the entire muckpile of a blast. In table 3, the final loading rate for each blast is detailed. Noticeable from these results is the apparent random nature of the loading rates. This may be attributed to moderately different geological conditions, different loaders or different operators. This is reflected in the graph shown in figure 12, which shows lower loading costs (higher loading rates) for the first three test blasts, followed by two blasts producing higher loading costs or lower loading rates. The trend however is positive, with a gradual increase in loading cost with increasing fragmentation mean size.

Table 2: Fragmentation Summary

	Benchmark 1000/4	1000/16	1000/18	1000/20	990/06	990/11	990/09	990/35
Uniformity Index n	0.9	1.04	0.73	0.86	0.76	0.73	0.79	0.64
Mean Size (mm)	79.86	93.75	83.73	87.44	113.01	47.22	89.6	137.4

Table 3: Donkerpoort West Loading Rates

	Benchmark 1000/4	1000/16	1000/18	1000/20	990/06	990/11	990/09	990/35
Loading (Tons/hr)	1005±233	1233	1302	1177	987	1760	775	1132

* Highlighted in blue is a possible anomaly – block 990/11

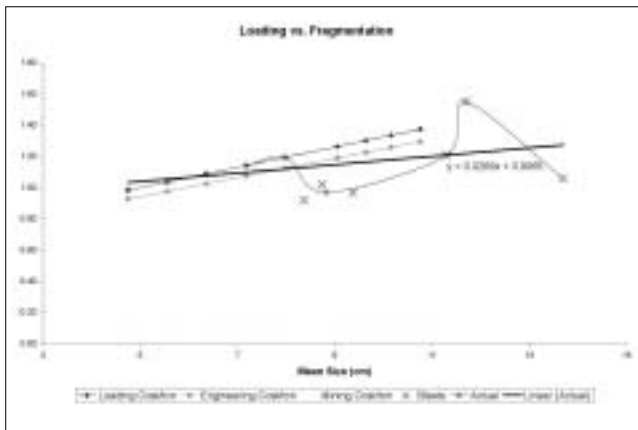


Figure 12: Redefined Loading vs. Fragmentation Graph

Other Results

The effect of these pattern changes on the remaining operations such as hauling and secondary equipment is taken to be consistent with the original assumptions made in the initial model.

Application of Results

In order to generate the ‘actual’ curve defining the mining operation at Donkerpoort West Pit, these results had to be introduced into the model. The actual fragmentation mean sizes for each test blast and the resultant loading rates were entered into the model and the new graphs were generated.

With the introduction of the mean fragmentation sizes after all the test blasting, the model was re-calibrated resulting in adjusted fragmentation distribution for each design and as such a slight shift in all of the resultant curves. This was achieved by adjusting the rock factor (A) shown in figure 2 from 1.92 to 2.2 to yield mean sizes approximating the measured sizes shown in table 2.

The drilling and blasting cost per ton is calculated automatically by the model based on unit explosive and initiation system prices entered into the model.

As mentioned in the previous section, the model uses the recorded loading rates to calculate the loading cost per ton. Figure 12 shows the plot of the loading cost per ton for each of the blasts as well a trend line of these points. The equation of this trend line, $y = 0.0269x + 0.9065$, is then

used to generate the new ‘actual’ loading cost per ton versus mean size line. It can be seen that this line is not as steep as the initial assumed line but still has a positive slope indicating increasing loading cost with increasing coarseness in fragmentation.

The resultant total cost versus fragmentation curve is shown in figure 13. Also shown, is the original curve to highlight the differences between predicted and actual. It is apparent that the increase in mean fragmentation size (applied to the model through the increase in the value of the rock factor) has resulted in a shift in the position of the curve. This adjusted rock factor was applied to all the test blasts, including the benchmark, as there was an increased confidence in this number, arrived at through more extensive test work than was carried out for the benchmark. In effect the position of the benchmark is shifted slightly in terms of mean size but the total cost per ton at this point (R5/ton) is comparable with the original benchmark (R5.04/ton).

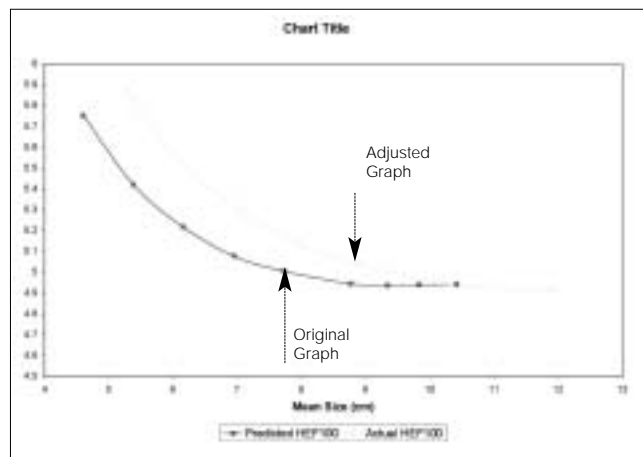


Figure 13: Redefined Total vs. Fragmentation Curve

This adjustment in mean size coupled with the new loading curve has resulted in increased costs per ton to the left of the adjusted benchmark and marginally lower costs per ton to the right of the adjusted benchmark, compared to the original predicted curve.

The validated model suggests that there is room for improvement by reducing powder factors and generating larger mean fragmentation sizes, while reducing the overall

cost per ton from R5.04/ton down to R4.91/ton. Assuming an annual waste mining tonnage of 30Mtons, this equates to a saving of R3 900000/year.

Discussion

It is reasonable to assume that with ever-increasing fragmentation the resultant cost per ton will ultimately reach a point where an exponential increase will be experienced. The model shows no indication of this for the fragmentation sizes considered here (figure 13). This is in line with the assumption made, during the initial development of the model, that only a narrow window of the total possible fragmentation size generation will be considered. This was done due to practical limitations, where blasting to generate larger fragmentation sizes is restricted.

The exercise of validating the model has delivered a tool, which could be used to compare the effect of different blast designs on the efficiency of the overall operation. To further validate the model, the actual effect of varying fragmentation (as negligible as it may be) on hauling and secondary equipment costs, should also be determined. This would require a long-term process of producing different fragmentation sizes and monitoring the effect of this on the equipment costs, particularly the engineering component of this cost and the tyre component from a mining point of view.

The tool is capable of giving a good indication of what the most effective blast design or explosive would be to deliver the most efficient operation.

The first step in achieving continuous improvement in the mining operation is understanding the current operation in terms of the effect of changing variables on efficiencies.

The further development of this proven model will ultimately allow for more accurately forecasting the degree of economic change produced by implementing changes to blast designs or techniques.

Change of Explosive

The proven Donkerpoort model has been used to compare the efficiency of the operation with the introduction of different explosives. In figure 14, P700, which is a doped emulsion (65% emulsion, 35% Ammonium Nitrate prill blend), is compared with ANFO and HEF100, a pure emulsion. The lower unit costs coupled with higher relative effective energy of ANFO and P700 result in a more efficient operation when compared with HEF100. Although the unit costs for ANFO and P700 differ dramatically (~R1.80/ton versus ~R2.30/ton respectively), the model shows that, with the improved fragmentation generated by the blend product, a lower overall cost per ton will result if the pattern is expanded beyond the current pattern of 6.4m x 7.4m. The difference between the minimum cost per ton on the ANFO curve and the P700 curve is R0.03/ton which equates to cost savings of around R900 000 a year, assuming 30Mtons of waste are mined in one year. In addition to this, due to the finer fragmentation produced when blasting with P700, wear on machinery should be reduced, which, over an extended period should lower mining and engineering costs.

Change of Initiation System

Electronic detonators have delivered a number of improvements to various operations around the world such as Optimum Colliery in South Africa (Hough, 2001). These proven results have shown an increase in uniformity of the muckpile with a reduction in fines and oversize material. From discussions with Claude Cunningham, it became apparent that a factor could be applied to the calculated uniformity index for pyrotechnic blasts to predict the

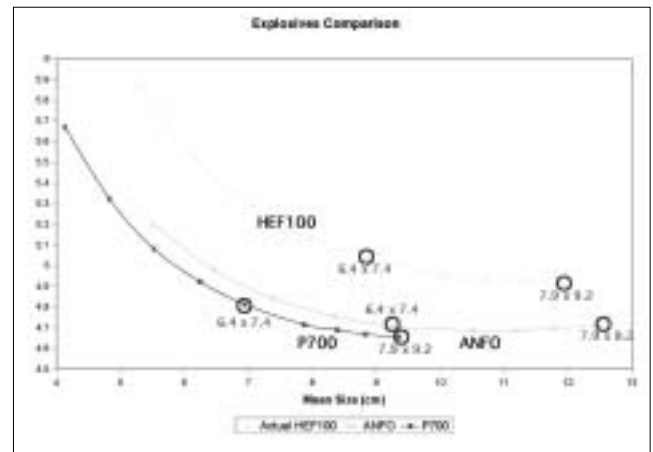


Figure 14: Cost Comparison of Various Explosives

fragmentation distribution from the same blast initiated with electronic detonators (Cunningham, 2005). A figure of 1.3 was applied with confidence, as the resultant fragmentation curve matches actual results achieved in the field². The economic effect of this is illustrated in figure 15 with mean size on the x-axis replaced with 80% passing. This change in the measure of fragmentation is done, as theoretically speaking; applying a positive change to the uniformity index does not affect the mean size, but reduces both fines and oversize percentages. The marked reduction in oversize material, with the introduction of electronic timing, results in a significant lower cost per ton for the mining of this coarser material. The consequence of this would be a further reduction of overall mining costs.

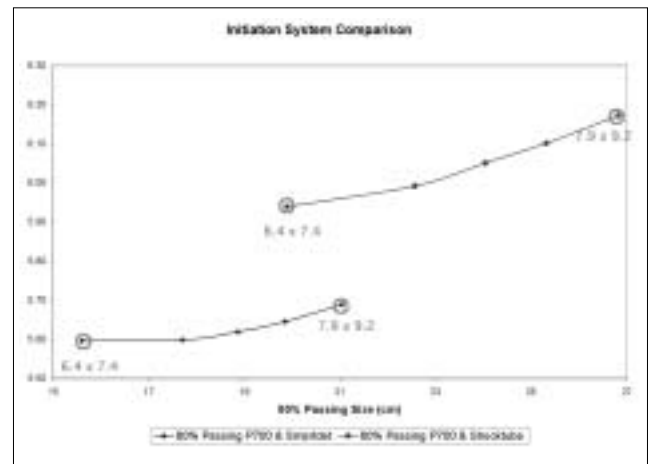


Figure 15: Shock Tube vs. Electronic Detonators at 80% Passing

This option would require further test work to develop confidence in the assumptions made in the model concerning the effect of timing accuracy on fragmentation.

If the decision is taken to implement either or both of these options, the model could be further validated by monitoring the consequences of any changes experienced over a period of time. It is important to note that mining conditions (equipment, rock properties etc.) will always be in a state of change and it is therefore necessary, in this process of continual improvement, to constantly monitor all the processes in the operation.

It must be remembered that the results of the test work will be relevant only to Thabazimbi. The site conditions encountered here are unique and if this model is to be employed at different sites with differing geological

² From discussions with Claude Cunningham, AEL's Consulting Engineer (2004).

conditions, explosives or equipment, then all the data related to the new site will have to be captured and entered into the model.

CONCLUSION

The intention of this project is to implement a step change in mining efficiencies at Thabazimbi Iron Ore Mine, through the application of new ideas and attention to the blasting operation.

The importance of blasting and its relationship to the efficiency of the entire mining operation is widely acknowledged. The core focus of this project was defining this relationship and consequently determining key areas where efficiency could be uplifted.

The result was the development and validation of a tool or model based on the defined relationship between fragmentation sizes and operating costs per ton across the relevant mining operations.

Ultimately the proven model was used to identify areas of opportunity for improvement. The implementation of a doped emulsion and an appropriate expanded pattern, which would replace ANFO across the mine, was shown by the model to have a potential for improving efficiencies across the mine. Considering the level of confidence in the model at this early stage, this would be the obvious first

step, and the consequent monitoring of any changes in operational efficiency would build further confidence into the model.

The second option of implementing electronic detonators would require further test work to increase confidence in the assumptions made in the model concerning the effect of timing accuracy on fragmentation in the rock formation encountered at Thabazimbi Mine.

LIST OF REFERENCES

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