Blast fragmentation optimization at Tarkwa Gold Mine using 6 Sigma methodologies

by A. Amiel*

Synopsis

Tarkwa Gold Mine is owned by Gold Fields Ghana, IAMGOLD and the Government of the Republic of Ghana in a 71%, 19% and 10% ratio. The mine is operated by Gold Fields Ghana. This large, low-grade, open pit, gold mining operation is located in Tarkwa, in the Western Region of Ghana, approximately 320 kilometres by road, west of Accra, the capital of Ghana, West Africa.

In the Financial year ended June 2007, the operation mined a total of 108 million tons of which 22 million tons was ore. The mined ore is processed through three gyratory crushers supplying two heap leach pads (north and south) and a carbon-in-leach (CIL) plant.

Before the 6 Sigma project commenced, the current fragmentation was resulting in sub-optimal feed size to these crushers. It was decided to use 6 Sigma methodology to improve the fragmentation. A defect was defined as a fragmentation analysis indicating less than 95% passing 750 mm. The objective was to improve fragmentation in order to achieve a constant throughput to the north heap leach crusher of 1500 t/h, a 5% increase in pit loading efficiency and a 50% decrease in rock breaker hours, equipment damage costs and in-pit sheeting costs respectively.

However, this was not to be achieved at the expense of grade control as Tarkwa is exploiting a low grade, high volume deposit and therefore ore dilution must be kept to a minimum.

This paper is intended to take the reader through the various 6 Sigma phases of the project (define—measure—analyse —improve—control), which have resulted in a 10% reduction in loading times, of which half has been attributed to improved fragmentation, as well as a substantial increase in blasted stocks.

The focus has been on both drilling and blasting parameters as both processes had to be taken into account. These parameters are technical but personnel factors were also identified and dealt with as they arose.

In order to measure the impact of any change in the process parameters on the fragmentation size distribution, cameras have been acquired. One has been installed looking into the bowl of the north crusher and the other one was dedicated to field observation, of individual blasts. Both are used for ongoing fragmentation analysis.

At Tarkwa, mining efficiency is strongly dependent on good fragmentation as well as the presence of unblasted ‘toes’ on the pit floors. Crusher throughput depends on an acceptable ore fragment size. Compliance with plan for actual hole depths was temporarily monitored by manual hole dipping, but this is now being replaced with a fully automated drill data management system developed by Sandvik and Modular Mining.

The Six Sigma methodologies, using control charts based on data collected in the field, allowed the mine to improve methods for the control of blasted material. It also enforced the implementation of a quality control programme encompassing the entire drill and blast process.

Introduction

The primary objectives of the optimization are to maximize crusher throughput and minimize loading times. The greatest influence on both can be realized through improved fragmentation of the blasted ore and waste within the pit.

The measure of the effect of the size distribution of the blasted material was done via:

- Analysis of pictures taken in the pit, after the blast, or from a camera newly installed facing the bowl of the north crusher. This was done with software acquired from Split Engineering
- Monitoring of the rock breaker hours
- Continuous monitoring of loading times for all the mine’s excavators

After the first phases of the 6 Sigma methodology, define—measure—analyse, the improve phase will introduce new procedures and their effect will be evaluated by monitoring the effects of such changes in blasting and mining parameters that affect fragmentation.

Tarkwa Gold Mine

Location and history

Tarkwa Gold Mine is located in Southern Ghana, approximately 320 kilometres by road, west of Accra, capital of Ghana. It is an open pit gold mining operation situated 5° north and 2° west.

The current mining area is 56 square kilometres.

The summary of the mining history given hereunder is based on the work of Griffis, *et al.* (2002), Brown (2000), Smith (1996),

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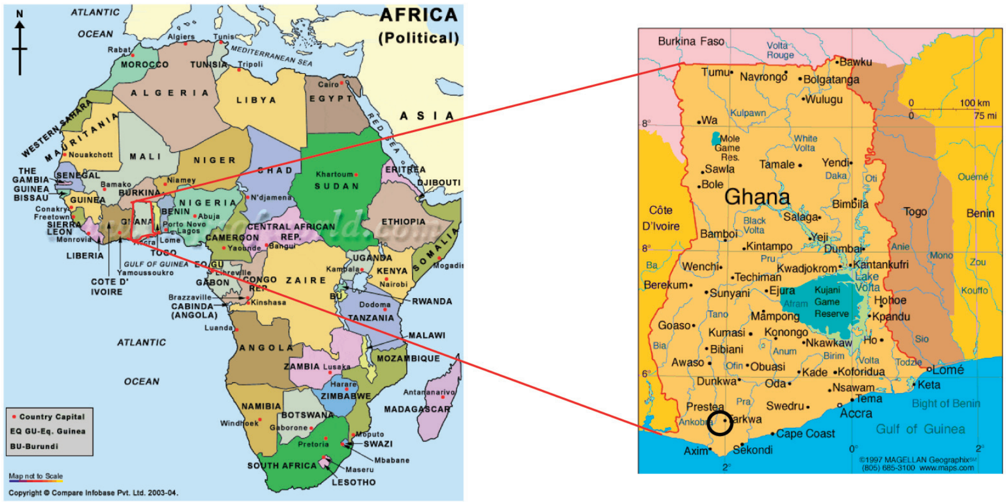


Figure 1—Map of Africa and Ghana. Location of Tarkwa

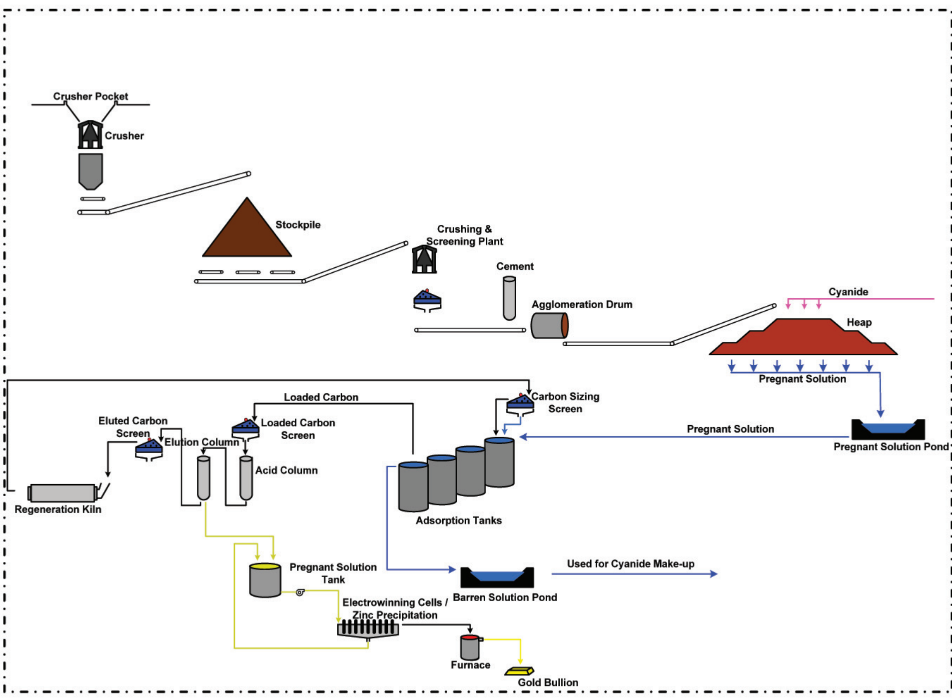


Figure 2—Heap leach flow diagram

Spathelf (2002), Karpeta (2002) and the unpublished reports of Cole (2004 – Abosso Deeps review of previous work) and Morcombe (2005). Records of The Ghana Chamber of Mines have also been used.

Small-scale gold mining activities are thought to have taken place in the Tarkwa district for several centuries. In 1877, rumours of extensive artisanal workings led Marie-Joseph Bonnat to investigate the Taquah area, where he subsequently acquired a 40-year mining lease in 1878. In 1888, the concession passed into the hands of the British registered Tarkwa and Abosso Gold Mining Company. The company was reconstructed twice, once the following year and again in 1900.

The company known as 'Taquah and Abosso Mines Limited' came into existence in 1927 as a result of the reconstruction and amalgamation process, including the, Abosso, Adja Bippo and Cinnamon Bippo Mines and the Taquah Mine located within the Tarkwa town itself.

Amalgamated Banket Areas was registered in 1935 comprising the Abontiakoon and Taquah properties. This was followed by the opening up and development of the Mantraim, Pepe and Akontansi properties.

In 1961 the State Gold Mining Company was registered and this organization took over operations. Amalgamated Banket Areas was later incorporated in to Tarkwa Goldfields in late 1972.

Blast fragmentation optimization at Tarkwa Gold Mine

In 1992 the State Gold Mining Company invited Gold Fields to perform due diligences of both Prestea Goldfields and Tarkwa Goldfields and Gold Fields took over operations at Tarkwa in July 1993.

Surface mining operations began in 1997 and underground operations were discontinued in 1999 once the ore in the underground syncline was exhausted.

Geology

The Tarkwa orebody is a paleoplacer deposit. The reefs are a part of the Banket formation, which consists of several conglomerate horizons separated by barren quartzite.

Reefs can be subdivided laterally and vertically. Lateral subdivisions identify channel deep, channel flank and interchannel environments, each of which has a characteristic gold content, channel flank being the highest.

Vertical subdivisions differentiate time units (T1 to T4) each of which has a different origin and gold content, T3 being generally the highest.

These lateral and vertical subdivisions can be identified in core and in the pits. Their identification facilitates the selection of homogeneous domains.

Due to the alternance of reef/waste layers within the orebody, selective mining is practised at Tarkwa. This allows the mine to achieve planned grades by separating the ore from waste in a way that minimizes dilution and minimizes ore loss.

Mining

The load and haul and drill rig fleets at the time of the project consisted of following:

➤ Liebherr 984 excavators	4
➤ Liebherr 994_200 excavators	4
➤ Liebherr 994B excavators	2
➤ Liebherr 994B face shovel	1
➤ O&K RH120 excavator	1
➤ Caterpillar 785C trucks	36
➤ Tamrock Pantera 1500 drill rigs	20

As from July 2008, the fleets will be increased by 3 excavators, 8 trucks and 2 drill rigs.

Truck allocation (dispatching) is performed by Modular Mining's Intellimine Dispatch Fleet Management System.

Currently, Tarkwa Gold Mine produces an average total of 9 million tons of broken rock per month. Of this total, 7.3 million tons are waste stripping and the remaining 1.7 million tons are gold bearing ore, which is recovered by means of selective mining.

Of the 1.7 million tons of ore, 1.2 million tons are directed to the two heap leach (HL) plants at an average grade of 1.3 g/t, and 485 000 tons are directed to the carbon in leach (CIL) plant at about 1.6 g/t, for gold recovery.

Processing

Currently, an average of 1.4 million tons of heap leach ore and 410 000 tons of CIL/Mill ore is crushed on a monthly basis.

Primary crushing reduces the bulk ore to a fragment size of about 100 mm, from where the CIL material goes straight to the mill.

The HL material goes through secondary and tertiary crushers to reduce the fragment size to an average of 8 to 12 mm, before it gets routed on a series of conveyors to the agglomeration plants.

Heap leach

The crushed ore is conveyed to the agglomeration plant, where it is mixed with about 5kg of cement for every ton of ore.

The agglomerated ore now follows a conveyed route to the leach pads where it is routed to the top of the pads by a series of step-like conveyors. The leach pads are equipped with an integrated irrigation system, which sprays cyanide onto the pads.

The cyanide filters down through the porous gold bearing ore and absorbs the gold to produce a 'pregnant' solution. The pregnant solution is contained at the base of the pads and then routed along a series of channels and drainage pipes to the respective ADR plants. During the final recovery process, the gold in the pregnant solution is adsorbed onto activated carbon. It is then stripped from the carbon with a caustic soda/cyanide solution at elevated temperatures and then precipitated out of this solution by using zinc. The gold is hereafter recovered on a filter press, calsined and smelted.

Tarkwa Gold Mine currently produces an average of 1.1 to 1.3 tons of gold per month, through the heap leach plants.

Carbon in leach

Tarkwa Gold Mine currently produces an average of 630 kg of gold on a monthly basis, through the CIL process.
See Figure 3.

Define, measure, analyse

Define

Define consists of confirming the issue, recognizing there is a problem and obtaining leadership buy-in. The problem statement must be defined clearly, and in our case it is as follows:

- ➤ Current fragmentation results in sub-optimal feed size to crushers. The defect statement is: fragmentation less than 95% passing 750 mm.
- ➤ The goal statement is: To improve fragmentation in order to achieve a constant throughput of 1500 t/h to CR02 consistently, a 5% increase in mining efficiency, a 50% decrease in rock breaker hours, equipment damage costs and in-pit sheeting costs respectively.
- ➤ The target benefit estimation is: an estimate of \$8 300 000 saved per annum.
  The Target timescale: Measure: 07/2007
  Analyse: 08/2007
  Improve: 9 -12/2007
  Control: 01-02/2008
- ➤ The resources: Ralph Adjah (D&B superintendent), Kofi Kaningen (Mine Superintendent), Alexandra Amiel (Section Geologist), Francis Mensah (Chief Surveyor), Louis Gyawu (Planner), Peter Thomson (Technical Services—Unit Manager), Patrick Kpekpena (Mining Manager) Sponsor.

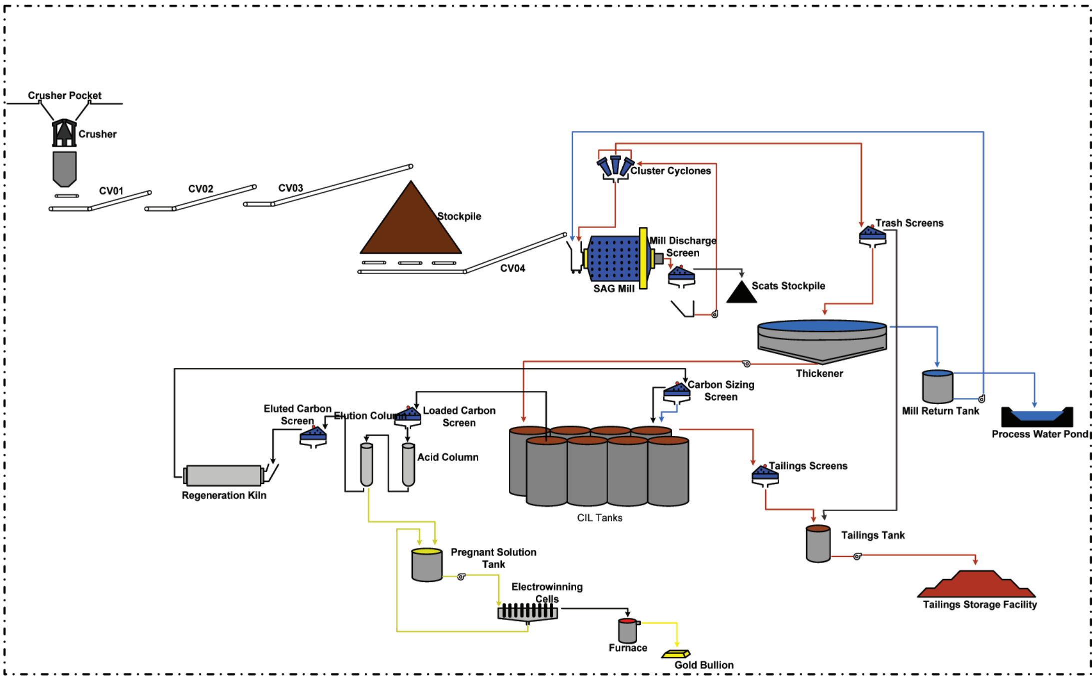


Figure 3—CIL flow diagram

Measure

This step characterizes the opportunity, defines the process, identifies the key inputs, determines the performance against critical to quality (CTQ) customer specifications, and makes lean efficiency improvements.

The voice of the customer (Figure 4) helps identify the key process characteristics:

- ➤ Which of these are critical to delivering customer needs?
- ➤ What is the impact of the measurable things on each of the customer demands?

Customer Demands (VOC) \ Quality Characteristics (VOP)	Relative importance to customer	Proportion blasted on target (%)	No. of lost hours due to damage equipment	No. of rock breaker hours	Hole depth versus planned depths in metres	Amount of in-pit sheeting in $	Quantity and quality of explosives	Fragmentation size (in % passing)	% redrilled
High crushing rate	◉		◉	○	○		◉	◉	△
No toes	○	△			◉		◉	○	
Block design respected	◉	◉				△			
Footwall design respected	◉	◉			◉			○	
Blast according to plan	◉	◉	○			◉			○
No metal GET	◉								◉
Good blasted stocks	◉	◉	○		○	○	◉		◉
Good hauling rate	○					◉		○	
No equipment damage	◉				△		◉	◉	△
Good loading rate	◉		◉		○	◉	◉	◉	○
Totals		20.0	16.2	3.6	21.3	18.6	21.0	21.9	22.2

CTQ

Figure 4—Voice of the customer

The results show that the % redrilled, the fragmentation size, and the hole depths come first in the impact on production and crusher throughput.

The SIPOC (suppliers, inputs, process, outputs, customers) diagram supplies a high level scoping for the process that generates the problem (process divided into sub-processes) and has been established, see Figure 5.

The flow chart, describing the original process, before the project is as per Figure 6.

Analyse

This step establishes the relationship of progress inputs to the customer CTQ and quantifies the key inputs.

At first work consists of defining what parameters are considered to have a crucial impact on the quality of the fragmentation. A fish bone diagram is then established (see Figure 7).

At Tarkwa, the following parameters which have been highlighted have to be quantified:

Groundwater levels are linked to the fragmentation as this results in an increased number of holes to be redrilled, which in turn have a relationship with achieved fragmentation.

The impact of competent drilling supervision and of drilling to design boundaries on fragmentation are difficult to estimate from data and test hypotheses. However, we studied performances according to the different crews, drillers and machines.

Compliance of actual hole depth with design hole depth was monitored and a relationship determined between compliance and fragmentation.

We linked the quality of the explosive to the achieved fragmentation by taking photographs of the different blasts for which we have recorded the quality of the product. The studies also monitored the performance of the different MMU (manufacturing mobile units) trucks delivering the explosives.

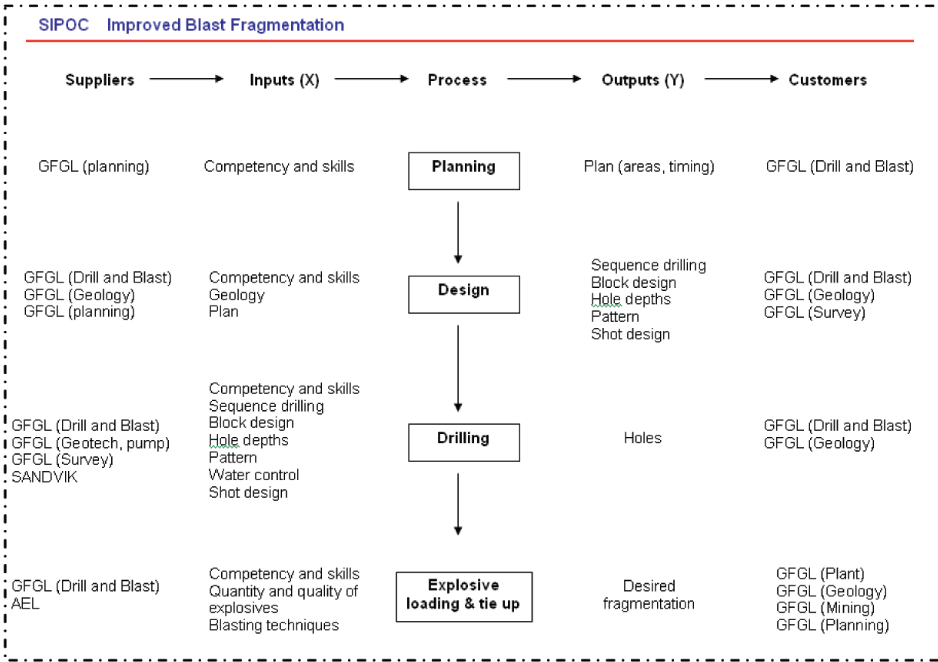


Figure 5—SIPOC

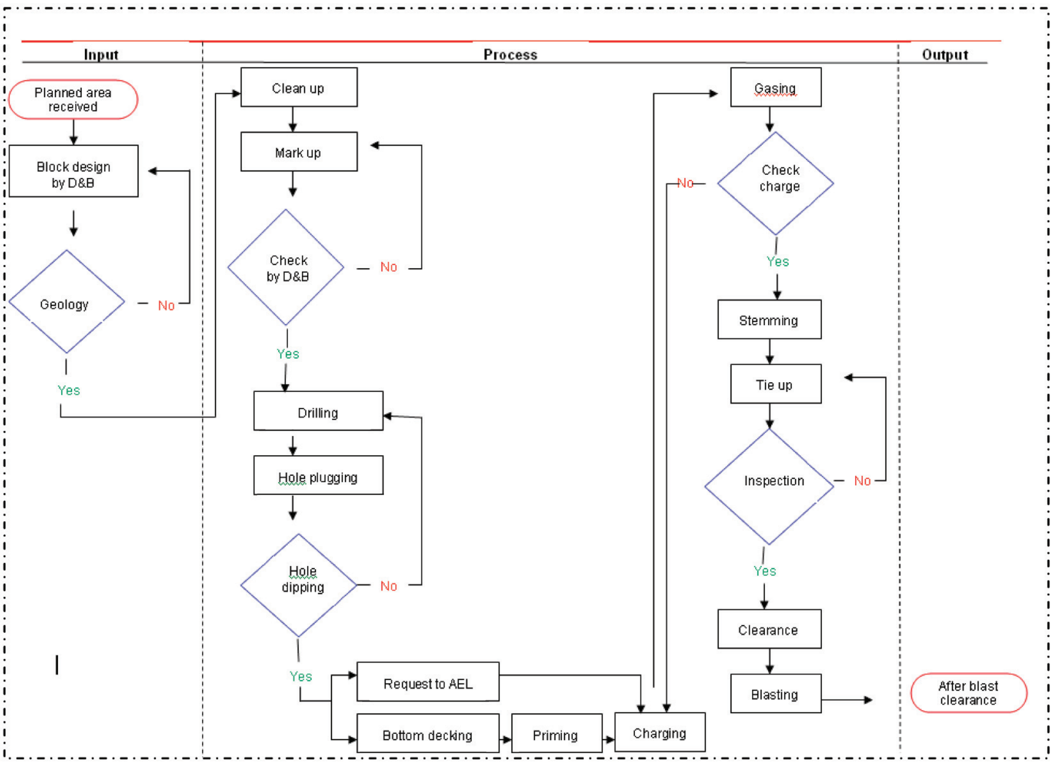


Figure 6—D&B process flow

Data

The parameters identified in the preceding phase had to be checked as being the 'crucial ones'. This was done by using data and performing numerous tests.

The 6 Sigma methods used to analyse the data require knowing the kind of data we work with, in terms of distribution, as well as a minimum number of data for it to be accurate and representative.

If we take the case of the holes not drilled to the correct depth, we are working with a proportion of defects. Therefore, the formula we have to use is: $n = (1.96 / 0.05)^2 \times 0.4 \times (1–0.4)$ as we want 95% confidence, with 20 cm

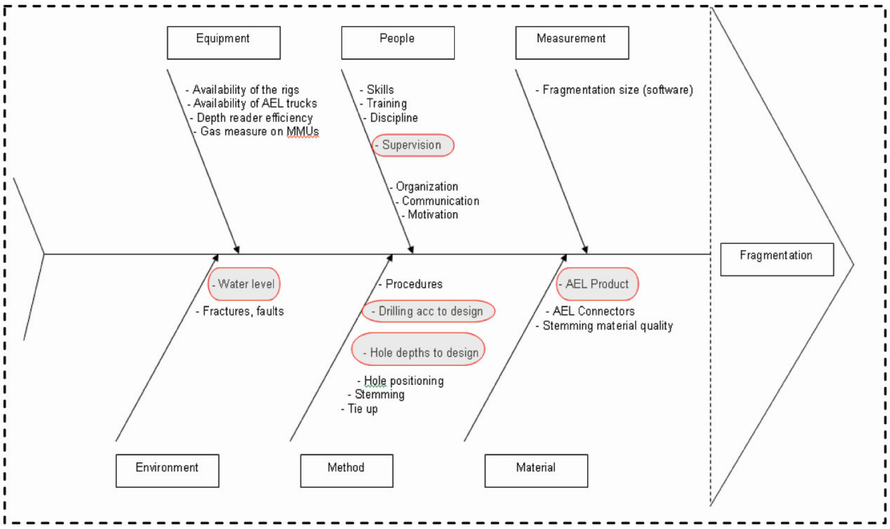


Figure 7—Fish bone

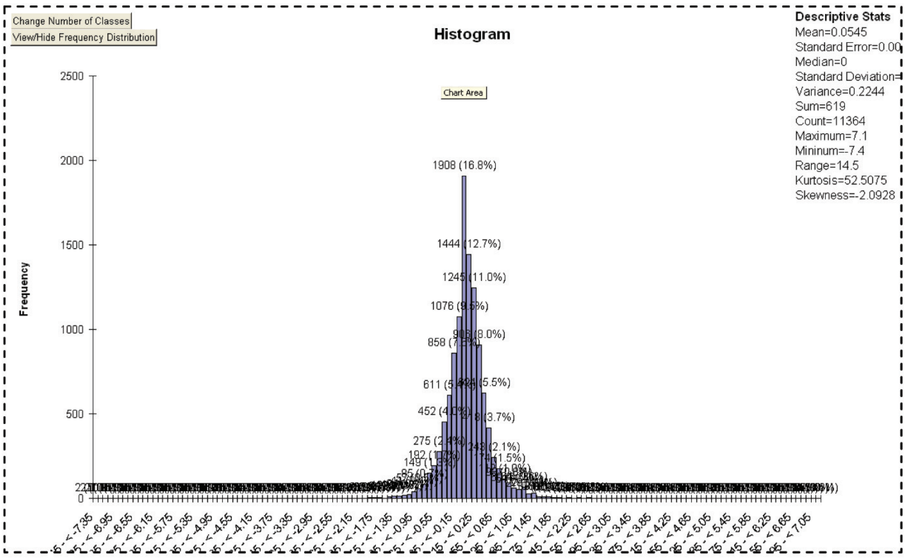


Figure 8—Histogram for the discrepancies between the actual/planned depths (11 365 data points from week 43 to week 45, 2007)

margin of error and knowing that according to various studies 60% of compliance, in average, is met. Which gives us n = 369 holes. All our studies relative to the hole depth compliance use much more data than this minimum number.

Moreover, the distribution of the data shows a normal distribution (see Figure 8), which allows us to perform some parametric tests. In general, we could collect enough data to make all the studies relevant.

Effects of the rainfall

The graphs in Figure 9 show that the proportion of redrilled holes follows the trend of the rainfall.

In terms of water level, the hypothesis tests show clearly that we must solve the water management problem as the amount of redrilling is very dependent on the amount of water present. Redrilling affects fragmentation (loss of power) and is costly.

Supervision and drilling to depth

Drill depth data was collected by employing additional surveyors for a period of three months. These surveyors followed behind the drill rigs, day and night, and dipped each hole drilled

The conclusion of the test hypothesis on this data shows that:

- ➤ Drilling performance may depend on the areas to be drilled
- ➤ Drilling performance does not depend on the crews.
- ➤ All the tests showed that, overall, the crews are performing the same way
- ➤ Drilling performance does depend strongly on the individual operators.

Therefore, even though the crews are performing in the same way overall, they all present ‘good and bad’ performances from individual drillers.

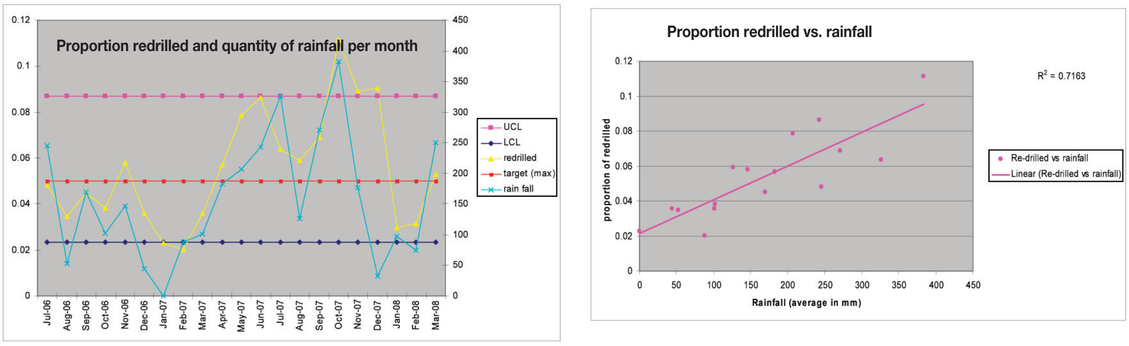


Figure 9—Rainfall in Tarkwa and redrilling

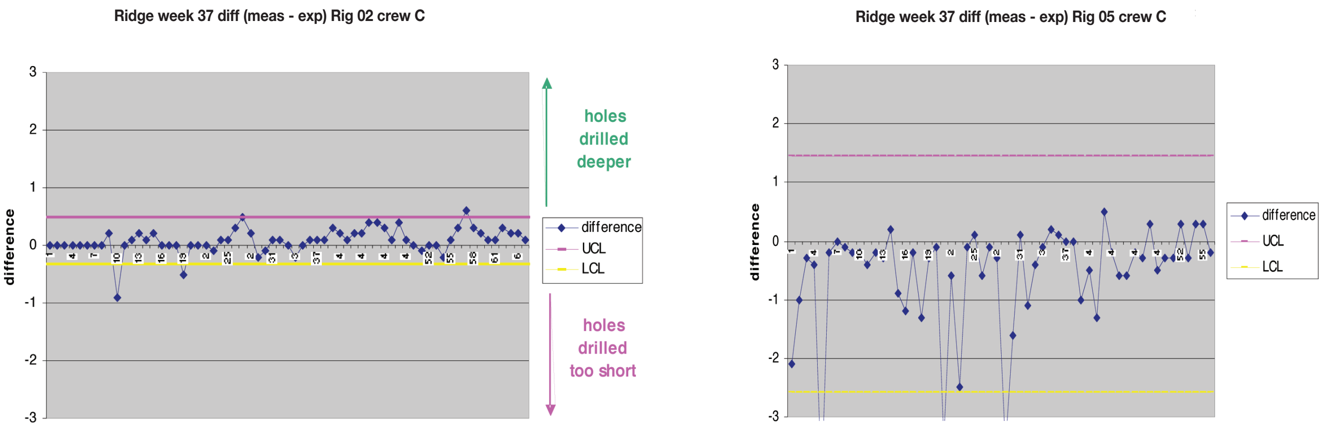


Figure 10—Comparison between the efficiencies of two drillers

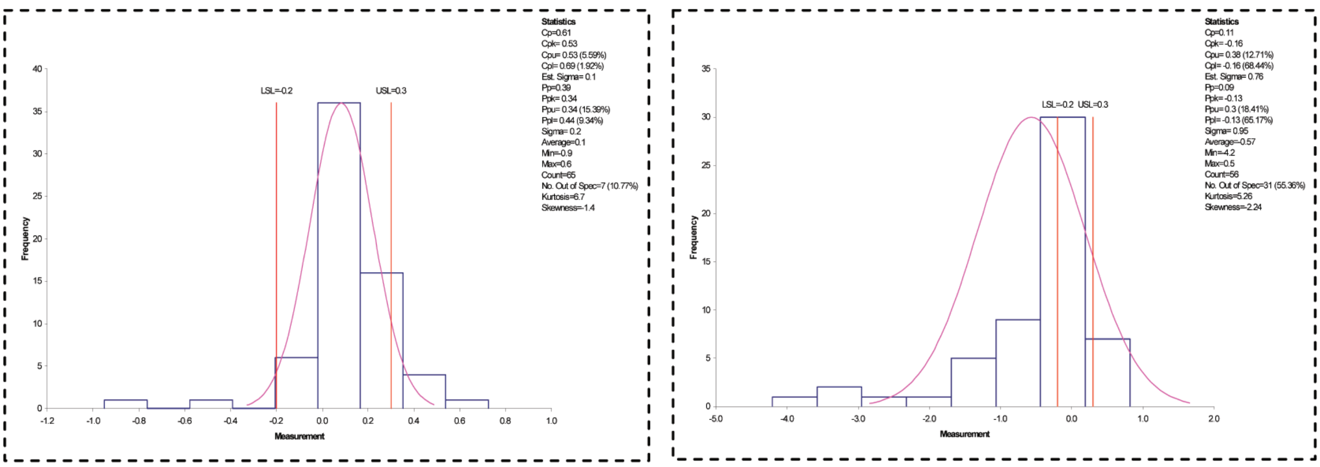


Figure 11—Process capabilities for Rig 02 and Rig 05

Process capability (Cpk) compares the actual variation within a process to its allowed limits of variation. The allowed limits of variation are indicated as USL and LSL (upper and lower specification limits). A process capability of 0.33 indicates a process running at one Sigma. Typical goals for capability indices are greater than 1.33 (4 Sigma).

In our case:

➤ The process capability analysis for Rig 02, with USL = +30 cm with LSL = -20 cm is shown in Figure 11 and indicates a Cpk of 0.53 with only 10% of the result falling outside specification interval. Note that most of the holes outside specification have been drilled deeper and not shorter.

➤ The process capability analysis for Rig 05, with USL = +30 cm with LSL = -20 cm is shown in Figure 11 and gives a Cpk of -0.16, which is extremely poor, with 55% of holes falling outside the specification interval. Note that most of the holes out of specification have been drilled shorter, which means planned floor levels may not be achieved.

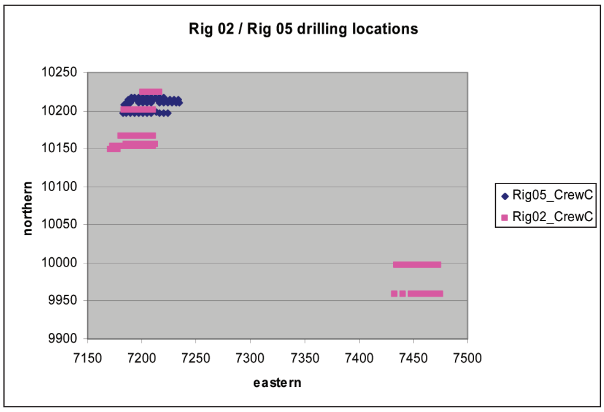


Figure 12—Rig 02 and Rig 05 drilling locations

Figure 12 shows the holes drilled by both rigs to be in the same area. Figures 11 and 12 show clearly that with the same conditions, the performances of the rig operators are very different.

Toes and drilling to design

Studies indicated that the number of 'toes' is linked directly to the ability in achieving design boundaries. Designs must be performed carefully in order to avoid irregular shapes and must be followed strictly in the field. This will help the D&B process to achieve the required fragmentation.

Indeed, a study made before the 6 Sigma project showed that the occurrence of the toes was linked to the irregular shapes of the boundaries between the blasts. To avoid the presence of 'toes' and boulders, the design must be as square as possible and must be followed in the field as per design. An example is shown in Figure 13 and indicates the presence of toes where irregular boundaries meet.

The explosive product

Some tests have been carried out on:
- ➤ The MMU (mobile manufacturing unit) performance
- ➤ The quality/quantity of explosives.

The conclusions show that:
- ➤ The performance of the trucks is the same (the Cpk can, however, be different)
- ➤ The measurements confirm the theory, i.e. the powder factor has an impact on the quality of the fragmentation.

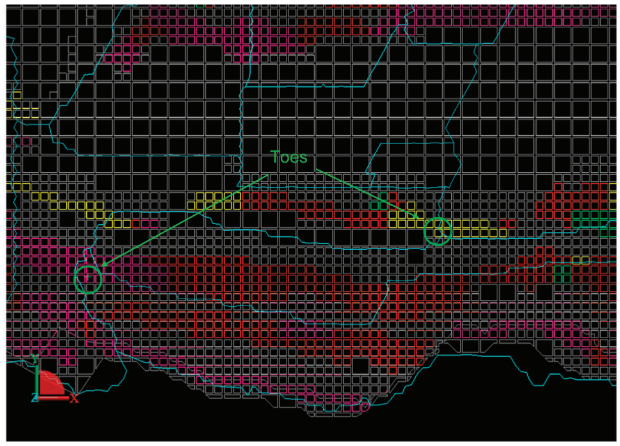
Note that the monitoring of the fragmentation has been possible due to the acquisition of the Split engineering software and the cameras.

According to the conclusions emanating from the tests that have been conducted, indications were that focus must be on the parameters that were identified at the beginning, as per the fish bone.

Improve, control, results

Improve

Determines, validates and implements solutions to achieve the goal statement.



Akontansi Central – 114 and 120 RL flitches

Figure 13—Toes and boundaries

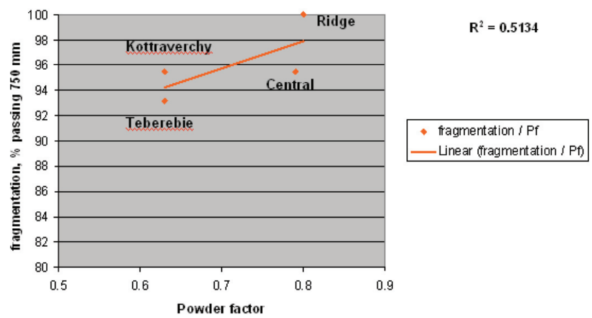


Figure 14—Fragmentation and powder factor

Water control

A programme has been established by the Six Sigma team covering all the pits. The problems have been identified and solutions proposed to reduce them. This programme has been sent across the mine for eventual input from various departments and the final version is with management. A trench and other construction works have been implemented.

D&B is using small cones, placed on top of the newly drilled holes to avoid collar collapse.

Drilling to design boundaries

The design is established by the D&B engineer and must take into account planning, geology and in-pit roads, etc. The design is then marked out in the field by the surveyors upon request of the planners.

The mark-up has been improved as the limits of the blasts are indicated with tapes and not just by pegs representing the corner of the blast, as was the case previously.

The position of each hole to be drilled is marked out by the Survey department using GPS. Measuring ropes (a primitive way of laying out blast patterns) is used only in exceptional cases should there be difficulty in surveying.

Where there is difficulty in achieving the required design, a form (sign-off sheet) exists and defines the compromise that could be found in the field by consulting geology and / or planning.

Floor clean-up, prior to mark-up, was a major factor in delaying blasts and/or leading to blasts not complying with planned boundaries. This item has been improved by involving the production crews in the clean-up operations. A weekly schedule is issued each week by the D&B engineer with deadlines. Each production crew is responsible for cleaning allocated pits.

Supervision and drill depth compliance

Surveyors used to write the required depths on the pit floor during mark-up. This has been stopped as the depths could be erased by heavy rainfalls experienced in Ghana. The required depth for each hole is indicated on plans prepared by the surveyors. The plans are given to the drill rig operators who must align themselves in the field and respect the required depths. The beginning of each row of holes is indicated with flags numbered as per the drilling plans, allowing the drillers to locate individual holes. Hole dippers check depths and short holes are redrilled immediately.

An automated system is currently being installed in each of the mine's 20 drill rigs. This system has been developed by Sandvik and Modular Mining. Once it is up and running, hole depths will be shown on a rig operators' graphics console and the depth of the hole recorded along with the planned depths. Control charts of compliance will then be created automatically for each operator.

The transmission of information has been improved as well. At shift change, the supervisors are arriving earlier to pass on the necessary information and make a round of the pits. This minimizes the misunderstandings of job locations.

A notice board has been installed and shows the future blocks to be drilled and blasted. In parallel, some files have been created on the server for a better communication between the different players within the D&B process.

Training has been intensified. Two information sessions took place for the drilling crews as well as a rock tools session. For the blast crews, a session with the explosive company took place. The geologists have been shown a presentation to improve the communication between these two departments and to update them on the new methods put in place.

A Surpac training session has been held concerning the D&B design function and a multidisciplinary team (consisting of the main actors of the D&B process) attended.

An extra position has been created, a D&B junior assistant. Appointments have been rewritten and signed off. In general, responsibilities are redefined and explained clearly. People must be accountable for their achievements and failures.

Procedures have been rewritten: the improvements put in place are integrated into the procedures and presentations of the job-specific training.

The explosive product

In order to improve gassing control, AEL has been asked to design an automatic alarm system for the MMUs to indicate a fault in the gassing process.

To avoid forgetting charging of any holes, a blue flag is used to indicate if a hole has not been charged.

New techniques

Tests have been carried out to improve the efficiency of the D&B process using new techniques.

First, burden and spacing are now dependent on rock hardnesses as indicated by the geological model. As the pits get deeper, so the rock gets harder. Staggered patterns have been maintained. The original stemming height was maintained as well. Blasts are orientated to throw along strike to minimize ore dilution.

The density of 1.09 g/cc for the explosives has been tested

EMULDENS GASSED EXPLOSIVE CALCULATOR

		Cup	Base	:Default densities	
Explosive Type:	P600	1.00	1.39		
		Lower	Upper	Input	
Hole Diameter	mm	25	450	115	
Cup density	g/cc	0.9	1.25	1.09	1.00
Base Density	g/cc	1	1.45	1.39	1.39
Air pressure	kPa	84	102	99	
Cup temperature	C	10	65	30	
Firing temperature	C	10	65	30	
Gas Loss factor	%	0	30	0	
Stemming length	m	0	10	2.2	
Stemming density	g/cc	1	2	1.2	
Hole Depth	m	2.2	42.4	7	
Bottom density	g/cc			1.208	
Average density in hole	g/cc			1.178	
Total mass	kg			58.7	

Altitude		Pressure
m	*ft*	*kPa*
0	0	101
200	656	99
400	1312	97
600	1968	94
800	2624	92
1000	3280	90
1200	3936	88
1400	4592	86
1600	5248	84
1800	5904	81
2000	6560	79
2200	7216	77
2400	7872	75
2600	8528	73
2800	9184	70
3000	9840	68

Instructions
1 Enter data in Blue cells including explosive type
2 Cup and Base Densities suggested in Red cells
3 Take Air pressure from yellow table above vs altitude
4 Ignore Gas Loss Factor for now
5 Bottom Density goes critical at 1.28, limiting depth of use
6 Refer Claude Cunningham
September 30, 2002

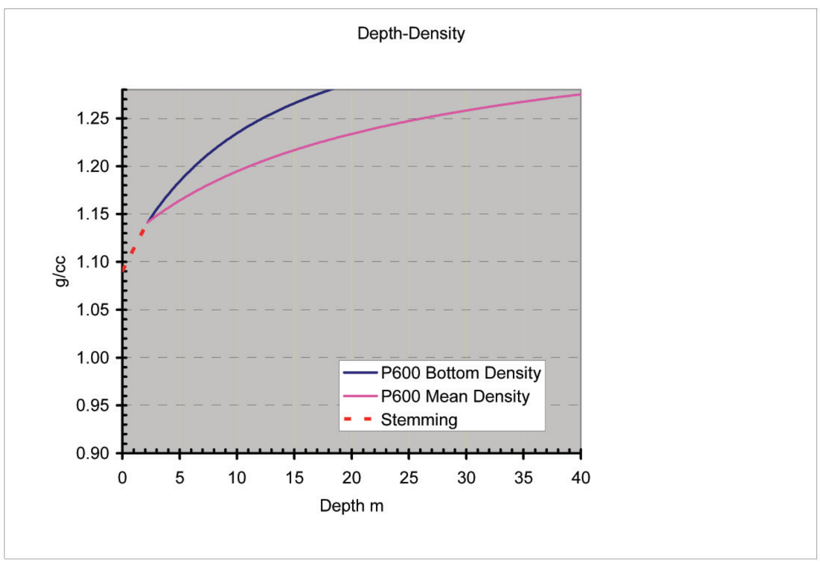


Figure 15—Calculations of the in-hole density with d = 1.09 g /cc

instead of an original density of 1.15 g/cc. This has resulted in cost savings without affecting the fragmentation quality. All the tests so far have been successful. This allows the mine to save money, while maintaining a high efficiency in terms of fragmentation (a saving of around $793 000 per year).

The detonation limit is 1.08 g/cc (i.e. there is no detonation below this density), therefore the 1.09 product is not used for footwall designs where holes are shorter.

Two trials were undertaken using electronic detonators and no discernable difference was observed.

Tulip plugs have been tested with very good results, in wet and dry conditions, see Figure 16:

- Drilling floor improvement
- Less spent ore for in-pit roads
- Loading times reduced
- Powder factor reduced
- Lower heave
- Sub- drill can be reduced
- Increased uniformed fragmentation
- Tyre life could be increased.

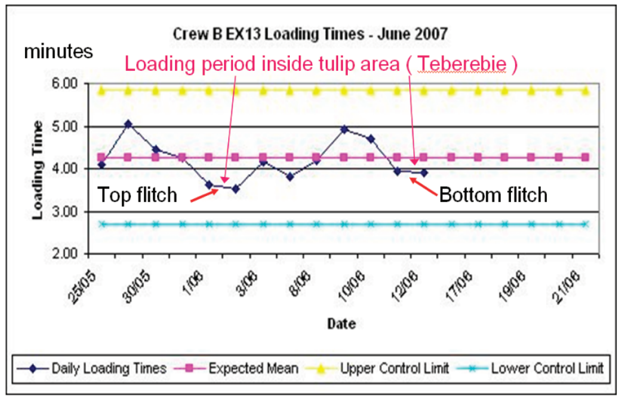


Figure 16—Tulips and fragmentation

Control

The control phase ensures that improvements are sustained and creates an environment of continuous improvement. A control pack has been given to the D&B engineer assistant with instructions to follow.

What is monitored /tested:

- Blast boundaries
- Drilling depths
- % Redrilling
- % Passing 750 mm at the crusher rock breaker hours
- Tests to be done (density, tulips, electronic, casings, bigger Ø)

Each day the D&B engineer assistant has to check the achieved/planned blast boundaries and sends a report to the Chief Geologist, the Manager Mining, and the D&B Superintendent.

The depths of the holes will be monitored by the new system, which should be up and running soon. At present 14 drill rigs out of 20 have been equipped with the system and programmed to transmit relevant data back to the office. One report per week to the mining manager should be sufficient.

Each time poor fragmentation is encountered, a full investigation is carried out. One way of tracking the poor fragmentation areas is to look at the daily loading time control charts established for each digger. For instance, in Figure 17 the digger's capability analysis is -0.06, which indicates that the digger is incapable of operating as expected. This is due to the poor blast in the area in which this digger is working.

Figure 18 is used to describe the roles and responsibilities of people operating a process or delivering a project. It is especially useful in clarifying roles and responsibilities in cross-functional/departmental projects and processes. It has been presented to the D&B personnel involved.

A quality control process map has been established as well. The original flow chart has not been modified intensively but some control points have been added to the process. (See Figure 19.) Financial tracking is also in place to monitor the evolution and financial performance of the project after closure.

Results

Blasted stocks

Blasted stocks have been increased and this allows for flexibility in terms of planning. This is the result of improved organization in the drilling phase. (See Figure 20.)

Rock breaker hours

Rock breaker hours are plotted on the graph in Figure 21 and show that the oversize material arriving at the crushers has decreased dramatically.

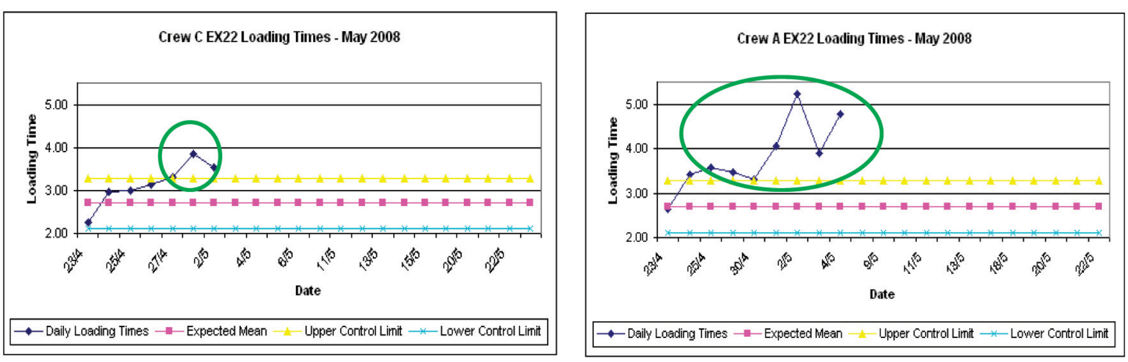


Figure 17—Evolution of the loading time when encountering a poor blast area

Drill and Blast Field RACI

R = Responsible
A = Accountable
C = Consulted
I = Informed

	Sponsor & Pit Manager	Drill and Blast Superintendent	Drill and Blast Engineer	Assistant Drill and Blast Engineer	Senior Drilling Foreman	Section Geologist	Chief Surveyor	Planning Engineer	MMRS	Senior Blasting Foreman
Clean up complete and signed by Section Geologist	I	A	R	I	R	C				
Safe distance maintained between drill rigs	I	A	R	I	R					
Squared up under supervision	I	A	R	I	R					
Rigs drilling along strike	I	A	R	I	R					
Drilling plans available	I	A	R	I	I		R			
Drilling plans used by drillers	I	A	R	I	R					
Blast design tapes in place	I	A	R	I	I		R			
Blast design tapes adhered to	I	A	R	I	R	C				
Drilling flags present and used	I	A	R	I	R					
Hole depth measurement performed	I	I	I	I	I	I	I	I	RA	I
Correct pattern applied to different pits	I	A	R	I	I					
Use of sign off sheets for square up, berms …..	I	A	R	I	R	C		C		R
Cones used to prevent collapse of holes	I	A	I	I	R					
Blue flags available and used	I	A	C	I						R
Tulip plugs available and used	I	A	R	I						R
Density of Product sampled	I	A	R	I						R
MMU sign off sheets signed off correctly	I	A	R	I						R

Figure 18—RACI diagram

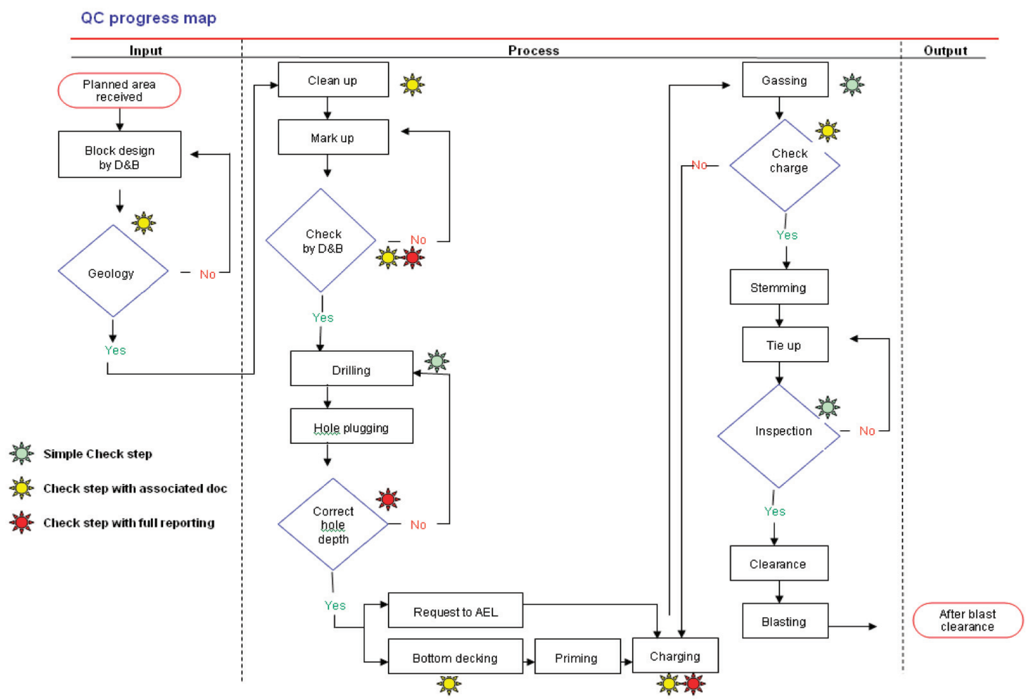


Figure 19—Quality control process map

Proportion of blast to design boundaries

Examples of improvement in blasting according to design are shown in Figure 22. The incidence of toes in the pits has been reduced.

Fragmentation

Fragmentation of 98.5% passing 750 mm was achieved. See Figure 23.

Grade

Dilution may be subdivided into two components, the 'planned' dilution and the 'extra' dilution. Planned dilution is the waste at the top or at the bottom of the reef that is allowed to be taken during select mining. This is quantified (20 cm at the bottom 30 cm at the top of the reef) and included in the ore grade estimates. See Figure 24.

The 'extra' dilution is not included in the ore grade estimates. This is tracked by reconciling truck counts and model estimates in terms of tons. If fragmentation is poor, conditions will not allow select mining to be optimized (the planned dilution will not be respected) and the grade reconciliation can be poor as a result. See Figure 24.

Grade control reports versus metallurgical plant check-out for the period of the project shows a reasonably good correlation with lower variations amplitude. (See Figure 25.)

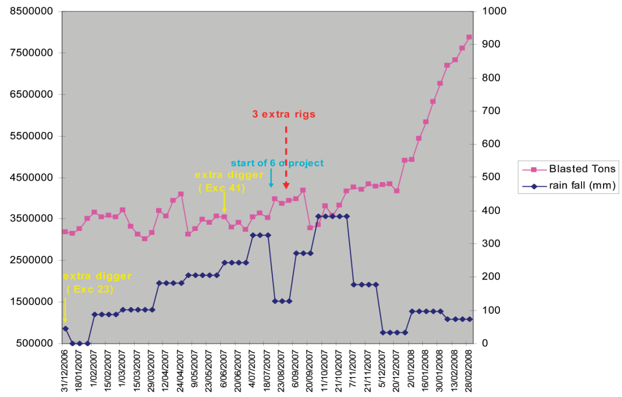


Figure 20—Blasted stocks evolution

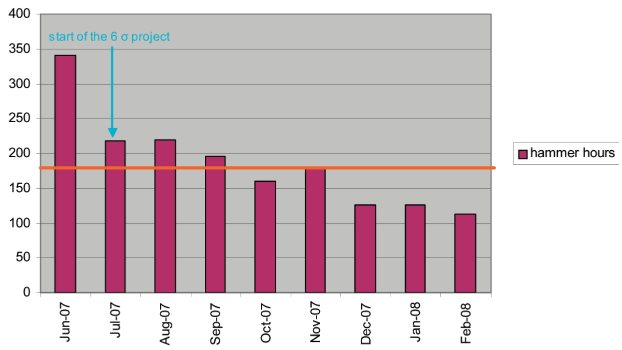


Figure 21—Hammer hours evolution

This is due to many factors and a good fragmentation could have contributed.

Costs

In term of cost savings, the incremental increase in the drill and blast cost with the Six Sigma project is minimal in comparison to the additional revenue as a result of decrease in the loading times. (See Figure 26.)

Record crusher throughputs were achieved during the project.

Conclusions and recommendations

Increased focus on drilling and blasting parameters has been identified as critical to the decrease in loading time and for grade control.

The Six Sigma methodology allowed decisions to be based upon strong data collection and analysis. The implementation of new procedures has been measured and evaluated. Fragmentation size analysis has made it possible to link the quality of the drilling and blasting with the parameters influencing it. The presence of a camera facing the bowl of one of the crushers (with automatic pictures taken every 5 seconds) will provide more than sufficient photographs for interpretation and monitoring.

Some parameters, such as drilling depth compliance, will be monitored in real-time and control charts and plots will be integrated into the automatic system used on the mine.

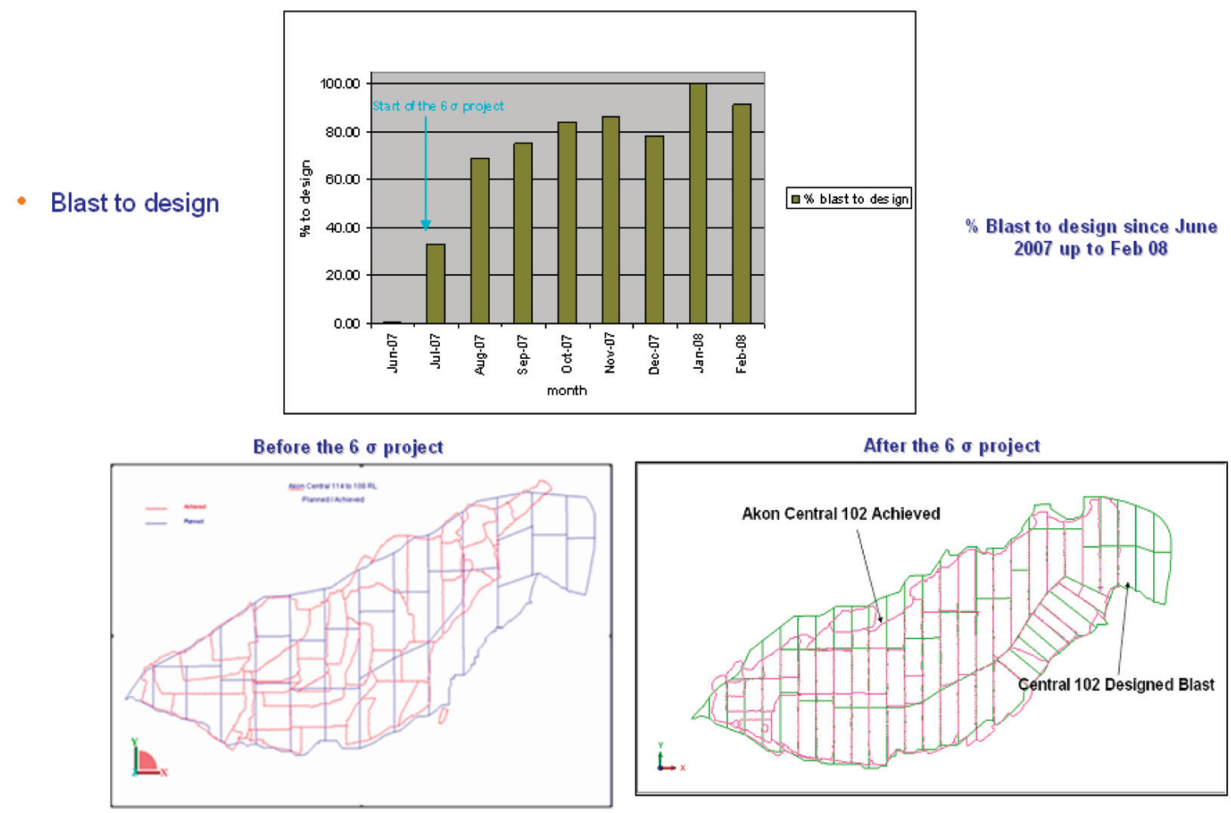


Figure 22—% Blast to design evolution

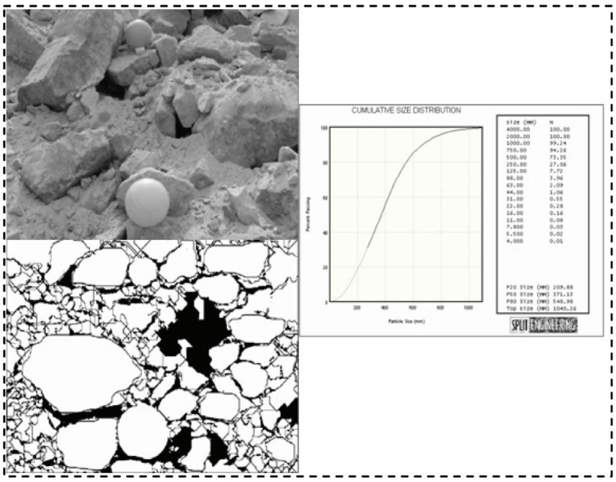


Figure 23—Fragmentation

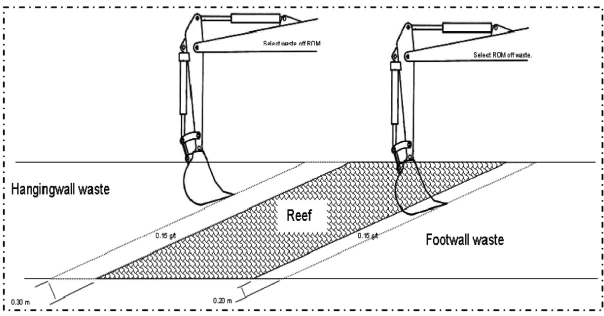


Figure 24—Select mining

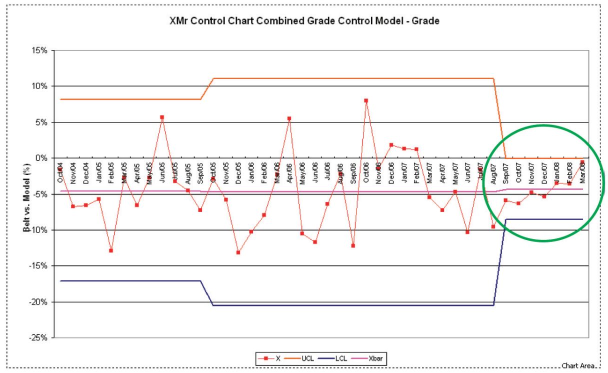


Figure 25—Control chart, belt grade vs. model grade reconciliation

This will allow immediate decisions to be made in order to continuously improve fragmentation.

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	Jan-08	Feb-08	Mar-08	Apr-08
Input				
number of holes @ 1.09 g/cc	2 571	0	3 797	24 334
Loading time average	3.98	4	3.9	3.75
number of tulips used	0	1 486	10 000	18 451
Benefits				
Pot. Additional gold revenue	$1 106,947.91	$1 012 933.72	$1 610 617.34	$2 353 474.46
Tulip Explosive savings	$0.00	$4 623.09	$31 111.00	$76 898.23
Reduced equip damage	$50 000.00	$50 000.00	$50 000.00	$50 000.00
Reduced expl density	$4 169.65	$0.00	$6 157.97	$52 868.05
Reduced R/Brkr Hours	$8 450.26	$9 756.04	-$10 194.41	$10 222.39
Costs				
Tulip costs	$0.00	$3 715.00	$25 000.00	$46 127.50
Drilling flags	$750.00	$750.00	$750.00	$750.00
Others				
Net benefit	$1 164 648.18	$1 072 847.86	$1 655 783.93	$2 443 717.59

Figure 26—Financial tracking