Improvements in Blasting Technology at Cliffs Natural Resources

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ABSTRACT

Blasting is one of the lowest cost yet most critical parts of the mining cycle. This paper discusses the findings of an audit conducted on the blasting operation at an iron ore mine. The purpose of the audit was to review current blasting practices in order to identify opportunities for production/cost improvements. The approach taken in the audit was to observe general blasting practices, their related downstream effects and to compare current procedures to established best practices.

The findings of the audit indicated improvement could be achieved in productivity and lower costs for the shovels and loaders through improved diggability and reduced oversize material in the muck pile. The reduced occurrence of oversize would also improve the crusher operation and reduce the cost of re-handling material in the surge pile.

Based on the findings of the blast audit, a Six Sigma® Diggability Team was formed that utilized the audit report to develop productivity improvements, reduce oversize and lower overall mining costs. The paper discusses the principal blast optimization efforts undertaken and how they improved the mining operation in terms of production. In addition, an overview of the processes developed to quantify and maintain the achieved improvements is included. Description of additional continuous improvement projects currently being implemented and their anticipated benefits is provided.

INTRODUCTION

Cliffs Natural Resources (CNR) is an iron ore mining, concentrating and pelletizing operation located in Michigan, the second largest iron ore producing state in the United States. Near Palmer, Michigan on the Marquette Iron Range in northern Michigan, CNR will move 106 million long tons (104 million metric tons) in 2009 to support the production of iron ore pellets for sale in the United States and Canada. Michigan Operations was formed in 2003 by combining the Empire and Tilden mines. Recognizing that blasting is one of the lowest costs, yet most critical parts of the mining cycle, the mine began a thorough review of blasting technologies to improve mining operations. A key component of this process was a blast audit that occurred during the period of 23 April to 10 May, 2007.

The principal objective of any production blast is to produce a muck pile with characteristics that optimize the downstream mining processes. Although many operators can describe the optimum blast results for a specific mining function, they typically lack a methodology whereby they can relate the key blast parameters to performance of the downstream mining processes and establish an overall optimum blast. The following describes how information obtained from an audit of the blasting operations was utilized to guide a project in optimizing downstream processes and the improvements achieved.

KEY OPERATIONAL ISSUES AT TILDEN AND EMPIRE MINES

The mine management had identified several areas of interest prior to the blast audit. It was requested that the audit consider these concerns which included the following:

- The mine wanted to increase safe production. If the costs could also be lowered that would be an additional benefit.
- The productivity of the LeTourneau loaders was a concern as they frequently experienced difficult digging conditions. The role of the LeTourneau loaders was to provide flexibility to the production while the shovels provide the base production. Due to the difficulty with the LeTourneau loaders, the mine lacked the desired production flexibility.
- A variety of explosive formulations were used at Tilden and Empire mines. Many of these formulations contained aluminum which significantly increased the cost of the explosive. The mine wanted to determine if the aluminum was actually necessary.
- Production was primarily limited by the truck fleet. However, production was also limited by the shovels.

AUDIT FINDINGS

Drilling and Blasting Practices: Design parameters traditionally were based on the last results obtained at the specific location of the blast and the type of rock being shot. The parameters adjusted for the production blasts were the burden, spacing, explosive, and delay timing. The traditional design methodology was to design the pattern to meet an average explosive energy level throughout the blast. The energy level targeted was based on past experience and personal judgment. Nominal blast information is provided in Table 1.

Table 1. Description of nominal blast design at Empire/Tilden.

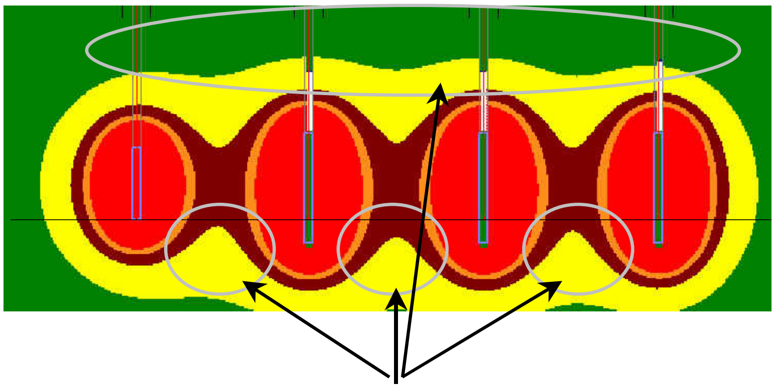
	Production
Burden	35-45 ft (10.7-13.7 m)
Spacing	35-45 ft (10.7-13.7 m)
Pattern	Square
Hole Diameter	16 inch (406 mm)
Bench Height	45 ft (13.7 m)
Hole Depth	52 ft (15.8 m)
Sub-drill	5-7 ft (1.5-2.1 m)
Stemming	26 ft (7.9 m)
Explosive Product	Varies
Lb. per Hole (Ave)	2,800-4,300 (1,270-1,950 kg/tonne)

Two basic explosive types were loaded at the Tilden and Empire Mines. They were a 50/50 emulsion/ANFO blend (an augured product for dry or dewatered holes) and a 67/33 emulsion/ANFO blend (a pumpable product for wet holes). Aluminum was regularly added to both products in amounts ranging from 2% to 7%. The actual product selected for a hole depended on the amount of water in the hole and the hardness of the rock.

The average powder factor during 2006 was approximately 0.54 lb/Lton (0.240 kg/tonne). As of the end of March 2007, the average powder factor has been increased to 0.57 lb/Lton (0.254 kg/tonne). The increase in the powder factor was made in an attempt to improve the diggability of the muck piles for the LeTourneau loaders.

Energy Distribution: The most common approach to blast design is to determine what the optimum bench height would be for a given operational scenario and then select an appropriate hole diameter. The remaining blast geometry parameters are then based off the bench height and hole diameter. The goal of this technique is to design a blast with the appropriate stiffness ratio (defined as the ratio between the bench height and hole burden) to achieve the desired blast results. Generally speaking when displacement and loosening of the broken rock is desired, the stiffness ratios are high with a high percentage of the hole length being loaded with explosives. When it is desired to minimize the rock displacement, small stiffness ratios are employed with less than half of the hole being loaded with explosive. The energy distribution of the first scenario favors rock breakage and therefore is frequently used for rocks that are difficult to break. Conversely, the energy distribution of the second scenario favors rock types that are much easier break.

The stiffness ratios at the Tilden and Empire mines traditionally varied in the range of 1.28 to 1.00 – relative low values which make it difficult to properly fragment the harder rock formations encountered at the mine. Rather than adjust the stiffness ratios, the mine would increase the total explosive energy contained in the blast hole to compensate for the geometric constraints when blasts occurred in the harder rocks. This was accomplished by adding various amounts of aluminum into the explosive. Although the addition of the aluminum did increase the gas energy of the explosive, it also reduced the shock energy and was not sufficient to overcome the geometric issues of the design. Because of the larger burdens and spacings used, the actual explosive energy levels were very high around the blast holes and much lower between the holes. This type of energy distribution in hard rock is prone to produce oversized fragments and hard digging toes.



Potential areas for poor or oversized fragmentation

Figure 1. Energy distribution calculation showing concentration of explosive energy near boreholes with reduced energy between holes and above the level of the powder columns.

Hole Layout: At the time of the audit, all the blast patterns employed square hole layouts. When square patterns are used in difficult rock conditions, it is common to experience oversize fragments and/or poor digging in the center of the square formed by the blast holes. This situation was exacerbated by adjustments in the actual pattern. As in most metal mines, the geometry of the area to be blasted typically could be irregular with sides that were not parallel. In order to compensate for these geometries, the traditional approach to hole placement was to adjust the burdens and spacings within the pattern. This produced patterns with variable pattern footage and hence variable energy distribution (Figure 2). Based on the extent to which the energy distribution varied within a pattern, it would be expected that rock displacement and breakage would also vary considerably within the pattern.

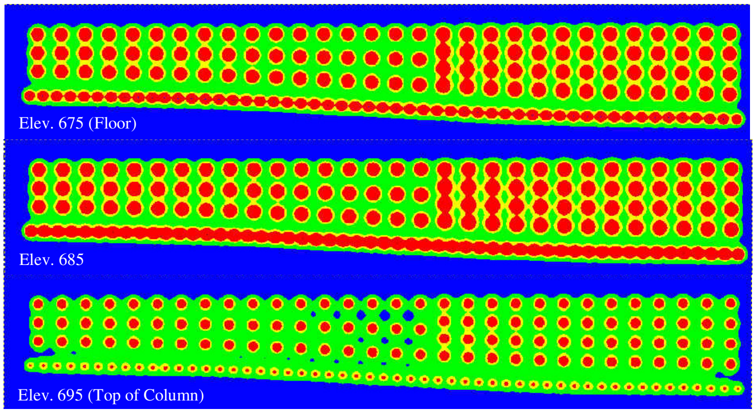


Figure 2. Uneven energy distribution due to variations in hole spacings and burdens.

In the areas with lower energy levels, the holes exhibited considerably more vertical movement and 'cratering'. Since cratering was the result of highly confined holes with little or no horizontal movement, it was expected that the diggability of the rock in the area that cratered would be difficult. This phenomenon was confirmed through interviews with the shovel operators and direct observations of muck pile digging.

Muckpile Characteristics: The digging conditions of the muck piles varied considerably. In the weaker more structured horizons the digging was much easier than in the stronger, more massive horizons. Generally speaking, the muck pile characteristics were found to have two major concerns. These concerns were somewhat interrelated, but not entirely so. The first was diggability of the muck pile and the second was the existence of oversize fragments in the muck pile.

The shovel operators consulted in the audit stated that the hardest digging usually occurred in the bottom of the muck pile. Several of them elaborated further by saying frequently the digging would be easier in areas that seemed to correspond to the location of a blast hole.

The situation for the LeTourneau loaders was worse given their limited bucket reach and wide bucket width and that loaders exhibit the greatest digging capability at the toe of the muck pile. Should the loaders encounter a hard toe that restricted penetration of the bucket, their principal digging advantage was lost.

All of the observed muck piles were found to stand vertically, or nearly vertical, during digging. In a few instances the muck piles were so tight that overhangs were actually created on the active dig face.

Material flow was minimal with occasional mass flow of material from the upper half of the muck pile when the dig face would become unstable. Front end loaders operate more efficiently when the dig face is angled back and the material flows towards the loader. In addition, the observed overhangs and mass flows that occurred presented safety hazards to the loader operator.

Crushing: The primary crushing experienced frequent blockages caused by oversize material. Crusher information from the mine dispatch system showed that for the year 2006, the three primary crushers at the Tilden/Empire mines had a collective total of 37 shifts (293 hours) of downtime due to blockages at the crusher. During times when the crusher was down, the haul trucks were rerouted to dump at the surge pile. The material dumped at the surge pile represented a considerable amount of waste in the process stream as the material required rehandling.

AUDIT RECOMMENDATIONS

Based on the findings of the blasting audit, several recommendations were made. Of these recommendations the following were determined to offer the greatest potential for blast optimization with the least disruption to the mining operation;

1) Staggered hole patterns should be used instead of the square patterns,
2) The hole layout process should be revised so as to maintain a more uniform explosive distribution throughout the blast pattern,
3) The timing between rows should be increased to allow for more rock movement while the timing between holes within a row should be decreased to improve fragmentation,
4) The addition of aluminum to the explosive was not required and in many instances would be counter productive to the desired blast results,
5) A Blast Optimization Team should be created to develop a framework for continuous improvement to identify, create, and capture value added solutions to the blasting process.

SIX SIGMA®

Six Sigma® is a registered trademark of Motorola University. In 1988, Motorola was awarded the Malcolm Baldrige National Quality Award. The award for excellence identifies firms that are role models for other businesses. One of Motorola's innovations was its Six Sigma® program. Motorola University is considered the corporate equivalent of MIT or Harvard. Six Sigma® is a quality improvement, metrics driven, process that has become a part of corporate culture from human resources to marketing and industries from mining to financial services.

Cliffs Natural Resources adopted the Six Sigma® methodology in 2005. At CNR, Six Sigma® teams analyze processes where the root cause of the problem is not easily understood. The Six Sigma® teams use sophisticated tools to discover the “root cause” of problems, eliminate variation and stabilize the processes. As a methodology, it’s analytical and statistical approach have provided substantial benefits to Cliffs.

SIX SIGMA® DIGGABILITY TEAM

A Six Sigma® Diggability Team was formed that utilized the blasting audit’s findings as the basis for blast design changes to improve diggability. Management mandated that the team complete its work in 5 – 6 months, so that all changes could be budgeted for the upcoming year. Because it can take several months to completely mine out a blast and review the results and because of the tight time frame given the team for completion, several changes to blast design were implemented simultaneously and evaluated together for effectiveness on diggability.

The Six Sigma® methodology applies five basic steps for improving existing processes. These steps are; Define, Measure, Analyze, Improve and Control.

Define: The define stage identified and validated the business improvement opportunity and launched the project. The team charter stated, "Currently blast results are highly variable and contribute to higher pit operating costs. Broken ground cannot be loaded efficiently with certain loading units, primarily the loaders. Too much oversize is generated resulting in plugged crushers, secondary handling and breaking of chunks. Loader operators and truck drivers are subject to too much risk." There was opportunity to change blast design criteria to improve diggability and safety.

The team was formed with the hypothesis, "If I change the blast design, will I improve diggability?" In Six Sigma® terminology the Big "Y", or the challenge and team focus, was lost loader production and employee injuries. Processes were mapped with critical customer/critical business requirements and "Quick Win" opportunities. Some of the quick win opportunities included, changing blast hole design layout from square/rectangular to staggered, implementing an information feedback system for operators to evaluate a blast's diggability, and changes in blast timing.

Measure: The measure stage identified and developed the measurement methodology. Cause and effect diagrams and other tools were used. Data collection as a measure of diggability was thoroughly reviewed. In all, seventeen measures of diggability were investigated. These included photometric fragmentation analysis, dynamic digging rates, plugged mill chute frequency and secondary breakage to name a few. Most of the measures were rejected because of inadequate records, safety issues, or were too subjective and cost prohibitive. The measures that could be validated were dynamic digging rates, chunk crusher delays, and incident reports. Blasting vibration complaint frequency was also analyzed as an ancillary project, not directly related to diggability.

Analyze: The analyze stage identified and validated the root causes determining the true sources of variation that led to diggability issues and safety related concerns. The extensive blast audit was the primary information source for the team during the 'Analyze' stage. The analyze stage consisted of both passive analysis of historical data and active analysis of blast design changes. Using both passive and active analysis, statistically it was proven that blast design changes did improve diggability. The key blast design changes evaluated for effectiveness on diggability included:

- Staggered patterns to improve energy distribution,
- Higher powder factor and energy levels,
- Electronic detonators for more precise timing,
- Changes in timing sequence between blast holes,
- Top and bottom priming for more efficient detonation,
- Elimination of costly aluminized blasting agents,
- Development of an information feedback system to track changes and results.

Improve: The improve stage identified, selected and evaluated possible solutions, determining the right diggability improvement solutions. Once the solutions were selected, a change management plan was developed and implemented with the final selected solutions. Analysis demonstrated that the blast design changes were statistically significant. The changes have been implemented on a permanent basis resulting in productivity gains, fewer crusher delays and greater operator safety (Figures 3 to 6). In the twelve months prior to team formation there were 9 'jostling' incidents with loader operators and truck drivers. Jostling incidents occur when a truck driver or loader operator is tossed around in the cab even though seat belts were worn. Difficult digging with poor bucket penetration in the mining face can cause a loader operator to be jostled. Similarly large chunks dumped into a production truck box can jostle the truck driver. Twelve months after team formation, there have been no jostling incidents. Blasting vibration complaints from surrounding communities averaged 5-6 per year prior to team formation. In the twelve months after team formation there were none.

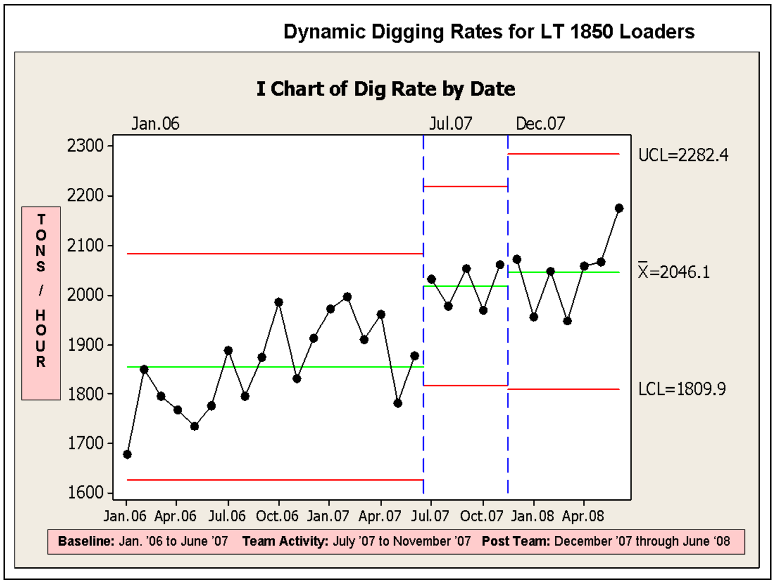


Figure 3. LT 1850 Loader Dynamic Dig Rate Before, During and After Team

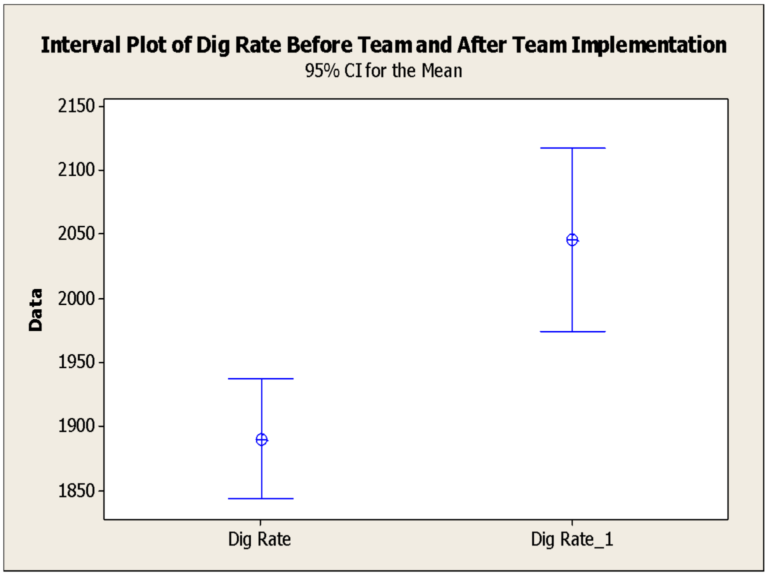
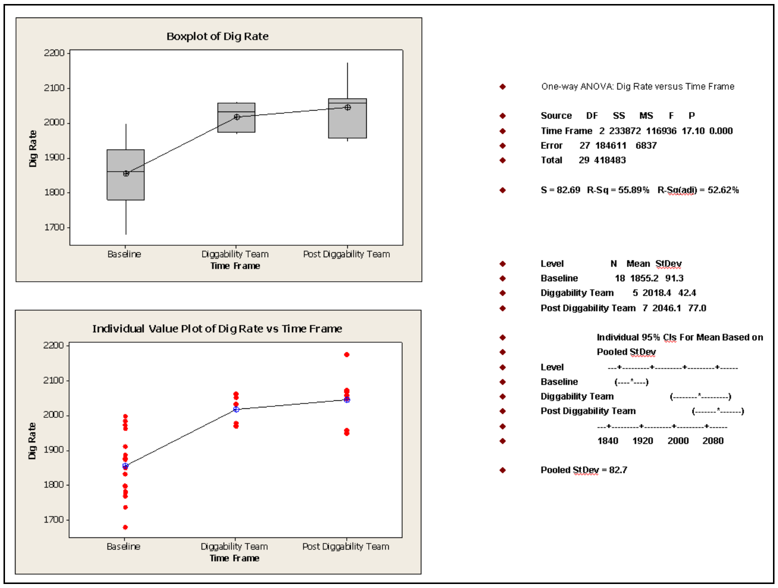


Figure 4. Dynamic Dig Rate Before and After Team with 95% CI for the Mean



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◆     One-way ANOVA: Dig Rate versus Time Frame

◆     Source     DF    SS      MS      F     P
◆     Time Frame  2  233872  116936  17.10  0.000
◆     Error      27  184611    6837
◆     Total      29  418483

◆     S = 82.69   R-Sq = 55.89%   R-Sq(adj) = 52.62%


◆     Level                   N    Mean  StDev
◆     Baseline               18  1855.2   91.3
◆     Diggability Team        5  2018.4   42.4
◆     Post Diggability Team   7  2046.1   77.0

◆                     Individual 95% CIs For Mean Based on
◆                     Pooled StDev
◆     Level              ---+---------+---------+---------+------
◆     Baseline             (----*----)
◆     Diggability Team                  (--------*---------)
◆     Post Diggability Team                   (-------*-------)
◆                     ---+---------+---------+---------+------
◆                      1840      1920      2000      2080

◆     Pooled StDev = 82.7
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Figure 5. Statistical Significance of Changes in Dynamic Dig Rate

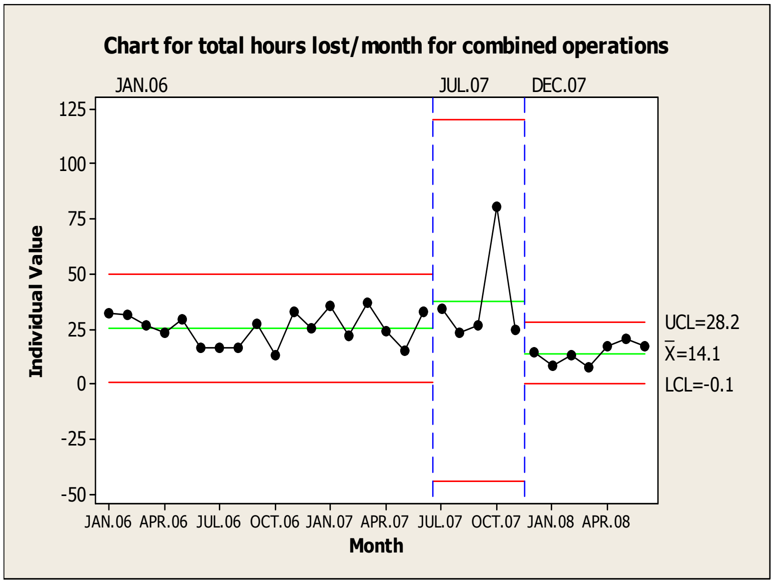

Figure 6. Combined crusher chunk delays Before, During and After Team

Control: The control stage, the fifth and final stage of the Six Sigma® business improvement process, formally implemented the improvement solutions, measured business impact, summarized the lessons learned, and created a process control plan for sustaining the improvements. Part of the continuous improvement process, included formation of a Blast Optimization Team which is a partnership of mine personnel, the explosives manufacturer and the local explosives supplier. The team reviews cost savings projects, blasting procedures, safety issues and technologic advances in drilling and blasting looking for opportunities that will improve productivity, cost savings and safety. The various activities of a Blast Optimization Team are shown in Figure 6.

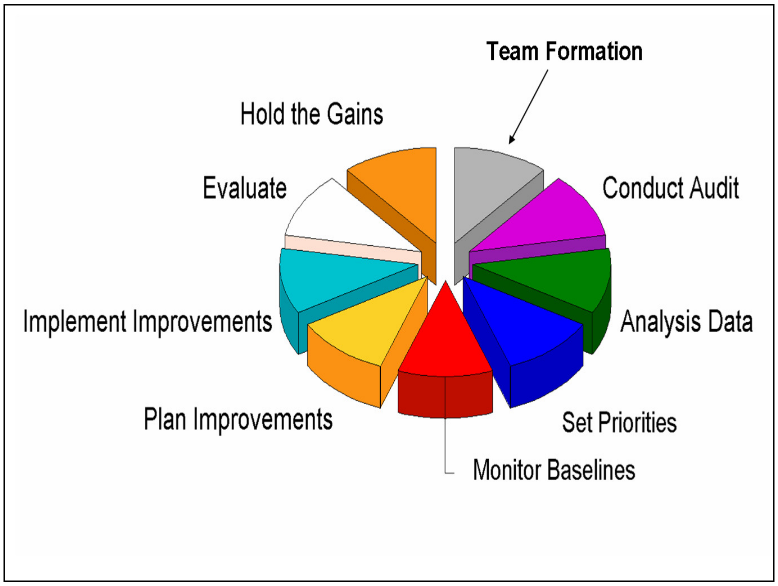

Figure 6. Blast Optimization Team

SUMMARY

Combining the blast audit with Six Sigma® methodology improved diggability through blast design changes. Using both passive and active analysis, statistically it was proven that changes in the blast design achieved the following:

- Improved LT-1850 Loader productivity by 9%
- Decreased crusher chunk delays by 44%
- Decreased blasting complaints from neighbors (5-6 per year to 0 in the 12 months after team formation)
- Improved safety for equipment operators through reduction of jostling incidents (9 incidents in the 12 months prior to the team formation compared to 0 incidents in the 12 months after team formation)

An independent technical and operating review of mining operations in January, 2008 stated, "The Motorola Six Sigma® quality improvement for mining processes focusing on defect elimination (improved rock diggability) is a notable recent success."(1) "The impact of the recent Diggability Six Sigma® initiative is evident and muck piles were well and evenly fragmented."(2) "We noted that the muck piles had excellent fragmentation during the visit. The process has been the subject of a Six Sigma® group focus which clearly enjoyed success. Continue to sustain the excellent performance seen during our visit."(3)

Currently a Six Sigma® Mine to Mill® Team and a Six Sigma Drilling Improvement Team continue to build on the success of the Six Sigma Diggability Team.

REFERENCES

(1) Jim Decker & Associates Inc., 2008, "CCMO Technical and Operating Review", page 6.
(2) Jim Decker & Associates Inc., 2008, "CCMO Technical and Operating Review", page 8.
(3) Jim Decker & Associates Inc., 2008, "CCMO Technical and Operating Review", page 19.