ABSTRACT: Too often, a mine’s operations, including drilling, blasting, loading, hauling, crushing, processing, etc., are considered independent steps, rather than a continuous process. In fact, these are interdependent operations with each step in the process having an impact on subsequent operations. If the effectiveness of the drilling and blasting operations can be improved, they will impact the entire mining process. Some of the resulting improvements include: level benches on grade; fragmentation and diggability with the result being reduced loading times; haul cycles improvements; and the crushing and milling operations will be more efficient and less energy consumed. Thunderbird refers to this as “Drill to Mill” information cycle or process.

This paper focuses on two of the technological enhancements Thunderbird has added to its drill monitors that allow the mines to impact the “Drill to Mill” concept. These enhancements are: incorporating global positioning satellites into drill monitors; and radio off-loading of data.

Thunderbird is part of the Integrated Mining Systems (IMS) alliance. IMS offers the mining industry the most comprehensive line of monitoring and navigation products available today for mobile mine equipment. In addition to Thunderbird’s drill monitors and GPS systems, the product line includes: Fleet Management Systems for trucks and loaders; dragline and shovel monitors; GPS based navigation systems for shovels, dozers and other mobile equipment; and surveying systems. IMS uses common communication systems, operating systems, and hardware components in order to provide a truly Integrated Mining System.

INTRODUCTION: Thunderbird and its predecessors have been involved with the development and manufacturing of blasthole drill monitors since 1980. Today, it has hundreds of systems operating worldwide in virtually every type of surface mine. During this time, significant improvements have been made in the electronic hardware and reporting software which have improved the reliability and capability of the systems. Two current technologies that are dramatically enhancing the value and capability of drill monitors are radio off-loading of the drill data and GPS. These, in turn, are beginning to impact the downstream operations, and over the next several years should make significant enhancements to the “Drill to Mill” process (Figure 1).

Among the specific benefits being seen by users of monitors and GPS on drills, are the following:

1. Reduced overdrilling
2. Increased rate of penetration
3. More time drilling—increased footage
4. Identifications of weak or strong zones
5. Help locating coal seams
6. Reduced geophysical logging
7. Optimizing blasts
8. Improved fragmentation and diggability
9. Reduced maintenance costs
10. More accurate hole locations and directions
11. Improved bench quality
12. Reduced surveying costs
13. Improved accuracy of data and reports

Global Positioning Satellites or GPS is having a major impact on mining today. GPS systems are being used for surveying, and are being incorporated into a number of other monitoring and navigation products. These include applications in products such as shovel monitors for grade and ore control; fleet management systems for determining equipment location, speed, and distance traveled; dozer systems for grade and reclamation work; and drills for navigation and hole location.

Thunderbird offers two types of GPS systems for drills. The first of these systems, DrillGPS, uses a single GPS receiver and is used to log the drill hole location. It is used in conjunction with the Stratalogger drill monitoring system. The second system, DrillNAV, is a fully integrated drill navigation system.

Figure 1: Drill to Mill Process Information System
DrillGPS allows the precise position of where each hole was drilled to be logged. This information can be incorporated into the blasting plan so there is no guessing as to where the hole was drilled. The use of this system also eliminates the need to resurvey the hole positions as is done at some mines to insure that they accurately correlate assay samples with hole positions for ore control. There is no operator involvement. The GPS information is automatically tagged to the hole drilling information in the Stratalogger database. This information can also be transmitted via radio so that the location and elevation of each drill is available in the mine office in real-time. These systems are being used on two large drill fleets at Kennecott’s Bingham Canyon mine and USS’s Minntac mine.

The system consists of an Ashtech GG-24 receiver and antenna, a Spread Spectrum radio and antenna, and interface firmware to the Stratalogger drill monitor. The GG-24 uses satellites from both the U.S. Navistar GPS system and the Russian GLONASS system. In deep pits, such as Bingham Canyon or Chuquicamata in Chile, conventional GPS systems have not proven to be viable. They have a high percentage of time where there are insufficient satellites to provide a reliable fix, and therefore the GPS systems on the drills cannot be used for navigation. The GG-24 GPS receivers have overcome these problems and are the standard receiver used by the IMS group for high precision navigation applications.

Thunderbird and its IMS partners have recently introduced the second generation of the DrillNAV system. The first of these systems was commissioned at Peabody’s Bengalla mine in Australia in 1999. This mine is a truly integrated mine. In addition to the DrillNAV systems, it has Thunderbird’s drill monitors; Tritronics’ Fleet Management System for trucks, shovels, water trucks, and dozers; and a Tritronics dragline monitor.

DrillNAV is a robust, easy to use, blasthole drill navigation system utilizing GPS technology. Mines can design drill patterns in the office and radio them to the drill, or the operator can layout the pattern while on board the drill. However designed, the pattern will appear on the operator’s touch, sunlight readable, VGA color display. It is a moving map display. (See Figure 2 for sample screens). As the drill navigates around the pattern, the map moves on the operator’s display. The operator’s screen shows where every hole should be drilled and the location of previously drilled holes. In addition, the operator sees the bit elevation above sea level as he is drilling allowing him to drill to a specified elevation rather than a depth.

DrillNAV was designed with the operator in mind. Effectively displaying the position of the drill, as well as the hole design location, enables the operator to quickly incorporate DrillNAV as another “tool” on the drill. After drilling two or three holes using DrillNAV, an operator can navigate effortlessly to within 20 cm of the designed hole location. System parameters are provided to the operator, with easy to understand information, including when the GPS accuracy is acceptable and when the drill is located within the mine’s hole position tolerance distance.

DrillNAV eliminates the need for surveyors or drillers to stake a drill pattern. There is no more guessing at hole locations due to lost or buried stakes, jockeying around a stake in darkness, or down time due to lack of staked patterns. DrillNAV operates on the same map file used by the surveyors to stake a pattern. All coordinates are in local mine grid coordinates. It allows holes to be drilled to a defined elevation above sea level, reducing over or under drilling. There are no hard toes to dig out causing non-level excavating. The result is level benches, with less water pooling, and smoother haul roads.
Figure 2: Sample DrillNAV Screens
The system allows for easy visualization of the blast pattern versus the blast results allowing pattern modifications to be made to improve the next pattern. Accurately drilled holes (parallel and to correct elevation) leads to better rock fragmentation and a decrease in overall blasting costs. Engineering’s confidence in the drilling will lead to less overloading of holes and better overall pattern design.

The drill and GPS data improves the geological model since the drill hole location of every assay is known and the information can be incorporated to update the model. When linked to drill monitoring, hard or otherwise difficult drilling zones can be located and the blasting adjusted. Blending can be used to optimize the hardness of the material being fed to the mill, or the mill can be given advanced warning of unusual feed characteristics.

DrillNAV uses the patented Ashtech GG-RTK™ (real time kinetic) positioning technology discussed previously. RTK is up to 100 times more accurate than Differential GPS. In addition, RTK only requires a short initialization period on power up until it has centimeter level accuracy. The GG-RTK receiver can fix integer ambiguities where no other L1 GPS-only RTK system can. Map data transfer to and from the drill is by Spread Spectrum radio. This radio operates in the 900 MHz range at 115 KBAUD. This frequency range at this power is unlicensed in the United States and most other countries. Data can travel 30-km line of site with these radios.

The on board operating system is QNX®, the market leader for mobile equipment applications requiring embedded PC compatibility. The processor is quick, allowing the operator’s screen to display real time information. DrillNAV uses solid-state inclinometers to provide mast angle, drill pitch, and roll data so the operator can set up level and angle the mast correctly. The on board compass allows the operator to set up on azimuth easily too.

In order to realize the full benefits of the “Drill to Mill” concept, drill data must be available in real time or at least by the end of each shift. This allows the data to be converted into information for use by operations, geologists and engineering. For this reason, Thunderbird has placed a real emphasis on having mines install radio systems for off-loading of the drill data. The goal is to minimize the human involvement and to have the data available in real-time or as close to real-time as is practical.

Historically, data was transferred from the drills to the office using a laptop computer. The problems associated with this method are self-evident—labor intensive, random timing, and historic data. An alternative, which overcomes most of these problems, is Thunderbird’s StrataCARD. This device uses a PCMCIA card. The drill operator transfers the drilling data from the Stratalogger drill monitor onto the StrataCARD at the end of the shift, and carries the card back to the office. Reports on the drilling productivity are thus available shortly after the shift change. A number of Thunderbird’s customers are now using the StrataCARD system, and some of the potential problems perceived with the product, such as lost or damaged cards, have not been issues.

The third alternative to the laptop and StrataCARD is off-loading or transferring the drilling data via a radio system. This method is the most complex and capital intensive, but provides the mine with the most timely and accurate information, and is done with no human involvement. Today, Thunderbird has radio systems operating in conjunction with Modular Mining, Tritronics, and Wenco fleet management systems, as well as its own dedicated drill radio system. In addition to off-loading the drill data, these systems allow for the real-time displaying of drill information and two-way communication, i.e. messages can be sent to the drill. Thunderbird is convinced that in order for a mine to maximize the
utilization of the drill systems, and particularly with larger fleets of five or more drills, a radio system is essential.

The world’s first drill monitoring system which used radios to off-load data, was a Thunderbird system installed at Quebec Cartier iron ore mine in Canada in 1992. The system utilizes the mine’s Wenco truck dispatch system radio infrastructure for the drills. The radio system was upgraded to DataRadio modems and Motorola radios operating at 4800 baud in late 1997. The drill fleet currently consists of two P&H 120s and five G-D 120s. The drill systems run trouble free. Thunderbird has not had an engineer or technician on-site since the radio system was upgraded. Hardware maintenance is carried out by mine personnel and Thunderbird supports the software via modem.

Some of the system features include: 1) real-time data is displayed in the office and on Wenco’s Mobile Supervisor Terminal in foremen’s trucks; 2) onboard messages and displays are in French; and 3) drilling data is uploaded into the mine’s mainframe. Benefits realized from the Stratalogger system include: reduced operating and maintenance costs; increased drilling performance; and much quicker follow-up on drill delays or maintenance problems due to the radio link. More specifically, QCM has reduced overdrilling by 3%; increased penetration rates by 1.75 meters/hour; gained a 15-minute per shift savings on delay follow-ups; and reduced maintenance costs.

In 1996, Kennecott’s Bingham Canyon copper mine purchased seven of Thunderbird’s Stratalogger systems for their Bucyrus 49R drills following a 12-month evaluation of competitive systems. The Strataloggers interface directly with the Allen Bradley PLC systems on the drills so that all of the drilling sensor data, as well as maintenance data, are collected directly through the PLC. Additional systems have been purchased for the more recent additions to the fleet—two P&H 120s and an Ingersoll Rand DMM3. These systems have been extremely reliable. During the past three years, the only part replaced has been an operator’s terminal which was damaged by an operator.

Bingham recognized that in order to achieve the full benefits of the systems, they needed to have the data in real-time. Manual off-loading was not practical with a drill fleet of this size. A dedicated radio system was considered, but ruled out in favor of using the same radio infrastructure Modular used for their Dispatch system. There were several reasons for this: 1) additional radio frequencies are difficult to obtain due to Bingham’s proximity to Salt Lake City; 2) Modular’s radio hardware could be used on the drills thus reducing the inventory, spares, and training of maintenance personnel; and 3) the radio system infrastructure was in place. The one concern of Modular was whether there would be sufficient bandwidth to handle the additional data. This has not been a problem. The system was commissioned in 1997 (Figure 3). Thunderbird created two programs that reside on Modular’s Sun computer. These programs control activities for incoming and outgoing communications.

In addition to off-loading the drill data, the system includes real-time screens displaying the current status of each drill (Figure 4). The off-loading of all drill maintenance data generated by the PLC systems on the Bucyrus and P&H drills was a feature added to the system. Previously, these fault codes had to be manually downloaded, and therefore, were not used by maintenance personnel on a regular basis. Now the codes are available in the maintenance office, in real-time, through the mine’s network. Thunderbird has created several reports to assist maintenance with the analysis of this data. Remote editing has recently been added to the systems. If the operator is not on the drill or if an operator has made an incorrect entry, the entry can now be corrected from the office through the radio system.
Following a test period with three GPS systems, DrillGPS hardware was ordered for the balance of the fleet. The differential corrections are sent via Spread Spectrum radio from the surveyors’ Ashtech GPS base station. The GPS is used to log the actual position where each hole is drilled. This information is then transferred via radio with the other data for the hole to the office. The geologist can then correlate this data with the ore samples taken from each hole. This has eliminated the need to survey the holes when the assay samples are gathered. Enhancements such as “drill to elevation” and navigation can be added to these GPS systems in the future.

Bingham’s approach has been to implement the system in phases and this has proven to be a successful approach. The mine superintendent reported at the World Mining Equipment Drilling 2000 Conference that the feet per shift had increased from 580 in January 1998 to over 800 by May 1999. He attributed this increase to implementing of action plans based on data from the Stratalogger systems. Rates of penetration have increased. However, the major contributing factor to the overall increase has been the accountability of all of the time. This has led to changes in operating practices, which means more hours are spent drilling during each shift. The manual drill reports have been eliminated, and each operator receives a monthly “report card” on his performance and how he is doing against the other operators. The drill systems at Bingham have high visibility, and there is a commitment from the mine management to utilize the systems.
A third mine fully committed to the “Drill to Mill” concept is US Steel’s Minntac mine. Minntac began to add Strataloggers to their drill fleet in 1996. Today, the mine’s six Bucyrus 59R and three P&H 120 drills are equipped with Stratalogger systems. The Stratalogger automatically records pre-selected drilling data in increments of 0.2 feet. Currently, the data includes penetration rate, bit loading, bit rpm, rotary amps, rotary torque, bit air pressure, horizontal and vertical vibration (59Rs only), and compressor temperature. Drill delays and other data are input by the operator as they occur.

The Stratalogger records two penetration rates values. The D-ROP represents the raw penetration rate without any delays. The D-ROP can be used for drill bit evaluations and as one of the blastability indicators. The E-ROP or effective rate includes the total time spent drilling a hole, including hole cleaning or reaming, bit retraction time, and other minor delays. The E-ROP does not include moving or delay codes entered by the operator. It is useful for planning purposes and operator performance comparisons.

Minntac has used the data to monitor drill bit performance and to compare bits from different manufacturers. Minntac has also used the data to point out to one of the drill manufacturers the logic problems with their drill automation program. Extensive work has been done looking at changes in drilling parameters, and how this data can be used for material recognition and to identify fractured strata. Approximately 2500 Stratalogger hole records, in 0.2-foot increments were compared to diamond drilling data. Graphs, with a statistical distribution for D-ROP, rotary torque, and specific energy (a value calculated from various sensor inputs), were developed for each material type. The results showed that the drilling characteristics could be used to identify various strata. Minntac uses this data to more accurately place the explosives in order to decrease fly rock and noise, and to improve the rock fragmentation.
Based on the work done at Minntac, 1998 funding was approved by the Iron Ore Cooperative Research Committee and the State of Minnesota, to have the University of Minnesota investigate the Stratalogger data further. The project aims were: 1) to develop new methods for data interpretation and information extraction; 2) to examine systematic variations in the data; 3) to investigate their correlation with other mine variables; and 4) to explore more effective uses of the drilling data in various mining operations such as drilling optimization and blast design modifications. The results of Phase 1 of the study were published in 1998 and were positive. Funding has been approved for Phase 2 of the project and is currently underway.

During 1998, a dedicated Thunderbird designed and supplied drill radio system was installed at Minntac to improve the access to the data (Figure 5). DataRadio and Motorola were chosen to supply the modems and radios. The system operates at 2400 baud and there have been no problems with bandwidth. The system has several features that were included to improve access to the drill data and its utilization. Ruggedized field laptops, with radios and modems, have been installed in the drill foremen’s trucks. This allows them to view the real-time drill screens in the field. In the future, they will be able to look at reports and edit data remotely. A client computer has also been installed in the dry room so drill operators have access to the drill reports and can measure their performance against other operators.

![Minntac Stratalogger Drill Monitoring System](image)

**Figure 5**

In addition to the applications of the Stratalogger system discussed earlier, the system is used to generate a monthly availability report. A similar, manually created report previously took the drilling engineer
three days to compile. A database report was created to produce the report from the Stratalogger data, and it is now available in ten minutes. Minntac believes that by increasing the pull-down force, the penetration rate can be increased without increasing overall drilling costs. They have a program in place to begin to make the increases. Using the Stratalogger data, they are able to monitor by drill and shift whether the increases are actually being made, and evaluate the results. Minntac has determined through an examination of the drill delay code reports that the drills are sitting or not drilling for a significant portion of each shift. They have implemented programs to increase the time spent drilling. For example, the operators no longer stop drilling during lunch breaks. Minntac’s management is committed to increase drill productivity and is using the Stratalogger systems to help achieve this goal.

Minntac has also installed DrillGPS systems. A total of four systems are operational. These systems are using the Ashtech GG-24 GPS receivers and Spread Spectrum radios to send the differential corrections. Two repeaters are required to cover the mine’s nine mile long pit.

A difficult, yet key component, in the “Drill to Mill” process is to be able to determine the effectiveness of the drilling and blasting operations. During the past couple years, several stand-alone systems have been introduced to the market to measure fragmentation. IMS’s new electric shovel monitoring system, ShovelPro, measures diggability, and therefore fragmentation in real-time. The system is now commercially available. The system measures a number of other production parameters including material weight and volume, loading times, cycle times, swing angle, delays, true bucket position, and bench elevation. A sister product is also available for draglines. These two products provide feedback to the operator, as well as send data to the office on the diggability. This allows operations and engineering to alter the drill patterns and/or loading plans, and receive immediate information on the impact of these changes from on-board monitors, which are providing a number of other operation characteristics.

It is anticipated that these new products will have an immediate and major impact on monitoring of the “Drill to Mill” process. When coupled with the information which is now available from drill monitors and the more accurate drilling which results from adding GPS to drills, Thunderbird believes there will be opportunities to dramatically improve the “Drill to Mill” process with higher productivity and lower total mining costs. Thunderbird, and its IMS partners, are continuing to develop new technologies, products, and applications which will make the implementation easier, more cost effective, and provide more useful data.

**REFERENCES**


