Abstract: BHP’s Navajo coal mine installed drill monitoring and high precision navigation systems on their three overburden drills during 2002 and 2003. Details of the DrillNav system hardware and reporting system will be discussed, as well as the significant benefits Navajo has achieved since the systems were installed. Navajo is not satisfied with the current results and plan additional upgrades to the systems. In addition, Navajo plan to integrate the data from their drill systems with data from other systems to achieve even greater increases in drill productivity and to reduce overall mining costs.

Introduction and Overview: BHP’s Navajo mine (Figures 1 & 2) is a surface coal mine located in the northwest corner of New Mexico, near Farmington. Production began in 1963. The mine produced 9.1 million tons of coal last fiscal year. All of the coal is sold to the APS’s Four Corners Generating Station.

Multiple seams (up to 9 seams) are mined and the current strip ratio is 5:1. Stripping is done with three draglines—a Marion 8750, an 8050, and a recently recommissioned older 7920. An internal, mine operated electric railroad is used to haul the coal from field stockpiles to the crushing and blending facility at the power station. The haul distances range from 6-10 miles.
During 2002 and 2003, Navajo purchased Leica’s Tritronics monitoring and navigation systems for all of their production and auxiliary equipment. The stated reasons for justifying the installation of the systems were:

- Increase productivity
- Improve operational process control
- Improve data accuracy
- Reduce operational delays
- Improve supervision
- Improve maintenance scheduling
- Use for benchmarking & sharing of information within company

The systems that Navajo installed during this period were:

- Drills: high precision navigation and monitoring systems
- Draglines: monitoring systems (navigation has since been added)
- Production equipment: monitoring systems for all coal haulers, overburden trucks, ash trucks, and loaders
- Auxiliary equipment: monitoring systems for water trucks, graders, dozers, and the rail locomotives
- Dozers: high precision navigation and monitoring systems
- Radio network for data and GPS RTK corrections
- IMS software to manage system and generate reports

The drill fleet currently consists of the following drills: two Atlas Copco DMM3, one Reedrill SKS, and one custom twin boom coal drill (Figures 3-5). Leica’s DrillNav systems are installed on the three overburden drills. The coal drill has a monitoring system to log the operator and operational delays. The overburden drills use 10 ¼” bits for the overburden. When they are used to drill coal, the mine installs a single piece of drill steel with a 6 ¾” bit that can be quickly moved between the drills.
The drill fleet statistics for FY 2006 ending June 30th were as follows:

- Overburden Drilling: 1.9 million feet
- Coal Drilling: 770,000 feet
- Overburden Holes: 51,500
- Coal Holes: 99,500
- Drill Operating Hours: 12,775
- Drilling Hours: 8,090
- Drill Shifts: 1,895

**Hardware and Operator Screens:** The DrillNav systems replaced older navigation systems on the overburden drills that Navajo had been using for several years. Navajo chose to replace the systems to have the latest technology so that all of the drill data would be in a single database with the data from the other systems. This simplified the overall management and support of the systems.

The drill navigation systems consist of the following components: A) the operator screen (Figure 6); B) the computer module that contains the system computer, the two GPS receivers, and the two radios (Figure 7); C) two mast head mounted GPS antennas (Figure 8); and D) the data and RTK radio antennas.
The operator screen (Figure 9) is the interface between the system and the operator. It is a color, VGA, daylight readable touch screen. While drilling, the Bit Depth, ROP, and Relative Hardness (current and previous hole) are displayed to the operator graphically. Also provided are Bit Depth in feet or meters, Depth from Bottom of Hole when bit is raised, Depth to Bottom of Hole, and Target Depth. The operator can use the Tag Hole button to record the depth at which coal or some other geological feature is encountered. This feature is used on a regular basis by the Navajo drillers to identify top of coal.

![Figure 9](image)

The operator can select from a list of twenty-three digital values (Figure 10) that he may wish to view or track. Once he has selected the information he wants to view, the screen set-up is recorded against his ID number, so that the next time he logs on to the drill, the screen layout will return to his preferred layout.

![Figure 10](image)
The Hole Setup Screen (Figure 11) is used to enter the Hole Number, Pattern Description, Target Depth, Bit Number, and Bit Type or Manufacturer. The Hole Number and Target Depth only need to be entered if the data is not included on the pattern maps sent from the office.

Figure 11

The drill patterns are laid out in the office by the D&B engineer, and are then sent to the specified drill or drills via the system’s radio system. The drill operator selects from the list of patterns (Figure 12) the pattern which he is required to drill. The system also allows for the drill operator to create his own pattern (Figure 13) if a pattern has not been sent to the drill. The operator trams the drill to a corner of the ‘pattern’, enters the overall dimensions, then the hole burden and spacing, and the new pattern is generated on the screen. The operator can proceed to drill the pattern.

Figure 12          Figure 13
After the pattern has been selected or created, it will appear on the Navigation Screen (Figure 14). The operator then trams to the desired hole. As he is traming, the screen will automatically zoom on the hole. The zooming rate is configurable by the operator. When he trams within the mine designated hole offset tolerance, the system automatically locks on the hole (Figure 15).

The drilling monitoring system accounts for every minute of each shift. This provides very accurate data on the activities of the drill which can be used to better manage the drill fleet. As soon as the drill stops drilling, the operator will be asked to enter a Delay Code (Figure 16). The Delay Codes are configured in the office and transferred to the on-board system via the radio network. Navajo has established several unique delay codes such as “Waiting on Mechanic or Electrician”. If a breakdown occurs, the operator enters one of these codes rather than a mechanical delay code. When the maintenance personnel arrive, the appropriate delay code is entered. This allows Operation to accurately measure how long it takes Maintenance to respond to a drill being down. This allows Navajo to better set priorities for the servicing of the equipment in its fleet.
Telemetry and Reports: A custom designed telemetry network (Figure 17) links the office server to each piece of equipment in the mine. It is used for the two-way transmission of data between the office and the equipment. It also transmits the GPS RTK corrections from the GPS base station to the high precision navigation systems on the drills, dozers, and draglines. The radio system uses 900 MHz spread spectrum radios transmitting data at 115k Baud. There are three separate channels: 1) the first is for the two-way transmission of data and maps; 2) the second is for the GPS corrections; and 3) the third is for the supervisor panels. These panels allow supervisors and foreman from their pickup trucks to have up-to-the-minute status information on all of the equipment in the fleet.

The base server runs on an MS 2003 operating system. It maintains the overall control of the system, i.e. the flow of the data through the radio network. All of the data from the Navajo equipment is stored on the server in the IMS database. The server uses a MS-SQL program to manage the data. It is an open, non-proprietary database. Data is available to users in real-time or reports can be generated for specified time period. Standard reports that Navajo uses on a daily or weekly basis can be set-up so they are automatically generated and sent to a printer, or emailed to the production manager or mine manager. The drilling supervisors typically review the previous day’s reports with their operators at the start of each shift. The following are standard daily reports for two overburden drills. Drill 253 (Figure 18) was drilling coal on this particular day and drill 243 (figure 19) was drilling overburden for a cast blast.
A number of other standard reports are available from the IMS database. These include Drill Hole Reports (Figure 20), Rate of Penetration graphs (Figure 21), Drill Bit Reports, Operator Reports, Downtime and Availability Reports, etc.

![Figure 20](image1.png)  ![Figure 21](image2.png)

The IMS database also has a Pit Display option. Navajo downloads dfx map files to the database, and the location of all the mine equipment will then be displayed on the mine map in real-time (Figure 22). The color of the equipment icons denotes the status of the equipment (operating, stand-by, maintenance, etc.). In Figure 23, the mine has zoomed in on drill 243. It shows the operator's name, and in this case that the drill is in a 'maintenance delay'. If the drill was drilling, it would show the current hole number being drilled.

![Figure 22](image3.png)  ![Figure 23](image4.png)

**System Benefits:** Several drill operators were interviewed for their feedback on the DrillNav systems and on the benefits they see from the systems. Their comments are summarized below:

- The system is very easy to use and we are totally dependent upon it.
- Speed—it is much quicker to tram to the holes and no staking is required.
- It allows us to drill to an accurate depth, and by watching ROP readout we know when we have intersected the coal. We use the Tag Coal button to mark the depth of the coal.
• When drilling overburden for a cast blast, the Compass on the display can be used to ensure the drill is properly aligned to the pattern face, and that all the holes are drilled parallel. The Mast Angle display is also useful for setting the mast angle during cast pattern drilling.

• We no longer have any reports to complete since all the information is collected electronically. The system tracks the delays much more accurately then when we did ‘Drill Reports’ in 15 minute increments.

• There are occasions when a pattern map has not been sent from the office and we need to drill a series of holes. Before DrillNav, we would have get out of the drill and mark the holes. Now we can create our own patterns on the DrillNav screen.

• It is much safer when drilling coal near the high wall since we do not have to leave the cab. In addition, hazardous locations are shown on the maps sent from the office.

Navajo have achieved significant increases in their overburden drill footage from 2002 through 2006 as shown on the following charts (Figures 24 & 25)—43%. While some of this increase is due to gradual upgrades to their drilling fleet, they also attribute it to the drill systems. More specifically:

• By monitoring and measuring ROP, and then working with the operators, they have been able to increase the ROP.

• The tramming time between holes has been reduced resulting in more holes being drilled per shift.

• Drill availability:
  • Track delays and downtime.
  • Following a mechanical or electrical breakdown, Navajo tracks how long it takes for maintenance to respond by an electrician or mechanic to begin servicing the drill. This allows the Operations and Maintenance departments to have meaningful discussions on service priorities.
  • Increased number of drilling hours.

• An additional benefit is that they have dramatically reduced surveying costs associated with drilling and the surveyors can work on other projects.
The Future: Navajo is not satisfied with the results that they have achieved to date, so they are looking at upgrades and additions to the drill systems, as well as the integration of data from the drill systems with data from other monitoring and high precision systems on site. These include:

1. Pit Ops Software: Pit Ops is new database software which will replace the IMS software currently being used by Navajo. Pit Ops has a number of enhancements including improved report layouts, real-time drill graphics, and overviews of the drill patterns.

2. Glonass: Because of the dependence on the navigation system, Navajo wants to insure that it minimizes the amount of time the system cannot be used due to an insufficient number of satellites. It is therefore looking at adding the Russian Glonass GPS system capabilities to the system. This can be done by simply upgrading the current GPS boards. The Glonass system currently has seven satellites and will be fully operational by the end of 2007. The Glonass satellites augment the US NavStar system and reduce the number of minutes when there are insufficient satellite to provide a system lock.

3. Drilling Index: The current monitoring system records Depth versus Rate of Penetration, and a plot can be made for each hole drilled. This provides an indication of the hardness of the material being drilled but can be skewed to the left or right as the operator changes the pull-down pressure, torque, or RPM. To overcome this shortcoming, a Sensor Manager with pull-down, torque, and RPM sensors can be added to the drill system. These values, along with ROP, can be input into an algorithm which will generate a Specific Energy of Drilling or Drilling Index value. Plotting this value against depth will provide a very accurate indication of the true hardness of the material being drilled, as well as its geology. This information can then be used to more accurately load the blast holes. This strategy is being used at several other mines in North America. In the blast pattern (Figure 26), the different colors indicate the relative hardness based upon the Drilling Index. When loading the holes, the mine will vary the stemming based upon the hardness from 16 to 20 feet. This results in better fragmentation, less flyrock and ground vibration, and lower explosives costs.
4. Dragline Data: Since their installation in 2002, the dragline monitors have had the capability of calculating a Diggability Index for each bucket loaded. This Index is a measure of the energy and time required to load each bucket, and provides a relative indicator of the ease of digging or the fragmentation of the material. Navajo recently added GPS systems to the draglines (figures 27 & 28). The DragNav provides a number of benefits to the operator since he now is shown on the screen the position of the bucket relative to a variety of design lines and the coal. The GPS also calculates the fill position of each bucket of material. This provides the missing link needed for the Dig Index to make the Index a truly valuable tool, since the precise fill position of each bucket is now known.

![Figure 27](image1.png)  ![Figure 28](image2.png)

5. Integration of Data: Navajo is currently investigating and testing the integration of the drill data (ROP or Drilling Index) with the Diggability Index. This will allow them to have a true correlation between Drilling, Blasting and Digging. By evaluating these relationships, it will allow them to alter the drilling pattern and/or powder factor to optimize the blasting and therefore reduce the Digging Index. If they can accurately measure these relationships and then implement on-going strategies to capitalize on them, this should provide a significant reduction in Navajo’s overall production costs. Navajo will use a 6 Sigma project to evaluate and implement this process.

**Conclusion:** The construction of the Desert Rock power station, to be built to the south of the Navajo mine, is under active consideration. If it proceeds, Navajo will be expanding their fleet, and installing additional monitoring and navigation systems. As with their current drill and other systems, the key factors to their successful installation and on-going usage will be: 1) a commitment from senior management; 2) a dedicated systems administrator; 3) operator training; 4) maintenance of the systems; and 5) continuous evaluation of opportunities to use data from the systems to improve its operations and reduce costs.