Integration of the mining plan in a mining automation system using state-of-the-art technology at De Beers Finsch Mine

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Synopsis

This paper will highlight the system components of a successful underground mining automation project recently launched at De Beers Finsch Mine. It will also show that integration of short-term mine planning with other upstream and downstream mining processes in the extraction of kimberlite ore from a block cave is not just critical to the future sustainability of this underground mining operation but also for profitability and cost-effectiveness. This paper will discuss the information data flow required from the mine-planning process through to production for underground block cave mining. The benefits associated with this type of integrated mine planning and automation system will be highlighted.

Introduction

Mining companies in collaboration with mining equipment manufacturers have invested heavily in the development of mining automation systems for underground mines. These automation systems and advanced vehicle automation technologies should have improved both the safety and profitability of these underground mining operations. However, most underground mining companies have conceptualized, designed and implemented these mining automation systems without considering the holistic view of integrating the entire mining value chain. As a result of this failure, the automation programme has failed or has been put on the backburner as operations lost faith in the actual use of this technology.

Most of the mining operations efforts were aimed at automating the equipment underground without considering the need for integration with mine planning. This lack of visualization has created ineffective operational systems, resulting in numerous production delays and system modifications and leading to its eventual failure.

This paper will discuss the integration of short-term mine planning in the overall automation process, considering all the various upstream and downstream constraints on the mining process. It will also show that integration of mine planning and production execution systems is now possible using state of the art technology. This paper will also describe the process of data flow from the mining plan to the loading and hauling execution plan and the associated reconciliation processes. The paper will highlight the system functionalities in these mine planning and execution systems. Benefits from the implementation of these associated mining and planning systems will also be briefly discussed.

De Beers Finsch Mine overview

Finsch Mine is situated approximately 165 kilometres west of Kimberley in the Northern Cape Province of South Africa. The Finsch kimberlite pipe is a near vertically sided intrusion into the dolomitic country rock, the latter consisting of dolomite, dolomitic limestone with chert bands and almost pure lenses of limestone. Mining of the kimberlite pipe started in 1964 utilizing an open pit mining method. Approximately 120 million tons of kimberlite ore was mined from the open pit.

Underground operations commenced during the latter part of 1990. The underground orebody is divided into mining Blocks 1 to 5 as shown in Figure 1. Each block terminates at varying depths below surface as 350 m, 430 m, 510 m, 630 m and 830 m respectively. Blocks 2 through to 3 are being exploited via a modified blasthole open stoping technique. Blocks 1 and 2 were mined out while Block 3 is nearing depletion in 2007. Block 5 is currently in the prefeasibility phase and is planned to be extracted using a mechanized block caving mining methods.

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SA ISSN 0038–223X/3.00 + 0.00. This paper was first published at the SAIMM Conference, Rise of the Machines, 14–16 March 2006.

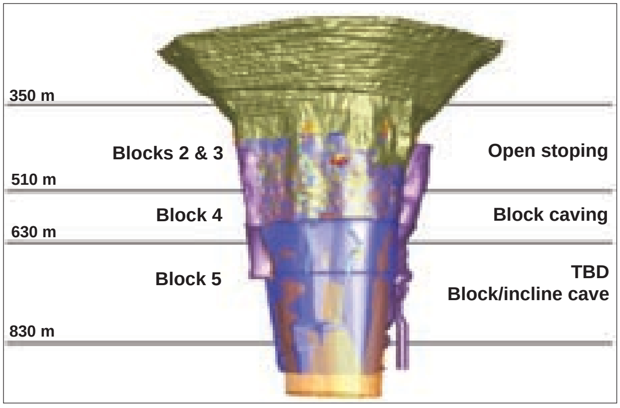

Figure 1—Geology and mining blocks

Block 4 is mined by means of a mechanized panel retreat block caving method, making use of an advance undercutting methodology. The undercut level of the block is situated on 61 level (610 m below surface). The main extraction level, trackless workshop infrastructure, autonomous truck haulage loop and primary crusher excavation and associated infrastructure are located on 63 level (630 m below surface).

The slot cutting process required to start the undercutting process commenced in April 2004. The hydraulic radius necessary to allow the caving process to start was achieved in the third quarter of 2005. The undercut tunnels are spaced at 15 metre intervals and allow for the mining of an inclined 12 metre high undercut profile. The undercutting process is planned to be completed in 2009.

The layout geometry of the extraction level as shown in Figure 2 is designed on a staggered herringbone configuration with 30 m tunnel spacing and 15 m draw point spacing. Based on geotechnical constraints and associated tunnel stability risks, the mining sequence on the extraction level is such that all drawbell and associated infrastructure will be required to be developed in the ‘shadow’ of the advancing undercut face—with only the extraction tunnels and draw point development allowed to take place ahead of the undercutting process.

Depletion of the block cave draw columns started when the hydraulic radius was achieved in 2005. The production build-up rate will be dependent on the rate of undercutting and the associated draw point maturity rules. A full production rate of 3.8 million tons per annum is planned to be achieved in 2007 and this steady-state production rate will be maintained until 2011. The production from this block will then reduce significantly until the Block 4 resource is depleted in 2015. To maintain production from the underground mine, Block 5, will have to start production during 2011, thereby ensuring the sustained production of Finsch Mine beyond 2020.

Ore management system overview

The ore management system (OMS) is an integrated system that manages the planning and optimal extraction of cave material from the Block 4 block caving operation. This system consist of two distinct but integrated segments that will be discussed in more detail later on in this paper, namely a high-level planning segment and an execution or tactical segment. Various other components or systems also form part of this integrated system and these components are depicted in Figure 3. These components will be mentioned only briefly.

The main components of the ore management system as shown in Figure 3 consist of the following:

The cave management system (CMS)

The cave management system (CMS) is an external system which resides in a different domain, that, from a system perspective, has the main function of providing a daily draw order (i.e. daily production targets and priority for each draw point) to the production control system (PCS). This system will be discussed in more detail later.

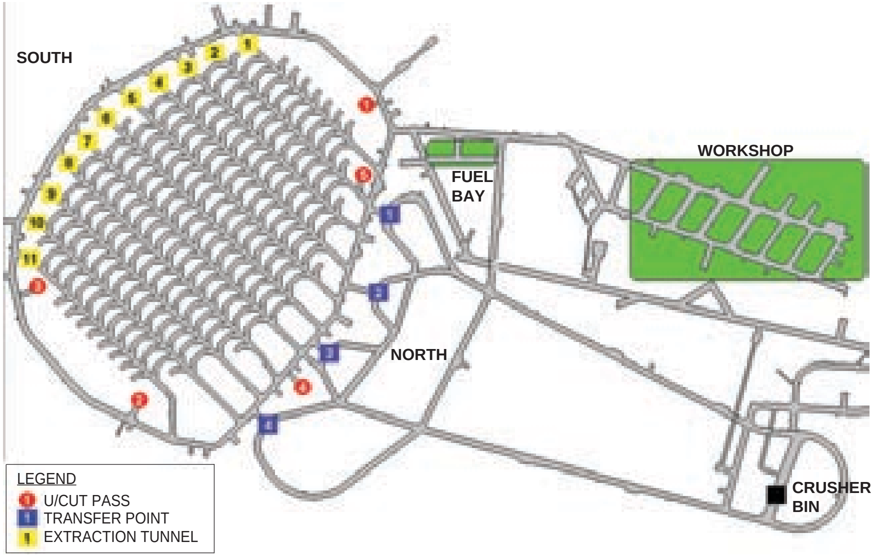

Figure 2—630 m extraction level infrastructure

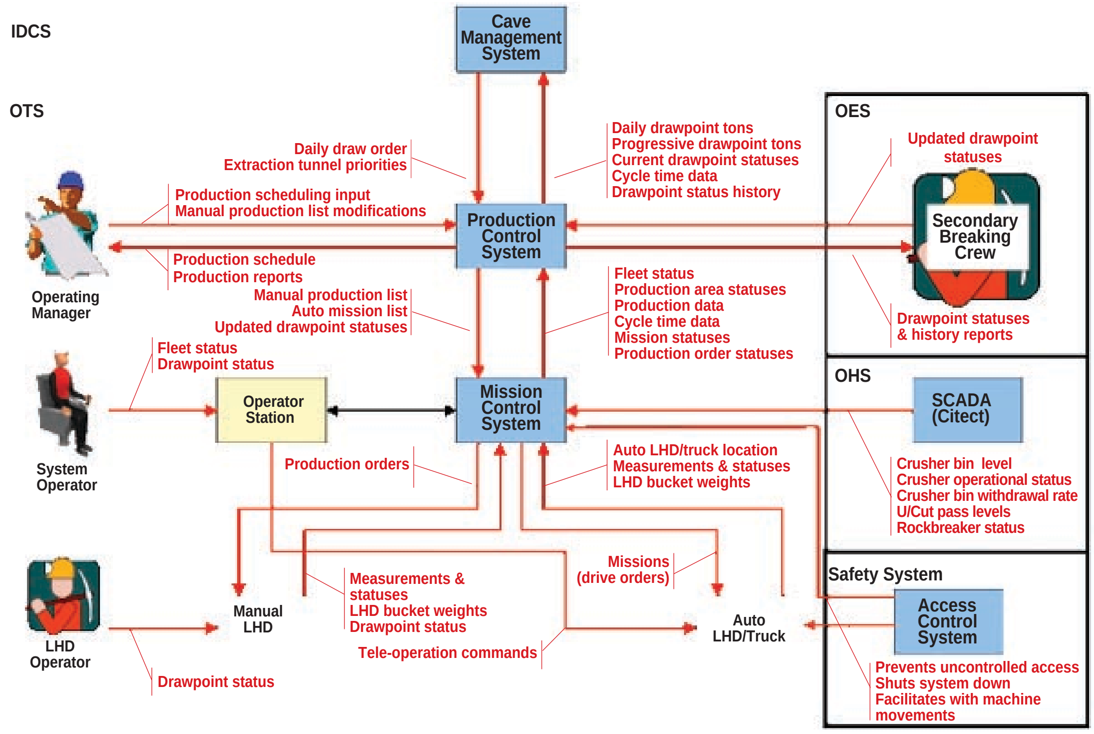

Figure 3—OMS system architecture with OTS system interfaces

The production control system (PCS)

The production control system (PCS) provides the main functions to schedule shift production and to manage the production execution by manual and autonomous LHDs and autonomous trucks. The functionality of this system will be detailed later.

The mission control system (MCS)

Mission control system (MCS) has the following main functions: it controls production execution by issuing manual production orders to manual LHDs and also creates and issues drive orders to autonomous LHDs and autonomous dump trucks. The system maintains traffic control and the management of truck loading by LHDs. In addition, it supervises the machines and production area resources, monitors the total fleet production, condition and status. It also provided a user interface for supervision and control of autonomous LHDs and autonomous trucks. This execution system will be further discussed later.

The access control system (ACS)

The access control system (ACS) provides the safety net around the autonomous loading and hauling operation. The system controls access to the autonomous area by restricting and detecting entry of unauthorized personnel. It furthermore prevents unplanned machine exits and assists with providing controlled access for autonomous machines in or out of this autonomous area without shutting down the production in this area.

The citect SCADA system

Citect is an external supervisory control and data acquisition (SCADA) system that provides data to the mission control system essential for the control of horizontal ore transportation to the underground gyratory crusher. This system provides information to the mission control system on the statuses of upstream processes such as storage pass levels, availability of the hoisting system, crusher bin levels, crusher operational statuses, as well as undercut pass levels.

The trackless equipment fleet

Ore is loaded by Toro 007 LHDs (load haul and dump trackless equipment) from 302 production draw points located within 11 extraction tunnels, as well as from 5 undercut passes. The LHDs then tram the loaded ore to 5 designated transfer points located on the perimeter of the orebody after which the ore is dumped into autonomous trucks. These trucks then automatically haul the ore and dump it into the primary crusher located at the shaft. LHDs are operated either manually or autonomously depending on the implementation stage. These implementation stages will be further discussed later. The trucks as shown in Figure 4 are Toro 50Ds equipped with a 24 m^3 rock boxes capable of hauling 50 tons. These trucks operate fully autonomously, i.e. without operators onboard. This combination of LHD bucket size and truck box size allows for 4 pass loading depending on the expected fragmentation size from the block cave, .i.e. larger blocks of ore would reduce the number of loads into the truck.

The planning and extraction process

The planning and ore extraction process from an underground block cave operation should be a relatively easy and simple process. The mine planner should calculate the required tonnage to be mined daily from the draw points using various mine-planning systems. The draw points that are behind in production should be provided with a higher

Figure 4—Toro 50D dump truck at ACS gate

extraction rate to catch up while the draw points that are ahead in production should be stopped or production from them should be reduced accordingly. However, in practice the execution of this short-term production plan is not that easily achieved. The environment where this plan is implemented is dynamic and continuously changing, and these tactical plans or schedules continuously need to be modified to take account of these changes. The production area resources required to execute this short-term plan need to be balanced, as too many or too little production resources would prevent the plan from being executed successfully. The execution of the plan could also be totally inefficient or very costly because of these additional idle resources not contributing towards production. By ensuring that the short-term mining plan is sent directly to the loader, all the previous mentioned hurdles for successful achievement of the short-term mining plan can be addressed effectively. The mine-planning and execution data flow as designed for Finsch Mine are depicted in Figure 5.

The short-term planning process using CMS and PCS

Daily draw control is an integral part of the planning and management of an underground kimberlite block cave mine. It requires routine gathering of actual production information and data such as tonnages, equipment cycle times and statuses of all the production draw points. This information must be stored, processed and distributed for efficient management of the block cave. These functions are relatively easily handled by the cave management system (CMS).

The objective of this CMS system is to ensure that the long-term mining schedule for the depletion of the block cave is adhered to and achieved on a daily basis and that any deviations from this mining plan are rectified before a new plan is produced. The objectives of long-term mining plans for block-caving operations are in many respects identical to those of other underground mining methods, but the operational and geotechnical requirements associated with block-caving operations add severe limitations to the process of planning and scheduling. Issues such as the overall shape of the block cave, the sequencing of development to open drawpoints, and maximizing net present value subject to various operational and geotechnical restrictions are all constraints to the process of planning and scheduling.

The CMS system at Finsch Mine caters for all these abovementioned requirements and its key functions are as follows:

- ➤ It should meet the monthly targets set by the strategic planning system
- ➤ It should be responsive to operational and geotechnical limitations placed on it for example excessive hang-ups and stress build drawpoints
- ➤ It should be able to modify the draw to take account of over or under drawn situations
- ➤ To ensure that the loading or achievement of this order is achieved safely, efficiently and effectively by production personnel

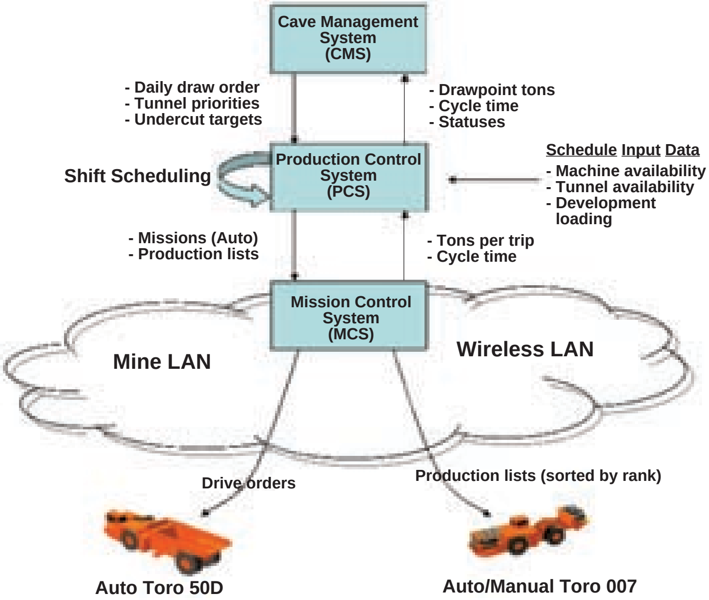

Figure 5—Data flow from planning to mining

- To be effective, captured data from the execution and achievement of the short-term plan need to be readily accessible for the people managing the draw control process.

Once all the operational and geotechnical limitations have been considered in the short- term plan, this plan needs to be executed and achieved by the production personnel underground. But this plan has not taken the status of the operational resources into account. This function is handled by the production control system (PCS) as highlighted earlier and depicted in Figure 6.

The objective of the production control system is to ensure the daily production plan (i.e. daily draw order) is executed in an efficient manner with the goals being to optimize ore transportation from drawpoints through to the crusher bin and to make efficient use of the operational production LHDs and autonomous dump trucks. The PCS is dependent on data from other systems in the transportation system, external systems and data input by the operational user situated in the surface control room. The PCS also provides data to other systems. The PCS is interfaced to the CMS and mission control system (MCS) with historical data being stored in a historian database. The historian database is a shared system element of both the PCS and MCS. The CMS obtains data from the PCS via the historian database as depicted in Figure 8. The PCS imports the daily draw order from the CMS directly while data originating from other external systems are received via the MCS.

The PCS uses data from external systems to schedule and control the production from the trackless automated fleet. The PCS controls the production by generating missions (for autonomous machines) and production orders (for manually operated machines). Missions and production orders are generated based on the daily draw order, current production area statuses and specific user assignments.

There are various benefits of using the production control system and these include the following:

- The shift schedules generated by the PCS always looks ahead and is proactive instead of reactive
- Shift production plans are balanced against drawpoint priorities and available trackless equipment and tunnel resources
- The PCS ensures draw control compliance because it is designed to follow the draw rules given by the CMS thus ensuring that LHD operators load according to the mining plan
- There is effective fleet supervision and loading exception monitoring, which puts the control room back into control
- There is optimization of the movements of the autonomous LHDs causing less congestion at the tipping points, producing more loading time and ultimately more production
- There is real-time production progress monitoring by production supervisory personnel.

Execution of the short-term plan by the mission control system

Once the short-term production plan is optimized against all production resources upstream and downstream the plan needs to be executed with precision. This can be done only by continuous monitoring of the execution by the mission control system with information it receives from the production control system. The mission control system forms a critical link between the production control system and the ore transportation production fleet and is responsible for supervising and controlling the execution of production based on missions and orders received from the PCS and statuses maintained in the MCS or received from other systems. The system also provides the primary user interface for the system controller providing functions and display screens to supervise the fleet and production area and to monitor fleet condition and production. The top-level function of the system, which is the supervision and controlled execution of production, is performed by the MCS for both manual and autonomous operations with suitable interfaces to other external systems as depicted in Figure 8.

The implementation of this mining automation system at Finsch Mine will be done in three distinct stages relating to the extent of LHD automation in the extraction LHD

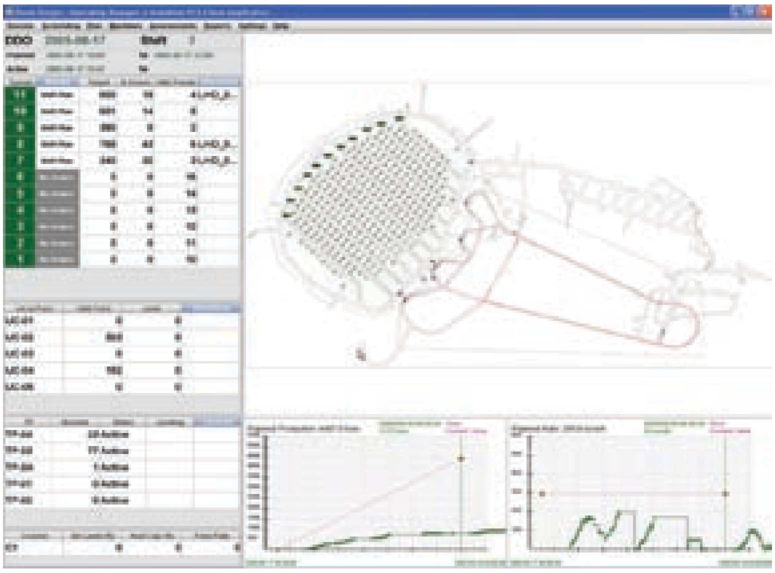

Figure 6—Production control system user interface

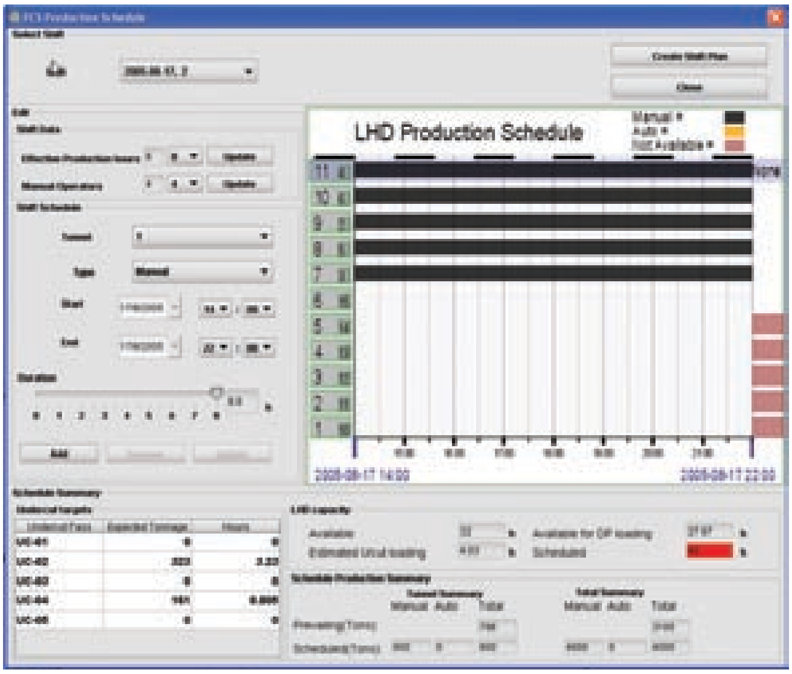

Figure 7—Shift scheduling in the PCS

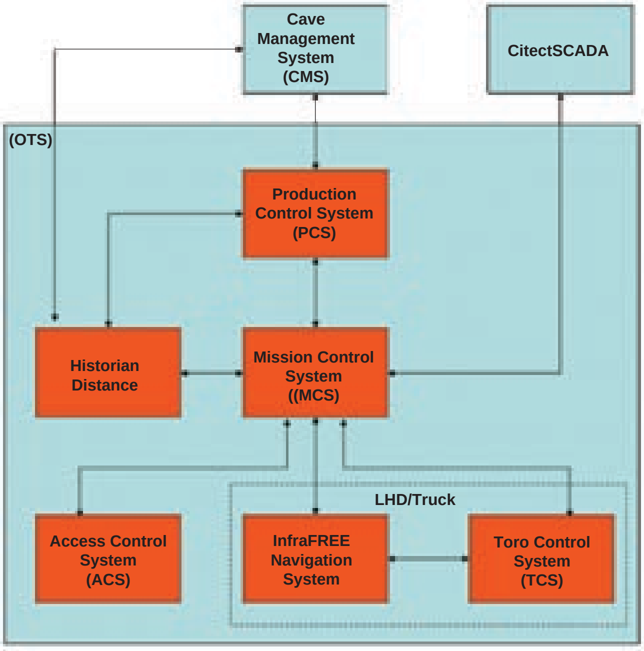

Figure 8—MCS system interfaces

production area, which in turn is related to the progress of the development of Block 4 and subsequent extension of the ACS. Stage 1 will utilize manually operated LHDs and autonomous trucks with the ACS covering only the automated truck haulage loop. The commencement of Stage 2 coincides with the introduction of the first automated LHDs in the LHD production area.

Stage 3 of the OTS implementation coincides with the final extension of the ACS to cover the entire LHD production area. At this point manual LHDs will be phased out and all production will be performed with autonomous LHDs. The mission control system is a real-time system based on well-known standard software products using a client-server configuration. The system controller situated in the surface control room will interact with the MCS via a window based graphical user interface, MCS client. Each operator station is equipped with a workstation (including monitor, keyboard and mouse as depicted in Figure 9) with the MCS client software, which provides functionality for system controllers to supervise and control the autonomous LHDs and dump trucks and to supervise the manual LHDs.

For the autonomous LHDs and trucks, the MCS takes the auto mission list received from the PCS and controls execution of the production by issuing orders to onboard

Figure 9 —System controller using MCS display

InfraFREE navigation systems after confirming the availability of the required production area resources. The MCS also controls the traffic of the autonomous LHDs and trucks in order to ensure safe driving. For manual LHDs, the MCS takes the manual production list received from the PCS and issues manual production orders to the LHD operator (via the Toro control system (TCS) display) for execution. The MCS collects and displays both condition and production monitoring data from the OTS fleet and stores the data in a historian database for access and reporting by other systems.

Benefits of an integrated automated transportation system

The Finsch Mine Block 4 ore transportation system provides all the functionality required to operate and supervise a manual and automated LHD and dump truck fleet from a surface control room located away from the production area. It provides the following benefits:

- One version of the truth as the only source of data that can be trusted
- The integration of different systems optimizes the mining processes and helps create higher value
- The effective management and control of a block cave through automation with improved quality of ore delivery to the treatment plant
- Improved machine fleet utilization resulting in increased production and revenue
- Lower maintenance costs due to smoother operations and reduced damage to equipment cutting down on maintenance expenses
- Increased safety through the use of the access control system (ACS), which protects the automated production area from both unauthorized access and uncontrolled or unplanned machine exits
- Improved working conditions whereby the system controllers are now located in a safe and comfortable control room environment situated on surface, which results in reduced occupational injuries
- Improved production control and monitoring with reduced stoppage times will result in improved ore extraction and recovery rates
- With real-time production follow-up and response using the mission control system interface the system controller can now easily monitor the production in real time and make the required adjustments to achieve the mining plan.

Conclusion

The main challenge for any underground mining operation currently is integrating multiple sources of production related information within a cost--effective and flexible mining automation infrastructure. But this integration must allow underground supervisory personnel to improve their short-term decision-making capabilities, while at the same time providing historical data to senior management so that they can make the necessary adjustments to the organization’s long-term goals. The key to success in the development and implementation of underground information management and mine automation systems is intelligently integrating or suitably interfacing these technologies. The successful deployment of underground mine automation and mobile vehicle production management solutions, accomplished and supported by an industry accepted information management system, will dramatically improve not only the safety and productivity but also the cost performance of an underground mine. The result is significant benefits in terms of the underground mining operations' revenue and cash flow, and the mines ability to manage the mining process more safely, efficiently and effectively, thereby ensuring sustainability.

Acknowledgement

The author is grateful to all his colleagues/partners at Finsch Mine and Sandvik Mining and Construction (SMC) who have contributed to the development of this integrated planning, execution and automation solution. Also, the author wants to acknowledge the permission given by the partners, Finsch Mine and SMC to publish this technical paper.

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