Short Interval Control in Today's Underground Mine: A Case Study

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Abstract

Applying Short Interval Control (SIC) in underground mining operations stems from the need for operations to be more efficient with shift time and the use of assets. Chelopech Mine in Bulgaria is aiming to double production and achieve a 44% improvement in unit cost, a task that requires processes and systems to be redefined and shift time to be better managed. This Case Study looks at how Dundee Precious Metals Inc. developed a new approach to manage shift tasks to achieve production targets while improving asset utilization. Overcoming prior communication barriers in underground mines provides the opportunity to manage activities and tasks as well as identify any delays or interruptions during the shift and take immediate action. This positions data collected during a shift as less of a historical reflection of past events and more of a current-state view to support work management.

Introduction

Chelopech Mining EAD (CMEAD) is a wholly owned subsidiary of Dundee Precious Metals Inc. (DPM) and operates the Chelopech copper, gold and silver underground mine and processing facility. The Chelopech operation is situated adjacent to the village of Chelopech, in the Sofia District of Bulgaria, 75 km east of the capital, Sofia, and at an elevation of approximately 700 m above sea level.

Following Soviet era exploration efforts in the 1950's, the Chelopech Mine, then part of several state-owned enterprises, was fully operational between 1970 and 1990 producing bulk copper-gold and pyrite concentrates. The mine was put into care and maintenance in 1990. A subsidiary of Navan Mining Plc acquired the rights to the Chelopech concession in 1991, and recommenced operations in 1994, continuing until late 2002, following which DPM concluded negotiations for the acquisition of the Bulgarian assets in September 2003. The operation, at that time, produced 550,000 tonnes per year using a sub level caving mining method that was sub-economic at that time. From 2004 to 2009 the company made significant investments to modernize the operation, changing the mining method to blasthole open stoping with delayed filling, and increasing the production to one million tonnes ore per year. The success of this effort led to the company approving a US$150M investment in 2009 to expand the mine and mill complex to two million tonnes ore per year. This expansion involved an upgrade and modernization of the concentrator facility along with a new crusher-conveyor ore handling system for the underground to replace the existing shaft hoisting and trucking system along with associated infrastructure facilities upgrades. The expansion works are scheduled to be completed in September of this year.

The basis for the economics of the investment was not only to double the production, but also to significantly reduce the unit cost of production to achieve a large margin enhancement. Analysis on the performance of the mining processes indicated that it was possible to achieve a doubling of production without the addition of any new mine production equipment if these production processes were managed to achieve higher productivity and better utilization of the resources. A mine improvement program was initiated in 2010 to realize these improvements. This program included the implementation of a new mine operating model based on a conceptual framework which covers detailed planning, scheduling and execution of work to achieve the production targets. The development and advancement of a number of new technologies applicable to the underground environment developed both in-house and with a number of key vendors were incorporated into this concept along with specialized software application tools to support the new production management processes.

A key concept that was introduced as part of this production management system is the concept of Short Interval Control (SIC). This involves the use of real-time production information to provide a Central Monitoring and Control Room (CMCR) with the real-time status of all tasks in the mine. It supports the key front-line decision making and resource allocation to achieve the maximum results for the shift. This paper discusses how this approach to production management is being applied to achieve significant improvements in asset utilization and production performance at Chelopech Mine.

The Challenge in Managing Underground Mines

The challenge facing underground mines is to manage the many tasks that must be accomplished to achieve the sustainable production rate targets. Typically there might be five or six core mining activities that must be managed including development, drilling, blasting, mucking, filling and ore transport and a number of other service or support activities such as maintenance and logistics that are necessary to carry out these core activities as illustrated in *Figure 1*. This can result in each shift requiring the assignment of people and equipment to activities and the coordination of as many as 50 to 100 or more separate tasks in the shift. Interruptions or delays that occur during the shift are often dealt with by the individual workers or occasionally with the help of one or more shift bosses or supervisors on shift. The use of radios underground have improved the response time to these shift problems but there is still significant room for further improvement. Often it is not known that a task was not completed as expected until the end of the shift when the operator reports verbally or on paper the results of the task for the shift. The reasons why the results were not achieved are often not provided or ignored and the opportunity to address these during the shift is lost.

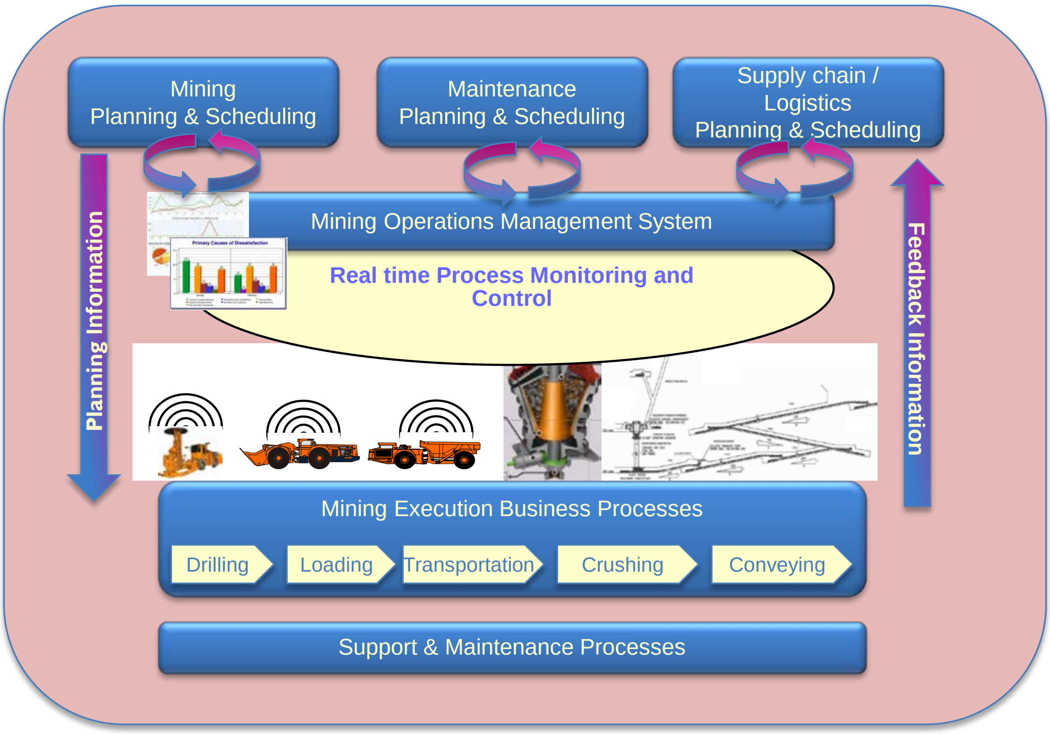

Figure 1: Planning to Execution Loop.

Even though the truth behind the story justifying the shift results is often the topic of much discussion and debate with middle and senior management, little comes out of these as the opportunity to do something has already been lost. Much of the paper data is collected (including the reasons for delays) and recorded into various databases. The accuracy and the validity of the data is often in question and typically very little analysis is ever done on this data or used to improve the processes.

To improve productivity and performance some underground mines are introducing new technology to try and automate some of the mining processes but this has proved to be a big challenge in the underground environment. Autonomous operation requires isolation of the personnel from the automated equipment and special procedures to control this interaction. Productivity gains have been achieved in specific cases in methods more suitable to autonomous operation such as block caving. This has not worked as well in mines where isolation of the autonomous machine restricts the ability to carry out concurrent tasks occurring simultaneously in the same area or level. *Figure 2* shows the levels of technology and automation typically employed in today's underground mines.

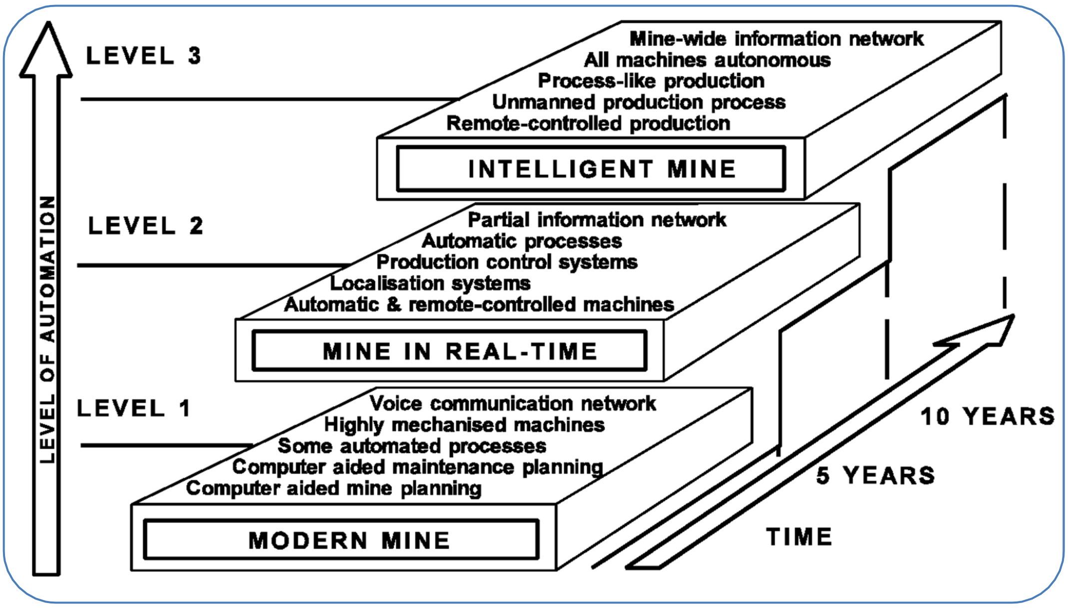

Figure 2: Increasing use of Technology.

The New Way of Managing in Underground Mines

The use of real time information is becoming increasingly common in underground mines. Discrete applications such as personnel and equipment location tracking, centralized blasting and monitoring, fixed equipment control and monitoring, and ventilation monitoring are all common place in today's underground mines. The enabling technologies have advanced significantly to the point where it is now cost effective to implement many of these ideas. The development of low cost off-the-shelf wireless networks (Wi-Fi) for underground has been the most significant recent advance. The use of this backbone for voice, data and video communications in a reliable and cost effective way is now possible.

The development of inexpensive wireless RFID (Radio Frequency Identification) tagging for vehicle and personnel location tracking is another key development. Voice-over-IP (VoIP) phones for communications, wireless tablets, on-board mobile equipment monitoring and wireless PLC controllers and cameras are all enabling technology pieces that form a part of this solution.

In the implemented solution we bring together a number of these recent technologies and software systems as part of an intelligent mine management system to provide real time production management and tracking in a broader concept for production monitoring and control.

The advanced concepts for production management and control are not new. They have been used in the manufacturing industry for some time. There are now standards such as ISA 95 which clearly describe the functional model and interface standards for such a system (see *Figure 3* and *4*). Although there are no standards yet developed for the mining industry these concepts can still be applied in a similar way with the technology currently available to the mining industry.

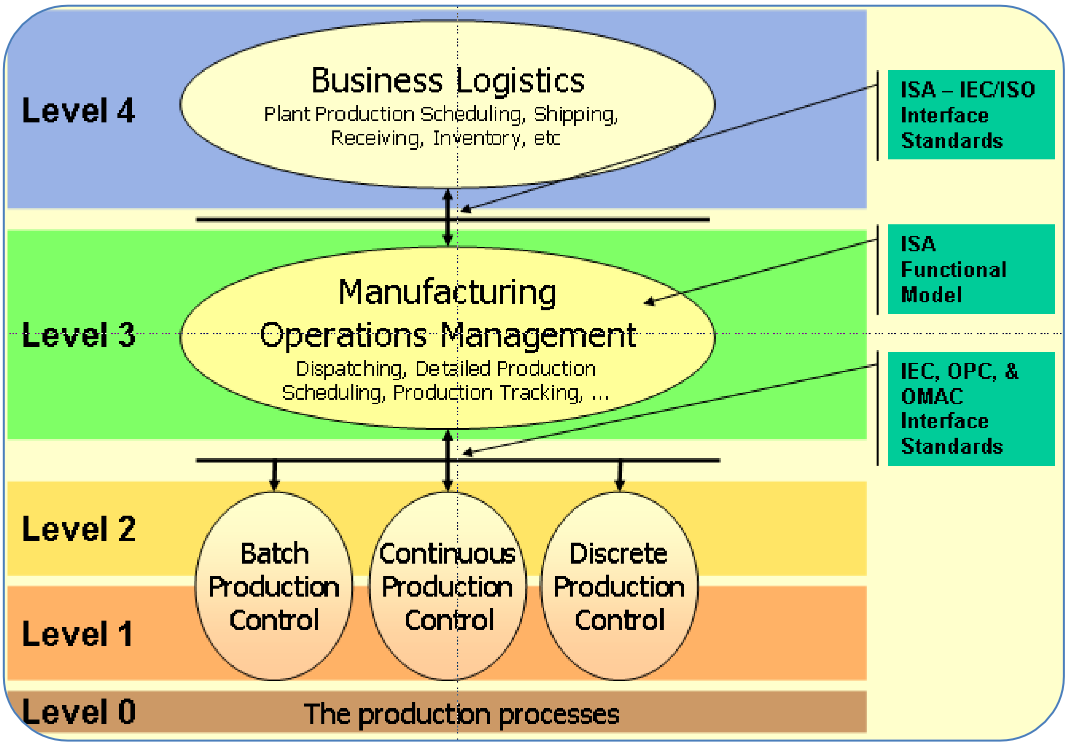

Figure 3: ISA 95 – Manufacturing Industry – Production Control Model.

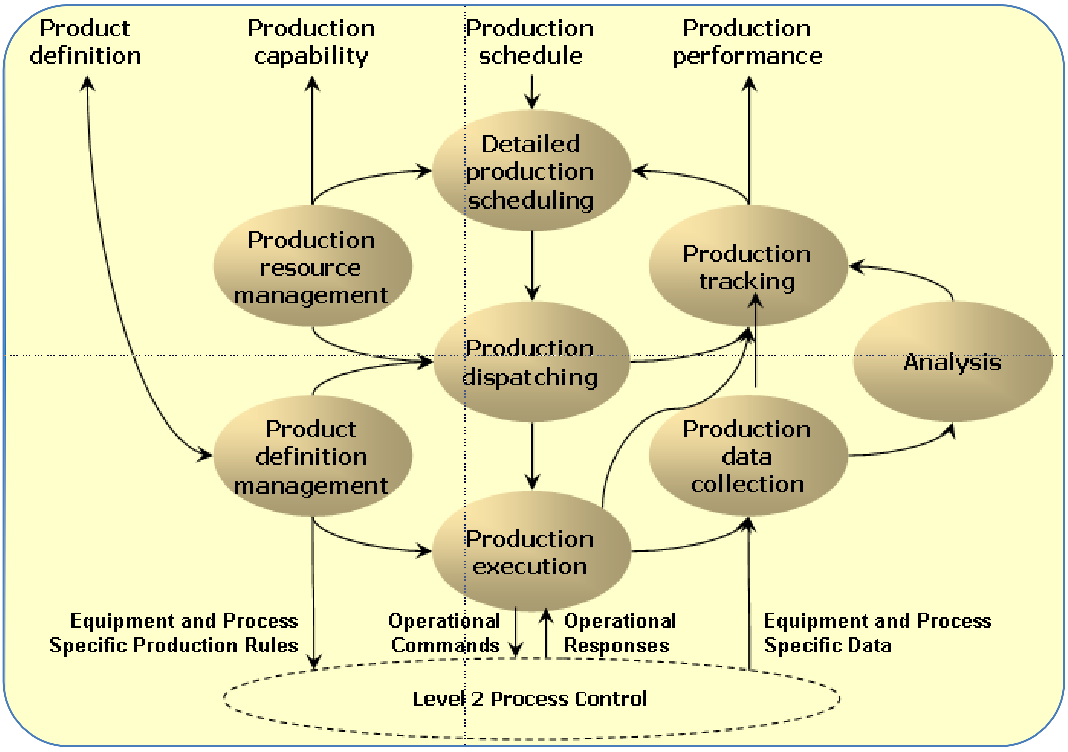

Figure 4: ISA 95 – Operations Functional Model.

The various application layers employed in the production management model at Chelopech Mine (similar to *Figure 3*) are shown in *Figure 5*.

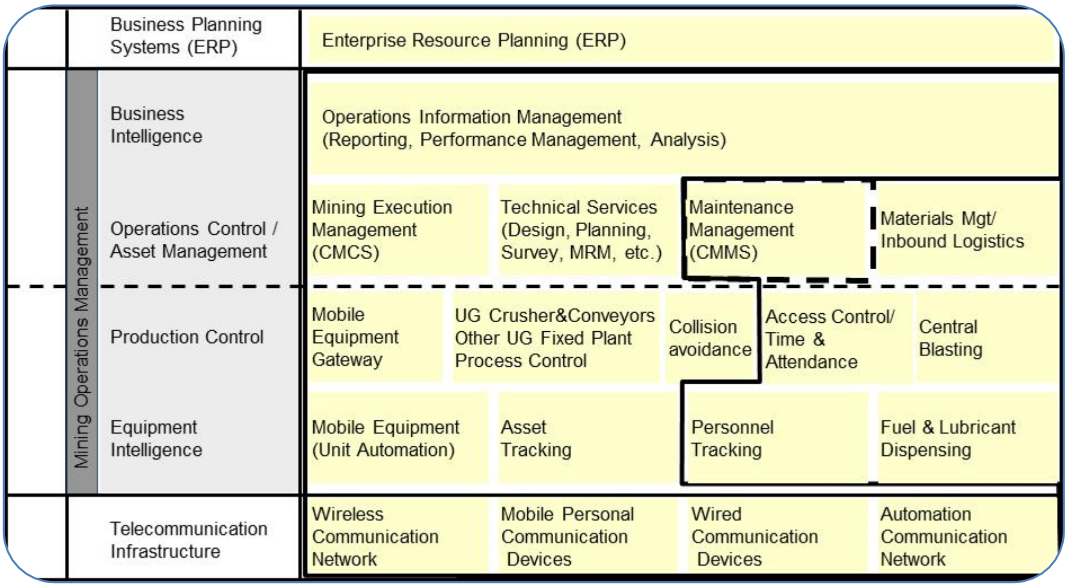

Figure 5: The Chelopech Application Layers.

The concept of Short Interval Control (SIC) has been applied in the manufacturing industry for a long time now. In essence short interval control is nothing more than providing a feedback loop on the production tracking against the expected production at short-term intervals so that decisions and intervening actions (dispatching resources) can be taken to minimize deviation from the expected outcome. The updating interval depends on the method of updating and the availability of the information. With real time information this can be updated as it happens. Where the personnel must provide the updated information either over phone, radio or tablet, the update interval is typically set at a minimum interval of every two to four hours in the shift or when a significant event occurs that interrupts the process.

In order for this concept to work there must also be a central command center where this real time or personnel-communicated information is collected and tracked against the assigned tasks for the shift. Based on information provided to the central monitoring and control room (CMCR), the control room supervisor can intervene when assigned tasks are deviating from expectations. This may include dispatching additional resources to address the problem faster or reassigning resources to the appropriate alternative tasks based on agreed-upon priorities. The goal is to complete as much of the scheduled work in the week as possible and to make maximum use of all resources on the shift. The premise is that the mine will sustainably achieve the production targets if they complete all the production, support and service work required on time as defined by the master schedule and the 7 day detailed work breakdown schedule.

The New Production Management Process

The overall Management Operating Model in *Figure 6* describes the key elements of the operations management framework being employed at Chelopech Mine. It incorporates the setting of sustainable production and asset performance targets through to developing a master schedule (minimum three months activities schedule) of activities which forms the basis for developing a detailed breakdown of that schedule into the production, support and services work tasks for the week. The measurement of the process performances and the analysis and improvement are then used to feed new targets to close the loop and create a continuous improvement cycle. The Central Monitoring and Control System ensures that the shift schedule is executed as planned. It supports the areas of work planning, scheduling and execution and in particular the execution of the work in the Management Operating Model.

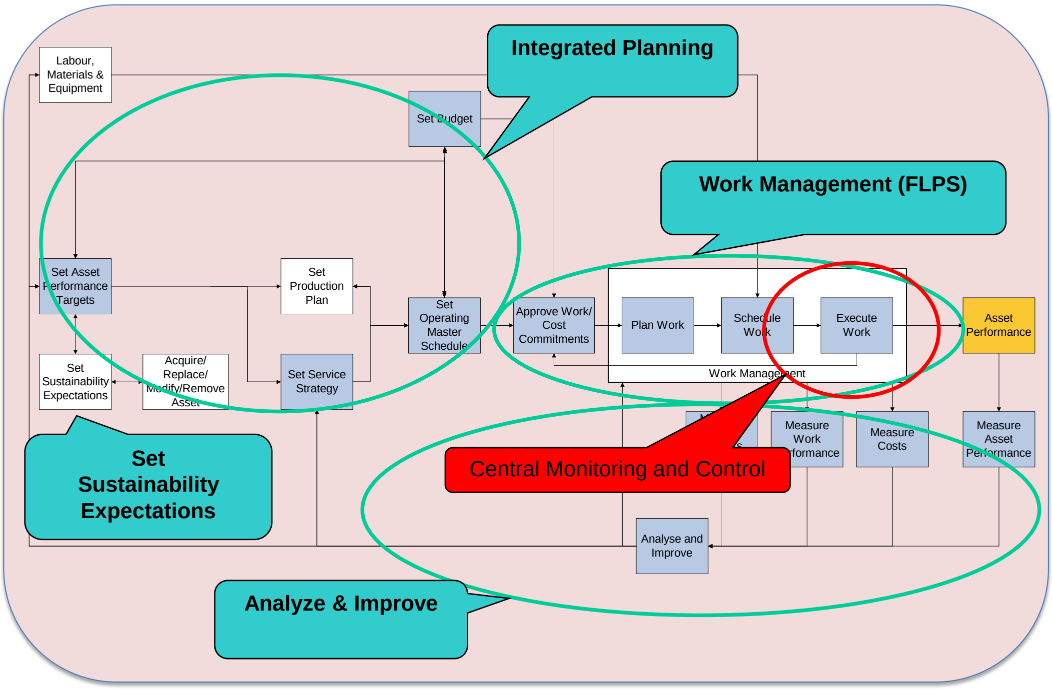

Figure 6: The Management Operating Model.

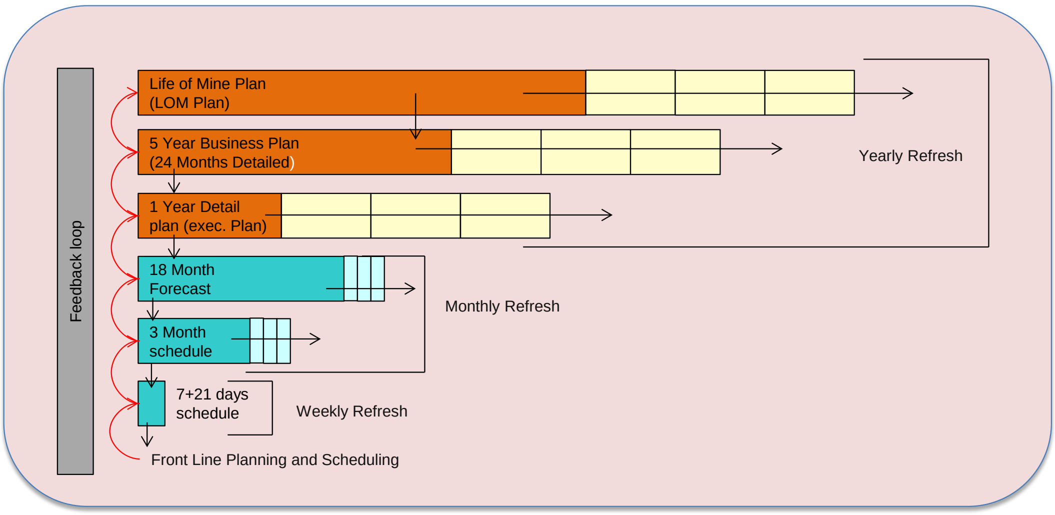

Figure 7: The Planning Cycle.

The first step in the process is to generate a detailed 7 day shift-by-shift breakdown of all activities in the master schedule into individual tasks to be assigned to the people and equipment. These include all production, service and support related tasks for the various workgroups which are integrated into a shift-by-shift 7 day schedule of tasks to be completed for the week. *Figure 7* illustrates the linkage of the various levels of planning down to this detailed level. The mine generates a short term production master schedule by activity which is updated weekly and goes out a minimum of three months. From this master schedule individual tasks are generated and integrated with service and support group tasks to create a detailed weekly schedule of tasks for every shift. This schedule of tasks is checked for any conflicts, corrected, reviewed and approved by all departments prior to the start of the week.

The CMCR supervisor receives this detailed shift by shift 7 day schedule loaded into the Gemcom InSite shift management software (see *Figure 8*). At the change of the shift any adjustments to the schedule for the next shift are made by the CMCR supervisor and the shift supervisor, prior to the shift supervisor assigning the tasks for the shift to the operators and equipment (see *Figure 9*).

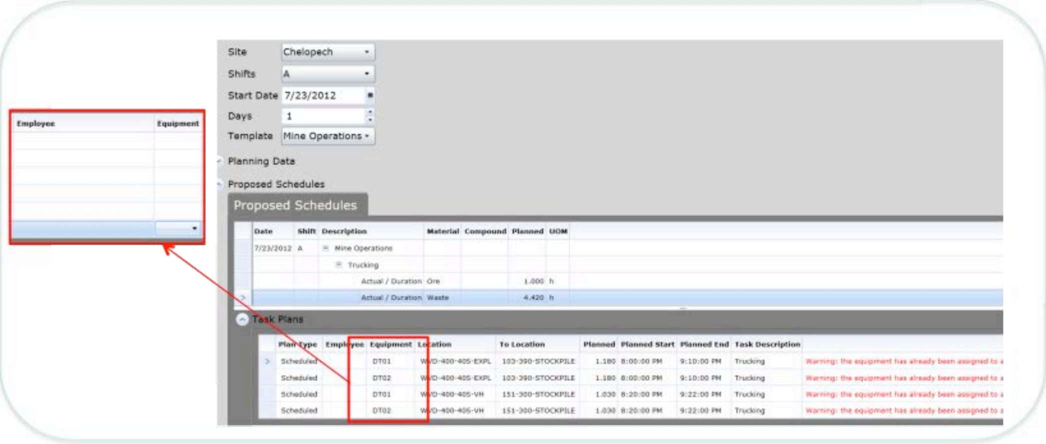

Figure 8: Tasks Imported into Shift Management Software.

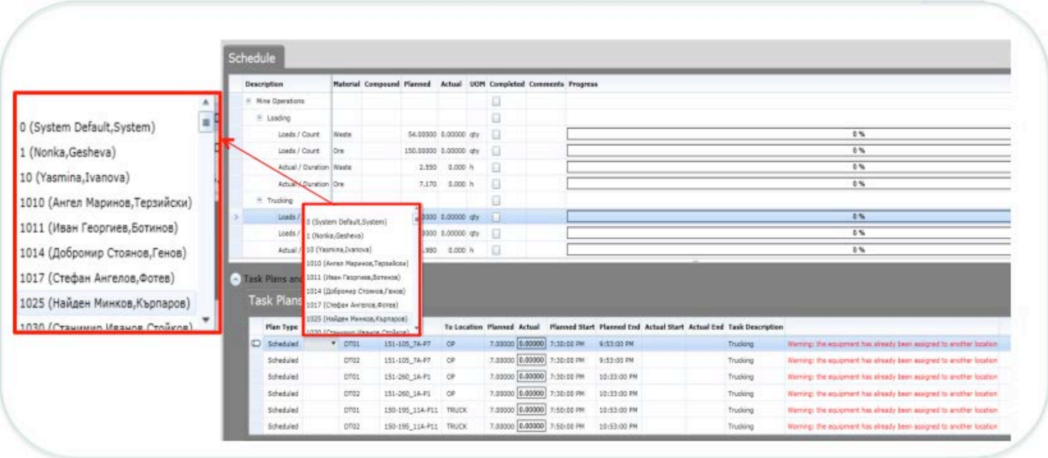

Figure 9: Tasks Assigned to Operator and Equipment.

Tasks are then sent to the tablets on the equipment for the equipment operators to see (see *Figure 10*). The information downloaded to the tablet includes the workplace location(s) as well as the quantity of expected output and time duration for the task. For the loaders and trucks the quantity of material moved is automatically recorded. For other tasks the operator provides an update on the work completed through the shift via the tablet. Machine and operator/service delays and status change, as well as status of work locations, can be reported via the tablets.

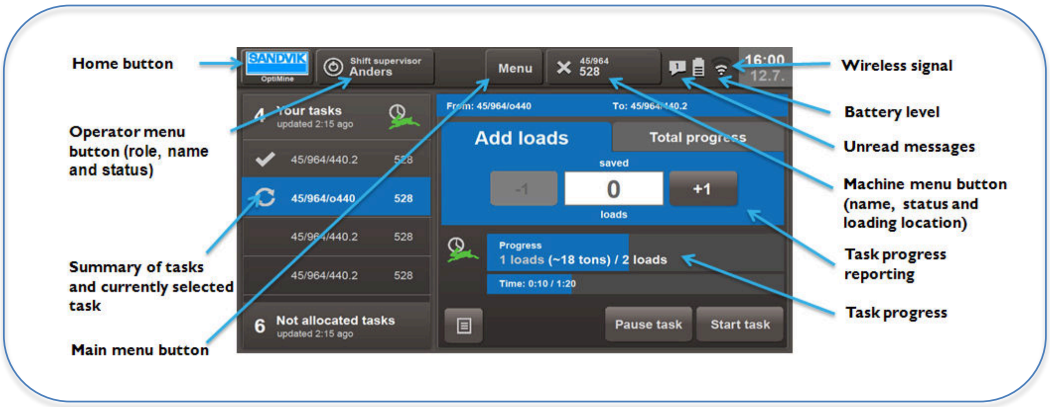

Figure 10: Touch Tablet Interface for Operators.

All updates of all tasks are logged and monitored in the CMCR. If no update is provided at the agreed intervals the CMCR supervisor can contact the operator directly to get an update and record this in the system. The shift supervisor also has a tablet and can monitor and update tasks for his/her crew. The shift management software allows the CMCR supervisor to see and monitor the progress of all tasks. Color coding of the progress allows the CMCR supervisor to quickly identify, by exception, those tasks which are behind schedule as the shift progresses (see *Figure 11*). He may contact the shift supervisor or operator directly to determine the cause for this and he may implement actions to improve the performance or reallocate resources to solve a problem. The CMCR supervisor can also take actions regarding any major interruptions to any process including re-allocating resources to other approved tasks by priority if a task cannot be completed for any reason.

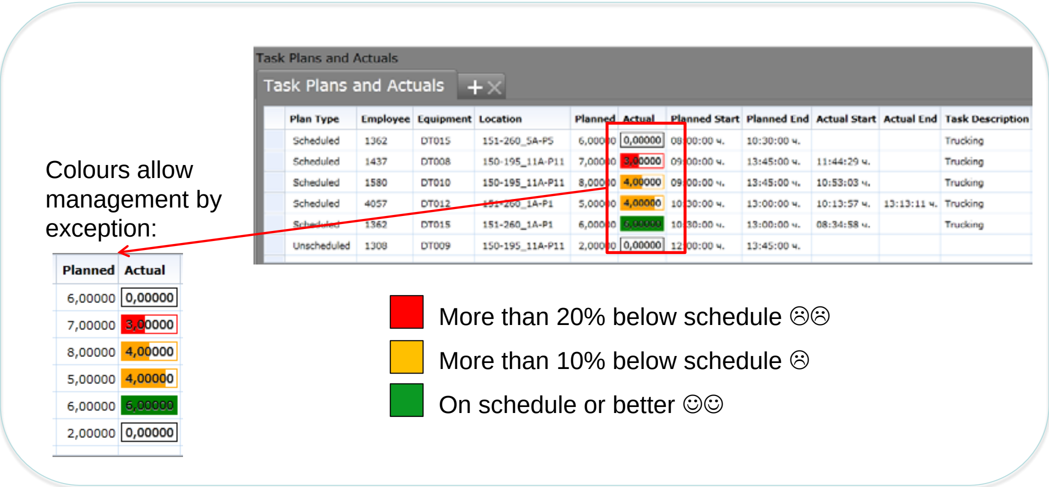

Figure 11: Task Progress Displayed in CMCR.

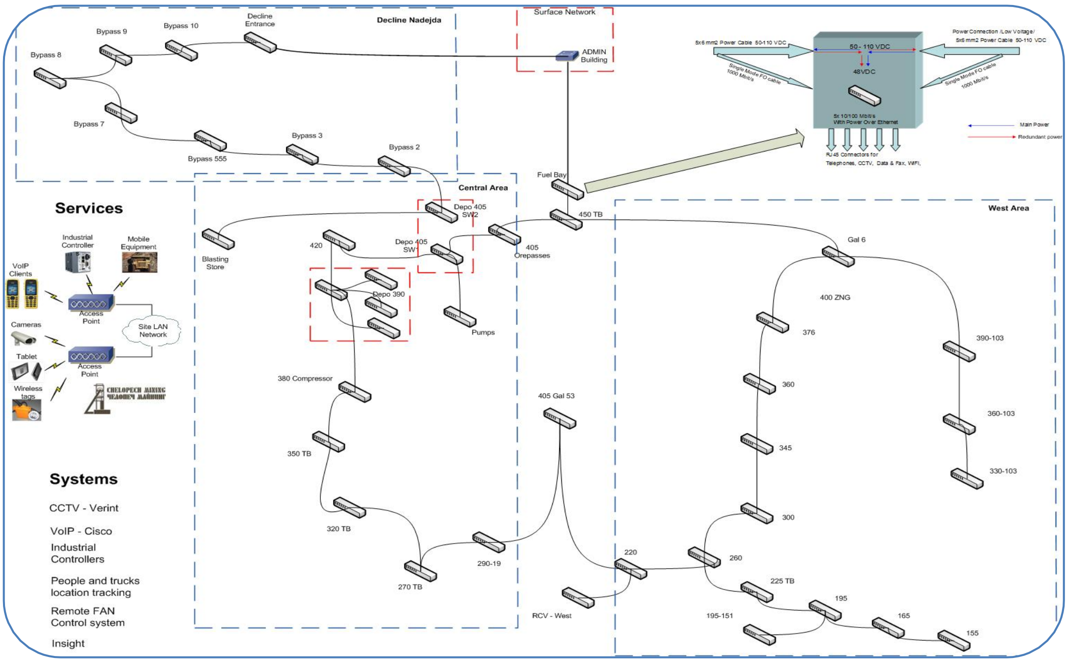

Figure 12: Underground Wireless Network.

Personnel and equipment are tracked using wireless RFID tags and a software location engine that locates the approximate physical location from the signal strengths to the closest wireless access points (AP) underground. *Figure 12* shows the layout of the wireless network and wireless AP. Coverage for this underground wireless network ensures better than 90% coverage over the entire mine. When there is no connection to the network the information is stored on the tablet and updated to the server when reconnected. The personnel RFID tags are mounted inside the miners' cap lamps. The equipment RFID tags are mounted inside the cabs of all of the mobile equipment. The current location information and recent movements of personnel and equipment are displayed in specialized software designed for this purpose showing the locations relative to the current underground workings (see *Figure 13*). This information is also displayed on level plans inside the shift management software showing active tasks and workplaces with relative locations of personnel and equipment plotted on the plans (see *Figure 14*). This information is useful for the CMCR supervisor to co-ordinate activities and locate personnel and equipment resources if needed. It is also beneficial in cases of emergency or central blasting to account for all personnel and manage the emergency response effort.

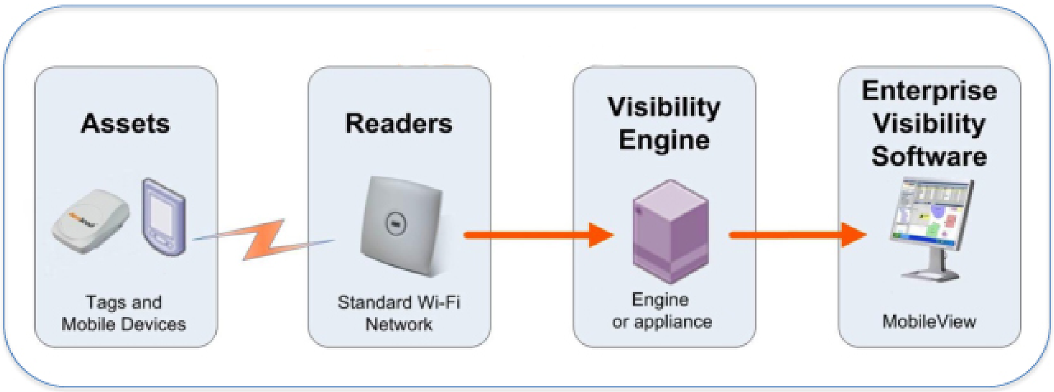

Figure 13: Wireless RFID Personnel and Equipment Location Tracking.

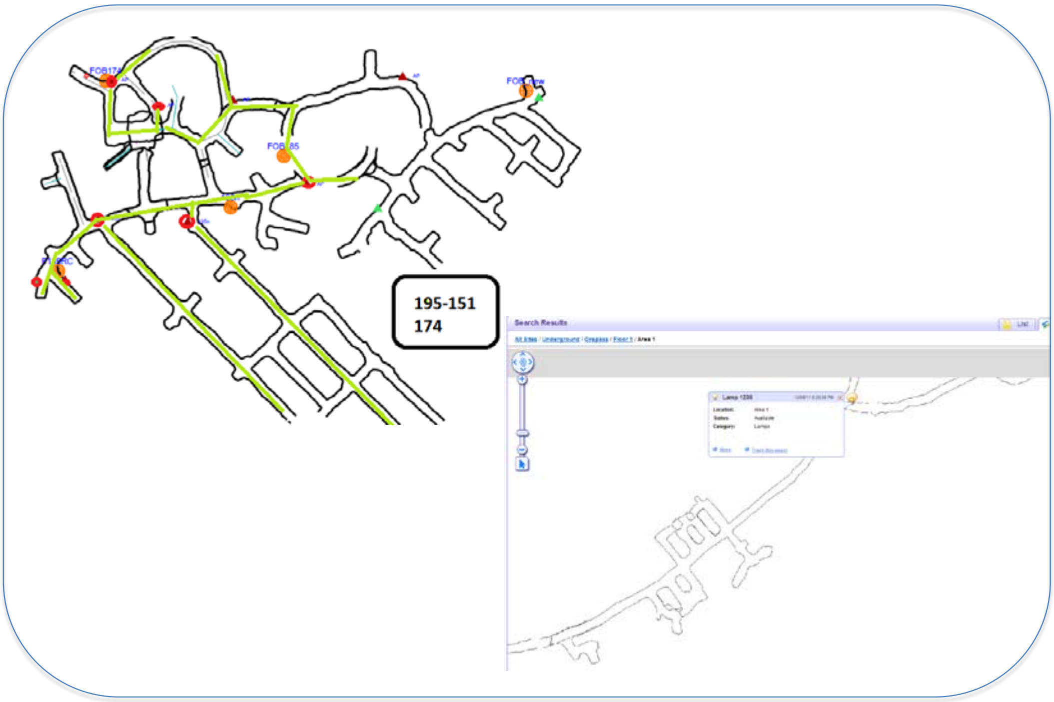

Figure 14: Level Display of Location of Workplace Activities, Equipment and Personnel.

On-board machine monitoring and reporting is installed by the manufacturer on the underground loaders and trucks and will later be installed on all of the remaining production equipment (see *Figure 15*). The on-board systems monitor the health of the vehicle through sensors located throughout the machine. Any warnings from the machine are sent to both the operator and the maintenance department. On-board sensors also determine load weights and can record the cycles and production performance of the machine which is sent directly to the CMCR to update the status of the tasks in the shift management software.

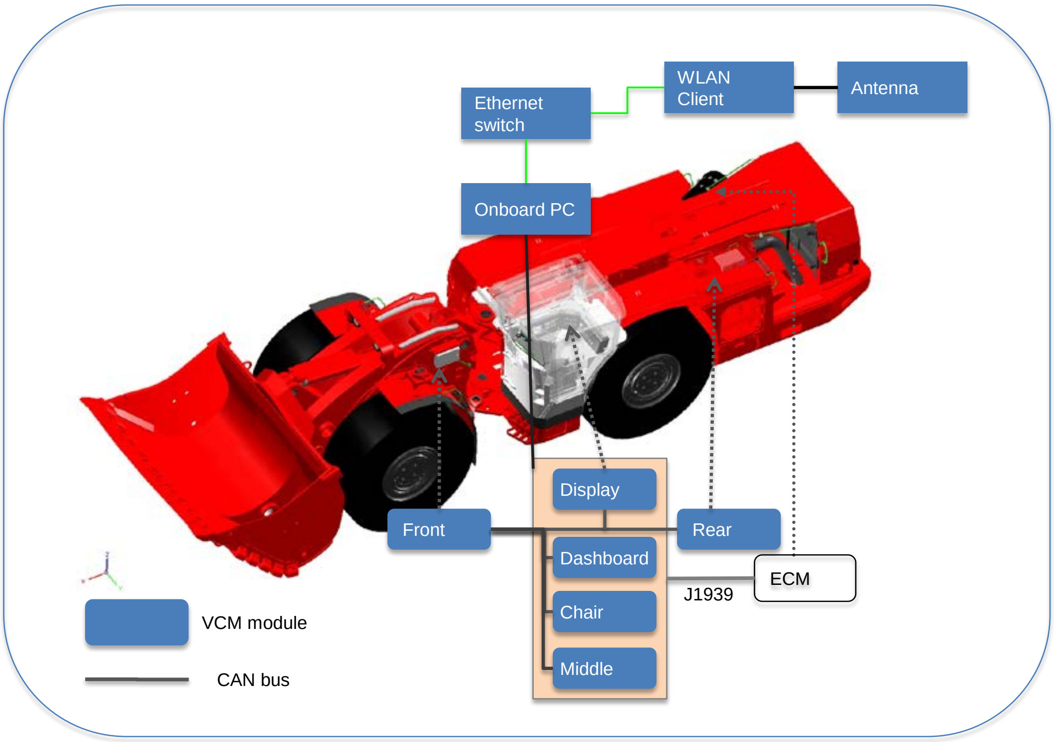

Figure 15: Production Equipment On-board Monitoring Technology.

Daily and weekly management routine meetings form a part of the overall work management process. At the end of each shift the CMCR supervisor creates a summary report of all tasks completed and not completed in the shift. The tasks that are not completed are flagged for a decision at shift handover as to whether or not they will carry-over to the next shift as additional work or displace scheduled work for the next shift. Any shortfalls in production activity are cumulatively reported and monitored daily for the week and mine management takes necessary action to ensure these activities are caught up to achieve the week's targets. Any new work identified is assessed within a 24 hour period to determine whether it is urgent or not and will bump other scheduled work in the current week or that work will be planned for a future week. The concept is based on achieving the "right work, at the right time, the right way". Following the plan and schedule as much as possible and completing as much of the scheduled work as possible is the goal for the week. If plans and schedules are followed the expectation is that the mine will sustainably achieve the production targets. Of course there will still be unforseen interruptions but this process calls for a structured and organized response to such interruptions and one which minimizes the upset to the overall plan.

At the end of each week a report is prepared that shows overall compliance to plan for the week and month to date and provides identification of any work not completed that needs to be scheduled in the upcoming week. The plan and schedule for the upcoming week incorporates this work and all new planned work, and the cycle begins all over again.

Project Organization and Participants

The effort to develop and build this system has involved a significant internal team working very closely in partnership with several key vendors of the technology pieces and integrating those pieces into one integrated system to deliver the concept we have developed. It is a very aggressive and challenging goal but one which we believe will have significant benefit to our current and future operations.

The shift management software has been provided by Gemcom/Dassault Systèmes and is part of the Gemcom InSite mine production management solution. The production equipment and the on-board production equipment monitoring have been provided by Sandvik through their AutoMine Process Management product that also includes the task management software with the tablet application. Sandvik have also assisted with systems design, integration and project management. The maintenance management software Tivoli Maximo was provided by IBM. The location tracking and tagging hardware and software has been provided by Aeroscout. The wireless network is based on Cisco components custom designed and packaged for underground by our own IT team. The VoIP phones are provided by Cisco with special features developed by our own IT team. The tablets are provided by HP with special mounting and installation hardware designed by our own IT team. KPMG in Bulgaria has assisted the project with systems documentation and training, as well as with project integration and management. The CMCR physical layout was designed by Bestech.

It is important that the technology is reliable and robust so that it works all the time in the harsh underground environment. A significant effort has been put into making all the pieces of technology reliable, and vendors have worked with Chelopech Mine, and with each other, to bring the latest technology to the project.

A New Way of Working

One of the most critical components of the project management proved to be the significant change management effort incorporated as the implementation requires a considerable change to the way the operation has worked in the past. The key is to show to people at all levels the benefits that this new way of work performance will bring to make life easier for them and to overcome the fear that "big brother is watching".

In order to ensure that all aspects of the system and macro process were considered, detailed shift management processes were designed with defined roles and responsibilities allocated to each step in the process. This was carried out for standard monitoring and control processes and in order for personnel to respond to exceptions in performance (for example managing breakdown events, operational and service task delays and deviations in expected production task performance). This allowed for roles and responsibilities to be specified for each stakeholder in the Management Operating Model, as presented in the framework (*Figure 16*). The below consideration of systems, processes, technology and people is needed to ensure that all stakeholders clearly understand:

- What needs to be done to achieve the target performance
- Who should carry out the defined tasks
- When the tasks should be carried out
- What systems and tools are necessary to complete the task
- What is the expected output of achieving the scheduled tasks

To ensure buy-in and understanding of the changes in the roles necessary to allow short interval control to be used effectively in the underground mining environment, effective communication with all levels in the mine is essential. Mine management used process and role specific training and communication materials to improve uptake.

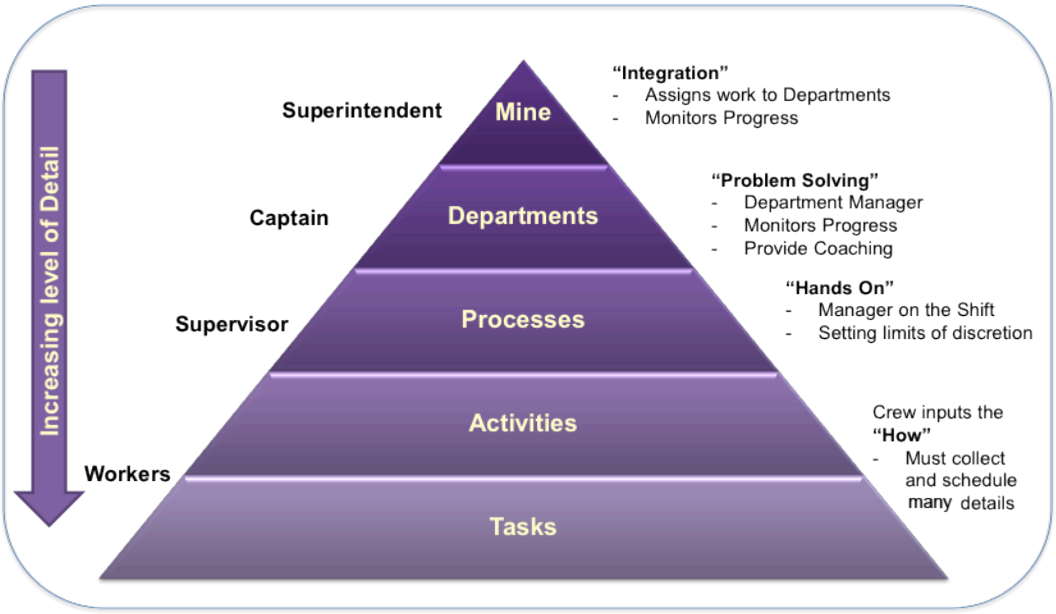

Figure 16: Framework for Aligning Stakeholders' Roles and Responsibilities to the MOM.

Project Status

Much of the system components are now installed in the mine with the remaining work expected to be completed by the end of 2012. Training on the new system and for the changes in roles and responsibilities is now underway along with preliminary testing of the system.

Conclusions

This new approach to production management using real time monitoring of the processes and short interval control is in its infancy in underground mines. Similar concepts are being applied in open pits and a few large scale underground caving mines today. This attempt to fully integrate the technological components necessary to make it a reality in a typical sized non-caving method underground mine is probably a first. It holds the potential to significantly improve management of the mine to achieve maximum performance and utilization of resources in an environment where the work is primarily accomplished by many discrete tasks.

This project is still in the early stages of implementation so it is too early to determine the quantifiable benefits. The authors believe there are a number of benefits of this approach to underground mine operations management that will be realized. These include the ability to see the whole mines activities through a single point of access in the CMCR. The CMCR will serve as the monitoring, dispatching and coordination center for the mine. It will also be a source of information for supervision and workers in the field. Through the SIC monitoring, critical issues on the shift can be identified and corrected at an early stage reducing the potential for lost production.

This approach will eliminate the need for paper reporting and will improve the data and information integrity. There will be only one version of the truth. Less time should be spent debating or explaining why variances have occurred and more time will be spent solving problems. Although the initial priority is to use the real-time process information to aid in shift management and work execution, the longer term plan is to use this information to analyse trends and improve processes in a closed loop continuous improvement cycle as explained in the management operating model.

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The authors wish to thank Dundee Precious Metals Inc., Chelopech Mine management and all the contributing vendors for permission to publish this paper. We would like to acknowledge the innovative spirit of all those who have been involved in making this concept a reality and the efforts of the Chelopech Mine operating staff for their commitment and dedication to make this work. In particular we would like to acknowledge the input of Mark Gelsomini, Corporate Director IT for DPM for his innovative design of the wireless network, voice communications and tablet components of the system. We would like to thank Gemcom for the collaboration on this project and their significant investment into the CMCR software development with the InSite platform. We would also like to specifically acknowledge the Sandvik team including Peter Persson, Giel Marais and Mike Andrews for their onboard fleet systems and for their project management support. We would also like to acknowledge KPMG in Bulgaria team led by Lozina Alexieva, Management Consulting Partner, for their project management and system implementation support.

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