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Towards autonomous operations in the mining industry: the role of human factors.

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ABSTRACT: In the past 30 years, Latin American mining industry passed under the sign of technological advances; first with the incorporation of mechanized equipment and then teleoperation and automation in many aspects of the excavation process. In that respect, Chile is the leading country, although lately Peru, Mexico and Brazil are showing a growing interest in introducing new technologies in their mining operations. Positive aspects of these changes can be seen in continuous improvements of operations and processes, increased in innovation and improvements in safety. However, with few exceptions, the involvement of top management in enabling innovation and rapid technological implementation has often been insufficient. This, however, is changing dramatically as mining companies look towards automatization to maximize productivity and profitability, remove mining personnel from dangerous environments as well as bypass human limitations to meet new challenges, which would allow the humans to make strategic decisions while being supported by the machines and the connected environment.

This paper examines the human factors issues related to the implementation of automated system in general with some examples from Chilean open pit and underground mines.

Keywords: Mining, automation, human factors, drilling, technology, innovation

1 INTRODUCTION

With the world´s fluctuating demand and commodity prices, the ongoing need to maximize productivity and profitability, and the heighten requirements for safety, mining companies commenced their road towards automation through innovative technologies many years ago (Cosbey et. al., 2016, SCOTT, 2017, Black Livingston et. al., 2018). Since 2013, there has been an unrelenting call to change. Rick Howes, CEO of Dundee Precious Metals (Rivard, 2013a), said "…compared to other industries, mining was decades behind in technology adoption … requiring new and innovative thinking to manage the entire mining asset cycle". The same year, the CEO of Anglo American, Mark Cutifani, advised the mining industry to look to other industries, such as petroleum, aviation and manufacturing, for technologies that had been used to address various needs such as design, mapping, modeling and simulation solutions (Rivard, 2013b) with proper adaptation in mining operations considering the ever-changing environment and mobility of mining equipment.

With the mining industry driven by two dominant factors, productivity and safety, and now pressured by the COVID-19 pandemic, the industry looks towards the automation, under various appellations (Mining 4.0, digitalization, and others) to increase efficiency and productivity while containing costs.

In this paper, we briefly examine the role of human factors in the implementation of new technology and autonomous systems in the mines with short description of how COVID-19 has affected mining operations in 2020. Case studies from Chilean mines are presented showing the central positions humans hold in the successful application of innovation in the mining industry.

1.1 *Automation and human factors*

In many industries, automation was introduced to bypass human limitations to meet new challenges, leading, to a certain degree, to a division of labor between human operators and the automated systems by appealing to their respective strength in decision making process and, thus, catering to improvements in process efficacy (Widzyk-Capehart and Duff, 2007; Widzyk-Capehart and Zabłocki, 2020).

The human-factors based definition of automation implies the existence of intermediate automation levels between manual and fully automated systems with each level incorporating a variety of action selection and decision-making scenarios and a wide range of cognitive and psychomotor tasks requiring real-time control within numerous domains (Endsley and Kaber, 1999). These scenarios range from the lowest, where the human operator must make all decisions and undertake all actions, through to shared autonomy, where decisions are made cooperatively between the computer and human operator, to the highest level, where the computer decides everything and ignores the human. In the mining industry, the adoption of automated and autonomous systems continues to grow due to technological advances occurring within and outside of the mineral industry and due to societal values affecting it: climate concerns and the recent ongoing COVID-19 pandemic.

The trends in the evolution of mining personnel, which have begun more than three decades ago (Sanders and Peay, 1988), continue to affect the productivity and the costs of mining operations today and will influence the mining industry in the future. Among them are the miners' age, experience, education and gender.

The miners are getting younger. The Australian Federal Government figures from 2014 (Department of Employment, 2014) stated "The mining industry employs a higher proportion of workers aged 25 to 44 years than all industries combined, with more than half the workers in mining (58.6 per cent) falling within this age group, compared with 45.4 per cent for all industries. By contrast, the proportion aged 15 to 19 years is lower than across all industries (0.8 per cent compared with 5.5 per cent), reflecting the industry's need for qualified and experienced workers". By comparison, the Chilean Mining Skills Council (Consejo de Competencias Mineras - CMM) reports that the average age of professionals employed in the mining industry in Chile has decreased by 2% between 2017 and 2019 (CMM, 2019). The average worker´s age has dropped from 44.2 years in 2017 to 43,9 years in 2019. This drop is said to be associated with the increase in the number of workers below thirty. CMM (2019) also pointed out that, generally, the average age should increase every two years; therefore, the change in recent years reflects a significant increase in young workers employed in the mining industry.

The newly hired miners have less mining experienced than the miners in the past, leading to the increase in training requirements and often to the decline in productivity. However, the young miners are, on average, better educated and have grown up immersed in technology, which will affect the approaches to learning and training. The CMM study (2019) show that the number of professionals with higher education employed by mining industry in Chile has increased by 4% between 2017 and 2019.

Furthermore, the proportion of female miners is increasing reflecting the changing social climate. In Chile, female participation increased at all levels of mining operation: from operators, maintenance workers to professionals and supervisors since 2012. In 2019, the global participation of women in the big mining workforce in Chile increased to 8.9% within mining operations (CMM, 2019). However, compare to other countries, such as Australia, with 16.6% of female workers, Canada with 17.9% of female workers (see Figure 1), South Africa, where women made up 12% of the mining industry in 2018 (Mineral Council South Africa, 2020) or Poland, where 11% of Poles employed in mining were women in 2019 (Poland Perspective, 2020), the female participation in the mining operations in Chile is still relatively low.

Figure 1. Female participation in the labor market (green) and the mining industry (brown). (Mining industry includes mining companies and service industry) (Source: CMM, 2019)

The trends toward younger, more educated workers with increasing numbers of women in the workforce though with less mining experience have implication for automated systems and the implementation of autonomous equipment in mining operations, especially, in the training area, which must be considered carefully by the mining companies.

1.2 *Mining and COVID-19*

The COVID-19 pandemic has affected the commodity markets and mining operations in a variety of ways.

In April 2020, Mining Review Africa (Shabir, 2020) reported drop in share prices and commodity prices quoting platinum and palladium price drop by more than 40% since mid-March while share price of Sibanye-Stillwater lost over 60% of its value within 4 weeks prior to the report. In addition, already in April 2020, mining operations commenced suspending non-essential operations, such as Rio Tinto in Mongolia, or shutting down productions, for example Alta Zinc project in northern Italy. South Africa's 21-day period of national lockdown grounded all local mining operations in April 2020, which were placed on care and maintenance, while quarantine in Peru led to a halt in operations of Anglo American, Pan American Silver and Newmont; the 15-day quarantine in Peru slowed work on Anglo American's major Quellaveco copper project to protect workers, demobilizing at least 8,000 out of the 10,000 construction workers pending safer conditions to restart project development (Ramdoo, 2020; Hoffman and Motta, 2020; Shabir, 2020). In Poland, the mines closed temporarily or reduced their operation after initial cases of COVID-19 infections were confirmed at the mine sites and further reduced their operations when the spread of virus has expanded rapidly, especially in the Silesia coal mining region. In Chile, Codelco temporarily suspended its contracts with suppliers in April 2020 (Ramdoo, 2020) while the COVID-19 impacted the diamond market with De Beers, the world's second-largest producer, reported a 28% year-on-year decline in sales in March 2020 (Mining Technology, 2020).

It must be pointed out that while lower global demand and reduced operations caused a decline in certain mineral prices, other parts of the sector (such as gold) have been thriving (Ramdoo, 2020).

Significant difference exists also between mechanized and labor-intensive mines. Mechanized mines with fewer staff have not slowed their operations to the same extent as labor-intensive mine sites; the automated Pilbara mines in Australia have recruited more workers as development projects continue while Syama mine production in Mali remained uninterrupted despite the crisis (Ramdoo, 2020).

With the continued challenges imposed by COVID-19 pandemic, the mining companies may look towards automatization as it can allow them to quickly implement greater social distancing and remote operations centers or, at a minimum, control rooms, allowing for isolation and protection of critical employees more quickly while accelerating the pace of technological adoption already in the pipeline (Ernst & Young, 2020; Ramdoo, 2020).

Clearly, COVID-19 will not be the main determinant in fast-tracking the move toward full automation in the near future partly because of the complexity of the industry, the cost of technology or because some operations deliberately do not introduce labor-saving technology for fear of repercussions from workers and host governments. However, these barriers to automation may now have been significantly lowered (Ramdoo, 2020) paving the way to the introduction of novel technologies and automation in greater number of mining operations.

It is evident that the companies need to adapt much quicker than in the past to the rapidly changing environment or risk becoming non-competitive in an ever-competitive market (Mitchel and Steen, 2017). There is also a growing realization that enabling fundamental improvements in the organization requires a shift in corporate culture as well as organizational structure and accountability, which shows that the greatest challenge (as identified by Mitchel and Steen, 2017) are with experience, coordination and supervision and the need for a higher level of skills development to enable long-term success. Therefore, technology, automation, innovation and various issues related to human capital will be at the core of sustainability of mining operations for the coming decades. Even with automation, the humans will be at the center of the operations as they will make the strategic decisions, while being supported by the machines and the connected environment.

1.3 *Training*

Teleremote and digitalization are accelerating the pace of the technological implementation and the need for competent professionals and innovative training. As is being discovered in other industries (CIEHF, 2020), ensuring that future mining personnel have the knowledge, skills and experience to undertake future mining roles and to improve safety will create new human factors challenges over the next few decades. Moving towards fully autonomous systems still requires a plethora of people working remotely proving that, for the foreseeable future, the human will still be part of mining operations. With the removal of mining personnel to remote operating centers, training for remote operation of equipment and supervisory role in the autonomous systems must be based on human factors and the understanding of the strength and limitation of human information processing and decision making as well as the understanding of how to integrate the human within the system to ensure that the performance of the human and the system is optimized. The human will still be responsible for system performance and safety while forced to manage the ever-increasing amount of information entering the control room from various sensors and autonomous systems.

The remote positioning of humans with respect to mining operations is already creating the need for automated trainee performance monitoring systems, providing real time evidence to assess progress and adapt the training provision to meet individual learning requirements and preferences (CIEHF, 2020).

Automation creates also greater dependence on simulator-based training to cater for the expanded skill set demanded of fewer, highly and diversely trained system controllers, and the lack of viable real – world training alternative. Moore (2019) emphasized a greater role of the simulators in operators training, especially in underground operations where "…there is a greater need ... to put emphasis on proactive behavior (of the operators), encouraging operators to recognize the warning signs before incidents occur". Takayasu Kashimura, CEO of Lumina Mining Chile (Kashimura, 2019) concurred with the need to impulse change in personnel's behavior" … many times our biggest challenge is to change the mentality of good professionals who bring practices and customs that are not necessarily the most effective in our context (of automation)". While it is hard to predict the skills in demand in the future, "… employers are looking for workers who have a combination of transferrable digital skills and collaborative, creative, communication and entrepreneurial and problem-solving skills" (Department of Industry, 2018).

Enhancing human performance needs to take into consideration that:

- Humans perform well when they can anticipate, thus, the machines must provide context-based information and data to assist with any planning task
- Humans perform best if they have enough time to act in an environment without stress, and
- Human performance can be affected by human errors – it is part of our normal behavior.

Portable digital technologies and simulation stations establish new means to deliver training whether through virtual reality and gamification or electronic applications in any place, at any time and at the convenience of the trainee. These systems will provide both the trainee and instructor with increased amounts of targeted information for use in training debriefs, shortening the timescale for achieving desired levels of performance. With the continuous upgrade of systems through life, the new age miners will also require timely and convenient retraining throughout their careers. The emerging technologies enabling human augmentation, such as, augmented, virtual and mixed reality interfaces, psychological and physiological monitoring devices must be adopted to the specific situations considering that human might not respond fast enough in an emergency regardless of the augmentation received. Since past examples show that placing human in supervisory position may have catastrophic consequences if the human information processing capabilities are not taken into consideration (Burgess-Limerick, 2020), training needs of the future workforce need to be tightly integrated with the mining operations.

2 CASE STUDIES

The implementation of novel technologies and associated automation requires careful planning, engagement between mining company and technology provider and commitment of human resources from management to machine operator.

2.1 *Case study 1: Computerized drill rigs for open pit operation*

This case study briefly discusses the implementation of the computerized drilling system in an open pit operation between 2014 and 2020. The planning must involve not only the operators and immediate supervisors or managers for the specific operational unit or within the specific area of the mine but must include top management, contractors, and suppliers´ involvements and commitments during the entire implementation process. This example especially highlights the importance of management involvement and provides conclusions based on observations of the collaboration between all the parties involved from the perspective of the contractor.

The equipment selected for the automation consisted of:

- 6 x Pit Viper 351 of 10$^{5/8}$" for drilling from control room using optic fiber and Wi-Fi, and
- 2 x Smart Rock D65 of 6½" for drilling from mobile vehicle via access point

The drilling equipment was provided by Epiroc, a company which has been at the forefront of the automation of drilling equipment for more than 2 decades. According to Izzo et al. (2020), drilling function of the Pit Viper machine were automated between 2008 and 2012 and the first generation of the autonomous Pit Vipers was in operation by 2015. To reach the autonomous operation, well-known technologies were adapted and integrated within the drilling applications, including, AI developments for drilling, high precision GPS for machine navigation and positioning, data and video communication through wireless networks and laser technology for safety purposes. Most of all, numerous sensors, which continuously monitor and collect information from the mechanical, hydraulic and electrical components were implemented and integrated into one coherent system. Advanced control algorithms were developed to control the drill rig and to enable customization of the drill functions depending on the machine and site conditions (Izzo et al., 2020).

Figure 2 shows the roadmap toward achieving the autonomous operation of the Pit Viper supervised from the control room called CIGA (note: RCS refers to Rig Control System, which does not include automated setting for the hole). The mining company commenced to implement the modernization plan, in conjunction with Epiroc, in 2016, when two remote operation consoles were installed in a vehicle and a point-to-point communication system was introduced in a pair of Pit Viper drills, thus enabling the equipment to be tele-armed with "line of sight" at a distance of up to 1,000 meters (see Figure 2). Subsequently, Wi-Fi communication systems and fiber optic network were implemented to operate six teams of operators from the Operational Management Room (office at the mine site). In February 2018, the operation of the fiber optic commenced and, a year later, the teleremote operation from the remote operating room could commenced (Epiroc, 2019). It is envisioned that fully autonomous Pit Viper will be operational in the first quarter of 2021. Overall, it took more than 5 years for all the operational steps to be completed

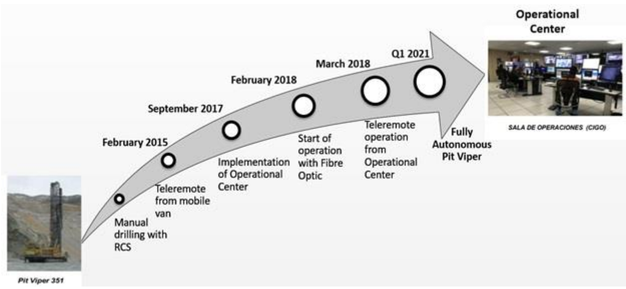

Figure 2. Roadmap defining path towards full autonomous drilling operation supervised from the control room (after Muñoz, 2018. Updated by Authors).

The analysis of the implementation of the computerized drilling system showed that higher productivity was achieved with Pit Viper, raising the drilling advance from 40m to 50m per operational hour, while higher utilization was reached through shift changes occurring in the Control Room and, thus, eliminating travel time to the drill rig, transportation for lunch times and evacuation for blasting. Most of all, improved safety and health was achieved as the operators were no longer exposed to dust, noise, UV radiation, low temperatures in winter months, high altitude effects and machine vibration.

The qualitative analysis showed that the productivity and safety benefits were reached due to the following human factors:

- The mining company developed a modernization plan at the global level, which commenced automation initiatives within various operational processes and thus commenced the cultural change at all levels of operations.
- The management of an open pit mine in Chile placed high importance on the development of the system that would improve the safety and working conditions of people
- The top management involvement and commitment was sustained over a long period of time
- The teamwork, commitment and interaction of mining and contractor´s personnel were maintained throughout the implementation process, and
- The training of operators and supervisors was undertaken with the assistance and direct involvement of equipment suppliers.

This successful implementation of the autonomous drill rig has had other Chilean operations moving towards the automation of drilling where the introduction process of the autonomous drilling equipment at other mines is much faster with one of the main reasons for rapid deployment being the top management involvement. For example, Los Pelambres mine has confirmed an increase in drilling performance (penetration rate) and effective utilization of drill rigs (Palma, 2020).

2.2 *Case study 2: Tunnel development using computerized drill rigs*

This case study is related to block caving footprint operation by mining contractor developing tunnels with various dimensions (5.0x5.0m, 5.5x5.6m, and others). Based on authors´ experiences, similar cases occur independent of the size of the mine and its production.

2.2.1 *Over- and under-excavation*

One of the main problems in the development of tunnels and galleries through drilling and blasting is over- and under-excavation, which driving the tunnel above or below the planned design dimensions. Due to the nature of the current methods used, deviations from the planned design are unavoidable. The factors contributing to the generation of over- and / or sub-excavation include (Cortes Zabłocki, 2018):

- Geological conditions: presence of faults and characteristics of the rock mass
- Precision of the perforation: deviation of the contour and auxiliary contour holes
- Explosive load parameters: distribution of the explosive charge
- Design of the firing diagram: the spacing, diameter and divergence angle of the boreholes

Over- and under-excavation generate various inefficiencies, which directly affect the performance and costs of the operation (Cortes Zabłocki, 2018). The over-excavation increases:

- Time to implement rock reinforcement, exposing the operator to rockfall and falling
- Damage to the contour of the tunnel, affecting its integrity
- Total cycle time, due to the negative impacts on the rest of the activities
- Volume of rock to be extracted, thus, increasing the duration and cost of rock removal.
- Rock reinforcement requirements, to keep the tunnel safe and of the planned dimensions, which requires the use of a greater volume of shotcrete is used, producing inefficiencies of time and costs.
- The sub-excavation leads to:
- Additional blasting to ensure compliance with the planned dimensions of tunnels.
- Irregularities in the floor of the tunnels, which will influence the travel speed of vehicles and could cause damage to suspensions and chassis.
- Increases of the total cycle time, due to the negative impacts on the remaining activities.

2.2.2 *Conventional drilling*

In this study, conventional drilling will be called drilling made with equipment with hydraulic systems, without electronic panels or screens. All the control and regulations of the equipment are carried out in an analog manner with handles, levers and valves.

The operation of a conventional drilling machine begins after the full marking of the work face. The equipment is positioned a few meters from the working face in a position that allows to position the arm(s) at all drilling points on the face. After connecting the equipment to the power through the cable that it carries on its reel, the drilling may commence.

Contour holes have an angle of divergence given by the operator based on working face conditions, requested by the shift manager and according to his/her judgment. After performing all the perforations, the operator removes equipment from the work face to proceed to explosives loading(Cortes Zabłocki, 2018).

2.2.3 *Computerized drilling*

In this study, the term computerized drilling or computerized control refers to drilling equipment that has intelligent control systems, that is, it has instruments, sensors, hydraulic and electronic valves and controls, which are connected to the computer through which the operator can manipulate the equipment. These systems include bore length sensors, allowing to know the position of the drill on the beam, and with this the drilled length motion and direction sensors on the arms to determine direction and positioning as well as laser calibration systems. All these sensors and instruments capture data that is processed by a computer located in the cabin, which displays relevant information on a screen, through which the user can interact, as part of the Rig Control System (RCS).

The RCS corresponds to the electronic interface through which the operator interacts with modern Epiroc equipment. Atlas Copco (now Epiroc) released the first version in 1998 and has since worked to perfect this interface. RCS 5, used in this study, corresponds to the latest version of the RCS. With a 380mm (15”) touch screen, the system combines the easy handling of smartphones with the power of technological automation tools. As can be seen in Figure 3, the RCS 5 controls are much smaller than the hydraulic ones used in the conventional Direct Control System (DCS), making the operator’s cabin much more spacious and comfortable for the operator. The RCS includes instruments and sensors that monitor the direction and position of the arms and is linked to the hole diagram previously loaded into the computer. This means that it is not necessary to mark all the holes on the working face but only the axis and the gradient.

Figure 3. Rig Control System (RCS 5) (Source: Cortes Zabłocki, 2018).

In Figure 4, the red circle indicates the position of the feed while the blue circle shows the angle of inclination, followed by the divergence distance at the end of the hole that is generated by this angle, and the angle of rotation of the arm. This is useful when giving the precise divergence angle to contour the holes and giving the same direction to all remaining holes. This allows for greater control of the tunnel contour and greater drilling precision to increase firing efficiency.

Figure 4. RCS 5 Screen (Source: Cortes Zabłocki, 2018).

2.2.4 *Results and Discussion*

The profile of a section developed with computerized control technology is shown in Figure 5, with an over excavation of 10.3%, close to the average of 11.1% . Figure 6 shows a topographic profile of a section developed using the equipment in a conventional configuration with an over-excavation of 22%.

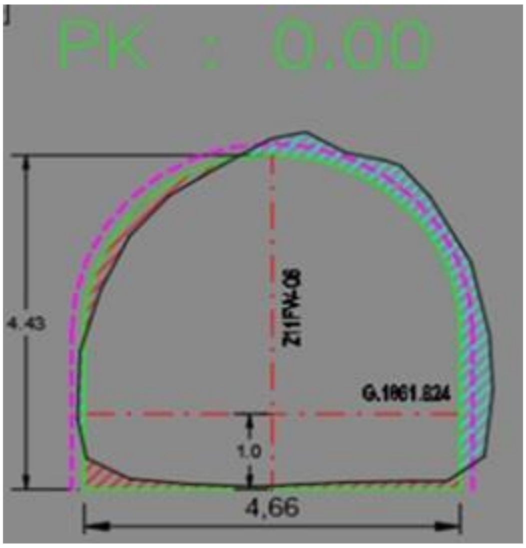

Figure 5. Topographic profile of the production level developed using equipment with computerized control (Source: Cortes Zabłocki, 2018).

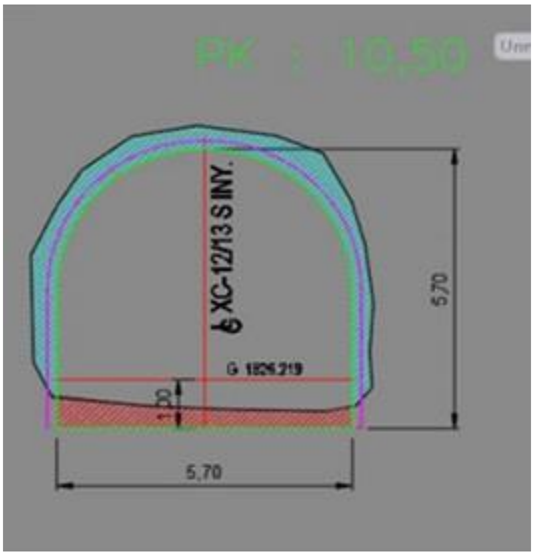

Figure 6. Topographic profile of a gallery developed with conventional equipment (Source: Cortes Zabłocki, 2018).

An average advance of 3.35 meters per blast was obtained for conventionally operated equipment and 3.54 meters per blast with equipment using computerized control (see Figure 7). On average, over-excavation using computerized drilling was 11.1% while drilling with conventional equipment resulted in 21.5% over-excavation (see Figure 7). Efficiency achieved with computerized control reached 89.5% compared to 84.7% with conventional equipment.

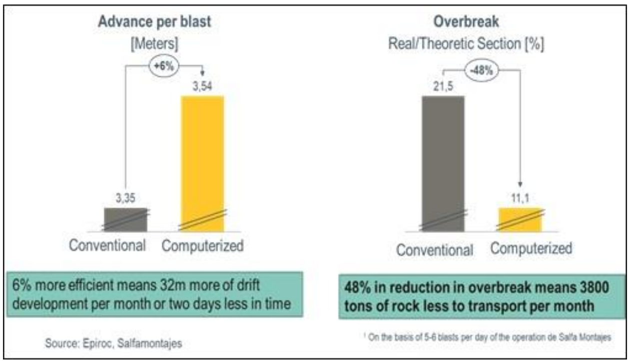

Figure 7. Comparison of conventional and computerized systems: advance-per-blast (left) and overbreak (right) (Source: Cortes Zabłocki, 2018).

The benefits of the computerized control were proven in the case of advance-per-blast and overbreak. For advance per blast, 6% higher efficiency was achieved using the computerized system as compared to the conventional system, which means that 32m more of drift development per month or two days less in time could be accomplished. In the case of overbreak, the 48% in reduction in overbreak with computerized drilling means 3800 tons of waste rock less to transport per month (see Figure 7). Figure 8 shows additional benefits of the computerized drilling system, some of which might not always be easy to valorize as might be the case with scaling and rock reinforcement with savings in time as well as costs.

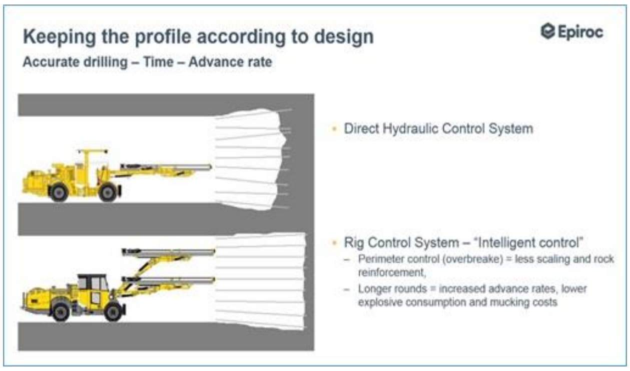

Figure 8. Benefits of computerized drilling versus manual/conventional drilling (Source: Zabłocki, 2018).

Despite of the obvious benefits of the technology, as shown during the study, the final implementation of this technology failed for various reasons, both technical and those related to human component (Cortes Zabłocki, 2018).

2.2.4.1 Technical reasons

The study identified various technical factors as contributing to the unsuccessful outcome of the technological implementation, including:

- Poor condition of the equipment in general, oil leaks, worn centralizers, and others. For example, the rubber bumpers were almost not existent
- Lack of sensors or sensors in poor condition and equipment out of calibration, which did not allow the team to use the technology properly
- Lack of spare parts despite the low cost of the replacement parts
- Poorly prepared operational area for access by drilling equipment. For example, the equipment operator had to request cleaning while already in a position for drilling or the equipment operators had to clean the area themselves before commencing drilling.

2.2.5 *Human factors reasons*

The human related factors, which contributed to the unsuccessful implementation included:

- High rotation of the operators mainly due to the harsh working conditions with 10x5 shifts yet salaries, which did not compensate for the work requirements. As a result, between 10 and 30 per week of new workers were being hired by the contractor company. Therefore, by necessity, the company hired low-skilled labor, some with limited or no mining experience
- Lack of proper training: maintenance personnel needs to be trained to learn the new system and how to maintain it (new electronic, hydraulic, and other components). The lack of training and thus knowledge, delayed repairs of the automated system and resulted in regressing to manual operation. In addition, over time, the number of trained operators decreased (see high rotation of the operators) and the value of the training was lost.
- Lack of proper communication between the owner, contractor and supplier, which resulted in poor planning by shift and field managers. Sometimes two jumbos arrived at the same forehead and one had to move again, resulting in lost time and thus lower productivity per equipment.
- Lack of management involvement
- Resistance to change by workforce due to fear of losing their jobs

In addition, maintenance and asset management strategies, a combination of technical and human factors, also influenced the application of the computerized drill rigs:

- Maintenance strategy: there was no culture of preventive maintenance. Maintenance was carried out only when a device had a fault and was out of service and was limited to solving the specific problem
- Asset management strategy: logistic problems hindered the full adoption of the computerized system: as computerized rigs are equipped with sensors and electronic components unknown to personnel in charge of spare parts supply. Many times, the basic and often inexpensive parts were not in stock, therefore, if the system malfunctions, the lack of spare parts stopped the use of the automatic drilling system and the system reverted to manual operation.

Furthermore, the pressure to reach production schedule did not allow for proper adaptation of the technology as it takes time to implement new technology i.e., “learning curve” and to obtain the benefits that the technology could provide.

3 CONCLUSIONS

During the next few years, the intelligent machines will increasingly redefine the need for human intervention forcing the mining industry to move towards more automated systems. However, for the implementation of innovative technologies leading to automation to be successful, it must involve people at all levels of the company, must be well planned and well executed. In that respect, an integration of technology providers, contractors, and companies with the involvement of universities and technical institutes providing appropriate skill base, would lead towards better preparation of the workforce to manage the technology implementation and the automated mines.

Once the systems are in place, integration between technology provider and companies is essential for successful implementation with a key challenge for the mining industry to help front-line employees shift to self-directed careers and embrace upskilling. The companies must address the training needs of the personnel and the resistance to automation by understanding the cultural basis for resistance and by involving the operators from the start or the earliest time possible in the planning and the implementation of the new technologies to dispose of the fear of automation and to allow the operators to “own” the technology. In addition, because of higher rotation and younger and less experience personnel, modern simulator training is becoming more important, improving and accelerating the learning process.

It was shown that the computerized control improved the operational parameters (over- and underbreak, advance per blast); further improvements might be possible by the integration of the blasting and drilling processes and the application of alternate explosive materials (emulsions).

There is no doubt that the mining companies must work on their implementation roadmap, which would include human factors at its core, to remain competitive in the new digital age.

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